

TWO FORMS OF INHIBITION OF RETURN DISSOCIATED BY REFLEXIVE  
OCULOMOTOR ENGAGEMENT

by

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## **DEDICATION PAGE**

To my favourite collaborator—Marilyn.

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## **ABSTRACT**

Inhibition of return (IOR) is usually viewed as an inhibitory aftermath of visual orienting typically seen in the form of slower responses to previously cued targets. Arguments have been posed for ‘attentional’ and ‘motoric’ components to this effect, as well as ‘space’ and ‘object’ distinctions. Taylor and Klein (2000) suggested that there may be two dissociable forms of IOR - one with its effect closer to the input end of the information processing continuum, and one effect closer to the output end of this continuum. This thesis will explore various boundary conditions on this dissociation in order to reconcile discrepancies between the ‘two forms’ account of inhibitory cueing and other theoretical frameworks for these phenomena. We conclude that there are two forms of inhibition of return: an input form that operates as a bias against previously attended objects, and an output form that operates as a spatial bias against orienting.



## LIST OF ABBREVIATIONS USED

IOR	Inhibition of return
CTOA	Cue-target onset asynchrony
RT	Response/reaction time
ACS	Attentional control setting
SAT	Speed-accuracy tradeoff
2AFC	Two-alternative forced choice
SOA	Stimulus-onset asynchrony
DVA	Degrees of visual angle
ANOVA	Analysis of variance
FLSD	Fisher's least significant difference
S-R	Stimulus-response
SRT	Saccadic reaction time

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## **CHAPTER 1: INTRODUCTION**

Inhibition of return (IOR) is described as an inhibitory aftereffect of visuospatial orienting (Posner & Cohen, 1984; Posner, Rafal, Choate & Vaughan, 1985). IOR is typically observed experimentally as slower responding to a target that appears in a location toward which an observer had previously oriented. This effect has stimulated a broad spectrum of research across various domains of cognitive psychology in attempts to determine its cause and effect. As well, much research has attempted to explain the neural mechanisms involved in this effect. Perhaps the most noteworthy stimulus to the myriad of research on this topic is the debate about the functional significance of IOR. However, only once we have answers to the more fundamental questions can we most accurately infer its utility. A more thorough review of this research will properly warrant these questions.

### **1.1 THE MODEL TASK**

IOR is typically explored experimentally in the spatial cueing paradigm (Figure 1.1 - left). The typical spatial cueing paradigm requires an observer to fixate some central stimulus on a screen. This central stimulus is usually flanked by two (or more) equidistant peripheral placeholder boxes. Some time after the start of a trial, a brief stimulus (typically 50-300ms in duration) occurs at one of the placeholder boxes. This onset could be a brightening of one of the boxes or the appearance of some stimulus within one of these boxes. This onset (also referred to as a cue), is typically uninformative as to the location of any subsequent stimuli. Some duration after the cue

(cue-target onset asynchrony; CTOA), a target appears in one of these boxes that requires some response. Various response types have been used to explore the effect, such as manual detection (Posner & Cohen, 1984; Maylor & Hockey, 1985), manual localization (Taylor & Klein, 2000; Hilchey, Klein & Satel, 2014), manual discrimination (Lupianez, Milan, Tornay, Madrid, & Tudela, 1997), temporal order judgments (Posner et al., 1985), and saccadic eye movements (Taylor & Klein, 2000).

The results that are obtained from these paradigms are typically biphasic (Figure 1.1 - right) - when the CTOA is short (<300ms), responses to targets that appear at the same location as the cue tend to be fastest. This effect is suggested to occur as a result of attention being captured by the cue. When the interval between the cue and target is longer (>300ms) and there is sufficient time for attention to return to fixation, responses to targets that appear at the same location as the cue tend to be slowest. This effect is suggested to occur as an attentional bias against the previously cued location. This inhibitory effect was first discovered by Posner and Cohen (1984), and subsequently named inhibition of return (IOR; Posner et al., 1985).

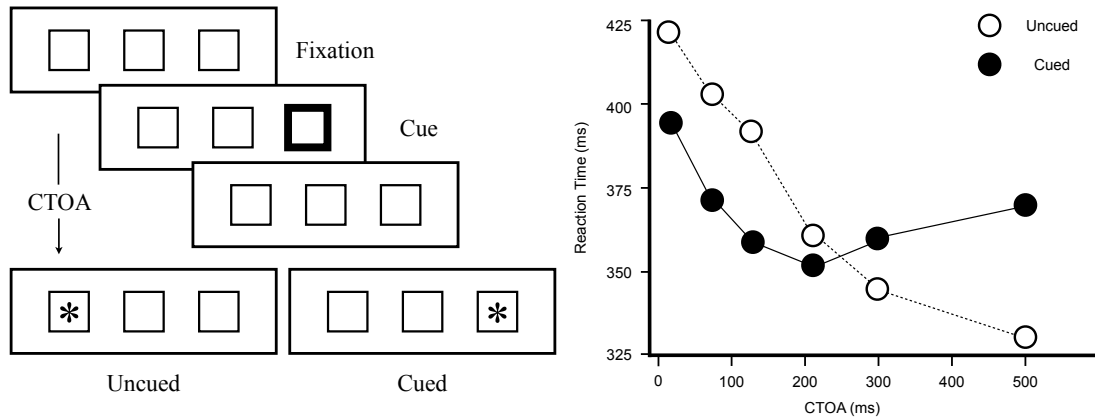


Figure 1.1. (Left) Sequence of events in the model spatial cueing task. (Right) Prototypical pattern of response times as a function of CTOA in the model task. Responses to targets at the cued location are represented with black circles, and responses to targets at uncued locations are represented with white circles (redrawn from Klein (2000)).

## 1.2 EARLY EMPIRICAL DISSOCIATIONS

Posner and Cohen (1984) attributed the cause of the inhibition to be any peripheral stimulus and suggested that the effect was to reduce the efficiency of target detection in the vicinity of this stimulus. However, in different variants of the model task Posner et al. (1985) identified oculomotor activation as the cause and a motor bias as the effect. Different causes and resulting effects between these two patterns of findings beg the question as to whether or not they are actually reflecting the same mechanism (for a more thorough review of these distinctions, see Hilchey, Klein & Satel, 2014; Klein & Redden, 2016).

Several years after these seminal studies, investigations into the phenomenon of IOR had considered dissociable aspects of this inhibitory mechanism. Tipper, Driver and

Weaver (1991) first implemented the “moving-box” paradigm, in which one of multiple moving placeholder boxes is cued. This novel method was designed to evaluate whether the inhibitory after-effect exists in a dynamic, object-based reference frame. In the moving objects condition, Tipper and colleagues reported slower responding to the cued object but not to the cued location when measuring with speeded manual button press responses. Because the size of the inhibitory effect was larger in their static boxes condition than in their moving boxes condition, it was suggested that two components of inhibition (space-based and object-based) may have contributed to the net effect in the static display, while only the object-based component contributed to the inhibition in the dynamic display.

Abrams and Dobkin (1994) also sought to determine if IOR was affecting dissociable components, however they hypothesized the dissociation at the perceptual and/or motoric stages of the information processing continuum. Abrams and Dobkin administered central arrow or peripheral onset targets in separate blocks and required saccadic responses to these targets following spatially uninformative peripheral cues. A central arrow target following a peripheral onset allows the evaluation of a motoric (output) contribution to the inhibition, as there is no repetition of the sensory pathway from the cue relative to the target. However, inhibition measured to a peripheral onset target can be attributed to motoric (output) and/or attentional/perceptual (input) processes as the cue and target are linked in retino/spatiotopic coordinates in static displays, and object-based coordinates in dynamic displays. 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. When the cued and uncued 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. Based on this pattern of results, Abrams and Dobkin concluded that there were two components contributing to IOR, and that only the perceptual component of IOR moves with objects whereas the motoric component does not.

Shortly thereafter, Taylor and Klein (2000) conducted a parametric investigation into the phenomenon of IOR to systematically explore the relative contributions of input and output mechanisms. They did so by assessing the relationships between mixed central arrow and peripheral signals across response modalities. By counterbalancing the response required to a spatially uninformative first signal (ignore, manual, saccade) and second signal (manual, saccade) over six experimental sessions, 24 unique conditions were created (Figure 1.2). The results showed that when observers were required to suppress oculomotor activity for the duration of a trial (Figure 1.2: cells 1 & 2), slower responding at cued locations was only found when the second signal was a peripheral event. Because this inhibitory effect could be generated by a centrally-presented arrow, these results preclude any sensory cause for the resulting effect as the central arrow and peripheral luminance signals do not overlap in location. Furthermore because inhibition can only be measured in responses to targets presented at the peripheral locations suggests that the effect exists at the spatial location and manifests on input mechanisms. In striking contrast, when observers were required to engage the oculomotor system at any point during a trial (Figure 1.2: cells 3 - 6), equivalent inhibition to both types of second signal was found, suggesting that this inhibitory effect operates on output

processes, and manifests as a bias against responses spatially compatible with the first signal. Taylor and Klein posited the dissociation as evidence for two forms of IOR. One form occurs when eye movements are prohibited, and affects input processes at the peripheral location compatible with the first signal. The other occurs when eye movements are required, and affects outputs in the spatially compatible direction of the first signal.

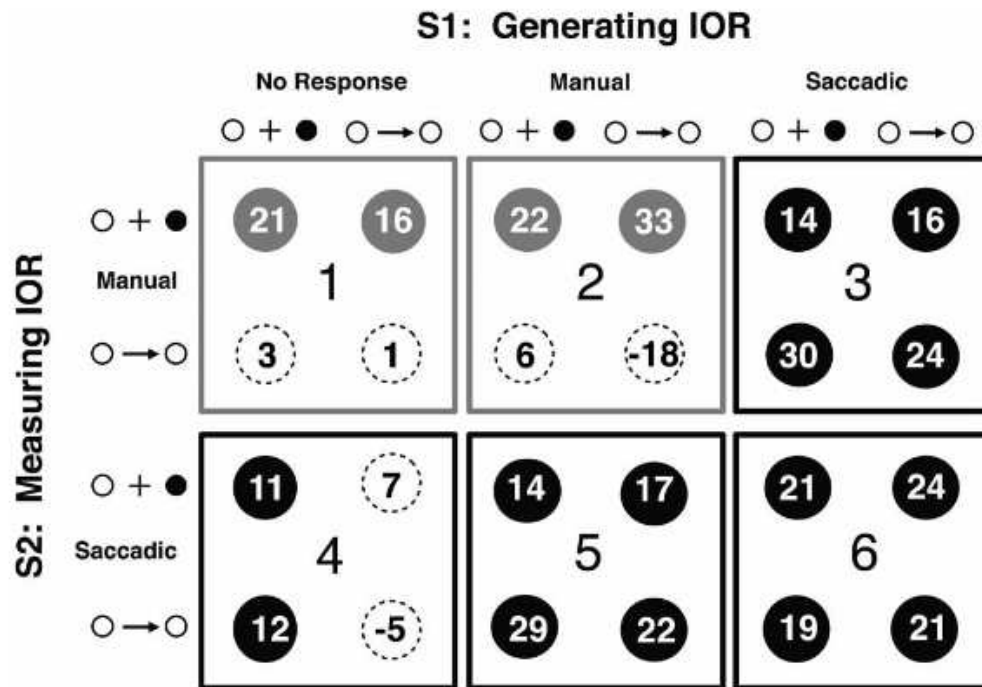


Figure 1.2. Results matrix (Cued RT - Uncued RT) from Taylor & Klein (2000). The large rows and columns represent the stimulus-response ensemble (numbered in the center of each panel). The small rows and columns within them represent the signal types. The conditions purported to elicit output-based effects are the black panels, while input-based effects are grey panels. Solid circles depict statistically significant effects.



### **1.3 ONE 'TWO COMPONENT' MODEL DEFEATED**

Abrams and Dobkin's two components model for IOR has been strongly opposed as a result of Taylor and Klein's findings. Although both studies similarly implemented a static display paradigm, Hilchey, Klein and Ivanoff (2012) astutely noted that a key methodological difference between Abrams and Dobkin (1994) static display experiments and that of Taylor and Klein (2000) was that Abrams and Dobkin implemented a between-subjects design to evaluate the effect of the different target diagnostics, while Taylor and Klein implemented a within-subjects design with cue and target types completely intermixed. While Abrams and Dobkin showed different magnitudes of inhibition between target types, Taylor and Klein (2000) showed statistically equivalent inhibition between target types in each cell in which the output form of IOR was generated (Figure 1.2, cells 3-6). Hilchey et al. hypothesized that when target types are blocked, observers could instantiate different spatial attentional control settings (ACS) - observers might more effectively filter the uninformative peripheral cue in blocks with central arrow targets because the cue never appears in task-relevant space. This would not be the case when targets are only peripheral onsets, or randomly intermixed between peripheral onsets and central arrows because the uninformative cue appears in a task-relevant location. Hilchey et al. directly compared this within/between blocks distinction and showed that when target types were randomly intermixed, there was equivalent inhibition for each target type. However, when target types were implemented in separate blocks, IOR only occurred with peripheral targets. Hilchey et al. thusly refute Abrams

and Dobkin's two component model for IOR and explain the pattern in Abrams and Dobkin's static display experiments as caused by a difference in spatial ACS.

#### **1.4 CURRENT DIRECTIONS**

Several questions remain unanswered in this line of research. What underlies the distinction between the two forms of IOR manifest in Taylor and Klein (2000)? Chapter 2 will present the first empirical investigation in this thesis. Here we will investigate whether any overt oculomotor response is sufficient to generate the output form of IOR by contrasting behaviour following either a prosaccade or antisaccade at the time of the cue. Comparing prosaccades with antisaccades is particularly analytic for this question as both type of eye movement can distance-matched within the spatial cueing paradigm, however the mechanisms that control each type of eye movement are suggested to be neurally distinct (Everling et al., 1999; Ignashchenkova et al., 2004). Furthermore, we ask to what extent do the findings in paradigms with dynamic displays accord with the 'two forms' theory that has evolved from Taylor and Klein? We will build upon the findings from the first empirical investigation in a series of experiments in Chapter 3 in order to begin to consolidate Tipper et al.'s two components ('space' and 'object') theory with the two forms ('input' and 'output') theory stemming from Taylor and Klein (2000).

**CHAPTER 2: INPUT- AND OUTPUT-BASED DISSOCIATIONS FOR  
INHIBITION OF RETURN AS REVEALED IN THE PATTERNS OF 2-AFC  
PERFORMANCE FOLLOWING PRO- AND ANTI-SACCADES**

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## 2.1 INTRODUCTION

Slower response times (RTs) to cued relative to uncued locations have been documented in the aftermath of both overt (i.e., with eye movements) and covert (i.e., without eye movements) orienting in the spatial cuing paradigm (Posner & Cohen, 1984; Posner, Rafal, Choate & Vaughan, 1985). When the task is strictly covert, slower RTs are observed principally when the cue and target occupy the same or proximal locations (Taylor & Klein, 2000; Fischer, Pratt & Neggers, 2003; Hilchey, Klein & Satel, 2014). This effect is commonly referred to as attentional/perceptual (Taylor & Klein, 2000) or, synonymously, as occurring nearer the input end of the processing continuum (Hilchey, Hashish, et al., 2014). When overt orienting is required, subsequent responding is biased against the location of the cue. As such, repeat stimulation of an input pathway is not required to observe the effect (see also Posner et al., 1985) which can be measured with stimuli in central vision requiring responses compatible with the location of the peripheral cue (Taylor & Klein, 2000; Rafal, Egly & Rhodes, 1994). This effect is commonly referred to as motoric/decisional (Taylor & Klein, 2000) or as occurring nearer the output end of the processing continuum (Hilchey, Klein & Ivanoff, 2012). Taylor and Klein (2000) deduced from these patterns that the form of inhibition following a spatially uninformative cue (i.e. one that does not predict the location of subsequent events) is contingent upon whether eye movements are made. Despite this dissociation, both of these inhibitory cueing effects are commonly referred to as inhibition of return (IOR).

Relatively recent investigative work has focused on identifying how the two forms of IOR – output and input – differentially affect manual non-spatial discrimination of visual stimuli. Placed in a broader historical context, early research suggested that IOR was limited to target detection and localization responses (see Klein & Taylor, 1994, for review; Terry, Valdes, & Neill, 1994); however, as first demonstrated by Hartley and Kieley (1995) and later reinforced by Lupianez et al (1997), IOR can be reliably measured in non-spatial discrimination tasks at cue-target onset asynchronies greater than 400 ms. Non-spatial discrimination tasks – unlike localization or detection tasks – have the added benefit of permitting meaningful analysis of both RT and accuracy. In the context of the input-/output dichotomy of IOR, accuracy is particularly analytic because, as illustrated by Ivanoff, Klein and Lupianez (2002), the two hypothesized forms make different predictions about IOR effects when these are plotted in speed-accuracy tradeoff (SAT) space (Figure 2.1). The form of inhibition that expresses itself as a response or decision bias should delay responding without directly affecting the quality of input information leading to the decision. Thus, output-based inhibition should result in a speed accuracy tradeoff (conditions with slower responses will have higher accuracy). In contrast, the form of inhibition that expresses itself as attentional or perceptual should impede sensory or sensorimotor processing. Thus, input-based inhibition should result in a genuine reduction in the efficiency of information processing (Ivanoff & Klein, 2006; see Ivanoff, Klein & Lupianez, 2002, for review).

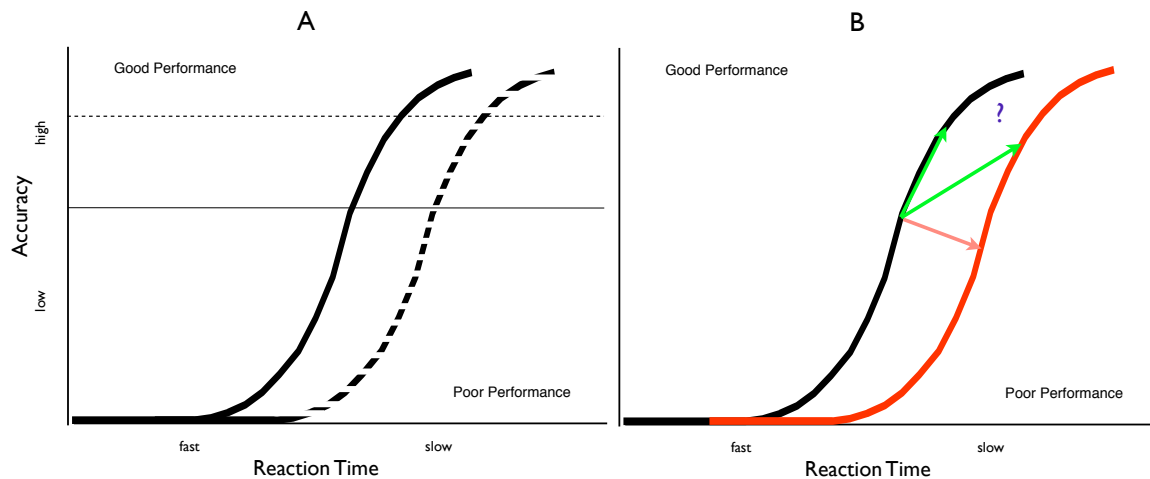


Figure 2.1: Illustration of the two theories of IOR. All functions represent hypothetical rates of information accrual where improvement in the accuracy of performance as response time increases; participants are responding to targets that appear and are neither masked nor removed. If the RT delay associated with IOR is caused a genuine deterioration in performance this would result in a rightward shift of the function (as shown by A: solid to dashed function, B: the red arrow) or a change in slope of the function (not depicted in this figure). Evidence for these results has been shown in studies where eye movements were prohibited (Chica et al, 2010 Exp 3A; Hilchey, Hashish et al., 2014). Another possible pattern, where observers demonstrate slower but more accurate responding (also referred to as a speed-accuracy trade-off or criterion shift), is represented. This has been observed empirically when eye movements were made (Chica et al., 2010 Exp 1B & 3B) or when participants were instructed not to make them but eye position was not monitored (Ivanoff & Klein, 2001) - suggesting the eye movement system may not have been effectively suppressed (A: solid to dashed horizontal lines, B: as shown by green arrows).

Investigations demonstrating delayed responding to or processing of previously cued targets in discrimination tasks since Hartley and Kieley (1995) have shown a high degree of variability in the effect of IOR on accuracy; indeed, a meta-analysis of 67 measurements reveals no clear pattern (see Figure 2.2). A recent investigation, however, offers a clue for explaining this between-experiment variability. Chica, Taylor, Lupianez and Klein (2010) used eye monitoring and manipulated, between-subjects, whether or not an eye movement was required toward a spatially uninformative peripheral cue that preceded a to-be-discriminated peripheral colour target.

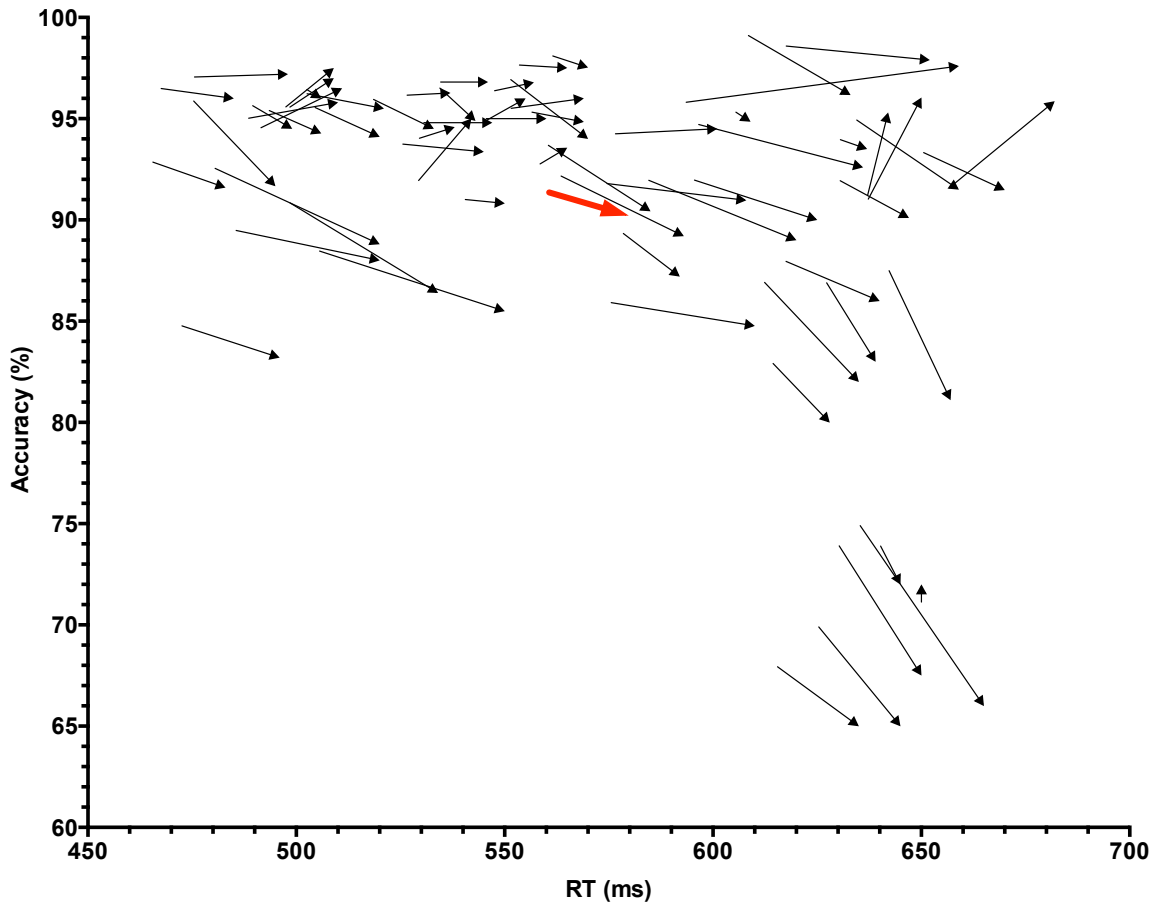


Figure 2.2. A meta-analysis of 67 conditions (19 studies) for which slowed RT was observed at cued locations in a non-spatial 2-AFC task (Redden, Ivanoff & Klein, 2016). Each arrow represents the results of an individual SOA (stimulus-onset asynchrony) within an experiment, where the arrow starts at performance for ‘Uncued’ targets and ends as performance for ‘Cued’ targets. The net vector (average results from all 67 measurements) is represented by the red arrow (Appendix A).

Two qualitatively different patterns emerged for the two cue-response conditions. When eye movements were expressly forbidden, responding was slower and less accurate to targets at the cued location, supporting an input-based attribution. However, when eye movements were required to the cue, responding was slower but more accurate at the

cued location, a pattern that converges on the output-based attribution made by Taylor and Klein (2000) and Posner et al (1985)(see also, Hilchey, Hashish et al., 2014).

Although the nature of the inhibition is modulated by whether the task involves eye movements toward stimuli, we question whether Taylor and Klein (2000)'s output-based inference generalizes to all instances of overt orienting (Klein & Hilchey, 2011; Hilchey, Dohmen, Crowder & Klein, in press). For instance, an overt orienting response may be made toward (prosaccade) or away from (antisaccade) a peripheral onset. At both the empirical and theoretical level, we have reason to believe that inhibition, when generated in the context of anti-saccades, is input-based. The empirical basis of our belief comes from studies in which observers are required to generate antisaccades. These studies almost exclusively show that the inhibitory effect can only be measured when the cue and target are presented in the same location (Rafal, Egly & Rhodes, 1994; Fecteau, Au, Armstrong & Munoz, 2004). The theoretical basis lies in the proposal (e.g., Forbes & Klein, 1996) that observers must inhibit the reflexive oculomotor system in order to behave according to instructions in the antisaccade task, a proposal for which there is support at the single unit level (see, Everling et al., 1999 and Ignashchenkova et al., 2004). On the basis of these behavioural and neurophysiological findings Klein and Hilchey (2011) proposed a more refined account of the two forms of inhibitory effect seen in Taylor and Klein (2000): They suggested that the nature of the inhibitory after-effect is contingent, not on whether eye movements are or are not made, but rather on the activation state of the reflexive oculomotor system. When the reflexive oculomotor



system is suppressed the input form is generated; when it is not suppressed the output form is generated.

The results from the prosaccade condition in Chica et al. (2010) converge on our theoretical conceptualization of the output form of IOR. However, we believe this finding is worthy of replication in order to verify the robustness of the effect, as well as to extend the result to other non-spatial 2-AFC tasks (e.g., from colour to form). In the present experimental design, at the time of the cue - as in Chica et al. - one group will be required to generate a prosaccade and return to fixation before the target whereas a second group will be required to generate an antisaccade. We expect to replicate the speed-accuracy tradeoff pattern reported by Chica et al. (2010) in the condition for which observers are required to make a prosaccade response to the peripheral cue. Two predictions remain for the heretofore untested antisaccade condition. On one hand, if the output effect is generated by all overt orienting responses (as implied by Taylor & Klein, 2000), then an SAT would be expected (slower but more accurate responding at the cued location). However, if it is the state of the reflexive oculomotor system that determines the nature of the effect (Klein & Hilchey, 2011; Hilchey, Klein & Satel, 2014), then an input effect would be expected at the location of the cue (as in Chica et al's 'ignore' condition).

Finally, we see the present experimental design as an opportunity to evaluate the relationship between IOR, the Simon effect and eye movements. In a non-spatial 2-AFC task, the Simon effect refers to the performance advantage for responses that spatially correspond with the location of the target (Simon corresponding) relative to responses that do not correspond (Simon non-corresponding). Previously, Ivanoff, Klein and

Lupianez showed (via a mega-analysis of the subject-by-subject data from 12 experiments) that IOR increases the Simon effect (see Figure 2.5A; see also Hilchey et al., 2011). However, since Ivanoff et al's mega-analysis focused specifically on an inhibition that was ostensibly generated in the context of covert orienting, in the present overt orienting context we can explore whether the relationship between IOR and the Simon effect is modulated by the activation state of the reflexive oculomotor system.

## **2.2 METHOD**

### 2.2.1 PARTICIPANTS

Fifty-nine (31 Anti; 28 Pro) naive observers (16 male; 5 left-handed) ranging in age from 18-51 participated in the study for course credit in one 60 minute session. All observers were recruited from the undergraduate subject pool at Dalhousie University.

### 2.2.2 APPARATUS AND PROCEDURE

The experiment was run in a dimly lit room on a 19" CRT monitor. Eye positions were monitored by EyeLink II head mounted equipment. Trials began with the presentation of three black placeholder boxes [1.5 x 1.5 degrees visual angle (DVA)] separated horizontally by 6.2 DVA on a grey background. The center box contained a black '+' (0.5 DVA) as a fixation stimulus. Trials began with a drift correction that required the observer to fixate the central stimulus and press space bar. If the observer was not accurately fixating the central stimulus no further visual events would occur and a tone would alert them to refixate. If the observer successfully fixated the central stimulus a circle measuring 0.9 DVA would appear surrounding the fixation stimulus and remain on the screen for the duration of the trial. Two hundred fifty milliseconds (ms)

after the appearance of the circle one of the lateral placeholder boxes flashed. The flash was created by filling the empty space in the placeholder box with grey. This stimulus lasted 90 ms and was not spatially predictive of any future events in the trial. Observers in the pro-saccade condition were required to generate a saccade to the stimulated placeholder box and back to the fixation stimulus. Observers in the anti-saccade condition were required to generate a saccade to the unstimulated placeholder box and back to the fixation stimulus. Trials on which inaccurate or early eye movements occurred were terminated and recycled. Feedback about eye movement performance was also given on these trials. Once successful eye movements to the first signal had been executed observers were required to maintain fixation for the duration of the trial. A target was presented in one of the lateral placeholder boxes (50% left, 50% right) 1000 ms after the onset of the cue. The target was equally likely to be either a '+' or an 'x' within a circle (1.3 DVA). Observers were required to make a speeded manual response to indicate the target identity by pressing either the 'z' or '/' key. Observers completed one practice block of 32 trials followed by a single experimental block of 200 trials. The sequence of events in a trial is represented in Figure 2.3.

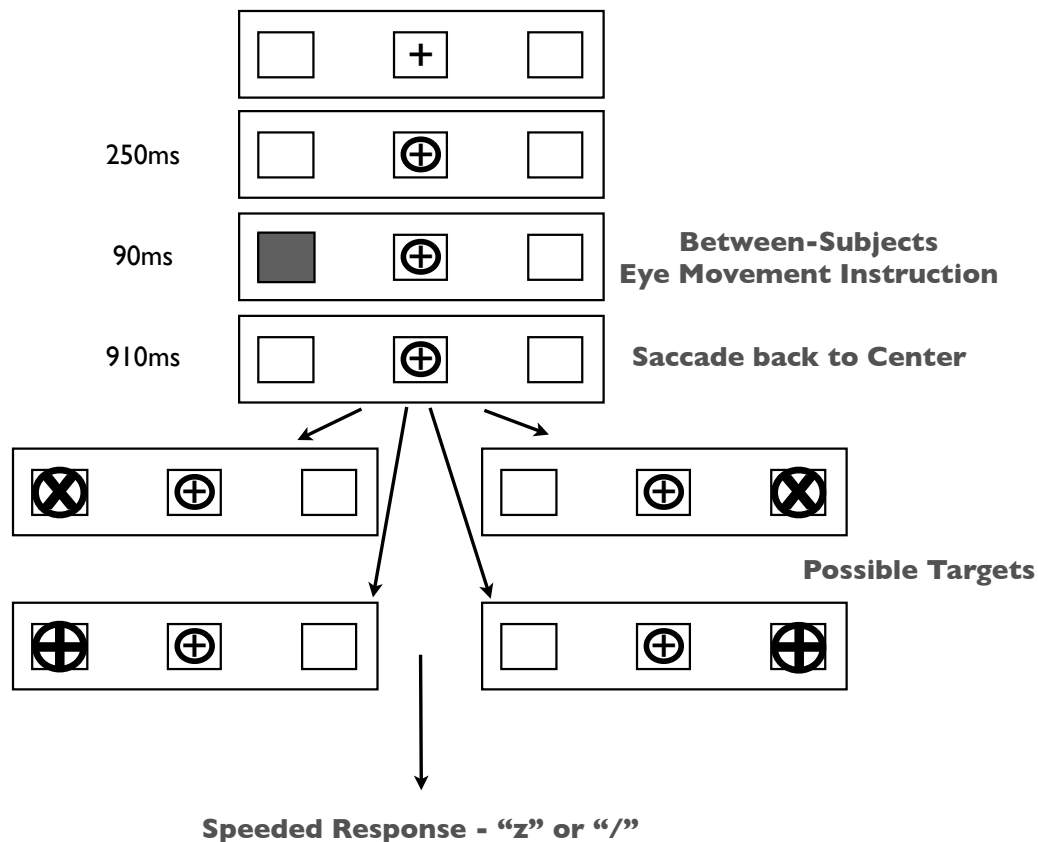


Figure 2.3. Methods figure depicting the time course of a trial in Experiment 1. Duration of each subsequent event is depicted to the left of the image. The between-subjects manipulation required either a pro- or antisaccade relative to the location of the cue.

## 2.3 RESULTS

In the prosaccade condition, trials on which the eye movement to the cue was not executed within 1.5 DVA of the cued peripheral placeholder were excluded from analysis ( $M = 22.2\%$ ). In the antisaccade condition, trials on which the first saccade was executed toward the cued placeholder (an incorrect prosaccade) were excluded from analysis ( $M = 28.3\%$ ). Trials on which eye movements occurred after the presentation of the target but before the manual response were excluded from analysis ( $M = 12.2\%$ ). After these

oculomotor criteria were established, 18 observers who failed to complete at least half of the trials were excluded from analysis (Pro = 8; Anti = 10). One additional observer in the antisaccade condition who performed the discrimination task with zero errors was also excluded<sup>1</sup>. Based on a histogram of the remaining reaction times (RTs), responses faster than 300ms (0.2%) and slower than 1200ms (1.5%) were excluded from analysis.

2x2 mixed analyses of variance (ANOVA) were conducted on each dependent variable (speed and accuracy) with the factors of Cueing (within: Cued and Uncued) and Eye Movement Task (between: Prosaccade and Antisaccade). The ANOVA on RT revealed a main effect of Cueing [ $F(1, 38) = 5.60, p = 0.02$ ], where observers were slower to respond to targets at cued locations ( $M = 664$  ms) than at uncued locations ( $M = 654$  ms). Neither the main effect of Eye Movement Task [ $F(1, 38) = 0.006, p = 0.94$ ], nor the interaction between Cueing and Eye Movement Task [ $F(1, 38) = 0.04, p = 0.84$ ] were significant.

The same factorial ANOVA on accuracy revealed no effect of Cueing on accuracy [ $F(1, 38) = 0.90, p = 0.35$ ] and no effect of Eye Movement Task [ $F(1, 38) = 1.04, p = 0.31$ ]. Importantly, a significant interaction between Cueing and Eye Movement Task was observed [ $F(1, 38) = 5.94, p = 0.02$ ]: Observers were more accurate responding to cued than to uncued targets in the Prosaccade condition (+1.5%) and less accurate responding to cued than to uncued targets in the Antisaccade condition (-0.9%). The relationship between speed and accuracy across conditions is shown in Figure 2.4.

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<sup>1</sup> This exclusion is practically motivated. No errors makes it impossible to detect the direction of performance in SAT space that is the focus of this experiment (see Figure 2.1).

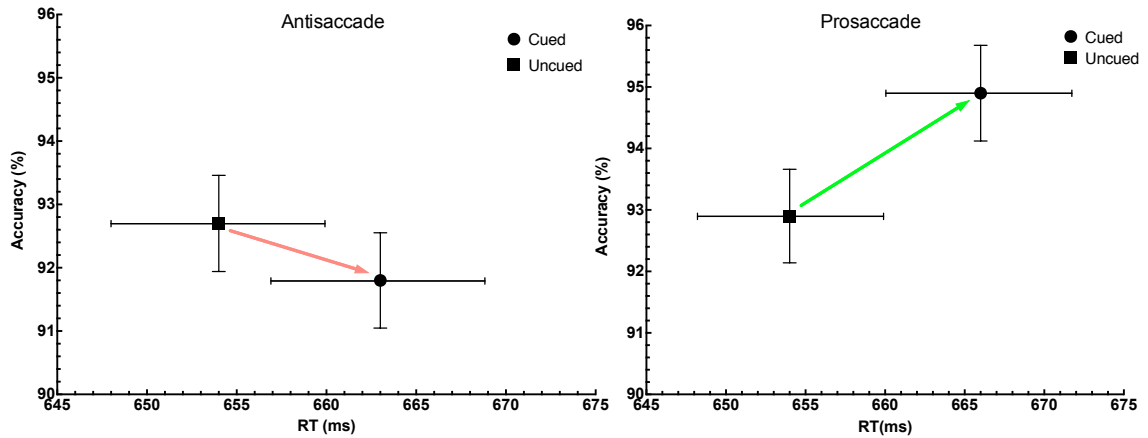


Figure 2.4. Results demonstrating the effect of Cueing between Eye Movement Tasks in SAT space. Error bars represent FLSD.

To explore how task and cuing interact with the Simon effect, a 3 x 2 x 2 mixed ANOVA was conducted for RT on Cueing (within: Cued and Uncued), Eye Movement Task (between: Prosaccade and Antisaccade), and Simon correspondence (within: Corresponding and Non-corresponding). This revealed a three-way interaction among these factors [ $F(1, 38) = 8.28, p < 0.01$ ], where Cueing enhances and reduces the Simon effect in the Anti- and Prosaccade tasks, respectively. This pattern is represented in Figure 2.5 panels B and C.

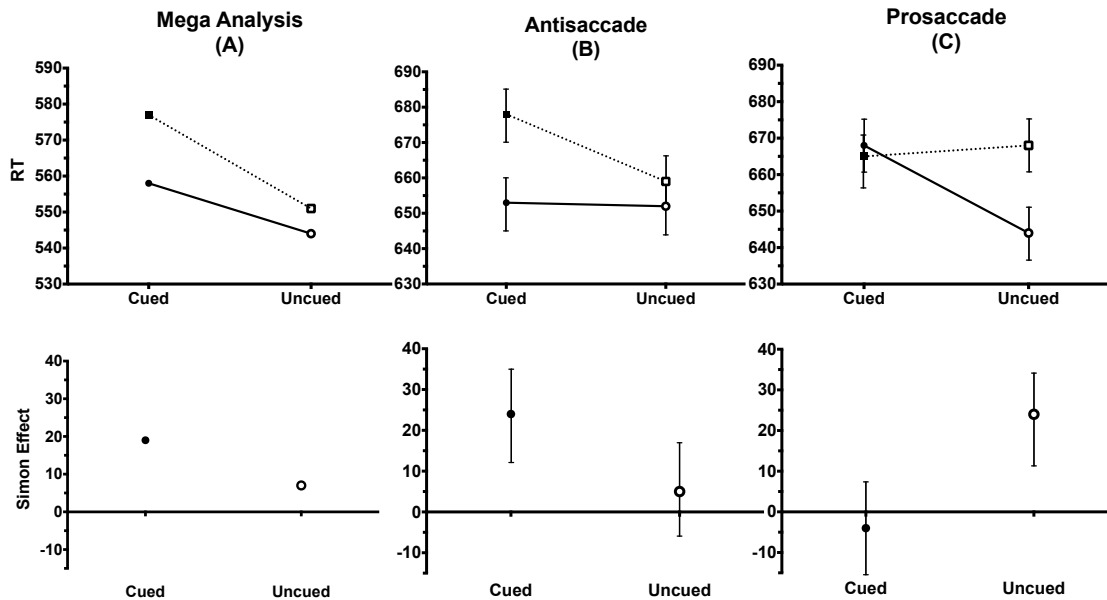


Figure 2.5. (A) Mean reaction time (in ms) from 159 participants analyzed by Ivanoff et al., 2002 as a function of cue condition and spatial correspondence. These data are from the 1000 ms cue–target SOA condition (redrawn from Ivanoff et al., 2002). (B & C) RT data from the present experiment for Antisaccade (B) and Prosaccade (C) eye movement instructions for Cueing split across spatial correspondence. For each upper panel, Simon Compatible is represented with the solid line and Simon Incompatible with the dotted line. The lower panels represent the Simon effect (with 95% confidence intervals for the estimate for B & C).

## 2.4 DISCUSSION

Consistent with output-based IOR, prosaccades led to slower but more accurate responses at the cued relative to the uncued location. A different pattern was obtained when observers made antisaccades. Here, the inhibitory after-effect manifested as a cost in both RT and accuracy: viz, a genuine decrease in processing efficiency at the cued location. Notably, the magnitude of the inhibitory effect on RT did not differ between saccade conditions.

The findings in the prosaccade condition thus accord with those of Chica et al. (2010) in which colour rather than shape discrimination was required. But going a step further, the absence of an SAT in the antisaccade condition dispels an ambiguity in the Chica et al. study concerning whether overt orienting responses are sufficient for output-based IOR. By demonstrating that the critical factor for determining the form of inhibition is not whether overt orienting responses are involved (*i.e.*, Taylor & Klein, 2000), but rather whether eye movements are permitted toward the source of stimulation, the data support the proposal that input-based forms of IOR occur when the oculomotor response system responsible for reflexively-generated saccades is in a tonically suppressed state (Klein & Hilchey, 2011; see also Hilchey, Klein & Satel, 2014). These findings converge with those of Hilchey, Dohmen, Crowder and Klein (2015) in which, as in the present study, observers were required to generate either a prosaccade or antisaccade at the time of a spatially uninformative peripheral cue. Following this first signal, observers were required to make a manual response to indicate the direction of an arrow (left or right) presented at fixation. When required to generate a prosaccade at the time of the cue, observers were slower to respond to targets compatible with the location of the cue, consistent with an output form of inhibitory effect. However, when required to generate an antisaccade at the time of the cue, there was no discernible effect of the cue on responding.

We also had the opportunity to evaluate how the two forms of inhibitory cueing effect might differentially modulate the Simon effect. This investigation demonstrates that when an input effect is generated, the Simon effect is enhanced for targets appearing



at the location of the cue. Inversely, when an output effect is generated, the Simon effect is attenuated when targets appear at the location of the cue. This interaction (Figure 2.5B,C) among the Simon effect, cueing and the activation state of the reflexive oculomotor system is noteworthy<sup>2</sup>. In the literature, the interaction between the Simon effect and cueing has not been a robust one (see also, Klein & Ivanoff, 2011). Indeed, it was observed only when individual studies were aggregated into a mega-analysis (cf, Ivanoff et al., 2002). An explanation for the non-robustness is suggested by the present findings: Perhaps, within studies, the two interactions we have observed here were both in operation, but to different degrees. This may have occurred because select subjects made eye movements or because, within subjects, the reflexive oculomotor response system was not in a tonically suppressed state. It bears noting that only one of the 12 experiments included in the mega-analysis reported monitoring eye movements or actively discouraging oculomotor responding (Lupianez et al., 1997 - Experiment 5).

Our results clearly dissociate two inhibitory mechanisms, and demonstrate different forms of interaction between each inhibitory effect (input and output) and the Simon effect. When the reflexive oculomotor system is suppressed, a cost in information

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<sup>2</sup> The astute reader may interpret these patterns simply as a consequence of generating an overt orienting response. These patterns could be seen as an RT cost as a result of the sensory input from the cue, and accuracy outcomes determined by where the eyes had landed. The ‘Cueing by Eye Movement Type’ interaction shows enhanced accuracy at the location to which an eye movement was made, and a cost in RT at the location of the cue. Also, the Simon effect is attenuated at the location to which the observer had previously moved their eyes. We believe this attempt at a parsimonious explanation of the present findings is unsound, because it is implausible that observers in Chica et al. (2010), or any of the studies reported in the mega-analysis shown in Figure 5A were performing antisaccades at the time of the cue.

processing efficiency is seen at the cued location. This input effect augments the Simon effect at the cued location by delaying both the task-relevant identity S-R code, and to a greater extent the task-irrelevant location S-R code (Hilchey et al., 2011). In contrast, when the reflexive oculomotor system is engaged, responding is delayed without a cost in information processing efficiency. This output effect leads to an attenuation of the Simon effect at the cued location, perhaps by delaying responses until after the decay of prepotent Simon activation (Ivanoff, Klein & Lupianez, 2002 - Figure 4, panel 4B). Klein and Redden (2016) have suggested that both of these effects could accomplish the novelty-seeking function attributed to IOR in the paper by Posner et al. (1985) - albeit by different means: The input form is assumed to decrease the salience of recently attended objects in the salience map whereas the output form biases orienting behaviors against previously attended locations in a priority map.

## 2.5 PREFACE TO CHAPTER 3

This chapter has provided converging evidence for the theory that there are two dissociable forms of IOR. The input form occurs when the reflexive oculomotor system is suppressed, and manifests as a genuine reduction in information processing efficiency - viz a decrement in both speed and accuracy of responding. The output form occurs when the reflexive oculomotor system is not suppressed, and manifests as a criterion shift - viz a cost in speed that is accompanied by an improvement in accuracy.

What remains to be addressed is to what extent the two forms of IOR may be mapped in a spatial and/or object reference. As described in Chapter 1, inhibitory cueing effects have been observed in object-based coordinates in dynamic displays. Tipper et al. (1991) argued for a spatial component and an object-based component contributing to IOR. Using saccadic responses to targets, Abrams and Dobkin (1994) argued that a perceptual component of IOR mapped into an object-based reference but the motoric component did not. In both of these sets of experiments, observers were instructed to ignore the uninformative peripheral cue. It is worth noting that the 'Ignore-Manual' instruction in Tipper et al (1991) would put their observers in a state that would render the input form in Taylor and Klein (2000)'s matrix (Figure 1.2 - cell 1). However, the 'Ignore-Saccade' instruction from Abrams and Dobkin (1994) would put their observers in a state that would engender the output form (Figure 1.2 - cell 4). This suggests, at least cursorily, that both forms of IOR have been reported to manifest in object-centered coordinates.

Recall, however, that Hilchey et al. (2012) demonstrated that a spatial ACS accounted better for the findings in Abrams and Dobkin's experiments in which a static display was implemented. This spatial ACS was allowed by having implemented the two target diagnostics between blocks, and thus undermines their two component theory for IOR. Since their object-based findings in their dynamic display conditions were determined based on the same untoward methodology used in their static display conditions, it is pertinent to re-examine these conclusions. It is the objective of the following chapter to determine the extent to which the output form of IOR may be manifest in object-centered coordinates.

**CHAPTER 3: OCULOMOTOR INHIBITION OF RETURN:  
EVIDENCE AGAINST OBJECT-CENTERED REPRESENTATION**

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### **3.1 INTRODUCTION**

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, Klein, & Bartolomeo, 2006). Theories about the functional significance of IOR as a novelty seeking (Posner & Cohen, 1984) or foraging (Klein, 1988) facilitator 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; 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.

#### **3.1.1 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. The "moving box" paradigm is similar to the standard spatial cueing paradigm, except the placeholder boxes are rotated on the screen around fixation. One of the 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 boxes 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.

### 3.1.2 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 dictate whether IOR's effect is on input or output processes (for a review, see Klein & Redden, 2016). 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 active, 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 when eye movements were required (see also, Hilchey, Klein & Ivanoff, 2012), strongly implying minimal effect of the cue on input pathways.

### 3.1.3 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 addition to the moving objects paradigm while requiring saccadic responses 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 a spatial response is required without presentation of a peripheral stimulus. 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 displays, and object-based coordinates in dynamic displays. 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 (Figure 3.1c). 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 (Figure 3.1a). Based on this pattern of results, Abrams and Dobkin concluded that perceptual component of IOR remaps dynamically onto objects whereas the motoric component IOR does not.

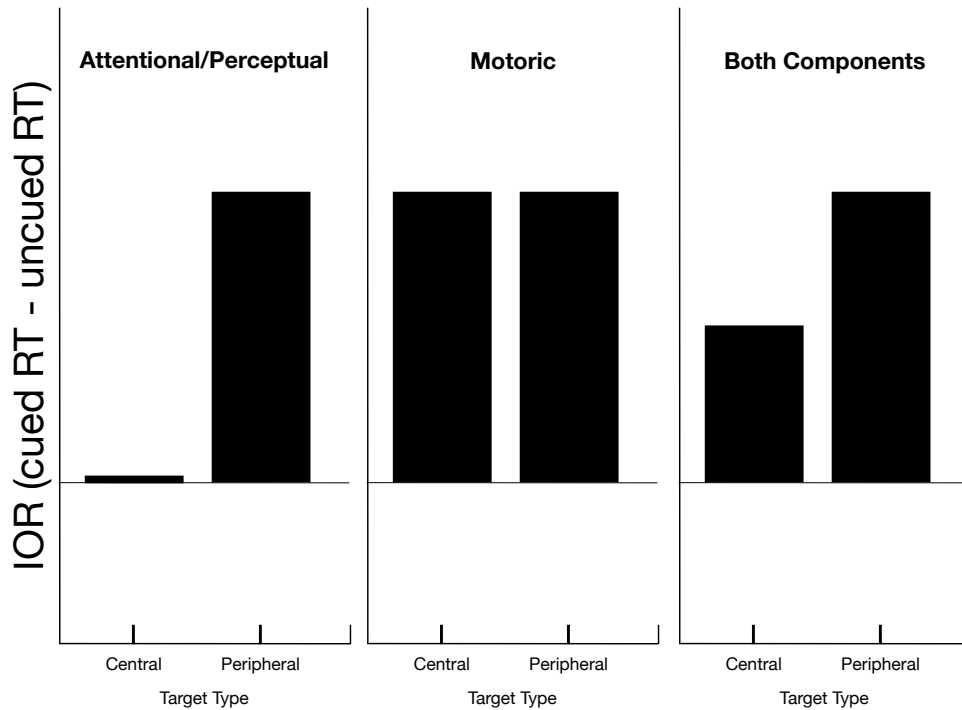


Figure 3.1: How the pattern of results when central and peripheral targets are randomly intermixed can be used to infer different forms (a & b) or different components (c) of IOR (redrawn from Hilchey, Klein & Ivanoff, 2012).

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 3.1c) in a stationary cue-target paradigm clashed with a pattern reported by Taylor and Klein (2000; Figure 3.1b) 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 that would allow for filtering of stimuli appearing in peripheral vision (for converging evidence, see Wang & Klein, 2012), thereby artifactually attenuating 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 3.1c) whereas, importantly, there was little discernible difference when these two target types were intermixed (Figure 3.1b). Thus, the evidence leading Abrams and Dobkin to propose two components was compromised by a methodological oversight 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 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 objects paradigm pioneered by Tipper, Driver and Weaver (1991). Modeled on Abrams and Dobkin's Experiment 3 and Experiment 4, in Experiment 1 we used 90 degree rotations while following Hilchey et al.'s methodological injunction we randomly intermixed the central and peripheral targets. 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 IOR (with either the central or peripheral targets), in Experiment 4 we precisely replicated Abrams and Dobkin's peripheral target condition (their Experiment 4). Finally in Experiment 5 we used only peripheral targets and randomly intermixed mixed motion trials with stationary trials.

## **3.2 EXPERIMENT 1**

Our methods in Experiment 1 were closely modeled 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. Mixing the two target types ensures that observers employ the same strategy at the outset of every trial.

### 3.2.1 METHOD

#### *3.2.1.1 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.

### 3.2.1.2 APPARATUS AND PROCEDURE

Observers completed eight blocks of 32 trials in a single experimental session. See Figure 3.2 for the sequence of events. The experiment was run in a dimly lit room on a 19" CRT monitor. Eye positions were monitored by EyeLink II head mounted equipment. Trials began with the presentation of two white 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. 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.

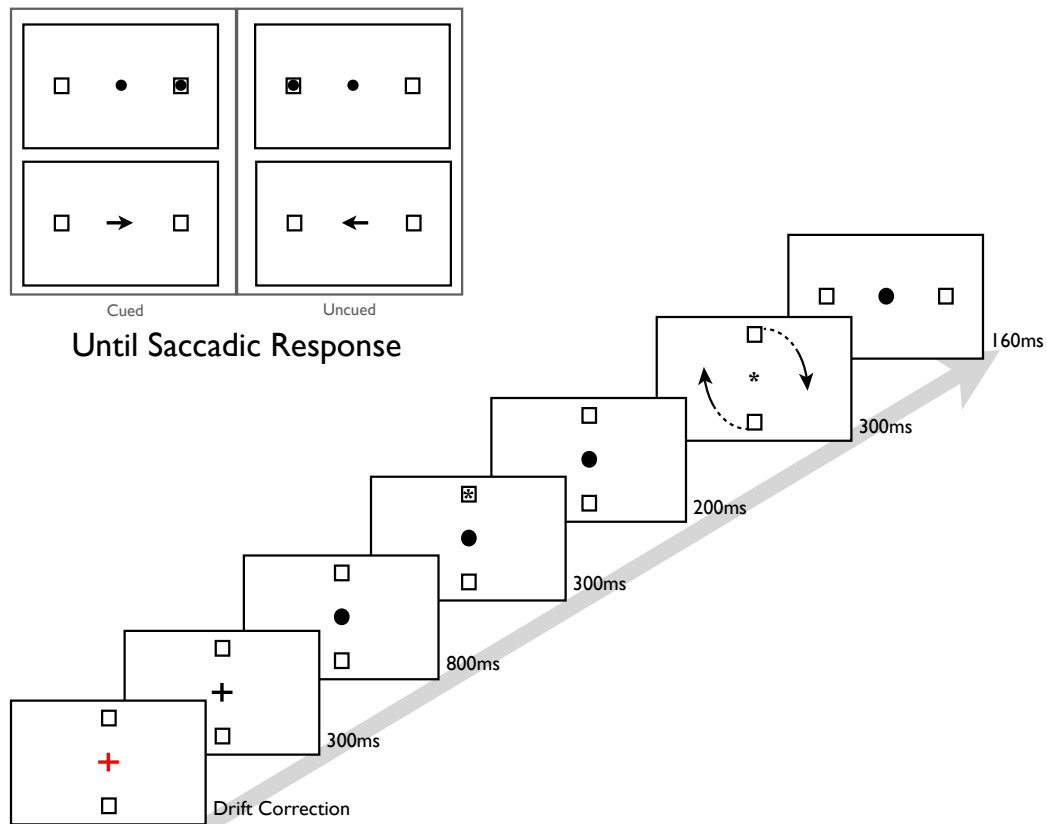


Figure 3.2: Sequence of events from Experiment 1, see text for explanation.

### 3.2.2 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 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 3.3) was analyzed via a 2 (cued or uncued target) x 2 (central or peripheral target) repeated measures ANOVA. This analysis

revealed a main effect of target type,  $F(1, 9) = 19.85$ ,  $p < 0.01$ , wherein responses to central targets (287ms) were slower than to peripheral targets (251ms). No main effect of cueing or interaction was observed. When block number was added to the ANOVA, there was a significant main effect of block,  $F(6, 54) = 15.47$ ,  $p < 0.01$ , wherein responses were faster as block number increased, however this effect did not interact with any other factors.

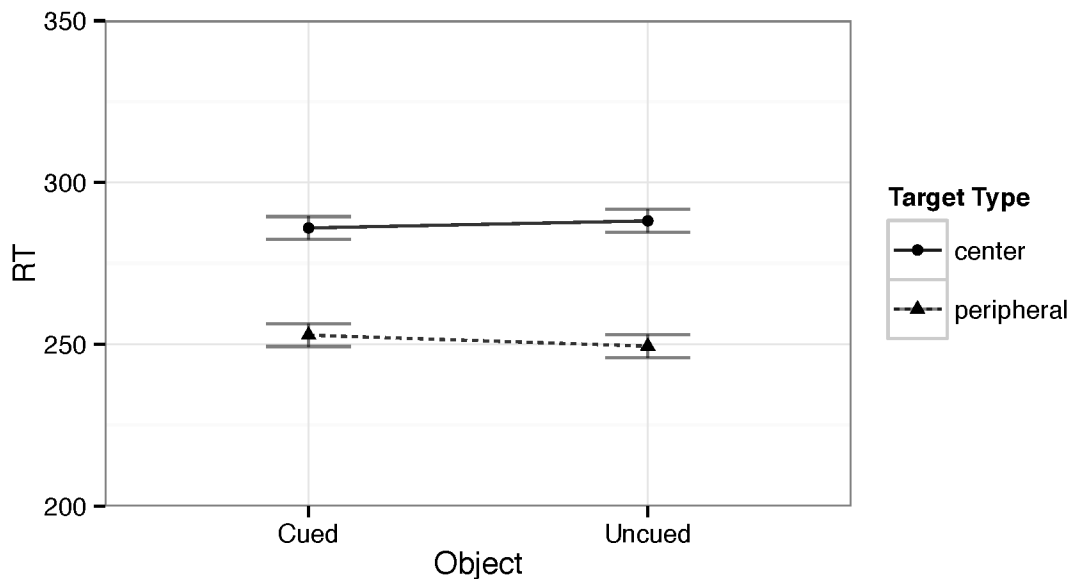


Figure 3.3: Mean saccade reaction time to cued and uncued central and peripheral targets in Experiment 1 after 90 degree rotation of placeholder boxes. Error bars are Fishers least significant differences (FLSDs).

### 3.2.3 DISCUSSION

As did Hilchey and colleagues (2012), we found that intermixing target types within a block rather than administering the two target types in separate blocks led to a different pattern from that reported by Abrams and Dobkin. Importantly, no evidence for object-based saccadic cueing effects was found; neither with central arrow nor with

peripheral onset targets. It has been shown that object-based cueing effects can diminish as a function of practice (Muller & von Muhlenen, 1996; Weaver, Lupianez & Watson, 1998). However our analysis shows that the non-effect of cueing on saccadic RT was not influenced by practice. It is conceivable, also, that observers in our task may have engaged in a task-specific spatial attentional control set (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. This possibility provides the impetus for our second experiment.

### **3.3 EXPERIMENT 2**

After observing no evidence for object-based cueing when intermixing target types in a task modeled on Abrams and Dobkin's Experiment 3 and Experiment 4, we sought to eliminate the possibility that observers might engage a spatial ACS that obscured the effect of cueing. 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 spatial ACS hypothesized to account for the data in Experiment 1 could not easily be employed in the present design.

#### **3.3.1 METHOD**

##### ***3.3.1.1 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.



### 3.3.1.2 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 3.4). 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.

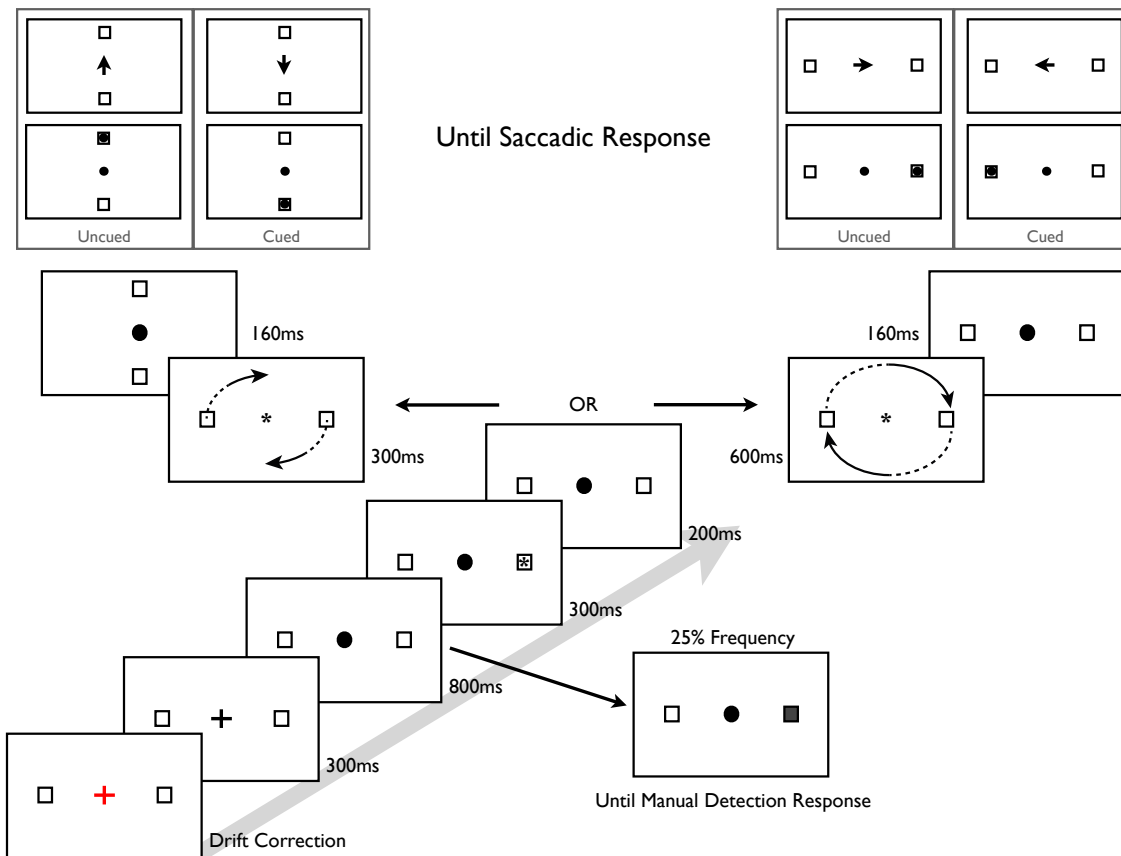


Figure 3.4: Sequence of events from Experiments 2 and 3. Note that this is a representation of a trial with placeholders starting on the horizontal axis. Time course and sequence of events was the same for vertical axis start. The manual-go signal that replaced the cue on 25% of the trials (illustrated by the box pointed to by the arrow) was used in Experiment 3.

### 3.3.2 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 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 (Figure 3.5). This revealed no main effect of cueing. There was a significant interaction between cueing and rotation,  $F(1, 7) = 12.54, p < 0.01$ , 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). When block was added to the ANOVA, one participant was excluded as they did not complete the fourth block. There was no main effect of block, nor did this interact with any other factors of interest.

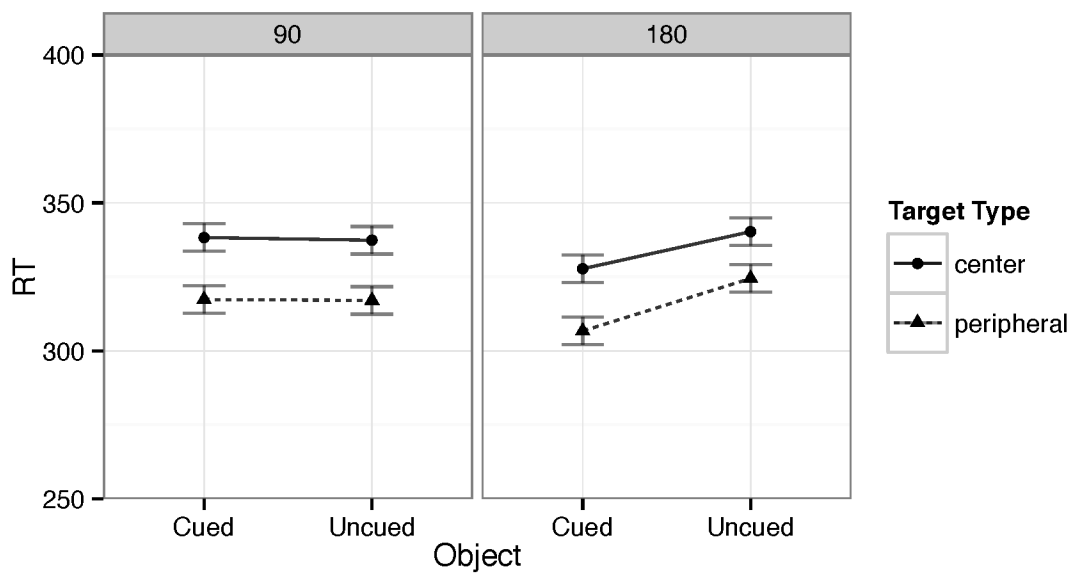


Figure 3.5: Mean saccade reaction time to cued and uncued central and peripheral targets in Experiment 2 after 90- and 180- degree rotation of placeholder boxes (Error bars = FLSD).

### 3.3.3 DISCUSSION

Similar to Experiment 1, the current 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 by putting cues and targets in the same locations. 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. Upon visual inspection of the data in Figure 3.5, this effect in the 180-deg condition could also 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. Furthermore, the cueing

effect was not influenced by practice. 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 encoded in either spatiotopic or retinotopic coordinates.

### **3.4 EXPERIMENT 3**

The present experiment instantiated the methodological considerations introduced in Experiment 2, while more greatly incentivizing observers to attend the locations containing the cues. 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.

#### **3.4.1 METHOD**

##### ***3.4.1.1 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.

##### ***3.4.1.2 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 black 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 3.4). No

RT data was recorded on these trials as this was not pertinent to our research question.

Observers completed 600 trials in a single block.

### 3.4.2 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%). Of the remaining trials, saccades initiated 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 (Figure 3.6). This analysis revealed no main effect of cueing nor any interactions. Trials were subdivided posthoc to create four blocks of 150 trials so as to analyze for practice effects. There was a main effect of block,  $F(3, 27) = 3.10$ ,  $p = 0.04$ , wherein participants responded faster as block number increased, however this factor did not interact with cueing.

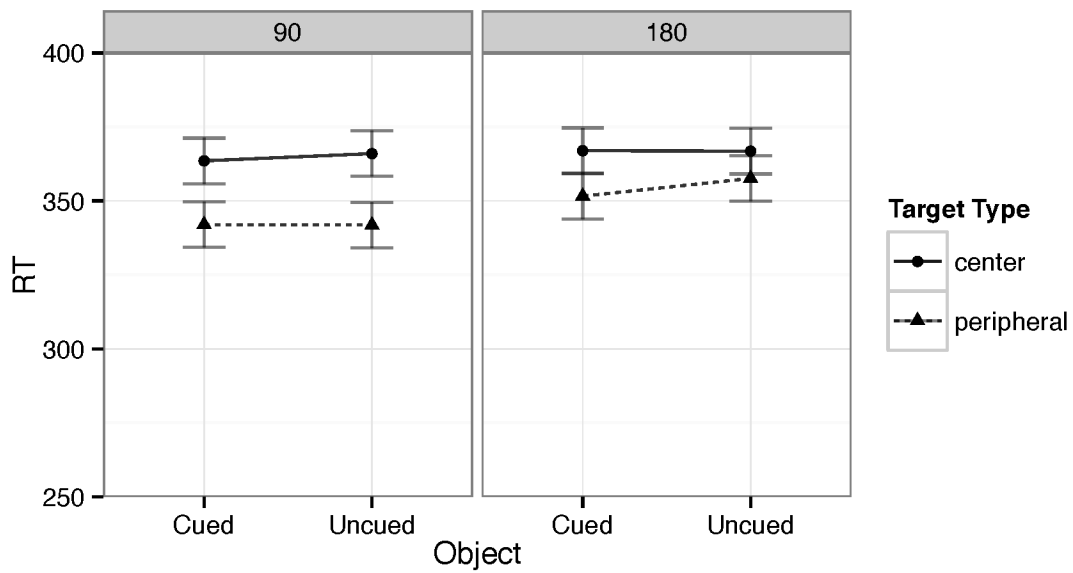


Figure 3.6: Mean saccade reaction time to cued and uncued central and peripheral targets in Experiment 3 after 90- and 180- degree rotation of placeholder boxes (Error bars = FLSD).

### 3.4.3 DISCUSSION

We continue to see little evidence for object-based inhibitory cueing effects on saccadic responding, even when observers are incentivized by task demands to covertly attend the cue. 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. As in the previous investigations, practice showed no influence on the cueing effect. Although our intention was to evaluate the input- and output- based contributions of saccade-measured object-based IOR, repeated failures to observe object-based effects have made this impossible. Thus, in Experiment 4, we seek simply to replicate the object-based IOR effect by returning to the methods used by Abrams and Dobkin (1994).

## **3.5 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.

### 3.5.1 METHOD

#### *3.5.1.1. 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.

#### *3.5.1.2 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 3.7). As the task was modeled precisely on the methods reported by Abrams and Dobkin, all experimental factors are identical between studies.

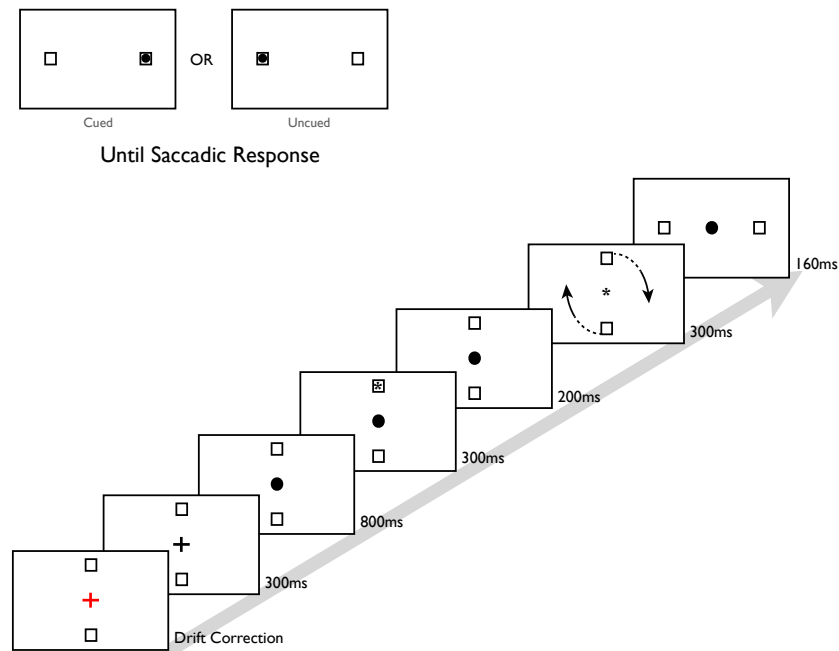


Figure 3.7: Sequence of events from Experiment 4 (n.b. placeholders started on the vertical axis and terminated on the horizontal after 90-degrees of rotation on all trials).

### 3.5.2 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 showed no difference in SRT for cued (227ms) and uncued (225ms) targets,  $t(8) = 0.60$ ,  $p = 0.565$  (see Figure 3.8). When combined in an ANOVA with block number as a factor there was a main effect of block,  $F(6, 48) = 5.60$ ,  $p < 0.01$ , wherein



participants responded faster as block number increased, however this factor did not interact with cueing.

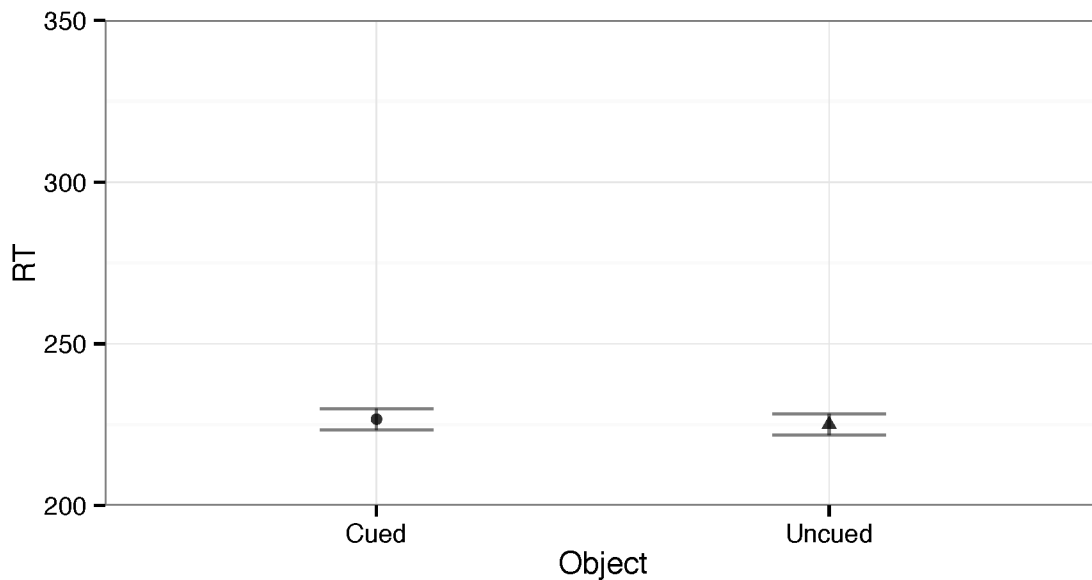


Figure 3.8: Mean saccade reaction time to cued and uncued peripheral targets in Experiment 4 after 90 degree rotation of placeholder boxes (Error bars = FLSD).

### 3.5.3 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. Furthermore, practice again did not influence this outcome. 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 within a paradigm using these stimuli.

## **3.6 EXPERIMENT 5**

This experiment seeks to demonstrate the existence of oculomotor IOR 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 spatial location where the cue occurred, as well as at the cued object.

### 3.6.1 METHOD

#### *3.6.1.1 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.

#### *3.6.1.2 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 3.9).

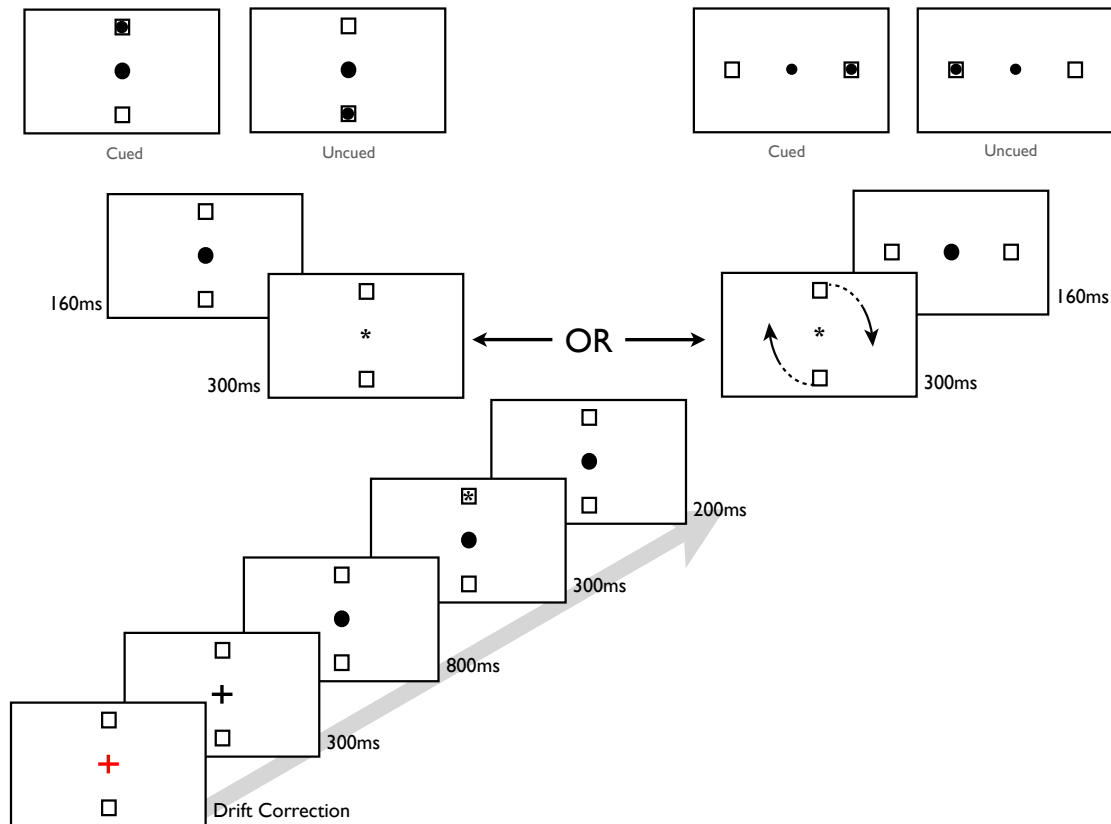


Figure 3.9: Sequence of events from Experiment 5, see text for explanation.

### 3.6.2 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. This analysis revealed a main effect of cueing,  $F(1, 9) = 26.01$ ,  $p < 0.01$ , wherein observers were slower to respond to cued targets. There was a main effect of motion,  $F(1, 9) = 80.25$ ,  $p < 0.01$ , wherein observers were slower to

respond to targets when there was no motion. There was an interaction between cueing and motion,  $F(1, 9) = 7.91$ ,  $p = 0.02$ , wherein the effect of cueing was larger in trials where there was no motion (Figure 3.10). When Block was added to the analysis, there was a main effect of block,  $F(1, 9) = 12.76$ ,  $p < 0.01$ , wherein participants responded faster as block number increased. This main effect of block interacted with cueing,  $F(1, 9) = 7.33$ ,  $p = 0.02$ , however this interaction was primarily driven by the elimination of the robust cuing effect in the last (8th) block of the stationary condition. To further assess this interaction between block and cueing, separate ANOVAs were conducted between motion conditions. On ‘motion’ trials there was a main effect of block,  $F(1, 9) = 5.70$ ,  $p = 0.04$ , no main effect of cueing and no interaction. On stationary trials, there was a main effect of block,  $F(1, 9) = 18.04$ ,  $p < 0.01$ , a main effect of cueing,  $F(1, 9) = 16.78$ ,  $p < 0.01$ , and an interaction between block and cueing,  $F(1, 9) = 6.17$ ,  $p = 0.03$ .

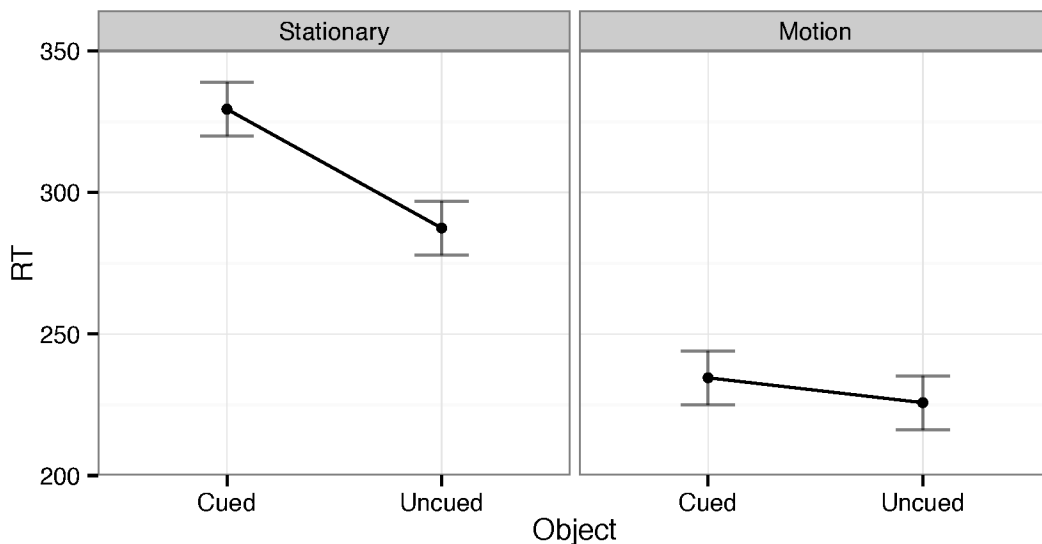


Figure 3.10: Mean saccade reaction time to cued and uncued peripheral targets in Experiment 5 across rotation conditions (Error bars = FLSD).

### 3.6.3 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 absence of an inhibitory effect in the rotation condition must mean that the IOR generated by the cue DID NOT move with the cued object. Therefore the present experiment shows little 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.

### **3.7 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 3.11.

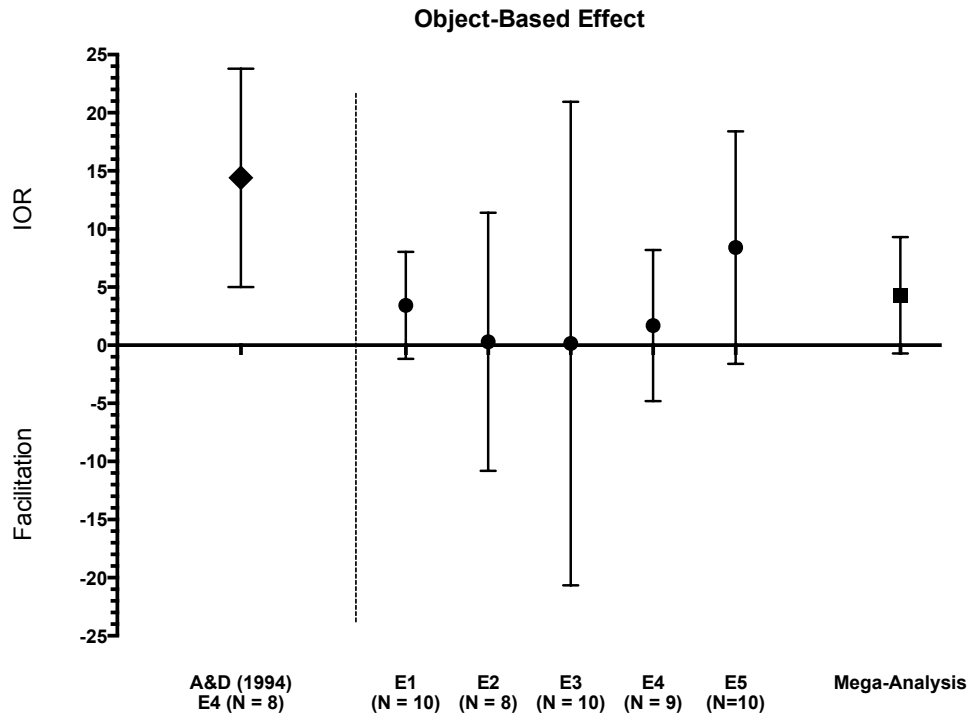


Figure 3.11: Effect sizes and 95% confidence intervals for the effect of object-based cueing for peripheral targets in the 90-deg rotation condition, as in Abrams and Dobkin (1994). Sample size for each experiment is reported in parentheses.

As can be seen in Figure 3.11, evaluating the evidence across experiments, as suggested by Cummings (2013), reveals little support for object-based oculomotor IOR. 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 estimate (from Abrams and Dobkin) with the five present experiments the hypothesis that oculomotor IOR exists in object-based reference has little support. When considering exclusively the precise context in which Abrams and Dobkin obtained the effect (90-degree rotation with peripheral targets), a mega-analysis across the five experiments for these levels of factors also shows little evidence for the hypothesis as well, which

includes the precise methodological replication. Standing alone, this finding lends 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 (Abrams & Pratt Experiment 1, 2000; Souto & Kerzel, 2009), it lends support for the empirical conclusion that oculomotor IOR is not object-based.

Future studies examining cueing effects in dynamic 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

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. Tas, Dodd and Hollingworth (2012) demonstrated object-based oculomotor IOR in a dynamic display design, 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) renders the object-based oculomotor effect more robust. Secondly, Tas et al. implemented a surface feature manipulation (colour change) that was not present in our designs. Due to this colour-change manipulation, 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 & Christie, 2015). While being mindful of Reppa's prescriptions for obtaining object-based effects, future work should examine the extent to which the perceptual processing demands of the task and the requirement to make eye movements to the cue modulate object-based encoding for saccadic eye movements.

Other investigations demonstrating 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) have measured the effect using manual responses. However, as demonstrated by Taylor and Klein (2000), the inhibitory effect of cueing is qualitatively different when observers are likely to be inhibiting the reflexive oculomotor system. Extant theories for oculomotor inhibition of return must consider the (near-)absence of evidence for object-based effects in dynamic displays when measured with eye movement responses.



## CHAPTER 4: GENERAL DISCUSSION

This series of experiments provides evidence to support the hypothesis that there are two dissociable forms of IOR. These experiments - when considered in the broader context of the literature - also support the hypothesis that the two forms have different causes and effects. The findings in Chapter 2 support the hypothesis that the activation state of the reflexive oculomotor system is the mitigating factor in whether the input or output form is manifest. This converges with similar dissociations reported when oculomotor responses are required to cues (Hilchey, Dohmen, Crowder & Klein, 2015), target stimuli (Hilchey, Klein & Satel, 2014), as well as when various manual response tasks are contrasted across reflexive oculomotor demands, such as go/no go (Hilchey, Hashish et al., 2013) and localization (Taylor & Klein, 2000) tasks.

Our findings converge with those of Chica et al. (2012), who showed that when observers are required to make a prosaccade to an uninformative cue, responses to targets at the cued location are slower than at the uncued location however this delay in responding is accompanied by an improvement in accuracy. Of note, when our observers were required to make an antisaccade relative to an uninformative cue, performance in this condition was similar to the condition in Chica et al. where observers were instructed to 'ignore' an uninformative cue - responses to targets at the previously cued location were both slower and less accurate. Had any overt orienting response been sufficient to generate the output form of IOR, we would have seen slower but more accurate responding to targets presented at the uncued location (i.e. an SAT in the direction compatible with the eye movement at the time of the cue). Because responding in the

antisaccade condition in our study replicates the pattern in Chica's 'ignore' condition rather than showing an SAT at the uncued location, our findings support those of Hilchey, Klein and Satel (2014), in that the output form of IOR is not generated in the context of any overt oculomotor responding - it is the activation state of the reflexive oculomotor system that will determine which form is manifest.

We have also presented evidence that the output form of IOR is not coded in object-based coordinates. The scant evidence in the literature for object-based oculomotor IOR (Abrams & Dobkin, 1994; Tas, Dodd, Hollingworth, 2012) considered in conjunction with the present non-replication of the seminal study provides converging evidence for our conclusion. We have demonstrated that the output form of IOR is in fact coded in spatiotopic coordinates. However, object-based IOR has been reported frequently in the literature (Tipper, Driver & Weaver, 1991; Müller & von Mühlénen, 1996; Weaver, Lupianez & Watson, 1998; Tipper, Jordan & Weaver, 1999) albeit, usually, with paradigms that require manual responding. Furthermore, Hilchey and Christie (2015) have shown in a meta-analysis and subsequent empirical investigation that the presence of placeholder objects is necessary to obtain inhibitory cueing effects when the oculomotor system is suppressed. These findings converge with the hypothesis that the input form of IOR may be coded in object-based coordinates. For studies using dynamic displays that have reported both spatial and object centered IOR concurrently (Tipper, Driver & Weaver, 1991; Tipper, Jordan & Weaver, 1999), we offer an explanation akin to that offered in Chapter 2 to explain the non-robustness of the Simon and IOR effects: it is plausible that in these studies the two forms were both manifest, but to different degrees.

This may have occurred because some observers had made eye movements or because, within subjects, the reflexive oculomotor system was not in a tonically suppressed state. Since these investigations were conducted without sensitivity to the likely cause of the dissociation between the two forms of IOR, it is not unsurprising that spatial and object-centered properties were attributed to a single IOR mechanism.

These data support the theory put forth by Klein and Redden (2016). Both of these effects could contribute to novelty-seeking - viz. the functional significance attributed to IOR (Posner et al., 1985) - albeit by different mechanisms: the input form by decreasing the salience of recently attended objects in a salience map whereas the output form by biasing orienting behaviors against previously attended locations in a priority map.

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## APPENDIX A

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