

Oculomotor inhibition of return:
Evidence against object-centered representation

Ralph S. Redden, Matthew D. Hilchey & Raymond M. Klein

Dalhousie University

This is the author-accepted manuscript. Please refer to any applicable terms of use of the publisher. This article may not exactly replicate the authoritative document published in Visual Cognition (doi: 10.1080/13506285.2018.1544598). It is not the copy of record.

Author Note

Ralph S. Redden, Department of Psychology & Neuroscience, Dalhousie University

Matthew D. Hilchey, Department of Psychology, University of Toronto

Raymond M. Klein, Department of Psychology & Neuroscience, Dalhousie University

The present work was supported by NSERC CGS and a Killam Graduate Scholarship awarded to RSR, NSERC PDF to MDH, and a NSERC Discovery Grant awarded to RMK.

Correspondence for this article should be addressed to Ralph Redden, Department of Psychology & Neuroscience, Dalhousie University, 1355 Oxford st., 3rd Floor LSC, Halifax, NS, Canada, B3H 4R2. E-mail: rredden@dal.ca

Abstract

Intermixing central, directional arrow targets with the peripheral targets typically used in the Posnerian spatial cueing paradigm offers a useful diagnostic for ascertaining the relative contributions of output and input processes to oculomotor inhibition of return (IOR). Here, we use this diagnostic to determine whether object-based oculomotor IOR comprises output and/or input processes. One of two placeholder objects in peripheral vision was cued, then both objects rotated smoothly either 90 or 180 degrees around the circumference of an imaginary circle. After this movement, a saccade was made to the location marked by a peripheral onset target or indicated by the central arrow. In our first three experiments, whereas there was evidence for IOR when measured by central arrow or peripheral onset targets at cued locations, there was little trace of IOR at the cued object. We thereafter precisely replicated the seminal experiment for object-based oculomotor IOR (Abrams & Dobkins, 1994; Experiment 4) but again found little evidence of an object-based IOR effect. Finally, we ran a paradigm with only peripheral targets and with motion and stationary trials randomly intermixed. Here we again showed IOR at the cued location but not at the cued object. Together, the findings suggest that object-based representation of oculomotor IOR is much more tenuous than implied by the literature.

Inhibition of return (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 (e.g., Posner, Rafal, Choate & Vaughan, 1985; Hilchey, Klein & Satel, 2014) and the reference frame(s) in which it is encoded (e.g., Maylor & Hockey, 1985; Theeuwes, Mathot & Grainger, 2014). The present empirical investigation was stimulated by a question that focuses upon these two distinctions about IOR's effects on subsequent processing: Is output-based, oculomotor IOR encoded in an object based reference frame? A brief background on each distinction is presented next to properly situate our experiments.

Object-based coding of IOR when measured with manual responses

If the processes underlying IOR subserve efficient foraging, then one might hypothesize that IOR "tags" are not affixed merely to previously attended spatiotopic coordinates but also (or rather) to previously attended objects. First exploring this possibility, Tipper, Driver and Weaver (1991) implemented the "moving-box" paradigm, in which one of multiple moving placeholder boxes are cued by a brief transient flash. In the moving objects condition, Tipper and colleagues reported slower responding at the cued object but not at the cued location when requiring speeded, simple manual button press responses. Because the size of the inhibitory effect was larger in the stationary boxes condition than in the moving boxes condition, it was suggested that inhibition in space-based and object-based reference frames may contribute to the net effect in the stationary display whereas only the object-based component contributes to inhibition in dynamic displays. Tipper, Jordan and Weaver (1999) further investigated the possibility of co-existing space- and object- based reference frames of IOR with the moving-box paradigm. Using three boxes and 120 degree rotation allowed separate measurement of performance at the cued object and location, as well as at a box unaffected by either space- or object-based cueing effects. Supporting Tipper et al.'s earlier suggestion, they found a cost in performance at both the cued location and object relative to targets appearing at the neutral box.

There are two forms of IOR: Oculomotor IOR is output-based

Recent studies have shown that the degree to which the reflexive eye movement system is active during a task will determine whether IOR's effect is on input or output processes (for a review, see Klein & Redden, 2018). Two diagnostics point in this direction. In non-spatial discrimination tasks, when the reflexive eye movement system is suppressed and thus eye movements are expressly forbidden, observers tend to be slower and less accurate to respond to cued targets, suggesting an effect of IOR that arises early in information processing or nearer the input end of the processing continuum. By contrast, when the reflexive eye movement system is not suppressed, observers tend to be slower but also more accurate to respond to cued targets, suggesting an effect of IOR that arises later in information processing or nearer the output end of the processing continuum (Chica et al., 2010; Hilchey, Hashish, McLean et al., 2014; Redden, Hilchey & Klein, 2016). A second diagnostic was pioneered independently by Rafal, Egly and Rhodes (1994) and Abrams and Dobkin (1994). Here, after IOR is generated (for example by an

ignored cue) it is measured by responses that are either toward a peripheral target or compatible with the location indicated by an arrow appearing at fixation (*e.g.*, a leftward arrow might require a leftward saccade or left-handed button press response). Using the arrow diagnostic, Taylor and Klein (2000) demonstrated that when the oculomotor system was suppressed - because oculomotor responses were discouraged and not required - the inhibitory aftereffect generated by a peripheral cue was only observed if the target was also in the periphery. By contrast, in the remaining conditions for which the reflexive oculomotor system was active - because eye movements were required - if IOR was observed with a peripheral target it was also observed in response to central arrow targets. Importantly, the magnitude of IOR measured with these two types of target was about the same (a pattern exemplified in Figure 1b) when eye movements were required (see also, Hilchey, Klein & Ivanoff, 2012), strongly implying minimal effect of the cue on input pathways.

Is oculomotor IOR object-based?

Whereas Tipper and colleagues demonstrated object-based IOR when manual responding was required (*ergo* no task-relevant overt orienting) to peripheral targets, Abrams and Dobkin (1994) used the central arrow target in the moving-box paradigm while requiring saccadic responses. This method was implemented by Abrams and Dobkin (1994) to determine if object-based IOR could be measured by eye movements, and if so, to measure whether the effect was operating on output or input processes or both. As noted above, a central arrow target following a peripheral cue permits evaluation of output-based contributions to IOR because the target does not stimulate the same input pathway as the cue. However, IOR measured by a peripheral target can be attributed to input or output processes as the cue and target are linked in retinotopic/spatiotopic/object coordinates in “stationary box” paradigms, and object-based coordinates in moving box paradigms. Abrams and Dobkin reported that when the cued and uncued objects were stationary, the magnitude of IOR was greater for peripheral relative to central targets (a pattern exemplified in Figure 1c). In contrast, when the objects moved before the target was presented, there was inhibition at the new location of the cued object, but only when the target was peripheral and therefore presented in the cued object (a pattern exemplified in Figure 1a). Based on this pattern of results, Abrams and Dobkin concluded that the perceptual component of IOR remaps dynamically onto objects whereas the motoric component IOR does not.

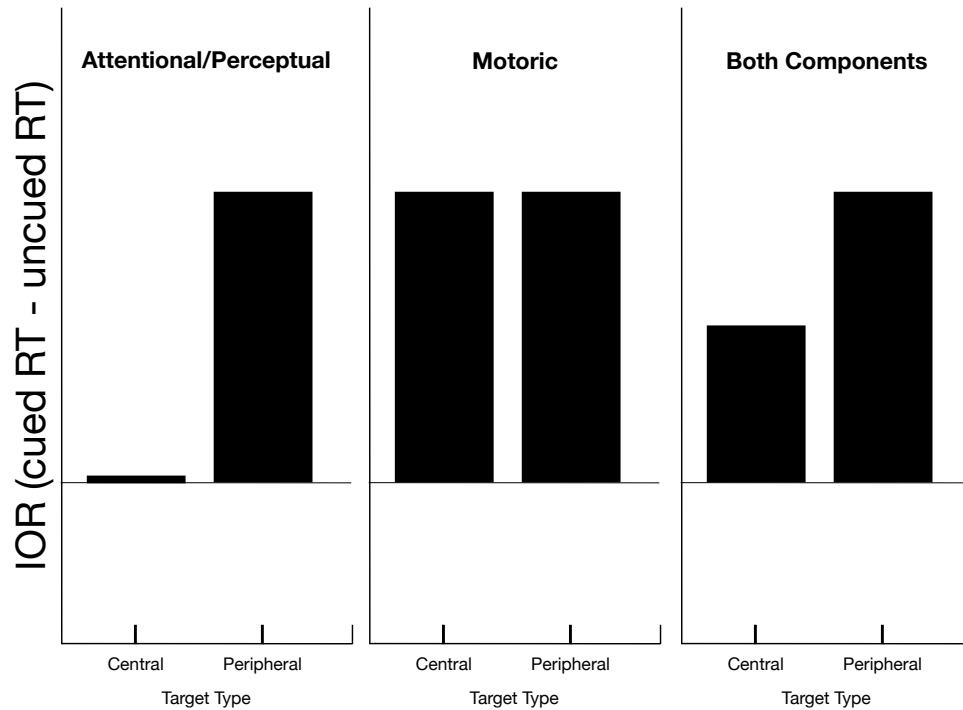


Figure 1: How the pattern of results when central and peripheral targets are randomly intermixed can be used to infer different forms (a & b) or different components (c) of IOR.

The empirical basis of Abrams and Dobkin (1994)'s two-component theory of saccadic IOR was recently challenged. Klein and Hilchey (2011) first noted that Abrams and Dobkin (1994)'s pattern (Figure 1c) in a stationary cue-target paradigm clashed with a pattern reported by Taylor and Klein (2000; Figure 1b) in which IOR following a saccade was the same when measured by a peripheral onset or central arrow, a pattern that implies a more output-based effect. Klein and Hilchey (2011) noted that Abrams and Dobkin (1994) administered peripheral and central targets in separate blocks whereas Taylor and Klein (2000) randomly intermixed them. Klein and Hilchey (2011) hypothesized that presenting behaviorally-relevant stimuli exclusively at fixation may have encouraged observers to adopt a spatial attentional control setting (ACS) that would allow for filtering of stimuli appearing in peripheral vision (for converging evidence, see Wang & Klein, 2012). Such a confound might have attenuated the effect of the cue in the central target condition. Hilchey, Klein and Ivanoff (2012) tested this hypothesis by either mixing or blocking the two target types in a replication of Abrams and Dobkin's stationary condition. They found that the magnitude of IOR was greater for peripheral relative to central targets when administered in separate blocks (Figure 1c) whereas, importantly, there was little discernible difference when these two target types were intermixed (Figure 1b). Thus, the evidence leading Abrams and Dobkin to propose two components was really due to different spatial ACSs being generated by their blocked designs. When the spatial ACSs are controlled in mixed target designs and, in agreement with Taylor and Klein (2000), the effect of saccadic IOR with stationary displays is primarily output-based.

Given that oculomotor IOR is principally output-based in stationary displays (Hilchey et al., 2012; Taylor & Klein, 2000; Hilchey, Klein, & Satel, 2014), the Abrams and Dobkin (1994) inference that only the input-based component of oculomotor IOR maps dynamically into object-based coordinates is necessarily suspect. The present investigation reevaluates whether oculomotor IOR is object-based by replicating Abrams and Dobkin (1994)'s original methods while ensuring that central arrow and peripheral targets are randomly intermixed within a block, so as to ensure that the distribution of processing resources in peripheral vision – and thus to the cue – is equivalent prior to the onset of either target type.

In all five experiments we adopted the moving box paradigm pioneered by Tipper, Driver and Weaver (1991). Modelled on Abrams and Dobkin's Experiment 3 and Experiment 4, in Experiment 1 we used 90 degree rotations and randomly intermixed the central and peripheral targets, as in Hilchey et al. (2012). Experiment 2 was very similar to Experiment 1 except we included 180 degree rotations. In Experiment 3 we encouraged attention to the cue by making the cue itself a "go" target calling for a button press response on 25% of the trials. Having failed to find any evidence of object-based IOR (with either the central or peripheral targets), in Experiment 4 we precisely replicated Abrams and Dobkin's peripheral target condition (their Experiment 4) and still failed to find object-based oculomotor IOR. Finally, in Experiment 5 we used only peripheral targets and randomly intermixed motion trials with stationary trials, where we found reliable oculomotor IOR at the cued location but no evidence that the inhibitory effect moved with the object.

Experiment 1

Our methods in Experiment 1 were closely modelled on those of Abrams and Dobkin (1994, Experiment 3 & Experiment 4) except that instead of presenting the central and peripheral targets in separate blocks in our experiment they were randomly intermixed, as in Taylor and Klein (2000), and Hilchey, Klein and Ivanoff (2012). Mixing the two target types ensures that observers are employing the same strategy at the outset of every trial, thus avoiding the confound of different spatial ACSs for the two target types when these are presented in different blocks.

Method

Participants

Ten naive observers (2 male; 1 left-handed) ranging in age from 19-51 participated in the study for course credit in one 60 minute session. All observers were recruited from the undergraduate subject pool at Dalhousie University.

Apparatus and Procedure

Observers completed eight blocks of 32 trials in a single experimental session. See Figure 2 for the sequence of events. The experiment was run in a dimly lit room on a 19" 60Hz CRT monitor. Eye positions were monitored by EyeLink II head mounted equipment. Trials began with the presentation of two white outline placeholder boxes (0.8 x 0.8 degrees of visual angle

[DVA]) presented on the vertical axis separated by 7.0 DVA from a red centrally-presented fixation cross (0.5 x 0.5 DVA) on a black background. Observers pressed the space bar to initiate a drift correction. If this drift correction was completed successfully, the central fixation changed from red to white to indicate that the trial had begun. After 300ms, the central fixation changed to a circle (diameter 0.5 DVA). A spatially uninformative cue (asterisk measuring 0.5 DVA) lasting 300ms appeared in one of the placeholder boxes 800ms after the onset of the central circle. After cue offset, 200ms elapsed before the placeholder boxes began to move. Simultaneous with the start of placeholder motion, the central fixation circle changed to an asterisk identical to the cue. The motion animation lasted 300ms and resulted in a 90-degree clockwise position change for the placeholder boxes. As in Abrams and Dobkin (1994), motion animation was generated by updating the spatial location of the placeholders every 20ms at 15 equidistant angular positions. The placeholder boxes stopped on the horizontal axis on every trial. The central asterisk abruptly changed back to a circle upon motion end and 160ms passed before the presentation of a target. The target, requiring a saccadic response to the corresponding placeholder box, was either a centrally-presented arrow (1 DVA width) pointing left or right, or a peripherally-presented circle (0.5 DVA diameter) within one of the placeholder boxes. Trials in which an eye movement occurred prior to target onset were aborted and recycled into the trial list. Due to the self-paced nature of the experiment (and the proceeding four experiments), observers were free to take breaks at any time in the sequence of trials.

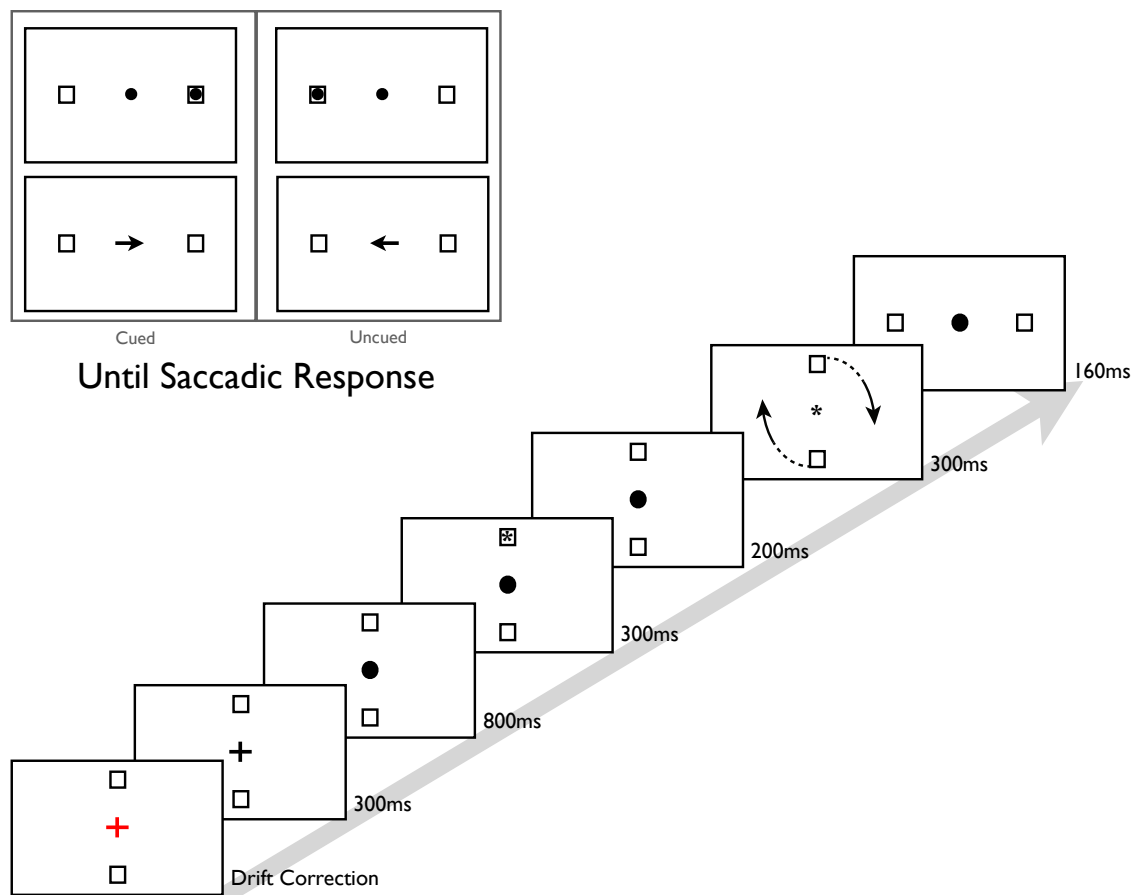


Figure 2: Sequence of events from Experiment 1, see text for explanation. In the actual experiments the stimuli were presented in white on a black background. In this and the remaining methods figures the contrast has been reversed.

Results

The first block was excluded from analysis as practice. Trials in which observers did not maintain fixation before the onset of a target were aborted and recycled (8.6%). Of the remaining trials, saccades initiated in less than 100ms (1.5%) or more than 700ms (0.3%) after the target onset were excluded from analysis. Trials that were considered inaccurate (when the saccade did not land within 3.0 DVA of the target) were also excluded from analysis (2.0%).

Saccadic reaction time (SRT, see Figure 3) was analyzed¹ via a 2 (cued or uncued target) x 2 (central or peripheral target) repeated measures ANOVA (56 trials/cell before exclusions). This analysis revealed a main effect of target type, $F(1, 9) = 19.85$, $p < 0.01$, $\eta^2 = .44$, wherein responses to central targets (287ms) were slower than to peripheral targets (251ms). No main effect of cueing, $F(1, 9) = 0.24$, $p = 0.63$, $\eta^2 = .00$, or interaction, $F(1, 9) = 1.63$, $p = 0.23$, $\eta^2 = .00$ was observed.

In order to quantify the evidence for or against the main effect of interest, a Bayesian paired samples t-test was conducted (naive prior, $\delta \sim \text{Cauchy}(0, 0.707)$) on the cueing effect in the peripheral-onset condition only. This test showed anecdotal evidence for a null effect of cueing, $\text{BF}_{10} = 0.89$.

¹ Frequentist analyses were conducted in R using the ez package (Lawrence, 2013), while Bayes factors were computed in JASP (JASP Team, 2018), and interpreted according to the scale proposed by Wagenmakers et al. (2018 - Table 1).

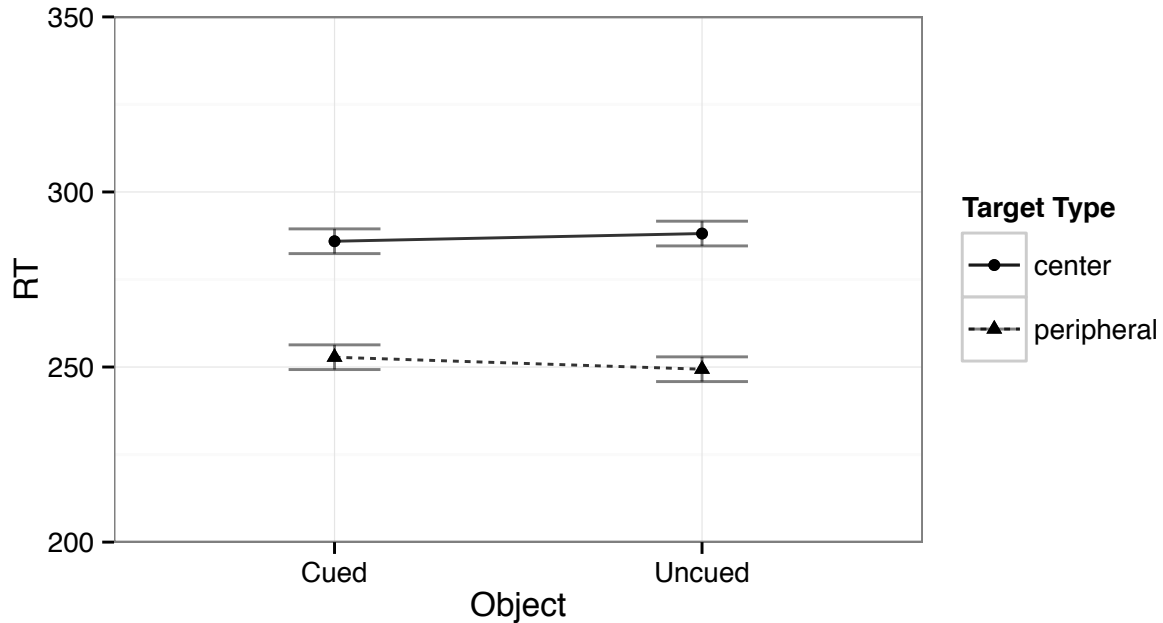


Figure 3: Mean saccade reaction time to cued and uncued central and peripheral targets in Experiment 1 after 90 degree rotation of placeholder boxes. Error bars are Fishers least significant differences (FLSDs).

Discussion

We found no evidence for object-based saccadic cueing effects; neither with central arrow nor with peripheral onset targets. It is conceivable, however, that observers in our task may have engaged in a task-specific spatial ACS that obscured any effect of cueing because the cues never appeared in task-relevant space; that is, cues were presented above/below fixation while targets were presented on the horizontal axis which may have allowed observers to preferentially attend the horizontal axis (Ishigami, Klein & Christie, 2009). This possibility provides the impetus for our second experiment.

Experiment 2

We sought to eliminate the possibility that observers might engage a spatial ACS to filter out the cue. We did this by randomly intermixing the starting position of the objects and whether the display rotated 90 or 180 degrees. Because all cues are presented in task-relevant space, the cue should be attended.

Method

Participants

Eight naive observers (2 male; 1 left-handed) ranging in age from 17-25 participated in the study for course credit in one 90 minute session. All observers were recruited from the undergraduate subject pool at Dalhousie University.

Apparatus and Procedure

All details for the present study were the same as Experiment 1, except for two factors. At the start of a trial placeholder boxes were randomly presented equally often on the vertical and horizontal axis (Figure 4). As well, the placeholders randomly rotated 90- or 180-degrees about fixation. The speed of rotation remained consistent between distances. This resulted in two CTOAs: 960ms for the 90-degree rotation and 1260ms for the 180-degree rotation. Observers completed four experimental blocks of 128 trials.

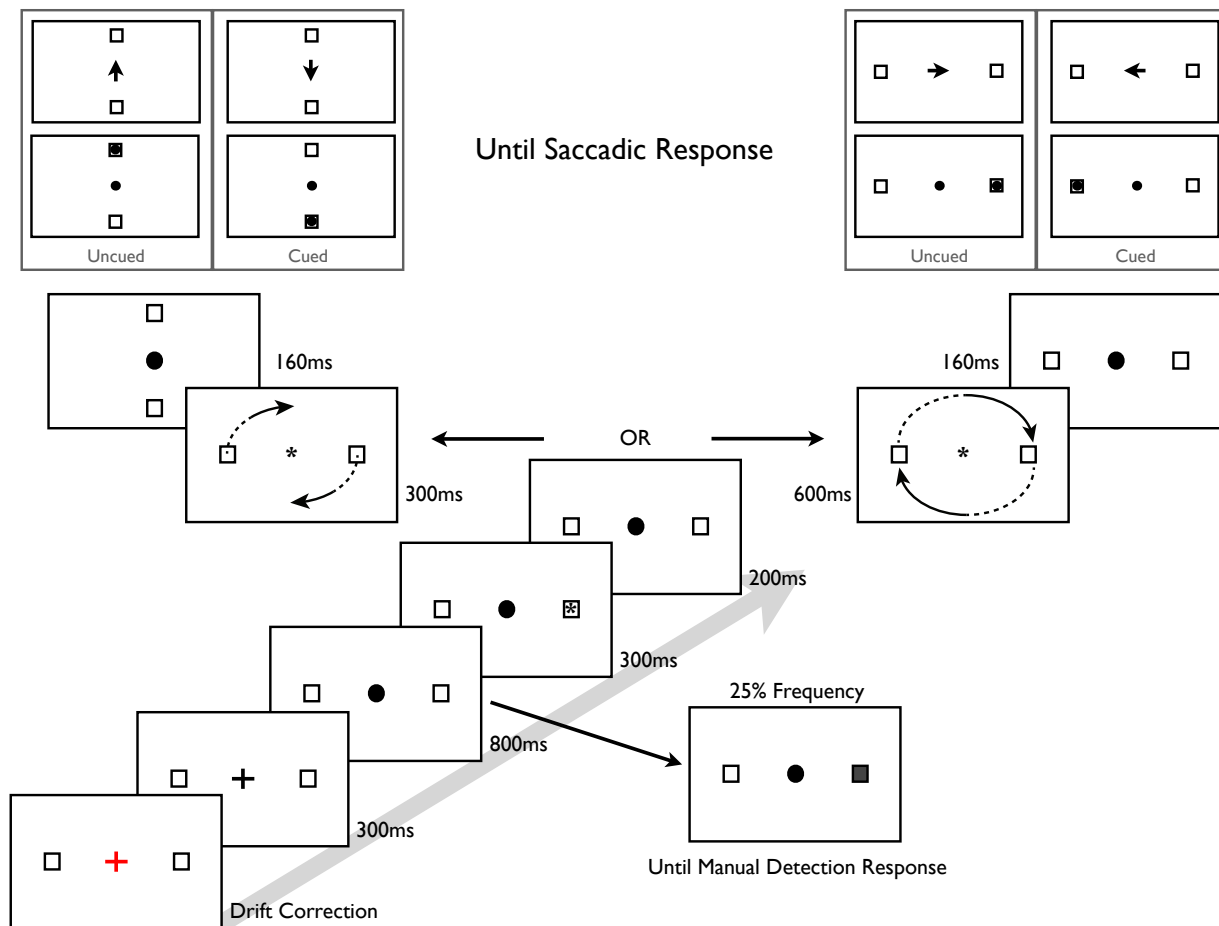


Figure 4: Sequence of events from Experiments 2 and 3. Note that this is a representation of a trial with placeholders starting on the horizontal axis. Time course and sequence of events was the same for vertical axis start. The manual-go signal that replaced the cue on 25% of the trials (illustrated by the box pointed to by the arrow) was used in Experiment 3.

Results

The first 30 trials in Block One were excluded from analysis as practice. Trials in which observers did not maintain fixation before the onset of a target were aborted and recycled (10.1%). Of the remaining trials, saccades initiated in less than 100ms (0.4%) or more than 700ms (4.6%) after the target onset were excluded from analysis. Trials that were considered inaccurate (when the saccade did not land within 3.0 DVA of the target) were also excluded from analysis (12.4%).

SRT was analyzed via a 2 (cued or uncued target) x 2 (central or peripheral target) x 2 (90- or 180-degree rotation) repeated measures ANOVA (60 trials/cell; Figure 5). This revealed no main effect of cueing, $F(1, 7) = 1.93, p = 0.21, \eta^2 = .00$, no main effect of target type, $F(1, 7) = 2.24, p = 0.18, \eta^2 = .03$, and no main effect of rotation $F(1, 7) = 0.43, p = 0.53, \eta^2 = .00$. There was a significant interaction between cueing and rotation, $F(1, 7) = 12.54, p < 0.01, \eta^2 = .00$, where observers were faster to respond to cued targets (317ms) than uncued targets (332ms) when the placeholders rotated 180-degrees, but not when they rotated 90-degrees (cued = 327ms, uncued = 327ms). There was not a significant interaction between cueing and target type, $F(1, 7) = 0.29, p = .61, \eta^2 = .00$, nor between target type and rotation, $F(1, 7) = 0.06, p = 0.82, \eta^2 = .00$. There was not a significant three-way interaction between cueing, target type and rotation, $F(1, 7) = 0.35, p = 0.57, \eta^2 = .00$.

As in Experiment 1, in order to quantify the evidence for or against the main effect of interest, a Bayesian paired samples t-test was conducted (naive prior, $\delta \sim \text{Cauchy}(0, 0.707)$) on the cueing effect in the 90-deg rotation/peripheral-onset condition only. This test showed anecdotal evidence for a null effect of cueing, $\text{BF}_{10} = 0.38$.

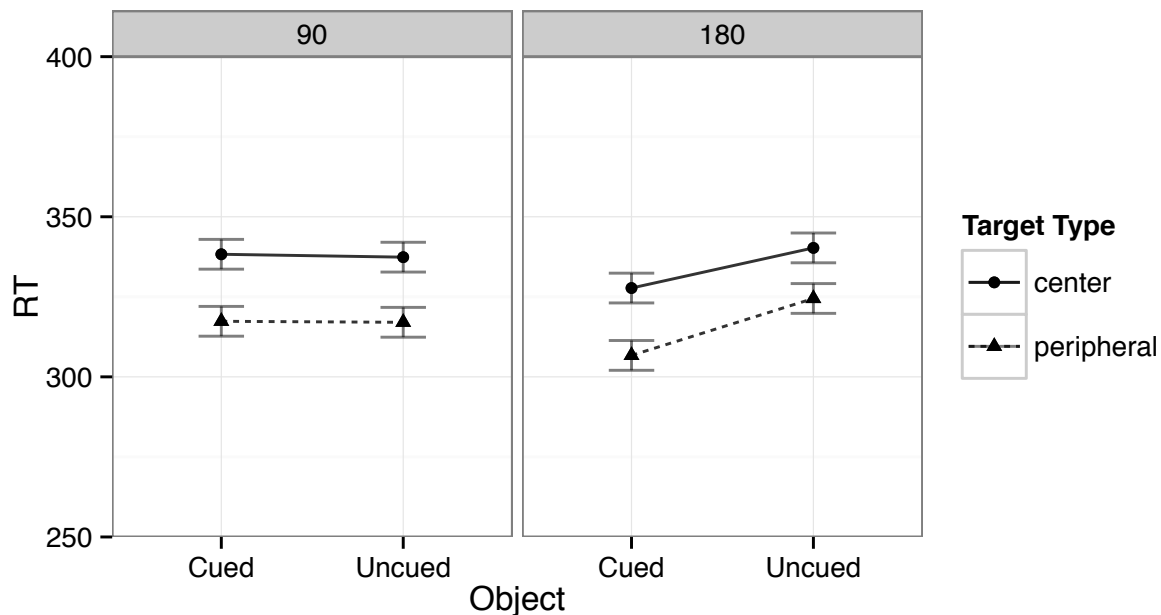


Figure 5: Mean saccade reaction time to cued and uncued central and peripheral targets in Experiment 2 after 90- and 180- degree rotation of placeholder boxes (Error bars = FLSD).

Similar to Experiment 1, this experiment shows no differential effect of cueing between target types. Focussing on the 90 deg condition, the results replicate what we saw in Experiment 1, even though a spatial ACS was made unlikely. We do demonstrate an inhibitory effect of cueing when the placeholder boxes rotate 180-degrees, however this inhibitory cueing effect is at the cued location, and not at the cued object. This location-based inhibitory effect shows the gradient of inhibition reported robustly in the literature (e.g., Vaughan, 1984; Klein & MacInnes, 1999; Hooge & Frens, 2000; Christie, Hilchey & Klein, 2013; Wang, Hilchey, Cao & Wang, 2014; Christie, Hilchey, Mishra & Klein, 2015; Jayaraman et al., 2016; MacInnes, 2017). Slowest responses occur at the cued location, and RTs decrease monotonically as cue-target distance increases². These findings are contrary to Abrams and Dobkin's suggestion that IOR should be observed at the object, and supports the proposal that oculomotor IOR is an output-based effect.

Experiment 3

Experiment 3 was the same as Experiment 2, with one additional factor intended to more greatly incentivize observers to attend to the visual periphery at the time of the cue. We accomplished this by introducing a manual go/no-go task. On relatively infrequent 'go' trials a target appearing in place of the cue required a manual response and the trial was terminated when this response occurred. On 'no go' trials the cue and remaining events were identical to the trials in Experiment 2.

Method

Participants

Ten naive observers (1 male; 1 left-handed) ranging in age from 18-30 participated in the study for course credit in one 90 minute session. All observers were recruited from the undergraduate subject pool at Dalhousie University.

Apparatus and Procedure

All details for trials in the present study were the same as in Experiment 2, except that on 25% of the trials one of the two empty peripheral boxes was filled white at the time of the cue. The observers task on these trials was to make a speeded button press to report the appearance of this "go" stimulus which terminated the trial (Figure 4). No RT data were recorded on these trials as they were not pertinent to our research question. Observers completed 600 trials in a single block.

² Upon visual inspection of the data in Figure 5, this effect in the 180-deg condition could be interpreted as object-based facilitation when contrasted with the mean RTs in the 90-deg condition. However, cue-elicited facilitation is short-lasting (<300ms) and not motoric (Hilchey, Klein & Satel, 2014) and is unlikely to be the cause of the effect at the 1260ms CTOA.

Results

The first 30 trials were excluded from analysis as practice. Trials in which observers did not maintain fixation before the onset of a target were aborted and recycled (6.2%). Observers made untoward eye movements to the go-signal on 16.1% of manual trials, and failed to record a response on 4.7% of manual trials. Manual false alarm responses were made on 1.2% of eye movement trials. Of the remaining trials, saccades initiated in less than 100ms (0.01%) or more than 700ms (5.4%) after the target onset were excluded from analysis. Trials for which inaccurate (not within 3.0 DVA) saccades to the target were executed were excluded from analysis (6.5%).

SRT was analyzed via a 2 (cued or uncued target) x 2 (central or peripheral target) x 2 (90- or 180-degree rotation) repeated measures ANOVA (71 trials/cell; Figure 6). This revealed no main effect of cueing, $F(1, 9) = 0.22, p = 0.65, \eta^2 = .00$, no main effect of target type, $F(1, 9) = 1.00, p = 0.34, \eta^2 = .02$, and a main effect of rotation $F(1, 9) = 17.5, p < 0.01, \eta^2 = .00$. There were no significant interactions; cueing x rotation, $F(1, 9) = 0.04, p = 0.84, \eta^2 = .00$; cueing x target type, $F(1, 9) = 0.03, p = 0.86, \eta^2 = .00$; target type x rotation, $F(1, 9) = 2.99, p = 0.11, \eta^2 = .00$. There was not a significant three-way interaction, $F(1, 9) = 0.41, p = 0.54, \eta^2 = .00$.

As in the preceding experiments, in order to quantify the evidence for or against the main effect of interest, a Bayesian paired samples t-test was conducted (naive prior, $\delta \sim \text{Cauchy}(0, 0.707)$) on the cueing effect in the 90-deg rotation/peripheral-onset condition only. This test showed moderate evidence for a null effect of cueing, $\text{BF}_{10} = 0.31$.

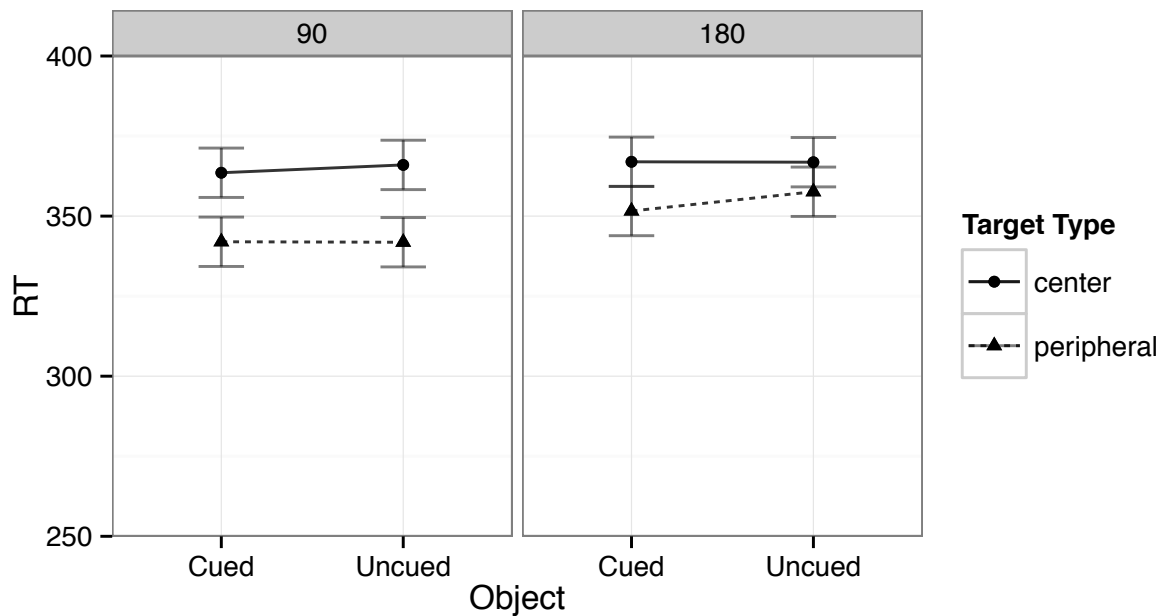


Figure 6: Mean saccade reaction time to cued and uncued central and peripheral targets in Experiment 3 after 90- and 180- degree rotation of placeholder boxes (Error bars = FLSD).

Discussion

We continue to see little evidence for object-based oculomotor IOR, even when observers are incentivized by task demands to covertly attend the cue. Previous studies have shown that increased task demands, such as a spatial working memory load (Castel, Pratt & Craik, 2003) or varying stimulus-response mappings (Lupianez, Milan, Tornay, Madrid & Tudela, 1997), can reduce or delay IOR. Thus, it is possible that increased cognitive load due to task demands at the time of the cue in the present study resulted in the attenuation of the cueing effect, that we believe was location-based and inhibitory, in the 180 deg rotation condition of the previous experiment. Although our intention was to evaluate the input- and output- based contributions of saccade-measured object-based IOR, repeated failures to observe object-based oculomotor IOR effects have made this impossible.

Experiment 4

Due to multiple unsuccessful attempts to observe object-based oculomotor IOR (with peripheral targets), we now seek to replicate precisely the design from Abrams and Dobkin Experiment 4, where the effect was first reported.

Method

Participants

Nine naive observers (3 male; 0 left-handed) ranging in age from 18-35 participated in the study for course credit in one 60 minute session. All observers were recruited from the undergraduate subject pool at Dalhousie University.

Apparatus and Procedure

Observers completed eight blocks of 32 trials. All methods in the present study were the same as in Experiment 1, with two exceptions. Only peripheral onset targets were administered, and the fixation dot disappeared at the time of target onset (Figure 7). The task was modelled on the methods reported by Abrams and Dobkin as precisely as possible given the details in their manuscript.

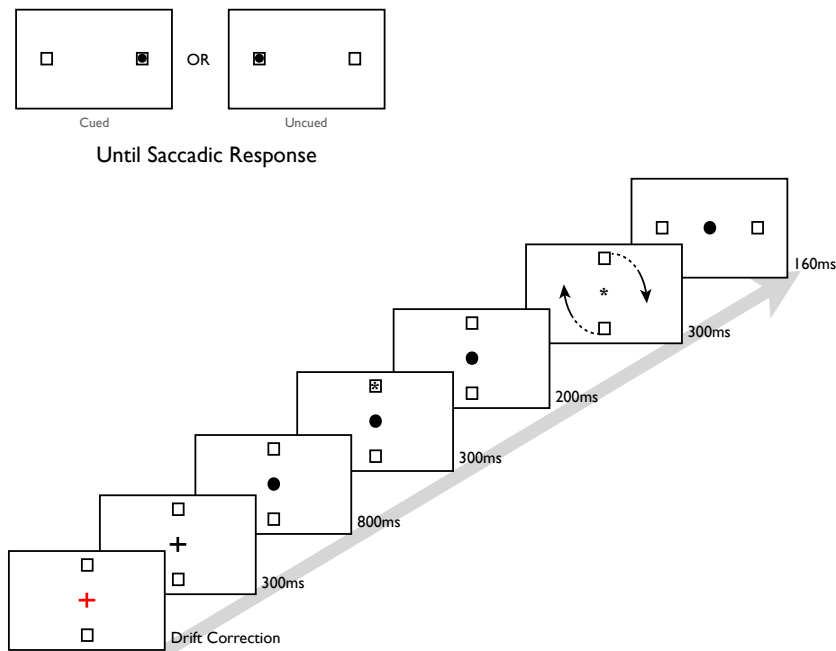


Figure 7: Sequence of events from Experiment 4 (n.b. placeholders started on the vertical axis and terminated on the horizontal after 90-degrees of rotation on all trials).

Results

The first block was excluded from analysis as practice. Trials for which observers did not maintain fixation before the onset of a target were aborted and recycled (7.9%). Of the remaining trials, saccades initiated in less than 100ms (4.7%) or more than 700ms (0.3%) after the target onset were excluded from analysis. Trials in which inaccurate (not within 3.0 DVA) saccades were made were excluded from analysis (2.8%).

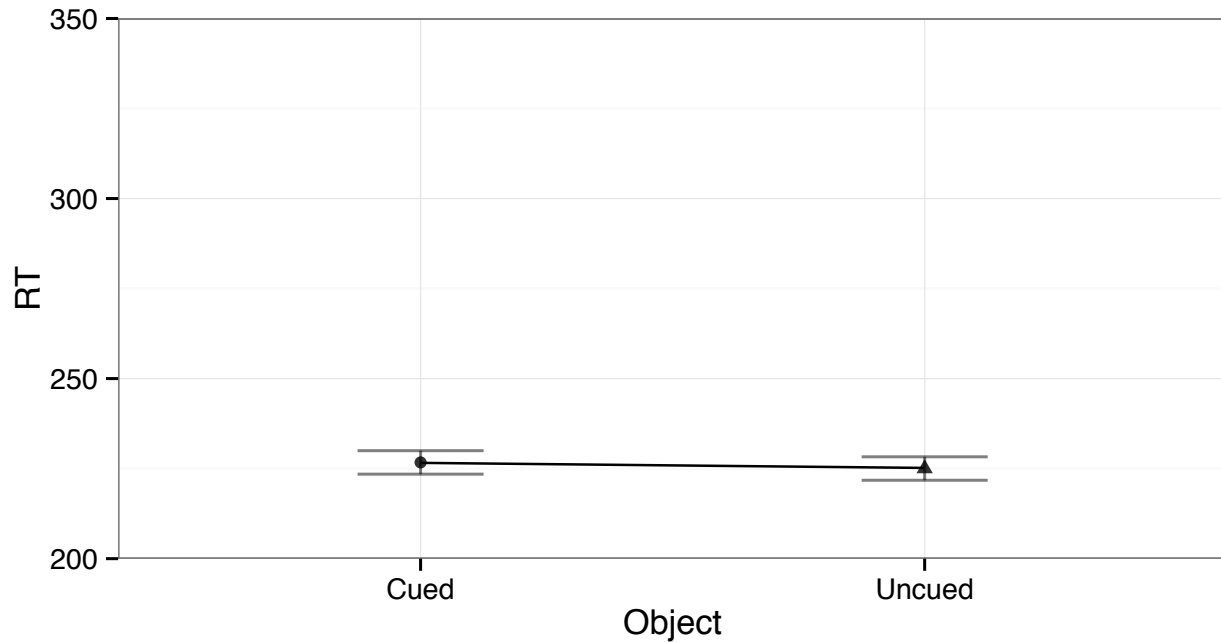
A t-test (112 trials/cell) showed no difference in SRT for cued (227ms) and uncued (225ms) targets, $t(8) = 0.60$, $p = 0.565$, $\eta^2 = .00$ (see Figure 8).

As in the preceding experiments, in order to quantify the evidence for or against the main effect of interest, a Bayesian paired samples t-test was conducted (naive prior, $\delta \sim \text{Cauchy}(0, 0.707)$). This test showed anecdotal evidence for a null effect of cueing, $\text{BF}_{10} = 0.37$.

Figure 8: Mean saccade reaction time to cued and uncued peripheral targets in Experiment 4 after 90 degree rotation of placeholder boxes (Error bars = FLSD).

Discussion

The present study replicated the methods from Abrams and Dobkin (1994)'s Experiment 4 but obtained a different result. As in the preceding 3 experiments, we found minimal evidence



for object-based IOR when responses to peripheral targets required saccadic responses. Due to the scarcity of significant cueing effects across all experiments to this point, we believe it is pertinent to now demonstrate the presence of IOR using this stimulus set.

Experiment 5

This experiment evaluates whether oculomotor IOR can even be obtained with the stimuli used in the previous experiments. Here we will replicate the conditions from Experiment 1, however without arrow targets. Furthermore, on half the trials the placeholder boxes will not rotate. This will allow the measurement of cueing effects at two locations - the location where the cue occurred, as well as at the cued object.

Method

Participants

Twelve naive observers (3 male; 1 left-handed) ranging in age from 18-21 participated in the study for course credit in one 90 minute session. All observers were recruited from the undergraduate subject pool at Dalhousie University. Two participants who completed the experiment were excluded due to a high proportion of eye movement errors resulting from poor calibration (44.1% and 64.9%), leaving ten participants for analysis.

Apparatus and Procedure

All details for the present study were the same as Experiment 1, except for two factors. In this experiment there were no arrow targets. Furthermore, on half the trials the placeholder boxes did not rotate (Figure 9).

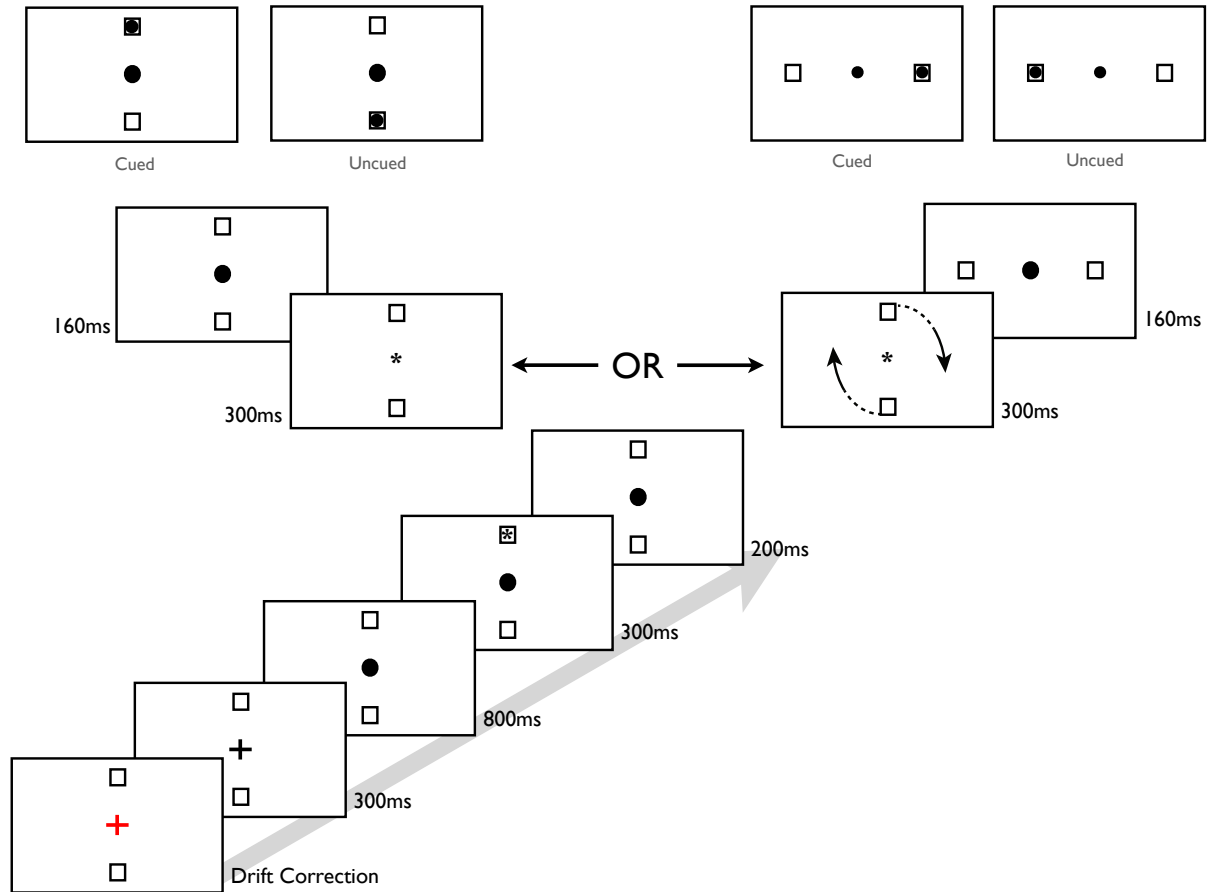


Figure 9: Sequence of events from Experiment 5, see text for explanation.

Results

The first block was excluded from analysis as practice. Trials in which observers did not maintain fixation before the onset of a target were aborted and recycled (11.8%). Of the remaining trials, saccades initiated in less than 100ms (0.1%) or more than 700ms (1.5%) after the target onset were excluded from analysis. Trials in which inaccurate (not within 3.0 DVA) saccades were made were excluded from analysis (3.2%).

SRT was analyzed via a 2 (cued or uncued target) x 2 (motion or stationary) repeated measures ANOVA (56 trials/cell). This analysis revealed a main effect of cueing, $F(1, 9) = 24.78$, $p < 0.01$, $\eta^2 = .15$, wherein observers were slower to respond to cued targets. There was a main effect of motion, $F(1, 9) = 78.60$, $p < 0.01$, $\eta^2 = .62$, wherein observers were slower to respond to targets when there was no motion. There was an interaction between cueing and motion, $F(1, 9)$

$= 7.83, p = 0.02, \eta^2 = .07$, wherein the effect of cueing was larger in trials where there was no motion (Figure 10).

As in the preceding experiments, in order to quantify the evidence for or against the main effect of interest, a Bayesian paired samples t-test was conducted (naive prior, $\delta \sim \text{Cauchy}(0, 0.707)$) on the cueing effect in the motion/peripheral-onset condition only. This test showed anecdotal evidence for an effect of cueing, $BF_{10} = 1.32$.

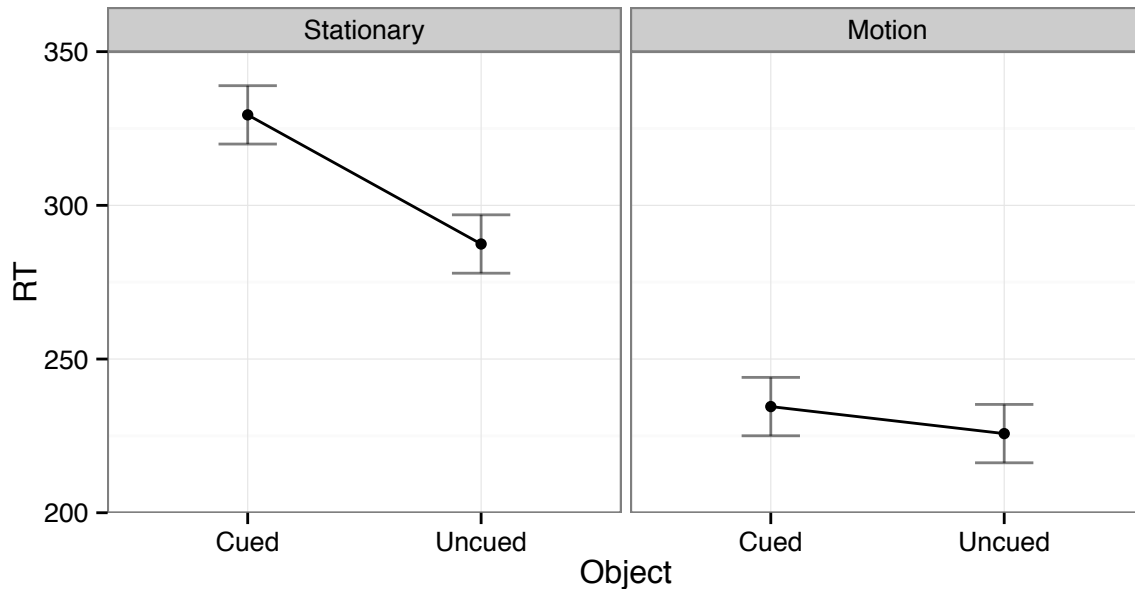


Figure 10: Mean saccade reaction time to cued and uncued peripheral targets in Experiment 5 across rotation conditions (Error bars = FLSD).

Discussion

Because robust IOR was observed in the stationary condition, we can be confident that IOR was generated by our cues. Because the same cues and targets were used in the stationary and rotation conditions the attenuated inhibitory effect in the rotation condition implies that the IOR generated by the cue did not move with the cued object. Therefore the present experiment shows little convincing evidence for object-based oculomotor IOR. These findings converge with the findings from Experiment 2 to support the hypothesis that oculomotor IOR is coded in spatial rather than object coordinates.

General Discussion

The pattern of results across all five experiments lends scant evidence for object-based oculomotor IOR. A mega-analysis of the results from the 90 degree condition across all five experiments ($N = 47$) is presented in Figure 11³.

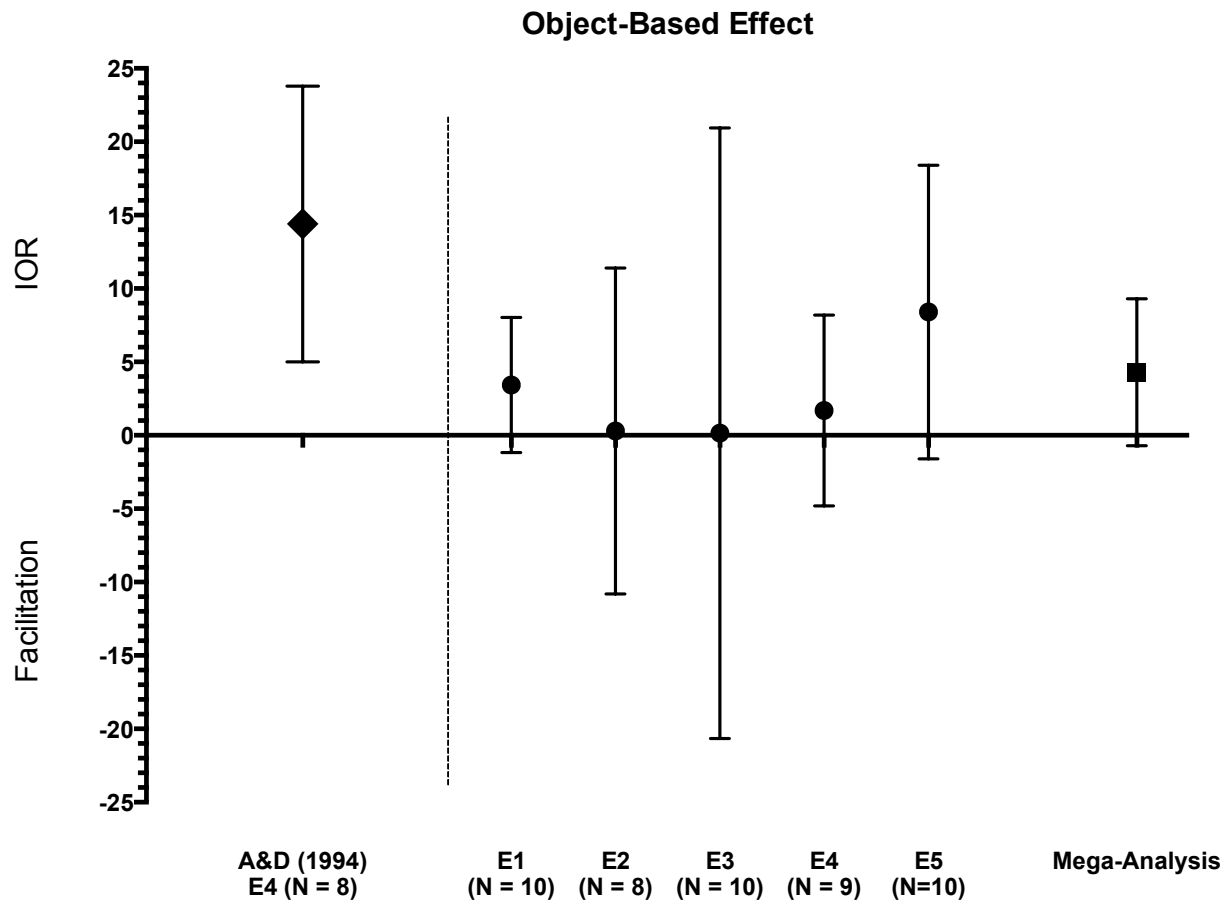


Figure 11: Effect sizes and 95% confidence intervals for the effect of object-based cueing for peripheral targets in the 90-deg rotation condition, as in Abrams and Dobkin (1994). Sample size for each experiment is reported in parentheses.

When considering exclusively the precise context in which Abrams and Dobkin obtained the effect (90-degree rotation with peripheral targets; Figure 11), a mega-analysis across the five experiments also shows little evidence for the hypothesis, with anecdotal evidence in support of the null⁴. All but one point estimate for the object-based effect of cueing - the original study - has a margin of error that captures 0ms as a plausible value. Comparing the original finding from Abrams and Dobkin with the present series of experiments the hypothesis that oculomotor IOR

³ When Abrams and Dobkin's 14ms result is included meta-analytically, the CI95 for the effect marginally excludes zero: 5.09 [0.63, 9.55].

⁴ Bayes factors from a Bayesian repeated measures ANOVA on the object-based cueing effect across the present experiments showed anecdotal evidence for the null for the main effect of Cueing, $BF_{10} = 0.426$, extreme evidence for the main effect of Experiment, $BF_{10} = 3.99e+3$, moderate evidence for a null model with both main effects, $BF_{10} = .20$, and strong evidence for a null model of the interaction, $BF_{10} = 0.10$.

exists in object-based reference has little support. Standing alone, our findings lend support for the need in the scientific community to encourage replication efforts. When considered with other failed attempts to demonstrate object-based IOR with saccadic responses to targets in variants of the moving boxes paradigm (Abrams & Pratt Experiment 1, 2000; Souto & Kerzel, 2009) and in Egly et al.'s double-rectangle paradigm (Şentürk, Greenberg, & Liu, 2016), it lends support for the empirical conclusion that oculomotor IOR is not object-based in the most basic approaches for testing it.

Future studies examining object-based cueing effects in moving box displays ought to consider five prescriptions offered by Reppa, Schmidt and Leek (2012) in their comprehensive review of the literature on object-based cueing effects. The experimental conditions that maximize the likelihood of obtaining object-based effects in a dynamic display include:

- 1) salient/unambiguous object cueing
- 2) salient cue-back to fixation
- 3) spatiotemporal continuity of objects
- 4) unpracticed observers
- 5) non-confounding facilitatory and inhibitory processes

Clearly, compliance with these prescriptions is not sufficient for generating object-based oculomotor IOR. Our experimental designs implemented each of these prescriptions and yet still did not replicate the findings of the original study. In fact, to our knowledge, only one study reporting IOR measured by eye movement responses in moving displays has satisfied each of these requirements (but see also Swalwell, Atkinson & Smith, 2018). Tas, Dodd and Hollingworth (2012) demonstrated object-based oculomotor IOR in a moving box paradigm, albeit with methodological differences from our design, any of which might have been responsible for the different findings. Firstly, Tas et al. required observers to saccade to the uninformative cue as well as to targets, whereas in each experiment of the present study observers were required to maintain fixation at the time of the first event. It is conceivable that the requirement to execute a saccade to the uninformative first signal (rather than ignore it) generates an object-based oculomotor IOR effect. Secondly, Tas et al. implemented a surface feature manipulation (colour change) that was not present in our designs. Observers in their study may have implemented a more perceptual ACS than observers in the present design, thus affording a context more amenable to an object-based effect (Hilchey, Pratt & Christie, 2016). Furthermore, the onset asynchrony between the central reorienting cue-back relative and the start of placeholder motion differed between the present experiments (0ms), Abrams and Dobkin (0ms), and Tas et al. (200ms). This difference could potentially influence temporal dynamics of the allocation of peripheral attention, and ergo potentially modulate the degree to which any object-based effect was either instantiated, or measurable. While being mindful of Reppa's prescriptions for obtaining object-based effects, future work should examine the extent to which any of these factors—the perceptual processing demands of the task, the requirement to make eye movements to the cue, and the temporal dynamics of allocating spatial attention—modulate object-based encoding for saccadic eye movements.

Our paper is exclusively concerned with the measurement of object-based IOR when the response to the target calls for an eye movement. There is a robust literature on object-based

cueing effects (Tipper, Driver & Weaver, 1991; Egly, Driver & Rafal, 1994; for reviews, see Grison, Kessler, Paul, Jordan, & Tipper, 2005; Reppa, Schmidt & Leek, 2012) when these are measured with manual responses. It would be compatible with the foraging facilitator and novelty seeking functions that have been attributed to IOR if object-based cuing effects were similarly robustly observed when measured with oculomotor responses. We are not denying this possibility. Rather, if object-based oculomotor IOR effects do exist (e.g., Tas et al., 2012), the optimal conditions for eliciting them remain largely unknown.

References

- Abrams, R. A., & Dobkin, R. S. (1994). Inhibition of return: effects of attentional cuing on eye movement latencies. *Journal of Experimental Psychology: Human Perception and Performance*, 20(3), 467.
- Abrams, R. A., & Pratt, J. (2000). Oculocentric coding of inhibited eye movements to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance*, 26(2), 776.
- Castel, A. D., Pratt, J., & Craik, F. I. (2003). The role of spatial working memory in inhibition of return: Evidence from divided attention tasks. *Perception & Psychophysics*, 65(6), 970-981.
- Chica, A. B., Taylor, T. L., Lupiañez, Y., & Klein, R. M. (2010). Two mechanisms underlying inhibition of return. *Experimental Brain Research*, 201, 25–35. doi:10.1007/s00221-009-2004-1
- Christie, J., Hilchey, M. D., & Klein, R. M. (2013). Inhibition of return is at the midpoint of simultaneous cues. *Attention, Perception, & Psychophysics*, 75(8), 1610-1618.
- Christie, J., Hilchey, M. D., Mishra, R., & Klein, R. M. (2015). Eye movements are primed toward the center of multiple stimuli even when the interstimulus distances are too large to generate saccade averaging. *Experimental brain research*, 233(5), 1541-1549.
- Egely, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General*, 123(2), 161.
- Grisson, S., Kessler, K., Paul, M. A., Jordan, H., & Tipper, S. P. (2005). Object- and location-based inhibition in goal-directed action: Inhibition of return reveals behavioural and anatomical dissociations and interactions with memory processes. In G. Humphreys & J. Riddoch (Eds.), *Attention in Action: Advances from Cognitive Neuroscience*. United Kingdom: Psychology Press.
- Hilchey, M. D., Pratt, J., & Christie, J. (2016). Placeholders dissociate two forms of inhibition of return. *The Quarterly Journal of Experimental Psychology*, 1-13.
- Hilchey, M. D., Hashish, M., MacLean, G. H., Ivanoff, J., Satel, J., & Klein, R. M. (2014). On the role of eye movement monitoring and discouragement on inhibition of return in a go no-go task. *Vision Research*, 96, 133–139. doi:10.1016/j.visres.2013.11.008
- Hilchey, M. D., Klein, R. M., & Ivanoff, J. (2012). Perceptual and motor inhibition of return: components or flavors?. *Attention, Perception, & Psychophysics*, 74(7), 1416-1429.

- Hilchey, M. D., Klein, R. M., & Satel, J. (2014). Returning to “inhibition of return” by dissociating long-term oculomotor ior from short-term sensory adaptation and other nonoculomotor “inhibitory” cueing effects. *Journal of Experimental Psychology: Human Perception and Performance*, 40(4), 1603–1616.
- Hooge, I. T. C., & Frens, M. A. (2000). Inhibition of saccade return (ISR): Spatio-temporal properties of saccade programming. *Vision research*, 40(24), 3415-3426.
- Ishigami, Y., Klein, R. M., & Christie, J. (2009). Exploring the modulation of attentional capture by attentional control settings using performance and illusory line motion. *Visual Cognition*, 17(3), 431-456.
- JASP Team (2018). JASP (Version 0.9)[Computer software].
- Jayaraman, S., Klein, R. M., Hilchey, M. D., Patil, G. S., & Mishra, R. K. (2016). Spatial gradients of oculomotor inhibition of return in deaf and normal adults. *Experimental brain research*, 234(1), 323-330.
- Klein, R. (1988). Inhibitory tagging system facilitates visual search. *Nature*, 334(6181), 430-431.
- Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, 4, 138–147. doi:10.1016/S1364-6613(00)01452-2
- Klein, R. M., & Hilchey, M. D. (2011). Oculomotor inhibition of return. In S. Liversedge, I. D. Gilchrist & S. Everling (Eds.), *The Oxford handbook of eye movements* (pp. 471– 492). Oxford, UK: Oxford University Press.
- Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological science*, 10(4), 346-352.
- Klein, R. M. & Redden, R.S. (2018). Two "inhibitions of return" bias orienting differently. Chapter for T. Hubbard (Ed.) *Spatial Biases in Perception and Cognition*. Cambridge University Press.
- Lawrence, M. A. (2013). ez: Easy analysis and visualization of factorial experiments. R package version, 4-2.
- Lupiañez, J., Klein, R. M., & Bartolomeo, P. (2006). Inhibition of return: Twenty years after. *Cognitive Neuropsychology*, 23, 1003–1014. doi: 10.1080/02643290600588095.
- Lupiañez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics*, 59(8), 1241-1254.
- MacInnes, W. J. (2017). Multiple diffusion models to compare saccadic and manual responses for inhibition of return. *Neural computation*, 29(3), 804-824.

- Müller, H. J., & von Mühlenen, A. (1996). Attentional tracking and inhibition of return in dynamic displays. *Perception & Psychophysics*, 58, 224–249.
- Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–556). Hove, UK: Erlbaum Ltd.
- Posner, M. I., Rafal, R. D., Choate, L., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, 2, 211–228. doi:10.1080/02643298508252866
- Rafal, R., Egly, R., & Rhodes, D. (1994). Effects of inhibition of return on voluntary and visually guided saccades. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, 48, 284–300. doi:10.1037/1196-1961.48.2.284
- Redden, R. S., Hilchey, M. D., & Klein, R. M. (2016). Peripheral stimuli generate different forms of inhibition of return when participants make prosaccades versus antisaccades to them. *Attention, Perception, & Psychophysics*, 78(8), 2283–2291.
- Reppa, I., Schmidt, W. C., & Leek, E. C. (2012). Successes and failures in producing attentional object-based cueing effects. *Attention, Perception, & Psychophysics*, 74(1), 43–69.
- Şentürk, G., Greenberg, A. S., & Liu, T. (2016). Saccade latency indexes exogenous and endogenous object-based attention. *Attention, Perception, & Psychophysics*, 78(7), 1998–2013.
- Souto, D., & Kerzel, D. (2009). Involuntary cueing effects during smooth pursuit: facilitation and inhibition of return in oculocentric coordinates. *Experimental brain research*, 192(1), 25–31.
- Swalwell, R., Atkinson, A., & Smith, D.T. (July, 2018). Are faces subject to IOR? Evidence from dynamic displays. In R.S. Redden & D.T. Smith (Chairs), *On the control of visual attention*. Symposium conducted at the joint meeting of the Canadian Society for Brain, Behaviour and Cognitive Sciences and the European Psychological Society, St. John's, NL.
- Tas, A. C., Dodd, M. D., & Hollingworth, A. (2012). The role of surface feature continuity in object-based inhibition of return. *Visual cognition*, 20(1), 29–47.
- Taylor, T. L., & Klein, R. M. (2000). Visual and motor effects in inhibition of return. *Journal of Experimental Psychology: Human Perception and Performance*, 26, 1639–1656. doi:10.1037/0096-1523.26.5.1639
- Tipper, S. P., Driver, J., & Weaver, B. (1991). Short report: Object-centred inhibition of return of visual attention. *The Quarterly Journal of Experimental Psychology*, 43(2), 289–298.

- Tipper, S. P., Jordan, H., & Weaver, B. (1999). Scene-based and object-centered inhibition of return: Evidence for dual orienting mechanisms. *Perception & Psychophysics*, 61(1), 50-60.
- Vaughan, J. (1984). Saccades directed at previously attended locations in space. In *Advances in Psychology* (Vol. 22, pp. 143-150). North-Holland.
- Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., ... & Meerhoff, F. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, 25(1), 58.
- Wang, B., Hilchey, M. D., Cao, X., & Wang, Z. (2014). The spatial distribution of inhibition of return revisited: No difference found between manual and saccadic responses. *Neuroscience letters*, 578, 128-132.
- Wang, Z., & Klein, R. M. (2012). Focal spatial attention can eliminate inhibition of return. *Psychonomic Bulletin & Review*, 19(3), 462-469.
- Weaver, B., Lupiáñez, J., & Watson, F. L. (1998). The effects of practice on object-based, location-based, and static-display inhibition of return. *Perception & Psychophysics*, 60, 993– 1003.