

PERCEPTUAL AND MOTOR IOR: COMPONENTS OR FLAVOURS?

by

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DALHOUSIE UNIVERSITY
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Abstract

The most common evidence for inhibition of return (IOR) is the robust finding of increased response times to targets that appear at previously cued locations following a cue-target interval exceeding ~ 300 ms. In a variation on this paradigm, Abrams and Dobkin (1994a) observed that IOR was greater when a saccadic response was made to a peripheral than to a central arrow, leading to the conclusion that saccadic responses to peripheral targets comprise motoric and perceptual components (the two components theory for IOR) whereas saccadic responses to a central target comprise a single motoric component. In contrast to the foregoing findings, Taylor and Klein (2000) discovered that IOR for saccadic responses was equivalent for randomly intermixed central and peripheral targets, suggesting a single motoric flavor under these conditions. To resolve the apparent discrepancy, a strict replication of Abrams and Dobkin was conducted in which central and peripheral targets were either blocked or mixed. In the blocked design, peripheral targets resulted in more IOR than central targets, while in the mixed design, replicating Taylor and Klein (2000), target type had no bearing on the magnitude of IOR (*i.e.*, equivalent IOR was obtained for both target types). This pattern of results suggests that the confound inherent in Abrams and Dobkin's blocked design generated a pattern of results that "masqueraded" as two components of IOR.

List of Abbreviations Used

IOR	Inhibition of Return
ACS	Attentional Control Setting
SC	Superior Colliculus
RT	Response Time
SRT	Saccadic Response Time
SOA	Stimulus Onset Asynchrony
S1	First Signal
S2	Second Signal
S-R	Stimulus-Response
LSD	Least Significant Differences
MS	Millisecond
S	Second
LIP	Lateral Intraparietal

Chapter 1 Introduction

When the interval between an uninformative transient cue and target [commonly referred to as a stimulus onset asynchrony (SOA)] is short (< 300 ms), responses to detect or localize a stimulus appearing in close spatial proximity are speeded relative to stimuli appearing at distance-matched, uncued regions. In contrast, when SOAs are in the range of 300 ms - 3 s (Samuel, & Kat, 2003), responses are slowed as compared to uncued locations. This pattern of results satisfies the classic conceptualization of inhibition of return (IOR) whereby an initial period of facilitation to the cued location is followed by long-lasting inhibition (Posner, & Cohen, 1984). Since the discovery of IOR in 1984, extensive research has demonstrated the robustness of this effect and, accordingly, it has been observed reliably for ballistic eye movements (“saccades”) and manual keypress responses to precued targets in a rich assortment of tasks that have exploited variations on the cue-target paradigm (synonymously referred to here as the “Model task” or “Posneran cueing paradigm”). Variations on the Model task, have centered, in part, on a dedicated effort to determine the extent to which motoric and attentional/perceptual processes contribute uniquely to the effect of IOR. Despite this, conflicting empirical results and interpretations have abounded. Consequently, current opinions in the field vacillate considerably as to whether IOR exerts its influence distinctly over attentional/perceptual systems (Reuter-Lorenz, Jha, & Rosenquist, 1996), motoric systems (Klein, & Taylor, 1994; Taylor, & Klein, 1998); or some combination of the two (Abrams, & Dobkin, 1994a; Taylor, & Klein, 2000).

Experimentally, one particularly influential line of reasoning maintains that the contributions of IOR to attentional/perceptual and motoric effects can be inferred from the

magnitudes of the IOR scores when comparisons are made between designs in which one process is involved as compared to designs in which two processes are involved. More specifically, these inferences can be made depending on the extent to which one allows for particular features of the design, principally the spatial quality of the imperative stimulus, to uniquely involve attentional/perceptual or motoric processes. If an allowance is made for one particular target type to involve motoric and attentional/perceptual processes, for example, whereas another target type requires the engagement of motoric processes only, an increase in response latencies on IOR for the dual-component task as compared to a unitary component task might reflect the contribution of two largely orthogonal processing centers that, eventually, must converge for the execution of a motoric response.

Following this line of reasoning, Abrams and Dobkin (1994a) developed a paradigm to test whether IOR comprised both attentional/perceptual and motoric components. After having established an IOR effect of approximately 21 ms in a condition in which an eye movement had to be suppressed to a non-informative peripheral onset cue but executed to a peripheral target that appeared at an SOA of 960 ms (peripheral target condition), Abrams and Dobkin engineered a paradigm in which the imperative stimulus, rather than being a peripheral target, was a centrally presented rightward or leftward pointing arrow (central target condition). The rationale behind this manipulation was relatively straightforward. Because the cue and target occupy the same location in the peripheral target condition, there is a possibility that a) the cue degrades the processing of stimuli occurring >300 ms later in close spatial proximity (the attentional/perceptual view) causing increased processing time to arrive at the criterion required to elicit a motoric response and b) that there is a co-occurring increase in response time (RT) because IOR

has a unique effect on delaying (or increasing the criterion specifically for) the execution of the decision to make a saccadic responses (the motoric view). In the central target condition, in contrast, the to-be-detected target appears at a location that has not been stimulated by a non-informative cue, consequently there is no possibility that repeated stimulation at a peripheral location degrades subsequent information processing (the attentional/perceptual view). A delay in responding to a central arrow that points in the direction of the uninformative peripheral cue can, however, be attributed to IOR operating on motoric processes.

Allowing for the assumption that responses to a central target arrow would be affected by a motoric component of IOR whereas responses to a peripheral target stimulus would be affected by both motoric and attentional/perceptual processes, these different target conditions can be used to determine the relative contributions of motor and attentional/perceptual processing to the IOR effect. From this reasoning, concrete behavioral predictions can be derived. If there is a single motoric effect to IOR, the magnitude of IOR will be equivalent for peripherally and centrally presented target [$\text{IOR}(\text{peripheral target}) = \text{IOR}(\text{central target})$]. If there is a single attentional/perceptual effect, centrally presented targets will show no IOR effect whereas peripherally presented targets will [$\text{IOR}(\text{central target}) = 0$ and $\text{IOR}(\text{peripheral target}) > 0$]. If there are two unique components to IOR, the magnitude of behavioral IOR should be greatest in the condition in which two components are contributing additively to the effect relative to the condition in which only one component is acting on RTs [$\text{IOR}(\text{peripheral target}) > \text{IOR}(\text{central target})$]. Corroborating this latter prediction, Abrams and Dobkin found that the magnitude of IOR was ~ 10 ms in the block of trials for the central target arrow condition whereas the magnitude of IOR was ~ 25 ms in the block of trials for the peripheral target condition. This

difference was statistically reliable and has been an influential empirical result driving theories that center on the notion that saccadic responses in IOR paradigms can comprise attentional/perceptual and motoric components.

Whereas Abrams and Dobkin (1994a) presented evidence for two additive components of IOR, their pattern of results was *not* replicated in an experiment in which central arrow and peripheral target conditions were intermixed (Taylor, & Klein, 2000). Both studies had comparable SOAs (960 ms as compared to 1000 ms in Taylor & Klein), both studies adopted the convention of instantiating a cue back at fixation, and both studies entailed ignoring a non-informative peripheral cue. Whereas Abrams and Dobkin, however, demonstrated that the magnitude of IOR was ~ 15 ms greater in the peripheral target condition, Taylor and Klein demonstrated that the magnitude of IOR was statistically equivalent between the two conditions.

Taylor and Klein (2000) interpreted their findings in the context of a comprehensive investigation of 24 conditions (including the conditions from Abrams and Dobkin) under which IOR had been either previously (10 cells) or never tested (14 cells). The trial structure in many ways resembled the Model task except the cue (S1) could occur with equiprobability as either a noninformative leftward or rightward-pointing central arrow or a peripheral onset and, similarly, the target (S2) could occur with equiprobability as a leftward or rightward-pointing arrow or a peripheral onset. Prior to a block of trials, participants were explicitly instructed to either make a manual, a saccadic or no response (the traditional 'ignore' the cue condition) to S1. Furthermore, they were instructed to make either a saccadic or a manual response to S2. Eye movements were assiduously monitored and all possible response combinations between S1 and S2 were tested, leading to 24 total combinations (2 cue types (central arrow or peripheral target) x 2 target types

(centrally arrow or peripheral target) x 3 S1 response types (no response, saccade or manual localization responses) x 2 S2 response types (saccade or manual localization responses). These combinations and the cued - uncued differences are illustrated in Figure 1.1. Encouragingly, Taylor and Klein found IOR in all cells in which IOR had previously been observed.

Upon analyses of the findings, Taylor and Klein determined that the results from these conditions could be neatly dichotomized into two flavours of IOR depending on whether a saccadic eye movement was made in a block of trials. In the no response(S1)-manual response (S2) and in the manual response(S1)-manual response (S2) conditions, IOR was generated by central and peripheral cues but was only measurable by peripheral targets suggesting that IOR was having an effect on early attentional/perceptual processes rather than late motor processes. This type of IOR, occurring only when the oculomotor system was quiescent throughout the task, became known as the attentional/perceptual flavor. Conditions in which an oculomotor response was required to S1 and S2 or in which both manual and oculomotor responses were required, IOR was observed ubiquitously for all cue and target types. In the no response-saccade condition, in contrast to the exclusively manual conditions, IOR was manifest only for peripheral onset cues. These last few conditions, more closely related to late motor processes and are treated collectively under what is known as the motoric flavor of IOR, can be dissociated from the attentional/perceptual flavour in several key ways.

First, and most relevant to the present investigation, that IOR was equivalent for central and peripheral targets demonstrated (contra Abrams and Dobkin, 1994a) that there was no apparent effect of repeated sensory stimulation on saccadic response times [SRTs, *i.e.*, that there was no additional attentional/perceptual component in that particular cell]. Second, that IOR

when measured by a saccadic response, in contrast to IOR in conditions under which saccadic responses are strongly discouraged, was not generated by centrally presented stimuli demonstrated a cause-based dissociation. Third, and this is the final unifying principle for all conditions incorporated under the motor flavour of IOR, *whenever* IOR was observed in a condition in which a saccade had been made to S1, S2 or both, it occurred for both peripheral and central targets at equivalent magnitudes suggesting an effect on late motor processes (and not early attentional/perceptual processes).

What can be gleaned from this discussion is that the conflicting empirical results between Abrams and Dobkin and Taylor and Klein clearly entail two radically different theoretical implications for IOR. In essence, one pattern of results (*e.g.*, Taylor, & Klein, 2000; Figure 2, this manuscript) suggests a single motoric conceptualization or flavour to IOR, when measured by a saccadic response, whereas the other pattern of results (*e.g.*, Abrams, & Dobkin, 1994a) suggests a two-components view (*i.e.*, the IOR measured by saccades to peripheral targets has two additive components). In an effort to reconcile the empirical discrepancy between these two investigations, the methodologies were contrasted. Critically, these studies diverge conspicuously on two major methodological aspects.

First, in Abrams and Dobkin (1994a), for peripherally presented targets only, fixation offset coincided with target onset. This confound was not present in Taylor and Klein (2000). Removal of fixation at the time of the target (step gap) is well-known to reduce SRTs (Saslow, 1967). Somewhat ironically, in a different paper published in the same year Abrams and Dobkin (1994b) reported that fixation removal *increases* the magnitude of IOR. Since 1994, some dissent has arisen as to whether a step gap increases (Abrams, & Dobkin, 1994a; Guimaraes-

Silva, Gawryszewski, Portugal, & Klausner-de-Oliveira, 2004) or decreases IOR (Hunt, & Kingstone, 2003; Souto, & Kerzel, 2009). Thus, it is somewhat difficult to determine whether the confound (gap with peripheral targets and no gap with central targets) in Abrams and Dobkin (1994a) was responsible for their finding of greater IOR with peripheral targets or whether it was operating against this finding. Nevertheless, it is clear that the peripheral target condition contains a methodological feature that is clearly absent in the condition to which it is being compared.

Second, Abrams and Dobkin (1994b) administered the central arrow and peripheral target conditions in separate blocks whereas these conditions were intermixed in a single block in Taylor and Klein (2000). *Prima facie*, this difference appears innocuous enough. Upon further analysis, however, one ought to recognize that prior knowledge about target type (centrally or peripherally presented) may act as a strong endogenous cue that would be liable, or perhaps likely, to affect the extent to which attention is allocated to the peripheries in the cue-target paradigm.

On this matter, there is a considerable literature that studies these types of spatial and non-spatial target expectancies that are typically subsumed under the label *attentional control settings* (ACSs). Evidence converges on the view that prior non-spatial or spatial knowledge about a target will affect the extent to which other aspects of simultaneously present elements of the visual scene will affect processing. With respect to non-spatial target expectancies, it has been shown that uninformative peripheral cues that share a feature with a to-be-discriminated target reflexively capture attention as indexed by significant facilitation at the irrelevant cue location when a target, by chance, occurs at that same location as the target at short SOAs (Folk,

Remington, & Johnston, 1992). Similarly, it has been shown that IOR is larger for likely stimulus-response (S-R) ensembles than unlikely S-R ensembles in two alternative forced choice task (Ivanoff, & Klein, 2004; Lupianez, Ruz, Funes, & Milliken, 2007). With respect to spatial target expectancies - the type of ACS that is most relevant for the present investigation - it has been shown that peripheral cues presented at a location where it is known in advance that a target will *not* be presented do not capture attention. (Ishigami et al., 2009; Yantis, & Jonides, 1990; Theeuwes, 1991).

An early demonstration of an ACS for space was provided by Laberge (1983). Laberge presented a five letter string horizontally in one of three task conditions. In one task condition (the word condition), five letter strings produced nouns. The primary task was to press a button when the five letter string produced a familiar name (a proper noun, *e.g.*, 'ALICE') and to withhold a keypress response when the letter string produced common nouns (*e.g.*, 'CHAIR'). We will call this the 'diffuse attention task'. In a second (letter word) and third (non-letter) condition, words and nonwords were composed by the five letter strings, respectively. In these conditions, a button press response was required if the middle letter was between A and G (as opposed to a set of letters from N through to U). Thus, the task was such that processing of the complete letter string was not required. We will call these conditions the 'focused attention task'. On 25% of the trials in all three conditions, instead of a letter string, a probe stimulus (7, T or Z) and four crosshairs ('+') appeared at the five letter locations. If the probe was a 7, a button press was required (the secondary task). Otherwise, the button press response was withheld. The primary task in the word condition was designed in such a way that successful performance necessitated attentional processing of all five letters in the string. In contrast, the primary task in

the letter word and non-word conditions could be performed successfully by simply attending the mid-point of the letter string.

The interesting results appeared from the secondary task. Laberge (1983) observed that if the primary task was a diffuse attention task, response times were largely equivalent among all probe locations. In contrast, if the primary task was a focused attention task, response times in the secondary task (*i.e.*, to the probe) increased linearly as a function of probe distance from the mid-point of the letter string. These results clearly suggest that task demands emphasizing processing at a mid-location can reduce the extent to which peripheral stimuli are processed.

Generally, the critical point here is that spatial processing can be increased or reduced in a visual scene to the extent to which particular locations are task-relevant. The idea that processing is enhanced at task-relevant locations to the exclusion of task-irrelevant locations has given rise to what Theeuwes and colleagues typically refer to as the *attentional window* (Theeuwes, 1994; Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Theeuwes, 2010a; Theeuwes, 2010b). From these theoretical considerations, it should be clear that Abrams and Dobkin (1994a) introduced a confound by blocking peripheral and central targets. In a block of central targets, because all task-relevant stimuli were presented at fixation, it is possible - if not likely - that processing or the 'attentional window' was narrowly focused to fixation in order to minimize any influence of the irrelevant (to-be-ignored) onset cue. Conversely in a block of trials with peripheral targets, the 'attentional window' would likely have been broadened to allow for processing of the task-relevant stimuli all of which were presented in the periphery. It is these differences in the allocation of attention between blocked peripheral and central

conditions that we believe may have been responsible for the IOR differences reported by Abrams & Dobkin.

In Taylor and Klein's (2000) experiment, for which a block of trials comprised both centrally and peripherally presented targets the participant's mental state at the time of the presentation of a target could not have been "tuned" to the central versus peripheral nature of the upcoming target because the two types were randomly intermixed. Thus, given a relative increased likelihood for targets to appear in the periphery in a mixed (balanced) design, it is more reasonable to assume that the observers are spreading attentional resources diffusely throughout the target display such that all potentially relevant elements are attended to some degree (Goldsmith, & Yeari, 2003).

To determine whether any untoward ACSs were generated by blocking the two target conditions, we first attempted to closely replicate the methodology from Abrams and Dobkin (1994a) by randomly assigning participants to a block of trials with only central or only peripheral target stimuli. We subsequently maintained the trial structures from Abrams and Dobkin while intermixing the two target conditions as did Taylor and Klein (2000). A comparison between mixed and blocked design allows for the following predictions: If the magnitude of IOR were greater in the blocked peripheral target condition as compared to the blocked central target condition but equivalent when intermixed, then the increased IOR for peripheral relative to central targets in the blocked conditions would be attributable to a central ACS undercutting the quality of parafoveal processing. Such a result - implying an unanticipated ACS spurred on by the confinement of targets to fixation - would severely undermine one of the central pillars of the two-components theory of IOR. In contrast, if the pattern of results from

Abrams and Dobkin (1994a) were replicated in a mixed design, the two flavours view of IOR would be undermined. Anticipating the results, we obtained evidence supporting the two flavours view. Later, to address our concern as to whether fixation removal was modulating the magnitude of IOR for peripheral targets, we re-ran the mixed target condition with a sustained fixation stimulus to determine whether differences between central and peripheral targets could be achieved in a paradigm devoid of the two aforementioned confounds. Again, evidence for the two flavours account was obtained.

		Second Signal (S2)			
		Manual		Saccadic	
		Central Arrow	Peripheral Onset	Central Arrow	Peripheral Onset
First Signal (S1)	Ignore	<u>1</u>	16	<u>-5</u>	<u>7</u>
		<u>3</u>	21	12	11
	Manual	<u>-18</u>	33	22	17
		<u>6</u>	22	29	14
	Saccadic	24	19	21	24
		30	14	19	21

Figure 1.1. All possible cue-target/target-target and response configurations from Taylor and Klein's (2000) comprehensive investigation into the causes and effects of IOR. The type of responses (no response, manual or saccadic) to the signal are underlined. The numbers represent the cued minus uncued reaction time and all IOR scores that were significant are shown in black circles.

Chapter 2 Experiment 1 - Methods

2.1 Rationale

In this experiment, a variation on the traditional cue-target paradigm (Posner, & Cohen, 1984) was implemented. The first stimulus event was a to-be-ignored peripheral onset whereas the second stimulus event, a peripheral target or a directional arrow, necessitated a saccadic eye movement to either the placeholder in which a target appeared or to the placeholder to which an arrow pointed, respectively. To test whether the increase in IOR that Abrams and Dobkin (1994a) detected for the peripheral target condition relative to the central target condition was owing to two additive components or an artifact spurred on by different ACSs in the blocked design, we closely replicated the sequence of events in their methodology while manipulating whether the peripheral and central targets were blocked or mixed. We fully expected to replicate the finding that the magnitude of IOR for saccadic responses to peripheral targets would be greater than the magnitude of IOR for saccadic responses to central targets when these were blocked. If, however, the difference in the IOR scores were attributable to distinct attentional deployment strategies for central and peripheral target blocks, then intermixing peripheral and central targets would theoretically eliminate any mathematical difference between these two target types. Experiment 1 then was designed to test this hypothesis.

2.2 Subjects

Eighteen undergraduate (11 females and 7 males) students from Dalhousie University participated in a single 75-90 minute session for course credit or monetary compensation (\$15 CDN). All participants were naive to the purposes of the experiment and reported either normal

or corrected-to-normal vision. Two participants were left-handed (one in the central and one in the peripheral target condition).

2.3 Apparatus and Procedure

All participants were tested in a dimly-lit room and all stimuli were presented against a black background. Stimuli were presented on a 19" ViewSonic Optiquest Q95 CRT monitor (Q95-3) connected to an Intel Core Duo processor, at a viewing distance of 22.5". An EyeLink II video-based eye monitoring system was used to monitor the eye movements of the participant from the initiation of a drift correction phase, which ensured the accuracy of the calibration parameters at the beginning of the trial, until a saccadic response was executed upon target presentation. The EyeLink headset was connected to a host computer, operating on a Pentium Intel 4 processor, which projected online gaze coordinates to a secondary monitor that was obscured by a black curtain during experimentation. After participants performed a 9-point calibration procedure to determine and validate the precision of the eye tracker within a half degree visual angle, the host computer provided accurate information about gaze position approximately once every 3 ms.

See Figure 2.1 for the sequence of events. At the beginning of every trial, a red fixation cross ($.28^\circ \times .28^\circ$) appeared at the Euclidean midpoint of an imaginary horizontal line segment between two placeholder boxes ($.45^\circ \times .45^\circ$). White placeholders were positioned equidistantly from the fixation cross at 3.9° to the left and right. At the beginning of every trial, a manual spacebar response was required when the observer's subjective experience was that of having successfully fixated the fixation cross. If this drift correction phase was completed successfully,

the fixation cross changed from red to white providing a clear demarcation between the stage that re-assessed the validity of the calibration procedure and the subsequent experimental phase of the trial. Otherwise, the fixation cross remained red and additional manual responses were made until the central gaze position was accepted by the eye tracker.

The first stimulus change occurred 3 seconds following the drift correction in an effort to minimize any contribution that a nonspatial manual response may have had on SRTs. At this point, the white fixation cross transformed to a white circle which (diameter = $.28^\circ$) remained onscreen for 800 ms. The cue, a noninformative peripheral asterisk (diameter = $.28^\circ$), then appeared randomly in one of the two placeholders for 300 ms. Participants were explicitly instructed that the cue was irrelevant in that it was completely unpredictable of the location of the second imperative peripheral onset and/or of the direction of the imperative central arrow. Two hundred ms following the transient peripheral event, the fixation symbol was replaced by an asterisk, a symbol, that was explained to participants, could inform participants that an imperative stimulus would be appearing soon thereafter, for 300 ms and then by a white circle for 160 ms. In the *blocked central target condition*, the white circle was replaced by a central leftward or rightward pointing target arrow (measuring $.56^\circ$ degrees visual angle in width) for which a speeded saccade was required to the placeholder corresponding with the direction of the arrow. In the *blocked peripheral target condition*, the onset of a white peripheral circle coincided with the removal of fixation thus satisfying the criterion for a step gap (gap = 0 ms, Saslow, 1967). In this case, a speeded saccade was required to the location of the peripheral onset target. In the *mixed target condition*, the two abovementioned target conditions and task demands were

randomly intermixed. After a saccade had been executed or, alternatively, after 1.5 seconds, the trial ended and 3 seconds later the next trial was initialized.

2.4 Eye movement monitoring

The calibration of the eye monitoring system was accepted if the subsequent validation procedure obtained an average accuracy less than or equal to $.5^\circ$ degrees visual angle. As aforementioned, a drift correction was conducted on a trial-by-trial basis to maintain the accuracy of the calibration procedure. In the rare event that the drift correction procedure failed, the participant was re-calibrated, the remaining trials were reshuffled, and participants returned to the block of trials in which they were performing. Every 2 blocks (64 experimental trials), eye monitoring was recalibrated.

Throughout a trial, eye movements, rather than being monitored selectively after the offset of the cue and immediately before the presentation of a target (Abrams, & Dobkin, 1994b), were continuously monitored (at a sampling rate of approximately once every 3 ms). If gaze position from fixation exceeded 1.67° visual angle at any point in time before the presentation of a target, the present trial abruptly ended and was reshuffled among the remaining trials. The velocity threshold to detect a saccade was set to $35^\circ/\text{s}$ and the SRTs were computed to be the interval between target presentation and the initiation of the saccade.

2.5 Design

Each participant was tested in one of three conditions (central arrow targets, peripheral onset targets, and mixed central arrow and peripheral onset targets conditions). They performed in 10 blocks of 32 trials each, the last 9 of which were treated as experimental blocks whereas the first block was discarded as practice. In all cases, the location of the first peripheral onset was

random and uninformative about target location. In the mixed and central arrow target blocks, the central directional arrow randomly signaled a leftward or rightward saccadic response. In the mixed and peripheral onset target blocks, the onset appeared randomly either left or right of fixation and signaled a prosaccadic response.

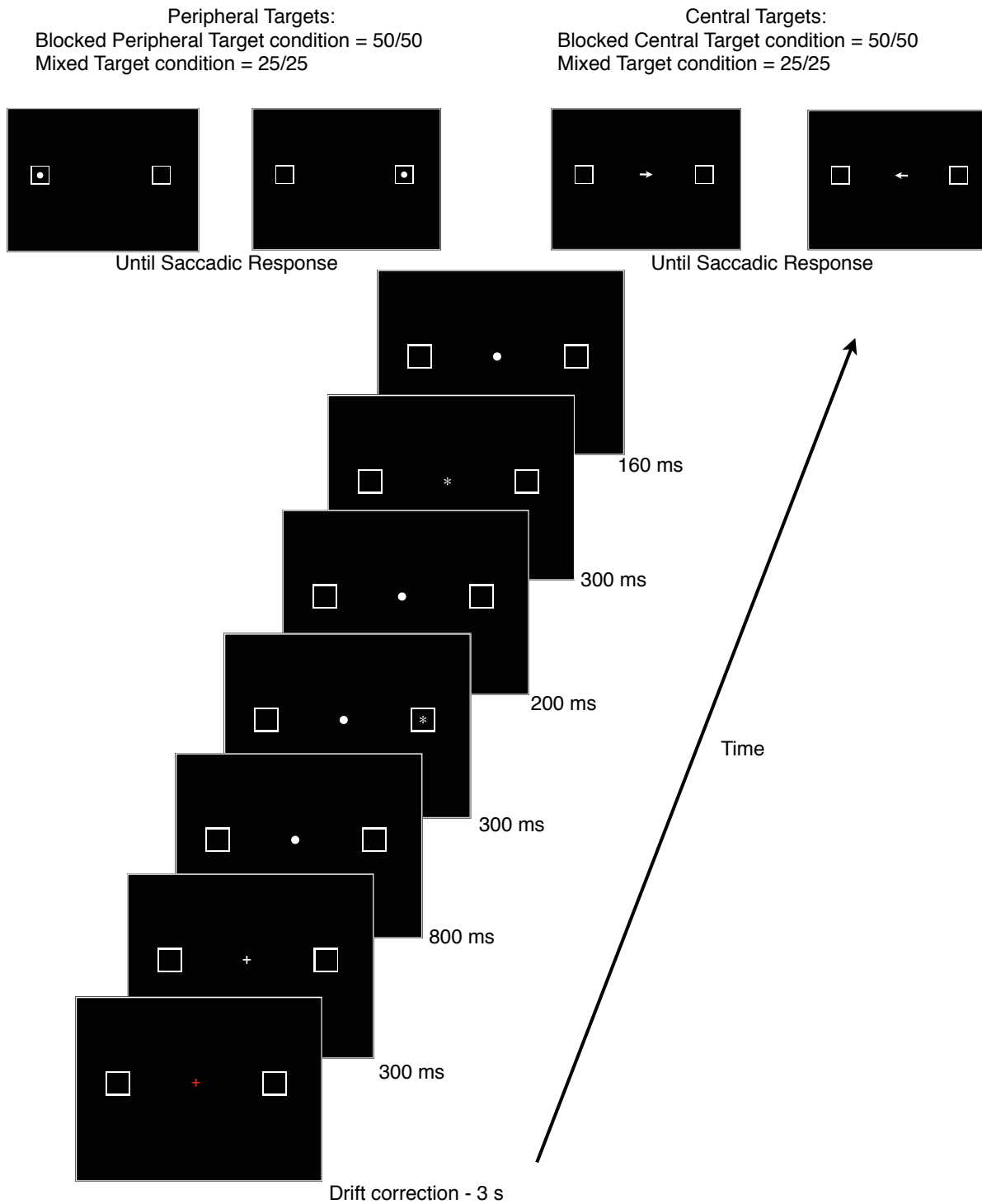


Figure 2.1 The sequence of events from Experiment 1 and 2. See text for additional details.

Chapter 3 Experiment 1 - Results

In all conditions, the first block of data was excluded from analyses as practice. In the blocked central target condition, blocked peripheral target condition and the mixed target condition, 239/1967, 323/2051 and 260/1988 trials, respectively, were terminated abruptly because the participant made an eye movement before target onset. Because these trials obviously contain no data about SRTs to the imperative signal, only the remaining 1728 trials in each condition were analyzed.

Of the remaining trials, following Abrams and Dobkin (1994a), those in which a saccade was made in the direction opposite to the peripheral onset or opposite to the direction of the central arrow were excluded from the SRT analysis. These trials were considered errors. Error rates were low for all target types and conditions resulting in the exclusion of < 2% of trials (see Table 3.1 for a the error rates by condition and target type). The threshold for anticipatory saccades excluded all SRTs less than or equal to 100 ms (Kingstone, & Klein, 1993). Saccadic anticipations were also extremely rare occurring in 0/1701, 12/1704 trials and 4/1712 and in the central target, peripheral target and mixed target conditions, respectively. Furthermore, we excluded all trials in which the SRTs exceeded 1 s reasoning that these SRTs were unlikely to be measuring the psychological processes underlying IOR. This criterion resulted in the elimination of very few experimental trials (<0.02% in all conditions).

The remaining trials were analyzed to evaluate Abrams and Dobkin's oft-cited finding that IOR is greater for peripherally presented targets relative to centrally presented targets. Figure 3.1 (left panel) shows the magnitude of IOR for central targets relative to peripheral targets in the blocked design. There was a main effect of cueing [$F(1, 10) = 5.96, p < 0.05$],

revealing IOR for central ($M = 6.35$ ms) and peripheral targets ($M = 9.13$ ms), and a main effect of target location [$F(1, 10) = 14.32, p < 0.05$], showing faster SRTs for peripheral targets ($M = 217.97$ ms) as compared to central targets ($M = 322.14$ ms). Importantly, and interestingly, the interaction between cueing and position did not achieve significance ($F < 1$) indicating that the IOR score was no greater in the blocked central target condition relative to the blocked peripheral target condition.

Figure 3.1 (right panel) shows the magnitude of IOR for central targets relative to peripheral targets in the mixed design. Analyses of the mixed target condition revealed a main effect of cueing [$F(1, 5) = 12.00, p < 0.05$], revealing IOR for central ($M = 20.12$ ms) and peripheral ($M = 20.41$ ms) targets, and a main effect of target location [$F(1, 5) = 12.00, p < 0.05$], revealing again that saccadic responses were faster for peripheral ($M = 259.76$) as compared to central target ($M = 325.99$ ms). As in the analyses of the blocked target conditions, there was no interaction between cueing and target location ($F < 1$).

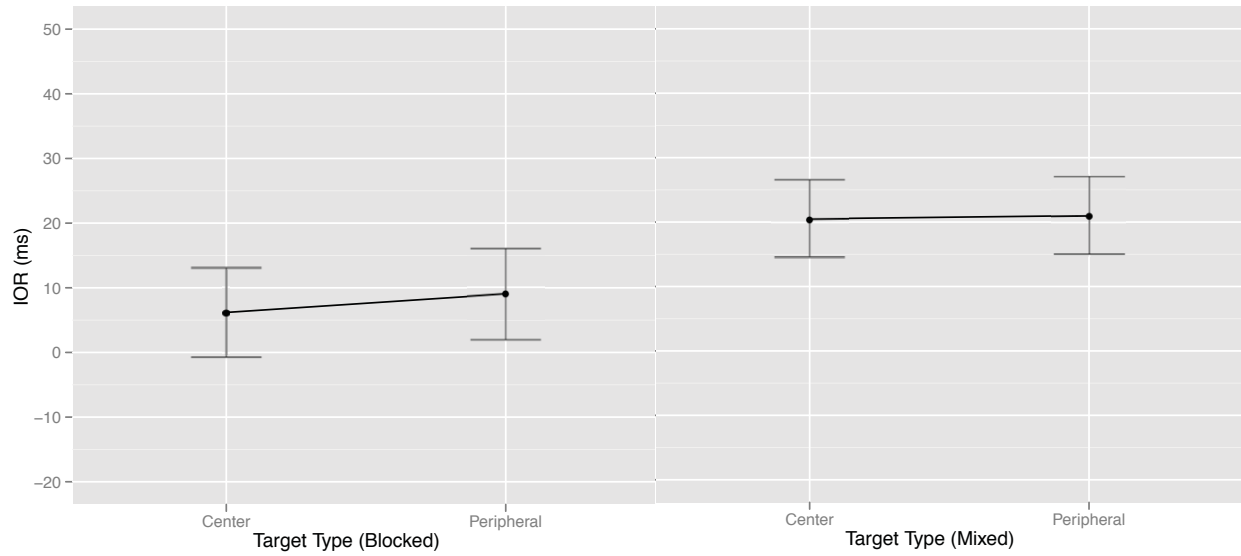


Figure 3.1 The magnitude of IOR for central and peripheral targets in Experiment 1 in the blocked design (left panel) and mixed design (right panel). The error bars are Fisher's Least Significant Difference (LSD).

Table 3.1. The composite data for the IOR scores, accuracy rates and IOR scores for all experiments. Standard deviations appear in parentheses.

Exp. #/Design/ Target Type	Cued RT (ms)	Cued Error (%)	Uncued RT (ms)	Uncued Error (%)	IOR (ms)
Experiment1/ Blocked/ Center	324.32 (61.46)	1.74	318.40 (59.80)	1.28	6.18 (13.82)
Experiment 1/ Blocked/ Peripheral	222.26 (29.65)	0.71	213.23 (29.34)	0.59	9.03 (6.46)
Experiment 1/ Mixed/ Center	335.61 (46.03)	1.68	315.11 (47.32)	1.42	20.50 (14.28)
Experiment 1/ Mixed/ Peripheral	270.22 (67.93)	0.23	249.22 (65.37)	0.00	21.00 (17.07)
Experiment 2/ Blocked/ Center	299.61 (26.18)	0.00	301.02 (33.08)	0.23	-1.41 (18.96)
Experiment 2/ Blocked/ Peripheral	270.31 (98.66)	0.00	236.06 (78.04)	0.23	34.25 (25.95)
Experiment 2/ Mixed/ Center	293.94 (68.93)	3.34	265.84 (57.06)	1.16	28.10 (22.75)

Exp. #/Design/ Target Type	Cued RT (ms)	Cued Error (%)	Uncued RT (ms)	Uncued Error (%)	IOR (ms)
Experiment 2/ Mixed/ Peripheral	215.60 (42.46)	0.48	194.91 (35.68)	0.00	20.69 (10.40)
Experiment 3/ Mixed/ Center	306.97 (49.16)	4.50	279.76 (38.77)	1.20	27.21 (25.96)
Experiment 3/ Mixed/ Peripheral	249.67 (63.26)	0.23	221.49 (49.95)	0.00	28.18 (18.33)

Chapter 4 Experiment 1 - Discussion

In the present experiment, IOR was obtained for endogenously and exogenously generated saccadic eye movements for both the mixed and blocked target designs. Clearly, unlike Abrams and Dobkin (1994a), we failed to show any statistical increase in IOR for peripherally presented targets rendering it difficult to attribute any unique contributory process to IOR for sensory signals that appear at the same location as an uninformative precue. Strangely, however, this finding is seemingly not attributable to an ACS spurred on by the organization of trials within the design (mixed versus blocked). While it is true that there is no indication in the present data set that a second component is involved in the detection of visual stimuli at a previously cued location, a challenge remains in accounting for the disparate pattern of results that Abrams and Dobkin obtained using a blocked design. After all, Abrams and Dobkin discovered that the magnitude of the IOR score was greater for peripherally presented targets as compared to centrally presented targets, a finding that is conspicuously absent in the present experiment.

To most, this will likely arouse some suspicion on the comparability of the two designs. This finding is especially challenging to the assertion that different ACSs were adopted in the blocked presentation of the peripheral target as compared to the central target condition. Thus, while we have clear evidence that the magnitude of IOR was equivalent, in all cases, for peripherally and centrally presented targets, we are in a precarious position given that we failed to replicate the original finding for blocked central and peripheral targets.

Upon re-evaluating the methodology used to elicit the foregoing IOR measures, the principle investigator was humbled to learn that the algorithm for computing the stimulus size in

degrees visual angle failed to account for the appropriate viewing distance. This error caused the presentation of all stimuli and, indeed, all stimulus-to-stimulus relationships to be approximately 1.8 times smaller than they ought to have appeared at a viewing distance of 57 cm. This omission is reflected in the methodology for Experiment 1 and, as can be seen, all stimulus sizes and stimulus size relationships are reduced by a ratio of approximately 1.8:1 in comparison with Abrams and Dobkin (1994a).

As a result, a very clear distinction can be made between the two methodologies: stimulus size and placeholder-to-fixation distance. First, and perhaps critically, this systematic methodological error in the present experiment made it extraordinarily difficult to disambiguate relevant stimulus identities, especially those appearing parafoveally. Consider how this might affect the ACS for the blocked peripheral target condition. In this condition, there are essentially several strategies or some combination thereof that one could adopt to perform the task successfully. One, the participant might choose to attend exclusively to the transient fixation stimulus until the appearance of an asterisk. This asterisk could then be used as a signal to allocate attentional resources to peripheral locations for an impending target. This is a strategy that, if used successfully, would – according to the ACS theory forwarded in the present paper – reduce the magnitude of IOR to the extent to which the participant could filter out the cue. While this strategy is undoubtedly complicated by a striking qualitative similarity between asterisks and a circles at fixation presented with a diameter of .28 degrees visual angle, it is possible that this strategy played some part in informing the decision-making process for a saccadic response.

Alternatively, the participant might select a strategy to differentiate the cue from the target on the basis of its features. After all, the peripheral cue is an asterisk whereas the

peripheral target is a circle. This strategy, however, would theoretically be more difficult to implement than the last one given that feature discrimination is superior in the cone-rich fovea as compared to parafoveal processing and it would be more difficult still given the qualitative resemblance between imperative and non-imperative stimuli. Relatedly, however, the observer might rely on the peripheral cue as something that is temporally informative. The onset of the peripheral cues may be attended not for its spatial properties but as a temporal signal that provides some indication as to where the observer is, temporally, in the trial and, incidentally, when a saccadic response will be required. Thus, processing of the cue might be used to provide participants with something of a temporal anchor or a reference point as to where they are in a paradigm that is essentially constantly changing. Moreover, in a blocked peripheral target condition, the cue might take on added value given that a reasonable strategy might be to simply 'ignore' the first peripheral onset and attend the second peripheral onset. In this way, most stimulus changes at fixation could be ignored and limited attentional resources could be allocated optimally to the peripheral locations (Awh, & Pashler, 2000). This would be tantamount to a counting strategy; in other words, 'ignore' (or do not behave for) peripheral event 1 but saccade to peripheral event 2.

Another strategy might be to enact a sort of attentional radar for all circular stimuli in the blocked peripheral target condition (*i.e.*, the target, Folk, Remington, & Johnston, 1992) - a strategy that might become extremely inefficient in the small stimulus condition if the relational account (Becker, Folk, & Remington, 2010) holds for geometry because of a clear perceptual ambiguity between an asterisk and a circle at reduced sizes - such that all stimuli resembling the

target will reflexively capture attention to some extent. To be sure, the cue and the target are qualitatively discriminable.

At this point in time, an assumption to the validity of the ACS theory would explain this result adequately by suggesting that the perceptual ambiguity of the stimuli caused similar ACSs for the blocked central and peripheral target conditions. Of course, this theory makes no claims as to what particular strategy or combination thereof had been used to produce the present results. Furthermore, it is an unfair assumption given that we have yet to demonstrate that the causal link separating the findings from Taylor and Klein (2000) from Abrams and Dobkin (1994a) is an ACS affecting the pre-target allocation of attentional resources. If stimulus size has any capacity to mediate ACSs (as described above), we should replicate Abrams and Dobkin's pattern of results if we increase the sizes of the stimuli and their distances from fixation in a precise replication of their experiment.

Chapter 5 Experiment 2 - Methods

5.1 Rationale

Experiment 2 was designed to better approximate the stimuli used by Abrams and Dobkin (1994a) by equating stimulus size and the distance of the placeholders from fixation. Experiment 1 showed no difference in the magnitude of IOR between blocked peripheral and blocked central target designs. This result was attributed to an effect of stimulus size on the ACS. This claim cannot, however, be endorsed strongly until it is demonstrated that mixed and blocked designs for central and peripheral targets generate different control settings that affect processing of the cue and, by extension, the magnitude of IOR. Experiment 2 was an exact replication of Experiment 1 except the stimulus dimensions were adjusted to reflect those in Abrams and Dobkin (1994a). The hypothesis remains unchanged: if the magnitude of IOR is greater in the blocked peripheral target condition as compared to the blocked central target condition but again equivalent when the target types are intermixed, it is most likely that an attentional strategy and not a second component related to responding to peripheral onsets is causing a difference in the IOR scores.

5.2 Subjects

Eighteen new undergraduate (11 females and 7 males) students from Dalhousie University participated in a single 75-90 minute session for course credit or monetary compensation (\$15 CDN). All participants were naive to the purposes of the experiment and reported either normal or corrected-to-normal vision. Two participants were left-handed (both of whom participated in the blocked peripheral target condition).

5.3 Apparatus and Procedure

Experiment 2 was identical to Experiment 1 in every way except that all distances and stimulus sizes were increased by a factor of 1.8 degrees visual angle (so that the stimulus dimensions and fixation-to-placeholder eccentricities from Abrams and Dobkin (1994a) were replicated). The eccentricities were set to 7 degrees visual angle. The placeholder boxes measured .8 x .8 degrees visual angle. All cues, fixations and peripheral onset targets were set to .5 x .5 degrees visual angle. The central target arrow was set to 1 degree visual angle in width.

5.4 Eye monitoring

The same eye monitoring procedure used in Experiment 2 except the fixation criterion was restored to 3 degrees visual angle as in Abrams and Dobkin (1994b).

5.5 Design

There were no changes to the organization of trials within the blocked peripheral target, blocked central target, and mixed target conditions.

Chapter 6 Experiment 2 - Results

In all conditions, the first block of data was excluded from analyses as practice. In the blocked central, blocked peripheral and mixed target conditions, 71/1779, 31/1759 and 136/1864 trials, respectively, were terminated abruptly because gaze position was outside the fixation criterion before target onset. Again, because these trials contain no information about saccadic responses to target onsets, these trials were excluded from analyses. There were thus 1728 total trials in the peripheral and mixed target conditions. In the central target condition, there were 1708 trials (20 less than the other conditions) because of an untimely power outage resulting in a loss of data in block 8 for one participant.

As in Experiment 1, the error rates were low in all conditions resulting in the exclusion of <2% of trials for the SRT analyses (see Table 3.1 for a the error rates by condition and target type). Saccadic anticipations and saccadic responses times in excess of 1s were rare in all conditions (combining for <1% of all trials in each condition).

The remaining trials were submitted for analyses. Figure 6.1 (left panel) shows the magnitude of IOR for the blocked central and peripheral target conditions. There was a main effect of cueing [$F(1, 10) = 6.26, p < 0.05$] that was overshadowed by an interaction between cueing and block [$F(1, 10) = 7.39, p < 0.05$]. Clearly, this interaction arose because IOR was greater in the blocked peripheral target condition ($M = 35.16$ ms) relative to the blocked central target condition ($M = -1.59$ ms) where there was neither numerical nor statistical evidence for IOR.

Figure 6.1 (right panel) shows the magnitude of IOR for central and peripheral targets in the mixed design. SRTs were faster for peripheral targets relative to central targets [$F(1, 5) =$

20.56, $p < 0.05$] and were slower for cued locations as compared to uncued locations [$F(1, 5) = 17.96, p < 0.05$], revealing IOR. Importantly, there was no interaction between target type and cueing ($F < 1$) indicating that there was no statistical difference in the IOR scores between centrally and peripherally presented targets. Indeed, the magnitude of IOR was numerically larger for central targets ($M = 30.34$ ms) relative to peripheral targets ($M = 21.00$ ms).

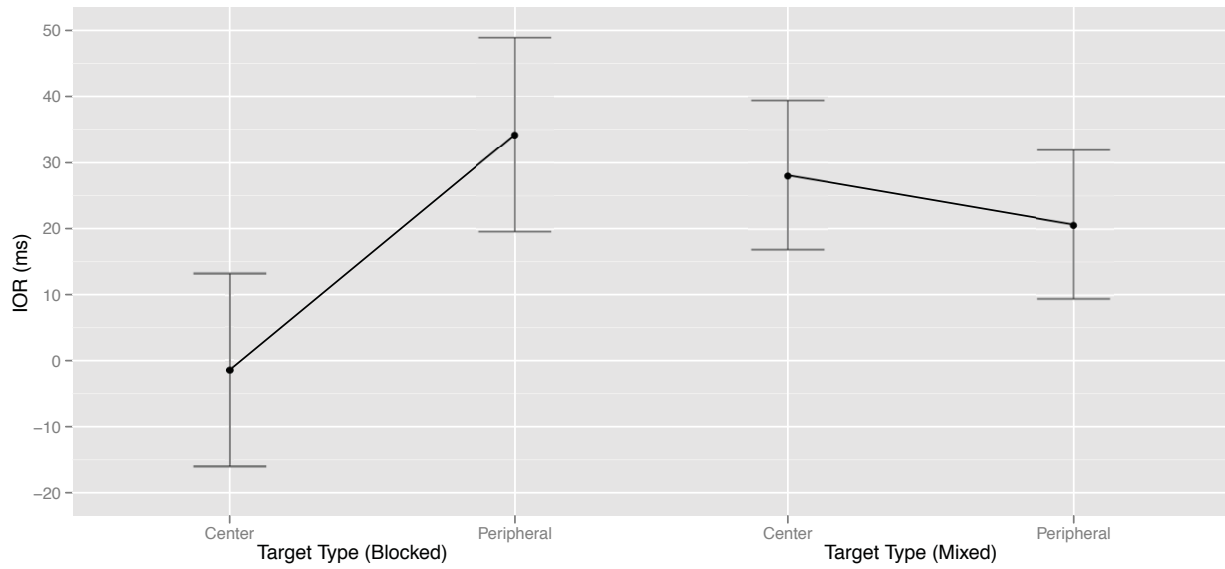


Figure 6.1. The magnitude of IOR for central and peripheral targets in Experiment 2 in the blocked design (left panel) and mixed design (right panel). Error bars are Fisher's LSDs.

Chapter 7 General Analyses of Experiment 1 and 2

7.1 Rationale - Blocked Designs

Earlier, an *ad hoc* hypothesis was offered suggesting that stimulus size and fixation-to-placeholder eccentricity might induce an ACS allowing for equivalent SRTs to be obtained between the blocked peripheral and central target conditions (Experiment 1). To test the validity of this hypothesis, the data from Experiments 1 and 2 were aggregated in an analysis of variance (ANOVA) with stimulus size/fixation to placeholder eccentricity ('small' and 'large') as a factor. If this hypothesis were correct, a three-way interaction between cueing (cued and uncued), block (central and peripheral target) and stimulus size (experiment 1 versus 2) would be expected if size interacted in a complex way with block to affect the ACS and, consequently, the expression of IOR.

7.2 Results - Blocked Designs

The general ANOVA revealed a main effect of block [$F(1, 20) = 10.44, p < 0.05$], a main effect of cueing [$F(1, 20) = 10.95, p < 0.05$], an interaction between cueing and block [$F(1, 20) = 7.029, p < 0.05$] and most critically, a three-way interaction between stimulus size, group and cueing [$F(1, 20) = 5.10, p < 0.05$]. Thus, the general analysis revealed, respectively, that SRTs were faster for peripheral targets, that there was IOR, that IOR was mediated by blocking (an effect of group on IOR), and finally, that stimulus size and group mediated IOR (an effect of stimulus size and group on IOR). A decomposition of the three-way interaction is readily observable from the results of Experiment 1 and 2. Clearly, group and cueing did not interact in Experiment 1 whereas these factors did in Experiment 2. Thus, all else being equal, stimulus size mediated the interaction between group and cueing.

7.3 Rationale - Mixed Designs

Stimulus size should have no effect on any interaction that might exist between target type (central or peripheral) and cueing in the mixed design. Simply, the mixed design is assumed to equate the ACSs for central and peripherally presented targets because there is no way to determine, before its presentation, the target's type (and to therefore adjust the distribution of attention within the visual scene); thus, any effect that stimulus size would have on the ACS would apply equally to centrally and peripherally presented targets.

7.4 Results - Mixed Designs

SRTs were faster for peripherally presented targets relative to centrally presented targets [$F(1, 10) = 54.25, p < 0.05$] and SRTs were slower for cued locations relative to uncued locations [$F(1, 10) = 29.53, p < 0.05$]. None of the interactions approached significance ($F < 1$).

Chapter 8 Experiment 2 - Discussion

Experiment 2 was a replication of Experiment 1 except the stimulus sizes and fixation-to-placeholder eccentricities from Abrams and Dobkin (1994a) were preserved because of the possibility that stimulus size had interacted with blocking to reduce the magnitude of IOR in the peripheral target condition. By retaining the stimulus dimensions of Abrams and Dobkin, we were able to demonstrate clearly that the magnitude of IOR in a blocked design was greater for peripheral targets than it was for central targets. Unlike that observed by Abrams and Dobkin (1994a), we found no evidence of IOR in the central target condition. To be sure, however, the magnitude of IOR in blocked central target conditions is typically small (*e.g.*, Rafal, Egly, & Rhodes, 1994) or non-existent (*e.g.*, Li, & Lin, 2002). Thus, while we have failed to replicate Abrams and Dobkin's (1994a) finding of some IOR for blocked central targets (whereas Experiment 1 did reveal some indication of IOR for blocked central targets), the present results converge with the findings of Li and Lin (2002) and point to the possibility that some observers might excel at filtering out the task-irrelevant peripheral cues when targets are never presented in the periphery.

More importantly, when these conditions were intermixed, as in Taylor and Klein (2000), again there was no statistical or numerical evidence that the magnitude of IOR was greater for peripheral than for central targets. Moreover, there was robust evidence for IOR for both centrally and peripherally presented targets. Given that the only apparent difference between these conditions (blocked and mixed) is the extent to which one might expect a target at center or elsewhere, it is likely that spatial expectancies about target onset are affecting the diffusion of attentional resources such that the cue receives less processing in a block of central arrows

relative to a block of peripheral onsets or mixed central and peripheral targets. When processing of the cue is equivalent, as in a mixed target design, there is no indication that repeated spatial, sensory stimulation plays any major role in IOR. Thus, while the perceptual/attentional account for IOR is severely discounted, the present results suggest that the distribution of attention to the sites of uninformative stimuli will determine whether IOR materializes.

Finally, an unintended consequence of the miscalculation of the stimulus dimensions in Experiment 1 was an opportunity to examine whether stimulus size/fixation-to-placeholder eccentricity might mediate an ACS. The general analyses afforded us an opportunity to explore this question. In short, it appears as if stimulus size can interact with an ACS established by a blocked design to affect IOR. This serendipitous finding is far removed from the goal of the present investigation and is not firmly grounded theoretically. Thus, while it appears likely that stimulus size or, perhaps more poignantly, the perceptibility of the stimuli can alter the ACS spurred on by a blocked design, it is not altogether clear which spatial selection strategy has been implemented to produce the present pattern of results¹.

¹ To this end, recall earlier that a number of attentional deployment strategies were reviewed that could theoretically be utilized in various ways to perform the task successfully. The implication of the three-way interaction is that stimulus size might make one strategy a less efficient candidate to perform the task successfully than any other thereby leading to the selection of a different strategy which might lead to more or less processing of the cue. All events contain some information as to when the target will appear and could be used to better inform oculomotor preparation and therefore each event in the trial and all information about target type, the physical expression of the target type and its kin provide important indices that might affect attentional deployment strategies. At present, one speculation might be that the perceptual ambiguity of stimuli in Experiment 1 requires increased attentional processing at fixation if one were to use those stimulus changes as temporal indices. But how might one then explain IOR for blocked central targets in Experiment 1 but not in 2? A possibility might be that the observer verifies his/her perceptual experience at fixation by attempting to associate the pre-cue stimulus change at fixation with the uninformative peripheral event when stimulus discriminability is difficult. That is, some amount of attentional processing is distributed to the periphery in the 800 ms interval between the fixation change and cue onset and that the ability to do so is tempered to some extent by the difficulty of stimulus processing at fixation. At any rate, while it must be acknowledged that stimulus size and target spatial expectancies (*e.g.*, blocking) can interact to affect the deployment of attention, it is not entirely clear how this occurs and specifically, why the pattern of results from the mixed design in Experiment 1 resembles the pattern of results from the same design in Experiment 2 whereas in Experiment 1 the blocked designs diverge on two findings: One, IOR was obtained for centrally presented targets in Experiment 1 whereas it was not in Experiment 2. Two, the magnitude of IOR for blocked peripheral targets in Experiment 2 far exceeded the null effect of IOR for blocked central targets whereas statistically equivalent IOR scores were obtained for both blocked conditions in Experiment 1.

Finally, one may wonder whether the step gap in the lynchpin Abrams and Dobkin (1994a) study that was replicated here might have been reducing the magnitude of IOR for peripherally presented target (Souto, & Kerzel, 2009; Hunt, & Kingstone, 2003). This appears to be a plausible behavioral outcome but it must be noted that Abrams and Dobkins (1994b), using a design that mirrored the present one on many dimensions, showed that a step gap increased IOR (although, strangely, IOR was not obtained in the traditional overlap condition). Nevertheless, the result of a step gap increasing IOR has been replicated (and IOR was obtained for fixation target overlap) in a dark room using light emitting diodes as stimuli (Guimaraes-Silva, Gawryszewski, Portugal, & Klausner-de-Oliveira, 2004). Clearly then, while the literature suggests that an interaction should be observed between IOR and the presence or absence of a gap, it is unclear whether a step gap will increase or reduce IOR in the present design. Because of this ambiguity, Experiment 3 was conducted to determine whether IOR would be equivalent for peripherally and centrally presented if the fixation point remained onscreen throughout the trial on both peripheral and central trials.

Chapter 9 Experiment 3 - Methods

9.1 Rationale

To determine whether the step in Experiment 2 was obscuring a second attentional/perceptual component to the peripheral target, Experiment 3 was conducted to replicate Experiment 2 with fixation and target stimulus overlap in the mixed target condition. If IOR is greater for peripheral targets relative to central targets, there will be clear evidence that exogenously generated IOR measured by way of a peripheral target contains a second attentional/perceptual component relative to the central target condition and that, accordingly, the reduction in IOR by the step gap obscured the effect in Experiment 2. To be sure, however, there is compelling data to suggest that when the stimulus at fixation is not removed there will be equivalent IOR when measured with central and peripheral targets (Taylor and Klein, 2000). Thus, there is little reason to suspect a difference between peripheral and central targets in this design.

9.2 Subjects

Thirteen new undergraduate (9 females and 4 males) students from Dalhousie University participated in a single 75-90 minute session for course credit or monetary compensation (\$15 CDN). All participants were naive to the purposes of the experiment and reported either normal or corrected-to-normal vision. All but one participants were right-handed.

9.3 Apparatus and Procedure

Experiment 3 was identical to Experiment 2 except only the mixed target condition was administered to participants and the step gap was removed from peripheral target trials (following Taylor, & Klein, 2000).

9.4 Eye monitoring

The same eye movement criteria from Experiment 2 were used in Experiment 3.

9.5 Design

There were no changes to the organization of trials within the mixed target condition but again, participants were not recruited to the blocked central and peripheral target conditions because it has already been established that blocking target type can induce an ACS that may reduce or eliminate IOR.

Chapter 10 Experiment 3 - Results

The first block of data was excluded from analyses as practice. Of the remaining trials, 399/4143 trials were terminated abruptly because gaze position was outside the fixation criterion before target onset. Again, because these trials contain no information about saccadic responses to target onsets, these trials were excluded from analyses. There were thus 3744 total trials.

Saccadic eye movement errors away from the target were rare (see Table 3.1) but the error rates for cued trials relative to the uncued locations on central arrow trials in the mixed target condition exceeded Fisher's least significant difference (.023 or 2.30%) revealing more errors for cued trials. Similarly, anticipations were rare but higher than previously reported, occurring in 1.81%² of trials. SRTs in excess of 1s occurred in 0.43% of trials. These data were excluded from analyses.

The remaining 3619 trials were analyzed. Figure 10.1 shows the magnitude of IOR for centrally and peripherally presented targets and a more complete treatment of IOR's composite scores can be found in Table 1. There was a main effect of target type [$F(1, 12) = 37.73, p < 0.05$] showing faster SRTs for peripheral ($M = 235.49$ ms) relative to central ($M = 293.21$ ms) targets. There was a main effect of cueing [$F(1, 12) = 37.84, p < 0.05$] revealing IOR. Critically, the interaction between cueing and target type was not significant ($F < 1$) demonstrating that IOR was equivalent for central ($M = 27.22$ ms) and peripheral ($M = 28.18$ ms) targets.

² One participant contributed 32 anticipations (and had an accuracy of 50% on these trials) to the data set which, in large part, explains the numerical differences in anticipation rates between the mixed condition in Experiment 2 and the present experiment. It should be noted that this participant's accuracy was at 98% when anticipations were excluded from analysis.

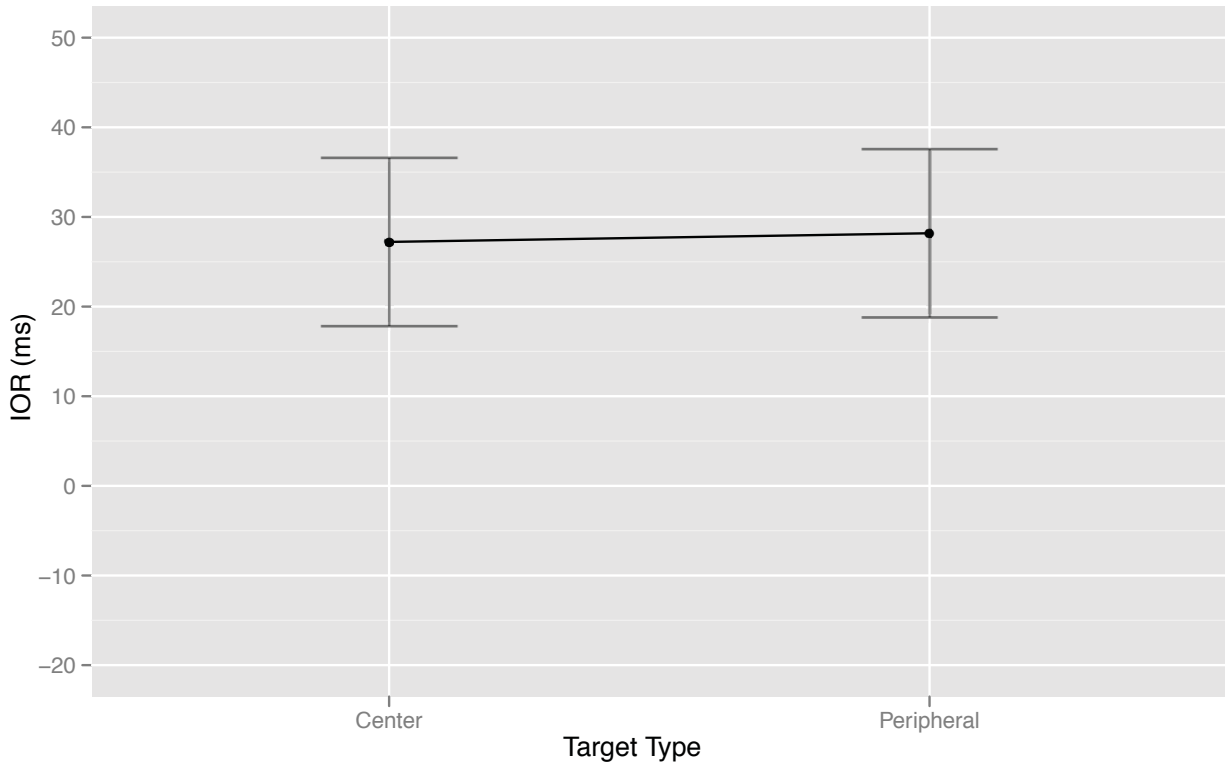


Figure 10.1. The magnitude of IOR for central and peripheral targets in Experiment 3, mixed design. Note that the error bars represent Fisher's Least Significant Difference (LSD).

Chapter 11 Experiment 3 - Discussion

Experiment 3 was conducted to determine whether including a step gap in Experiment 2 in the mixed condition for peripheral targets (following Abrams & Dobkin, 1994a) might have unintentionally lowered the IOR score in this condition, thus obscuring an attentional/perceptual component to IOR. On this matter, the data are clear. Like Taylor and Klein (2000), we obtained equivalent IOR for peripheral and central targets when target onset and the fixation stimulus overlapped. To this end, we have extended Taylor and Klein's findings by introducing the mixed design to Abrams and Dobkin's (1994a) paradigm (Experiment 2) and by replicating equivalent IOR by removing a suspicious, and possibly confounding, factor - the step gap (the present experiment); we have demonstrated that equivalent IOR between peripheral and central target types is obtained in earlier variations of the Model task (*e.g.*, Abrams & Dobkin, 1994a) without a step gap so long as target types are randomly interleaved within blocks of trials. These results, when compared to data sets obtained using identical stimulus dimensions and target to placeholder eccentricities for which target type was blocked (*e.g.*, Experiment 2 ; Abrams & Dobkin, 1994a) amply demonstrate the importance of blocked versus mixed target designs and point to the need for a stricter adherence to mixed designs in IOR research.

Chapter 12 General Discussion

The present investigation has led to two principle findings and one serendipitous finding. First, we have succeeded in demonstrating that the magnitude of IOR for exogenously and endogenously generated saccades is equivalent if spatial expectancies about the target are held constant by way of a mixed design. If a block of trials is comprised entirely of centrally presented targets, observers may be able to strategically adjust their spatial attention to reduce (Abrams, & Dobkin, 1994a; Rafal, Egly, & Rhodes, 1994; Godijn, & Theeuwes, 2004) or completely eliminate IOR (Li, & Lin, 2002, the present Experiment 1). Clearly then, it appears as though some prior allocation of spatial attention to the cue is required to cause IOR.

Second, that the magnitude of IOR measured by exogenously and endogenously generated saccades is equivalent in mixed designs (Experiments 1 and 2 with a step gap and Experiment 3 without a step gap) strongly suggests that if attentional resources are extended uniformly to the uninformative peripheral cue for centrally and peripherally presented targets, there is no behavioral evidence for a perceptual/attentional component of IOR. By extension, this suggests that differential attentional processing of the cue in the blocked designs is what gave rise to the different IOR scores for exogenously and endogenously generated saccades in Experiment 2 and from Abrams and Dobkin (1994b). To the extent that a central arrow gauges motoric effects to the exclusion of attentional effects (Abrams, & Dobkin, 1994b; Taylor, & Klein, 2000; Li, & Lin, 2002), the effect of IOR in this paradigm is purely motoric - a finding

that is consistent with a unified theory for IOR when the oculomotor system is active (*i.e.*, the motoric flavour of IOR).³

Finally, our unintentional manipulation of stimulus size (compare Experiment 1 to Experiment 2) revealed a serendipitous finding that certainly warrants further exploration: stimulus size can affect ACSs such that a cue may receive more or less processing and, consequently, IOR will be affected accordingly.

Implications for the literature

The discovery of an ACS producing disparate IOR scores between blocked central and peripheral target conditions was suggested as a possible way to explain an empirical discrepancy between Taylor and Klein (2000) and Abrams and Dobkin (1994a). This idea was motivated by the literature showing that ACSs can reduce or eliminate the effect of irrelevant abrupt onsets on response times (Yantis, & Jonides, 1990; Theeuwes, 1991; Ishigami et al., 2009) and by assuming that this allocation of attention might affect IOR. Applying the ACS theory (centered on spatial expectancies about target onset) to these data provides a viable account of the empirical differences between central and peripheral targets when blocked relative to when they are mixed. Although the principle aim of this paper was to determine whether IOR is equivalent for peripheral and central targets when processing of the cue is balanced by way of a mixed

³ Repeated, localized stimulation increases the magnitude of IOR for manual responses -a finding that has partly given rise to the 'habituation of the orienting response' view of IOR (Dukewich, 2009). This result would either not be replicated in the no response-saccade condition or, if it were, it would suggest that IOR is affecting the relationship between attention and oculomotor responses (Posner, 1980; Klein, 1980; Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Kingstone, & Ristic, 2006; Frischen, Bayliss, & Tipper, 2007; Kuhn, & Kingstone, 2009; Beloposky, & Theeuwes, 2009) and not the relationship between attention and perceptual processes as is commonly found in the no response manual condition (Lupianez, Milan, Torney, Madrid, & Tudela, 1997; Lupianez, & Milliken, 1999; Taylor, & Klein, 2000; Vivas, & Fuentes, 2001; Prime, & Ward, 2004; 2006; Prime, & Jolicoeur, 2009a; 2009b; Hilchey, Ivanoff, Taylor, & Klein, 2011).

design, the ACS hypothesis carries important implications for the IOR literature and calls for a re-evaluation of several findings. This point is best illustrated with examples.

Consider Godijn and Theeuwes (2004). Godijn and Theeuwes appear to demonstrate, in contrast to Posner and Cohen (1984) for manual responses, that IOR for saccadic response times can be caused by central arrows that are informative about the location of a to-be-ignored or to-be-attended abrupt onset cue. In their paradigm, four placeholders were positioned equieccentrically around a fixation point to form an imaginary square. Each placeholder was associated with a number (1, 2, 3, or 4). In a central arrow cue condition, an arrow commanded attention to one of four placeholders. A digit then appeared abruptly at the location to which the arrow was pointing and in the other three placeholder locations. If the number in the cued placeholder position was between 1-4, participants executed an eye movement to the placeholder corresponding with the number. If the number, however, was a 0 (appearing on half of the trials), participants had to refrain from making a saccade. Following an SOA suitable for observing IOR and after attention (in trials in which a 0 appeared at the cued location) or the saccadic eye movement (in trials in which the number 1-4 appeared) had returned to fixation, a digit between 1-4 appeared at the center location. Again, these digits mapped and instructed saccades to placeholder locations.

The critical result from this paradigm for the present investigation was that IOR was obtained in the informative central arrow cue condition [recall again that central arrows do not appear to generate IOR for saccadic responses (see Figure 1.1)]. This result led to an assumption that the arrow might play a role in generating an oculomotor program that is later inhibited (Rafal, Calabresi, Brennan, & Sciolto, 1989; see Chica, Klein, Rafal, & Hopfinger, 2010, for a

convincing non-replication of this finding under stringent conditions with eye movement monitoring). However, a more plausible alternative is that the informative arrow caused attention to be narrowly restricted to the location in which a to-be-fixated target would appear 50% of the time, and of course, on the other half of the trials, the location had to first be attended to ensure that a saccadic eye movement was not required. According to the ACS theory, this finding is easily explained. The central arrow, predicting precisely the location of a to-be-attended stimulus may have caused attention to be narrowly restricted to that region of the display, allows for the successful filtering of the other abrupt onsets [possibly precluding the vector averaging of IOR effect (Klein, Christie, & Morris, 2005)] while simultaneously causing increased processing of the abrupt onset. The ACS theory as applied to IOR maintains that it is this abrupt onset, that acted as a cue-back in half the trials in which an eye movement was not required, likely caused IOR.

Consider also Li and Lin (2002). In their ‘vertically instructed saccade’ paradigm, there were four placeholder locations equi-distant from fixation. Two placeholders appeared left and right and two placeholders appeared above and below fixation. The cue, a peripheral onset, appeared in either the left or right placeholder location. The target, however, appeared at one of the two locations on the vertical axis. A target at the top placeholder location on the vertical axis signaled a rightward saccade and a target at the bottom placeholder location signaled a leftward saccade. In this paradigm, there was no difference in RTs to saccades directed at previously cued and uncued locations which was taken as evidence against the motor view. Here, following the ACS theory, it now seems likely that the absence of IOR (and a rejection of the motor account) occurred because participants had adopted an attentional set to filter out the irrelevant horizontal

cues⁴. Results like these must be reconsidered in light of the present findings and we hope that these examples will encourage a more dedicated exploration of these matters.

On the causes of IOR

While the present investigation is primarily centered on assessing the effect(s) of IOR and not the cause(s), some may infer that attention causes IOR. Such reasoning makes some relatively subtle distinctions between the motoric and attentional/perceptual causes of IOR. From the suggestion that attention may be narrowly restricted to the mid-point of a display in a block of trials containing only central targets and that this focused beam of attention may reduce the impact of an uninformative peripheral cue on generating IOR, the implication might seem to be that IOR is caused, at least in part, by the extent to which attention is likely to visit a task-irrelevant stimulus. From this, it might be tempting to infer that IOR is generated by the exogenous orientation of attention and subsequently observed following the removal of attention or, alternatively stated, that IOR is a consequence of exogenous orienting (Danziger, & Kingstone, 1999; Hoge, Over, van Wezel, & Frens, 2005). To be sure, and to stress one well-corroborated aspect of this theory, the removal of attention from a cued location has long and likely correctly been believed to be necessary to unmask IOR (Klein, 2000; see Klein, 2004 for review; but see evidence showing that IOR is additive with endogenous attention [*e.g.*, Berger, Rafal, & Henik, 2005]). However, attributing the cause of IOR to exogenous orienting encounters tremendous difficulties in explaining why IOR is *not* manifest in conditions under

⁴ An alternative explanation for the absence of IOR in this condition centers on reasoning that tasks that preclude the reflexively oculomotor activation result in an attentional/perceptual flavour of IOR (Klein, & Hilchey, in press; discussed later in this General Discussion (“*On the effects of IOR: Pro-saccades versus anti-saccades*”).

which colored singletons involuntarily capture attention (Gibson, & Amelio, 2000; Pratt, Sekuler, & McAuliffe, 2001; Pratt, & McAuliffe, 2002).

An alternative way of thinking, consistent with a motor cause, is that the degree to which attention has previously been allocated to a region in the visual scene modulates the degree to which the oculomotor system is activated (Klein, 2000). This view allows for oculomotor activity, rather than the degree to which attention is reflexively captured by a salient onset, to be the principle cause of IOR when measured by saccadic responses (Klein & Hilchey, in press).

Notwithstanding the cause of IOR, while these data are clearly consistent with the idea that there is a motoric effect of IOR (Klein, & Taylor, 1994; Taylor, & Klein, 1998; Taylor, & Klein, 2000), they are also unmistakably inconsistent with the idea of a single unitary perceptual/attentional effect to IOR and with any two-component theory postulating an attentional/perceptual component in addition to a motoric component (Abrams, & Dobkin, 1994; Rafal, Egly, & Rhodes, 1994; Li, & Lin, 2002; Fecteau, Au, Munoz, & Armstrong, 2004; Khatoon, Briand, & Sereno, 2002). If one role of IOR were to degrade the input signal *at* a cued location in a no response-saccade paradigm, the magnitude of IOR would have been greater in the mixed condition for peripheral targets relative to central targets - a result that is conspicuously absent when the ACS for the cue is equated between target presentation conditions.

On the effects of IOR: The discrepancy between prosaccadic and antisaccadic paradigms

Although the data from the present investigation are clearly at odds with the idea that a perceptual/attentional component is involved for saccadic IOR, many will recognize the apparent contradiction between these findings and the antisaccade literature on IOR. The standard

implementation of the antisaccade task is identical in almost every way to the Model task except instead of a saccade *to* a peripheral target onset, a saccade in the opposite direction of the onset is required. The onset, as in the Model task, can be cued or uncued and the difference between the SRTs for those conditions is taken as an index of IOR. Interestingly, in the antisaccade task, SRTs are invariably slower when the second signal (the target onset) repeats the location of the earlier signal (cue or previous target) which has caused several researchers to suggest that there is a strong sensory or attentional/perceptual component to saccadic IOR and that there is, consequently, little evidence for a meaningful motoric component (Rafal, Egly, & Rhodes, 1994; Li, & Lin, 2002; Fecteau, Au, Munoz, & Armstrong, 2004; Khatoon, Briand, & Sereno, 2002).

To complicate matters, this attentional/perceptual interpretation is bolstered by single cell recording studies in monkeys using shorter SOAs, under conditions that are similar to the present paradigm (and not the anti-saccade task) and therefore under conditions that satisfy the criteria for the motor flavour of IOR. The neurophysiological data show decreased action potentials in visuomotor and visual neurons residing in the intermediate and superficial layers, respectively, of the superior colliculus (SC) when a cue appears at the same location as a target that correlates well with behavioral IOR (Dorris, Klein, Everling, & Munoz, 2002; Fecteau, & Munoz, 2005; see Berlucchi, 2006, for some additional coverage of this idea). The SC, a subcortical brain structure responsible for saccadic eye movements, has long been considered to play a role in IOR (Posner, Rafal, Choate, & Vaughan, 1985; Rafal, Calabresi, Brennan, & Sciolto, 1989; Taylor, & Klein, 1998; Sapir, Soroker, Berger, & Henik, 1999; Klein, 2000; Hunt, & Kingstone, 2003; Sumner, Nachev, Vora, Husain, & Kennard, 2004; Sereno, Briand, Amador, & Szapiel, 2006). That reduced cellular activity upon repeated sensory stimulation at a cued region correlates with

IOR produces a clear theoretical disconnect between this corpus of data and the present results.

There are then two main questions: 1. How can the flavours view link the present results with the antisaccade literature, and 2. Why does cognitive neuroscience point to an association between repeated sensory stimulation and IOR whereas the present findings suggest that there is no behavioral difference between measuring IOR with a central or peripheral target?

With regards to the first question, one possible way to reconcile the motoric account of IOR with the anti-saccade literature was suggested by Klein and Hilchey (in press). Recall that Taylor and Klein's (2000) view makes a fundamental distinction between attentional/perceptual and motoric flavours of IOR: when the oculomotor system is free to respond *to* a stimulus event, the flavour of IOR is motoric. In contrast, when saccadic eye movements are strictly prohibited, bottom-up activation of the oculomotor circuitry only poses a hindrance to successful task completion. It is in these conditions where the flavour of IOR is considered to be attentional/perceptual and this is presumed to occur through a top-down process that tonically inhibits the SC or, in other words, a process that makes the SC less responsive to visual inputs. The two flavours view can accommodate the antisaccade data which points to the attentional/perceptual favour even while IOR is measured using eye movements by assuming that the reflexive oculomotor circuitry is tonically inhibited when participants are required to make anti-saccades. This tonic inhibition is likely applied to ensure that the oculomotor system suppresses pro-saccades that would otherwise be frequently executed (as suggested by Forbes & Klein, 1996). This line of thinking clearly reinforces the notion of a two flavours theory of IOR whereby when the oculomotor system is free to reflexively cause saccadic eye movements, a motoric effect is observed whereas when the oculomotor system must suppress a natural tendency to respond to

inputs, an attentional flavour is observed (Taylor, & Klein, 2000; Pratt, & Neggers, 2008; Chica, Taylor, Lupianez, & Klein, 2010, but see, *e.g.*, Pratt, & Abrams, 1999).

If the the participant's strategy for performing an antisaccade task successfully is to tonically inhibit the SC, it is likely that IOR in its cause and its effect will resemble the attentional/perceptual flavour. One testable consequence of this line of reasoning is that a directional arrow at fixation or a stimulus that selectively increases the activity of S-cone photoreceptors (S-cone stimuli putatively bypass the SC (Sumner et al., 2004) in the periphery (no response to S1) should be just as likely to generate IOR in the anti-saccade paradigm when measured by a peripheral onset (antisaccade to S2). A second consequence of this line of thinking is that an antisaccade to a peripheral onset (antisaccade to S1) should *not* result in IOR when measured by a central arrow (manual response to S2). These results, if compared against identical designs except using pro saccades, should produce a telling double dissociation.

On the effects of IOR: The discrepancy between behavior and neurophysiology

Second, the neurophysiological evidence showing reduced activation patterns in visual and visuomotor neurons when cue and target repeat locations has been interpreted as strong evidence that IOR affects early stage visual processing given that visual neurons in the superficial layers of the SC seem to receive input very early in processing (Dorris, Klein, Everling, & Munoz, 2002; Fecteau, & Munoz, 2005). Interestingly, however, the capacity for a target to cause this type of sensory or attentional/perceptual effect dissipates very rapidly in monkeys (with longer SOAs). Nevertheless, we are thus confronted with a somewhat unusual dilemma given that repeated sensory stimulation is clearly not necessary to measure IOR in

humans (*i.e.*, a central arrow) nor does it appear to increase IOR relative to arrow-elicited eye movements. As a result, there appear to be more questions than answers. Among them and perhaps most obviously, is there a difference between monkeys and humans in the way IOR is generated and expressed? It is known, for example, that monkeys fail to show IOR in a saccade-saccade paradigm (Klein, Munoz, Dorris, & Taylor, 2001) whereas humans show an effect across a wide variety of saccade-saccade tasks (Taylor, & Klein, 2000; Gilchrist, & Harvey, 2000; MacInnes, & Klein, 2003; McCarley, Wang, Kramer, Irwin, & Peterson, 2003).

Is it possible that there is, in fact, an attentional/perceptual component to saccadic IOR that vanishes at longer SOAs (*i.e.*, 1 s) and that may only be observable in humans at the shorter SOAs at which monkeys are typically tested? This is an empirical question that is easily tested by reducing the SOA in the present paradigm. If there is an attentional/perceptual component at the short SOA, then surely IOR for peripheral targets would exceed the IOR for central targets.⁵

Is it possible that the effect that is being observed for peripheral targets is mediated by a different mechanism than the effect for central targets and that, by chance, they produce similar behavioral results? Indeed, this might be the preferred route for some neurophysiologists where it has been stated by Fecteau and Munoz (2005) that:

The distinct components of the inhibition of return effect can be manifest neuronally in several different ways: in early sensory processes (here), late in sensory processing (here,

⁵ Of course, such a result would strongly suggest that what the neurophysiology was measuring was not at all the sort of long-lasting IOR that has characterized much of the IOR literature but rather, a sensory process that is additive with IOR.

Bichot, & Schall, 2002⁶) and even with different neural epochs (cf., here vs. Bichot, & Schall, 2002). This indicates that inhibition of return does not originate from one single neural process nor does it appear to be a single phenomenon, instead, many neural processes can lead to this slowing of response time. (p. 1721)

A similar eclecticism has inspired the habituation account of IOR (Dukewich, 2009), which maintains that IOR is, in effect, habituation of an orienting response that can occur at many different stages of processing or, more pointedly, ubiquitously in the brain.

More specifically still, is it possible that the intermediate layers of the SC receive cortical input when an arrow is presented that somehow reduces neuronal activation for the cued side relative to the uncued side? To be sure, the SC does not exist in isolation; parts of the SC appear to receive input from a wide range of cortical areas (Munoz, 2002; Pierre-Deseillegny, Rivaud, Gaymard, & Agid, 1991). One such brain region that has aroused considerable interest is the lateral intraparietal (LIP), a region that Theeuwes and van der Stigchel (2009) have likened to a preoculomotor attentional map. In a recent neurophysiological investigation recording extracellular single-unit activity in the LIP of monkeys, Mirpour, Arcizet, Song Ong and Bisley (2009) administered a foraging task in a simple array comprising five potential targets and five distractors. The monkey searched the display (overtly with saccades) and was rewarded with juice if the correct target of five potential targets was fixated. The recordings revealed that in over half of the cells recorded from monkeys in this region showed a reduction in activity for targets appearing inside a receptive field that had already been fixated (Mirpour, Arcizet, Song

⁶ This late stage process appears to be related to target-elicited increase in activity for visuomotor neurons when a target appears at the uncued location and is conceptually similar to the opposite facilitation effect (OFE) that is sometimes observed behaviorally in IOR for manual responses (Pratt, Spalek, & Bradshaw, 1999; Bennett, & Pratt, 2001; Spalek, & Hammad, 2004; Spalek, & Hammad, 2005). The attentional momentum theory (or the OFE), however, has been convincingly rebuffed by Snyder, Schmidt, and Kingstone (2001; 2009) in the attentional/perceptual flavour of IOR. Smith and Henderson (2009), on the other hand, provide some evidence that an OFE might be observed behaviorally for human saccades in some naturalistic viewing tasks and thus, in the motoric flavour.

Ong, & Bisley, 2009) - a reduction that correlated well with a reduced a decreased likelihood of revisiting previously attended locations (Klein, 1988). Critically, Mirpour et al., explain that the LIP can rely on top-down information to differentiate between task-relevant and task-irrelevant stimuli; it is responsible for goal-directed saccadic activity and it is directly connected to the SC and frontal eye fields. Indeed the LIP appears to be a candidate mechanism for relaying activation patterns to the SC; furthermore it provides a locus for the generation of IOR, something that seems necessary given that Dorris et al. (2002) showed that the SC is not directly inhibited when IOR is present. Two lines of evidence from Dorris et al. support this view: there is increased activity in neurons in the SC at cued locations relative to uncued location during the SOA; and second, they showed that artificially inducing saccades to a cued target by way of microstimulation results in faster SRTs to that location relative to the uncued location.

While it appears as though IOR arrives at the SC from upstream processes it is unclear whether there is a role for LIP on neuronal activity in the intermediate layers of the SC in tasks that cause IOR with abrupt onset cues and measure it with saccadic responses to central arrow or peripheral onset stimuli. Because a goal of cognitive psychology and neuroscience ought to be to unite behavior with brain regions or networks, these are important outstanding questions that cannot easily be resolved here but that will require answers if we are to procure a better understanding of the neuronal mechanisms underlying the effect of IOR.

Chapter 13 Conclusions

At present and to recapitulate this investigation, we found that blocking target type leads to significantly more IOR for peripheral relative to central targets when Abrams and Dobkin's (1994b) methods were closely replicated. Mixing target types eliminates this statistical difference. In our estimation, this difference in the magnitude of IOR in the blocked design is due to an attentional field or beam that encompasses the cued location when a target may occur there (the blocked peripheral target condition) whereas a target occurring reliably at a single location allows for the effective filtering of irrelevant cues at non-contiguous spatial locations (*i.e.*, an ACS or an observer strategy to attend only to locations at which a target might appear will modulate the distribution of attention within the visual field). This distribution of attention prior to cue onset modulates the magnitude of IOR: increased attention to cues increases the processing of those cues by a mechanism (possibly oculomotor processing) that causes IOR. That IOR is equivalent for peripherally and centrally presented targets when the ACS is held constant for processing of the cue (as in a mixed design) strongly suggests that IOR is *not* attentional/perceptual in this cell - an interpretation that reinforces the view that the effect of IOR under conditions in which saccadic eye movements are made is motoric or, less dogmatically, that there is a single effect (Taylor, & Klein, 2000). On the surface, the motor view of IOR encounters some resistance from an antisaccade literature expounding on an attentional/perceptual effect to IOR in conditions that appear to satisfy the criteria for the motor flavour. However, the motor view agrees that the effect of IOR in an antisaccade paradigm is attentional/perceptual but it does so by making the simplifying assumption that top-down inhibition is required over the oculomotor machinery to suppress a natural tendency to execute saccadic eye

movements to visual input. Thus, the motor view likens the antisaccade task to the same type of tonic inhibition that might be present in the SC during keypress tasks. Finally, considerations from and on the extant neurophysiological evidence on IOR arouse some skepticism as to whether IOR for peripheral targets represents a different effect (possibly sensory adaptation in the SC, which is ultimately tantamount to a perceptual/attentional effect occurring in an oculomotor structure) than the effect for central targets (for which there are no known neurophysiological correlates in the IOR literature). Note, however, that both considerations attribute only one effect to each target type it is simply unclear whether the correlation between reduced activity in visuomotor and visual neurons and IOR is an attentional/perceptual effect that is observable only at very early SOAs in humans. Whether this effect is somehow prolonged in humans, whether this effect of IOR is neurophysiologically (as represented in the SC specifically) distinct from the effect of IOR when measured by a central arrow stimulus and how cortical structures modulate these IOR effects in the SC is unknown. These questions will remain unanswered until further investigative work, especially in the sphere of cognitive neuroscience, is undertaken.

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