The effect of scene removal on inhibition of return in a cue-target task

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Abstract Inhibition of return (IOR) is thought to be a phenomenon that biases orienting toward novel stimuli and/or facilitates foraging search. Although IOR has been explored using both the spatial cueing paradigm and the search paradigm, there is significant disagreement among scholars over whether these paradigms are reflecting the same underlying mechanism. We sought to address this disagreement by exploring whether a manipulation known to impact IOR in search - maintenance versus removal of the scene - might have a similar impact in the spatial cueing paradigm. As has been observed in both the cueing and search paradigms, we obtained a robust gradient of IOR around the cued location. Importantly, as in search tasks, scene removal resulted in the abolishment of IOR. This similarity lends support to the view that the spatial cueing and search paradigms are exploring the same IOR phenomenon.

Keywords Inhibition of return · Visual search · Attention

An organism's ability to effectively search its environment for an object is a crucial skill. One of the mechanisms thought to aid this process is called inhibition of return (IOR). IOR is usually viewed as an inhibitory aftermath of exogenous visual orienting, typically seen in the form of slower responses to targets presented at previously attended relative to unattended locations (reviews: Klein, 2000 and Lupianez et al., 2006). Theories about the functional significance of IOR as a novelty seeking mechanism

(Posner & Cohen, 1984) or foraging facilitator (Klein, 1988) have sparked intense interest in the sensory and/or motoric locus of the effect (Posner, Rafal, Choate & Vaughan, 1985; Hilchey, Klein & Satel, 2014) and the reference frame(s) in which it is encoded (Maylor & Hockey, 1985; Tipper, Driver & Weaver, 1991; Theeuwes, Mathot & Grainger, 2014).

To be a useful foraging aide outside the laboratory, IOR must survive the eye movements we make when searching a scene and the motions of objects we have already inspected. Posner and Cohen (1984) and Maylor and Hockey (1985) first demonstrated that IOR may be attached to environmental rather than oculocentric locations, which would preserve the inhibitory tags despite eye movements. By moving the objects after one of them had been cued, Tipper et al. (1991) demonstrated that the inhibitory tags could be attached to objects—at least when tested in the spatial cueing paradigm (but see also Christ, McCrae & Abrams, 2002).

However, in the real world, objects are embedded in scenes. Researchers have theorized whether the IOR that is observed in the model task is ecologically representative of the mechanisms involved in search, as described by Klein and Hilchey (2011, p. 481): “IOR was discovered using the model task originally developed by Posner for exploring covert orienting. Yet, in our typical interactions with the real world, gaze direction is free to move in tandem with shifts of attention; rather than discrete trials with individualized cues and targets, these interactions are characterized by sequences of acts of orienting within visual scenes of varying complexity that may be static or dynamic and may be examined for a variety of reasons. If IOR is the novelty-seeking, foraging facilitator as described above, it should certainly be operating in situations that involve sequences of orienting behaviours”. Accordingly, when IOR is assessed following an episode of search, rather than following an uninformative peripheral cue, it has been found repeatedly that maintenance of the scene is necessary to observe the inhibitory tags presumed to

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have been laid down by inspection of the possible targets in the scene (Klein & MacInnes, 1999; MacInnes & Klein, 2003; Müller & von Mühlenen, 2000; Takeda & Yagi, 2000; for a review, see Wang & Klein, 2010). The possibility that IOR is coded in scene coordinates, and hence might be lost with the scene as it is removed, was first put forward by Tipper et al. (1994) to explain early non-replications of Klein's (1988) seminal finding (but see also Thomas & Lleras, 2009). Converging with these demonstrations of the importance of a coherent scene, Tipper, Jordan and Weaver (1999) demonstrated that IOR was more likely to be tagged to objects in a scene than to locations in space when those objects were integrated or connected versus when they were separate or disconnected (see also Jordan & Tipper, 1998; Leek, Reppa & Tipper, 2003). Furthermore, Klein (2004, p. 550) stated that “when a relatively rich scene is presented, the inhibition is more likely to be tagged to objects in the scene than to locations in space, and hence removal of the search array is likely to remove the inhibitory tags”, which, when considered in context with the aforementioned findings, suggests the need for more investigations evaluating the role that scene complexity may play in the generation and maintenance of IOR.

Whereas the inhibitory aftereffects of an uninformative peripheral cue and of self-generated search behavior have both been referred to as IOR, it is not guaranteed that the tenets of IOR that apply in one paradigm will, ipso facto, apply in the other. Klein (1988; Klein & MacInnes, 1999), who was the first to explicitly test Posner's proposal that IOR might be operating during search, assumed that the inhibitory aftereffects he observed were the same as those measured in the cue-target paradigm. There is no visible debate about this in the IOR literature, but Dukewich and Klein (2015) discovered that many IOR scholars disagree with Klein's assumption. Indeed, in their recent survey of IOR experts, Dukewich and Klein discovered that, while about 60 % of the experts thought these were the same or similar phenomena, almost 40 % did not endorse this view. Evidence that these two inhibitory aftereffects are similarly or differently affected by experimental manipulations would be useful in helping experts to endorse one view or the other. It is this gap in understanding between the two task types that we seek to address in the present study. In doing so, we will focus on the effect of scene removal—a manipulation used numerous times in investigations of IOR in search (Klein, 1988; Klein & MacInnes, 1999; MacInnes & Klein, 2003; Müller & von Mühlenen, 2000; Takeda & Yagi, 2000; Thomas & Lleras, 2009). Despite the evidence for the modulation of IOR in dynamic cueing displays (Christ, McCrae & Abrams, 2002; Tipper, Driver & Weaver, 1991; Tipper, Jordan & Weaver, 1999), and robust elimination of IOR with removal of a scene in search, at present no known investigations have explored the effect of scene removal on IOR in the cue-target paradigm. Our study will fill this gap.

Each trial began with participants viewing a simple or complex scene. On half the trials, the scene was removed immediately after the cue, leaving a plain black screen with only the fixation

point visible. If IOR were stored in the observer's input-driven mental representation of the scene, then, by removing the scene we hypothesized that we might also remove the IOR. In contrast, if IOR in the cue-target paradigm were simply an aftereffect of processing at the previously cued location, then scene removal would have no impact on IOR. Furthermore, we wondered whether the degree to which the inhibitory tag that might be stored in the representation of the scene would be influenced by scene complexity, such that we would see an interaction between scene complexity and scene removal, with IOR more likely to be eliminated when the more complex scene was removed. As well, although we were interested primarily in the magnitude of IOR once it was revealed, we also probed responses at multiple stimulus-onset asynchronies (SOA) as it is possible that differences due to context or removal may have been manifest in the time course of the inhibitory effect (e.g., see Klein, Castel & Pratt, 2006).

Method

Participants

Twenty-three people¹ (5 men, 18 women) participated in the study either for credit in a psychology course at Dalhousie University or for monetary compensation. They ranged in age from 18 years to 34 years (mean age = 22.4 years). All reported normal or corrected-to-normal vision. All participants were naïve to the purpose of the experiment.

Apparatus and stimuli

Stimulus presentation and reaction time (RT) recording was carried out using Psyscript, running on a colour iMac computer with a 117 Hz refresh rate. The fixation point was a white outlined rectangle with a visual angle of $.52 \times .29$ degrees. The fixation point remained on the screen throughout the whole experiment. Trials started with a black screen presented for 500 ms. There were two between-block experimental conditions: Apartments or Squares (see Fig. 1). In the Squares context, the display consisted of 16 black boxes on a grey background arranged in a 4×4 grid. The squares were 1.72×1.72 degrees of visual angle (DVA), separated from adjacent squares by 1.14 DVA. In the Apartment context, the identical grid of 16 black boxes was embedded in a graphic of an apartment building wherein they appeared as windows. Cues and targets were presented in 8 of the 16 locations, forming a nearly equi-eccentric octagon centered around the fixation point (Fig. 1, left panel). The cue was presented 500 ms

¹ An *N* of 20 was the initial goal for sample size. Extra data was collected in the event any observers were to be excluded from analysis. Importantly, there is no difference in the outcomes of any statistical tests if the final three observers are excluded.

Fig. 1 *Left panel* Illustration of the eight locations where cues and targets could be presented relative to the fixation stimulus at the center of the display. *Middle panel* Squares context. *Right panel* Apartment context

after the onset of the background display. The cue was one of these eight boxes or windows being selected randomly and filled in with white for 60 ms. The ‘removal’ condition was selected randomly on each trial. The Apartment or Square display offset occurred simultaneously with the onset of the target. The target was the appearance of a large white asterisk centered in (or at the spatial location of) one of the boxes or windows that was displayed until the response was made. The target was presented randomly in one of the eight boxes/windows after one of four randomly selected SOAs (105 ms, 210 ms, 405 ms or 810 ms). The target remained on screen until a response was recorded.

Procedure and design

Participants sat 57 cm from the screen. Participants completed both scene conditions, with the order of contexts counterbalanced across participants. The sequences of events in a trial are illustrated in Fig. 2. Participants were instructed to remain fixated on the centre rectangle for the duration of each trial and to respond to the appearance of the target by pressing the spacebar as quickly and accurately as possible. On catch trials (approximately 11.1 % of the total number of trials in a block), no target was presented and any response during a 3-s post-cue interval was considered a

false alarm. Participants completed 20 practice and then 576 experimental trials (including 64 catch trials when no target appeared) resulting in 512 experimental trials ($8 \text{ cue locations} \times 8 \text{ target locations} \times 4 \text{ SOA} \times 2 \text{ removal conditions}$) with the first context (Square First: $N = 12$; Apartments First: $N = 11$). A short break was given after every 72 trials, and a longer break between blocks when they were shown the instructions for the second context condition. The 576 trial block of the second context was preceded by 10 practice trials.

Results

Based on inspection of the overall distribution of RTs we excluded as outliers RTs less than 180 ms and greater than 750 ms (amounting to about 1.5 %). Means for each cell of the design were computed from the remaining RTs, and these mean RTs were subjected to a variety of analyses as described below.

The mean false alarm rate was 8 % (SD = 6.3 %) with a higher false alarm rate when the background was removed (10.9 %) than when it remained (5.1 %) [$F(22,1) = 12.32$, $P < 0.01$, $g = 0.14$], which was probably due to a phasic alertness (Posner, Klein, Summers & Buggie, 1973) reaction to the change when the scene was removed.

We conducted a 4-way ANOVA with background Context (Apartment or Squares), Removal (whether the background was removed before the target was presented, or whether it remained on the whole time), Cuing (whether or not the target was presented at the cued location), and SOA (105 ms, 210 ms, 405 ms or 810 ms) as factors.² The full data set broken down according to the aforementioned design is presented in Appendix Table 1. The main effects of Removal [$F(1,22) = 20.22$, $P < .001$, $g = 0.013$] and SOA [$F(3,66) = 28.75$, $P < .0001$, $g = 0.074$] were significant, as were the

Fig. 2 The sequence of displays used in the four conditions of the experiment

² During reviews, Tom Spalek wondered whether such an effect of context might have been masked by carryover effects from our crossover design in which each participant received both contexts, but in different orders. We therefore conducted a 5-way ANOVA with Order as a factor. In this ANOVA there was a 4-way interaction that did not involve context (Cuing, SOA, Removal and Order [$F(3,63) = 2.79$, $P = .047$, $g = 0.002$]). That this interaction did not involve context provides no statistical basis for order effects masking an effect of context. Efforts to determine the source of the interaction (e.g. by conducting separate follow-up ANOVAs on the remains and removed trials separately) were unsuccessful.

2-way interactions between Removal and Cuing [$F(1,22) = 22.37$, $P < .0001$, $g = 0.007$] and SOA and Cuing [$F(3,66) = 10.96$, $P < .0001$, $g = 0.008$]. There was no main effect of Context [$F(1,22) = 0.001$, $P = .97$, $g < 0.001$], nor any significant interactions with cueing so this manipulation will not be discussed further.³

The interaction between SOA and Cuing, which is one diagnostic for IOR, reflects the typical pattern of early facilitation followed by later IOR. Because cueing is also qualified by the interaction with Removal, these results (RTs and cueing effects) are shown separated by this factor in Fig. 3. Here, it can be seen that the early facilitation was confined to the Removed condition, which did not show evidence of IOR at any SOA, and that the later inhibitory effect was confined to the Remained condition, which did not show significant facilitation at the early SOAs. Importantly, and consistent with our prediction based on the effect of scene removal during search tasks, there was NO evidence of IOR in the scene-removed condition.

Prior studies of visuo-spatial attention using multiple target locations have reported robust gradients of facilitation (Tsal, 1983; Henderson & Macquistan, 1993; Schmidt, Postma & de Haan, 2001) and of IOR, whether using a cue-target paradigm (e.g. see the single cue data from: Klein, Christie & Morris, 2005 and Langley et al., 2011; see also, Pratt, Spalek & Bradshaw, 1999, Exp. 3) or oculomotor search (e.g. Klein & MacInnes, 1999). To assess the effect of scene removal on the gradient of facilitation, we collapsed RTs across the two shorter SOAs and conducted an ANOVA with scene removal and cue-target distance as factors. This analysis revealed a main effect of removal [$F(1,22) = 21.53$, $P < .0001$, $g = 0.02$] (responses to a target in a removed scene were slower than when the scene remained). There was also a significant interaction between removal and cue-target distance [$F(4,88) = 6.24$, $P < .0001$, $g = 0.006$]. There was no gradient of facilitation when the scene remained (Fig. 4, left panel), yet, when the scene was removed, there was a gradient of facilitation with fastest RTs at the cued location, with RT increasing monotonically as the distance between cue and target increased. We conducted the same analysis to assess the effect of removal on the gradient of IOR by collapsing data from the two longer SOAs. This revealed a main effect of removal [$F(1,22) = 55.00$, $P < .0001$, $g = 0.05$] (responses to a target in a removed scene were again slower than when the scene remained) and cue-target distance [$F(4,88) = 20.18$, $P < .0001$, $g = 0.027$]. Importantly, these effects were qualified by a significant interaction between removal and cue-target distance [$F(4,88) = 6.46$, $P < .0001$, $g = 0.012$]. As can be seen in Fig. 4 (right panel), when the scene remained, there was a robust gradient with

maximum RTs at the cued location, and with RT decreasing monotonically as the angular distance between the cue and target increased. Removal of the scene resulted in the abolishment of this IOR gradient.

Discussion

We have shown typical patterns of behaviour over the time course of cueing: facilitation at short SOAs and IOR at long SOAs. Importantly, this relationship between cueing and SOA is also qualified by scene removal, where facilitation was confined to trials when the scene was removed, and IOR only to trials when the scene was maintained. This pattern can be visualized as inverse angular gradients (Fig. 4): there is a monotonic decrease of facilitation as a function of increased angular distance from the cue in the Removal condition that is not present in the Remains condition, whereas there is a monotonic decrease of IOR as a function of increased angular distance from the cue in the Remains condition that is not present in the Removal condition.

A priori, we expected facilitation to be present to a similar degree regardless of scene removal. Contrary to this expectation (Figs. 3 and 4, left panels), we found significant facilitation only when the scene was removed (in other words, when the scene remained present there was no significant early facilitation). We offer an ad hoc explanation for this pattern. Several scholars (beginning with Posner and Cohen, 1984) have suggested that IOR and facilitation can co-exist at the same location, with performance being influenced jointly by the simultaneously present effects (see Klein, 2000, Box 1). Perhaps there is equivalent facilitation whether the scene is removed or maintained, but the early presence of inhibition when the scene is maintained overshadows the facilitation, leaving no net benefit of cueing upon performance at the early SOAs.⁴ This possibility is consistent with behavioural and neuroscientific evidence reviewed by Klein (2004), and with the absence of a 3-way interaction in the analysis of the data plotted in Fig. 3.

When the scene remained on throughout the trial, IOR was clearly demonstrated at the two longest SOAs, and it was characterized by a gradient quite typical of what has been seen in previous cue-target and visual search studies (Klein, Christie & Morris, 2005; Klein & MacInnes, 1999). In contrast, when the

³ In conceiving this project we thought that the apartment background would be perceived as more scene-like than the matrix of black boxes, and that removing the more complex scene having a greater effect on the disappearance of IOR. Our failure to obtain such an interaction might be because our expectation was incorrect or because, phenomenologically speaking, the two conditions were so similar in complexity.

⁴ An alternative explanation of this pattern of results offered by Christian Olivers (personal communication, 8 March 2016) is that “the offset transient might generally slow people down, e.g. through interference. This may be stronger for uncued locations, or put the other way around: cued items may be protected against interference from surrounding transients (similar to cueing benefits in working memory).” If this were the case, and the cued items were in fact being protected from interference, there would be a gradient in the Remove condition in the late SOAs similar to the one seen in the short SOAs where RTs increase as a function of cue-target distance. Such an account would require additional qualification, as there is no difference in RT as a function of cue-target distance when the scene is removed (Fig. 4, right panel).

Fig. 3 Upper panels Reaction time (RT) for cued and uncued targets, lower panels cuing effects with 95 % confidence intervals [suitable for judging whether a score differs from zero at each stimulus-onset

asynchrony (SOA)], both as a function of cue-target SOA. Data shown: left Remains condition; right Removal condition

background array was removed, IOR was eliminated. This pattern converges with previous findings showing that scene maintenance is important in search paradigms when either overt or covert orienting is employed (Klein & MacInnes, 1999; Muller & von Muhlenen, 2000; MacInnes & Klein, 2003; Takeda & Yagi, 2000). This pattern is distinct from that found in object ‘present vs. absent’ designs, where it has been shown that the magnitude of IOR can be reduced in object-absent displays (Jordan & Tipper, 1998; Paul & Tipper, 2003; McAuliffe, Pratt & O’Donnell, 2001, Hilchey, Pratt & Christie, 2016). The typical ‘present vs. absent’ effect could be because it is harder to tag an empty location (i.e., it is harder to generate an inhibitory tag), or that the location was actually tagged, but without an object present it is less likely that the inhibitory tag is maintained. Thus, it is

unclear if the seemingly similar pattern of results is due to similar mechanisms. In our design, the cuing effect is generated under the same conditions on every trial as the scene is always present at the time of the cue, and our removal manipulation evaluates the maintenance of this effect. As well, the present cuing paradigm used a display sequence similar to that used in the visual search work described above. By having the scene present when the cue appears, there should be no difficulty in generating the inhibitory tag, just as in the visual search work. Also, just as in the visual search work, if scene removal prior to target presentation in the cuing paradigm reduces the IOR effect, then this suggests that the IOR reduction in both paradigms represent a failure to maintain the inhibitory tags. Contrarily, present/absent manipulations cannot disentangle whether any differences are

Fig. 4 The effect of scene removal on RT as a function of cue-target distance, where 0 represents trials in which the cue and target appear at the same location, and each increment represents a separation of one additional placeholder. Error bars Half Fisher's least significant

difference for the effect of distance within each ‘removal’ condition (allowing comparisons between cue-target distance values within ‘removal’ conditions)

attributed to the generation or measurement of the cueing effect. Importantly, the parallel role of scene maintenance we have discovered provides one important link between the cue-target and search paradigms—an important linkage given contemporary disagreements on whether both paradigms are eliciting the same phenomenon (cf. Dukewich & Klein, 2015). The similarity of our angular gradient of IOR to that seen by Klein and MacInnes (1999), and their similar abolishment by scene removal provides converging evidence for this linkage.

When Posner and Cohen launched the use of a simple “model task” (what most scholars now refer to as the “Posner cuing task”) to explore the inhibitory after effect(s) of orienting, they put forward the idea that the function of inhibition of return was a novelty seeking bias (Posner & Cohen, 1984; Posner et al, 1985) “that might operate in normal visual search (Posner et al., 1985, p. 226).” In the context of this functional explanation it is necessary for the community of scholars interested in visual attention to learn for certain whether the 30 years of data that have been generated on IOR using the simple model task are, or are not, tapping the same underlying inhibitory mechanisms as those operating in visual search. Whereas we are among the scholars who believe that the cue-target and visual search paradigms are eliciting the same IOR phenomenon, it is certainly the case that further studies akin to this one, demonstrating parallels between the inhibitory aftereffects generated in these two paradigms, would be helpful in getting more scholars to agree.

Appendix

Table 1 Reaction time (RT) and cuing effects as a function of display condition and stimulus-onset asynchrony (SOA)

Condition	Cue type	SOA			
		105	210	405	810
AP remains	Cued	354.94	343.439	352.833	379.293
	Uncued	353.819	342.721	336.251	361.539
	Difference score	1.121	0.717	16.582	17.754
AP removed	Cued	357.658	338.147	341.641	389.175
	Uncued	367.058	353.005	356.702	385.24
	Difference score	−9.4	−14.858	−15.062	3.935
SQ remains	Cued	346.106	341.886	360.204	380.679
	Uncued	349.996	335.005	337.725	356.627
	Difference score	−3.891	5.979	22.479	24.052
SQ removed	Cued	358.984	343.864	364.197	387.41
	Uncued	368.275	350.246	354.786	379.286
	Difference score	−9.292	−6.382	9.411	8.124

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