ARE THERE ANISOTROPIES IN COVERT AND OVERT VISUAL ORIENTING?

by

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Submitted in partial fulfillment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
July 2010

DALHOUSIE UNIVERSITY

SCHOOL OF HEALTH AND HUMAN PERFORMANCE

The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "ARE THERE ANISOTROPIES IN COVERT AND OVERT VISUAL ORIENTING?" by Jonathan Harris in partial fulfillment of the requirements for the degree of Master of Science.

Dated: July 26th, 2010

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DALHOUSIE UNIVERSITY

DATE: July 26th, 2010

AUTHOR: Jonathan Harris

TITLE: ARE THERE ANISOTROPIES IN COVERT AND OVERT VISUAL ORIENTING?

DEPARTMENT OR SCHOOL: SCHOOL OF HEALTH AND HUMAN PERFORMANCE

DEGREE: MSc. CONVOCATION: October YEAR: 2010

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ABSTRACT

Two recent studies suggest that Inhibition of Return (IOR) varies in magnitude as a function of target location for overt orienting tasks but not covert orienting tasks. Unfortunately, methodological differences between these studies prevent a direct comparison of their results. Thus the aim of the current study was to replicate and extend the results of these two studies within a single experiment while controlling for methodological differences. Participants (N=37) were assigned to a cue-target or a target-target group and were required to make manual (covert orienting block) or saccadic responses (overt orienting block) to peripheral stimuli occupying one of four peripheral locations. An analysis of target reaction times indicated that while IOR was present under all circumstances, it did not vary as a function of target location. A careful examination of our methods points to the importance of controlling set size (the number of possible target locations) in IOR studies.

LIST OF ABBREVIATIONS USED

IOR	Inhibition of Return
ANOVA	Analysis of Variance
SC	Superior Colliculus

ACKNOWLEDGEMENTS

Firstly, I wish to thank my committee members for their support in the completion of this thesis. Your ideas and expertise were always extremely helpful. Specifically, I would like to thank Dr. David A. Westwood for his continued mentorship over the past three years. Dave: you are as knowledgeable as you are personable. Thanks for facilitating such an enjoyable learning experience. Also, special thanks to my family members and friends for offering much needed encouragement as I worked to complete my MSc. research.

CHAPTER 1: INTRODUCTION

1.1 Selective Attention

The external environment contains a rich array of sensory stimuli. During everyday activities, humans are bombarded with an enormous influx of information from the visual, auditory, tactile, gustatory and olfactory senses. Depending on current behavioural goals, each of these pieces of incoming information can be considered either relatively important or relatively unimportant. Given the need to complete tasks efficiently, the staggering amount of incoming sensory information and the limited cognitive resources of the human nervous system, some mechanism is needed to determine which sensory events receive relatively more of our cognitive resources and which sensory events receive relatively less of these same resources. The method for selecting among and differentially processing sensory stimuli is known as selective attention (Desimone & Duncan, 1995). For the duration of the current discussion, I will consider selective attention as it relates to the processing of visual information.

Early in the study of selective visual attention (Posner, 1980; Von Helmholtz, 1910/1925), it became apparent that humans have the ability to direct attention to a peripheral object or event either overtly, by repositioning the eye to more effectively collect information about this object or event, or covertly, by shifting an "internal spotlight" of attention to the object or event of interest. Since overt and covert orienting share the common goal of facilitating the processing of interesting or important visual events, one may expect that these modes of attentional orienting also share some degree of similarity at the anatomical level. In fact, the premotor theory of attention (Rizzolatti, Riggio, Dascola & Umiltá, 1987) suggests that overt and covert orienting of visual attention are identical at the functional and anatomical level and only differ in that eye movements are voluntarily suppressed in the case of covert orienting. Indeed, a number of recent imaging studies suggest at least some degree of similarity in the brain regions responsible for generating overt and covert shifts of visual attention (de Haan, Morgan & Rorden, 2008; but see Fairhall, Indovina, Driver & Macaluso, 2009). However, the premotor theory of attention is subject to some amount of criticism. In a recent study, Khan et al. (2009) identified a seemingly clear dissocation between the ability to generate saccades (in response to an endogenous central cue) and the deployment of covert attention. It was shown that a patient with cortical damage was able to generate saccades to contralesional hemispace, but that the expected facilitation of processing for stimuli located in this region was absent. The authors reasoned that this reflected an intact ability to shift overt, but not covert attention to contralesional hemispace, and thus that the two forms of attention are separable at the behavioural level (Khan et al., 2009). In summary, the degree of functional and anatomical similarity between overt and covert orienting is still being debated (Fairhall, et al., 2009) and this debate is central to the rationale for conducting the current study. We will now proceed to introduce some common experimental methods used to investigate attention.

1.2 Visual Attention Methodology

Past studies have shown that one effect of attention is to facilitate (speed) responses to targets appearing in an attended location relative to targets appearing in an unattended location (Posner, 1980). Attention affects behaviour in a number of other ways, but the facilitation of reaction times based on location is most relevant to the current discussion. To summarize, past attention studies have typically involved an initial cue (a contrast change at one of two possible placeholders situated to the left and right of a central fixation target) used to attract covert attention. Usually, this initial cue is followed no more than 200ms later by a target square appearing with equal probability in either the cued location or the uncued location. When participants are required to respond to the appearance of the target with a keypress, results typically show that reaction times are faster in trials where the target occupies the previously cued location than on trials for which the target occupies the previously uncued location. Importantly, the eyes remain fixed at a central location in such experimental paradigms, so that any shifts in attention are covert in nature, in other words, reflecting the movement of some "internal spotlight" of attention, rather than the eyes or head. The generally-accepted explanation for these results is that the initial cue attracts covert attention which facilitates the processing of visual stimuli in this region, yielding shorter reaction times for targets appearing in the cued (attended) location than those appearing in an uncued (unattended) location. In trials where the target is presented in the uncued location, detection reaction times tend to be longer, presumably reflecting the need to shift attention from the previously cued region to the location of the target prior to initiating a response.

1.3 Visual Search

Often, one must search the environment using a series of saccades to locate an object or item of interest. Thus, the ability to dynamically shift location-based attention is essential to functioning effectively. Such simple experimental paradigms as the one described previously involve shifts of attention, but fail to capture the dynamic and complex nature of the role of attention in "everyday" tasks. To overcome the limited generalizability of studies employing such simple stimuli, shifts of attention are frequently studied using more ecologically valid visual search tasks. In such tasks, participants are generally given an array of items and required to identify whether a predefined target item is present or absent from this search array. Although there are a number of theories as to the way in which attention is involved in the successful identification of target items, at least one account (Treisman & Gelade, 1980) suggests that in cases where distracters and targets are similar enough to necessitate visual search, target identification is achieved by serially shifting attention from one item to the next until the target is identified or all items in the array have been inspected. That is, visual search relies heavily upon our ability to dynamically shift attention from location to location. To the extent that search proceeds in such a serial manner, some "memory" of which locations have been searched and which remain to be searched would be of some use in the successful completion of the task (Klein, 1988). Past research has repeatedly demonstrated the importance of a phenomenon known as Inhibition of Return (IOR) to the successful and efficient completion of visual search (See Wang & Klein, 2010 for a recent review); it has been demonstrated that when visual search task demands allow for the serial deployment of attention from item to item, IOR is observed and tends to increase the efficiency of the search (Wang, Zhang & Klein, 2010). In general, research shows that IOR discourages attention from returning to a location where it has recently been directed. IOR will be discussed in detail in the following section.

1.4 Inhibition of Return (IOR)

Visual search could be conducted most efficiently if some method existed to bias the direction of attention in favour of novel regions of space and away from those regions which have previously been searched and are known not to contain a particular item of interest. In fact, such a method appears to exist and has been termed inhibition of return (Klein, 1988, 2000; Posner, Rafal, Choate & Vaughan, 1985; Taylor & Klein, 2000). If attention is directed to some region of the visual scene and then removed from this location, IOR biases subsequent shifts of attention away from this recently inspected location and towards novel locations. Although introduced in the context of visual search, IOR has also repeatedly been demonstrated (and in fact, was first demonstrated) using the aforementioned covert orienting paradigm (Posner & Cohen, 1984). In such studies, covert attention is attracted to a peripheral location through the use of a peripheral contrast change. The peripheral cue is then extinguished, allowing covert attention to move away from this location and back to the foveated central placeholder location. When participants are required to manually indicate detection of a target presented more than about 300ms after the cue, detection reaction times tend to be longer when this target occupies the same location as the preceding cue than when this target occupies a novel, or previously unattended location. This represents a reversal of the previously described facilitation of reaction times seen at shorter time intervals between cue and target presentation. This slowing of reaction times, presumably owing to an inhibition of events occurring at previously cued locations and a resulting reluctance to return covert attention to the cued location (Posner & Cohen, 1984), is one way in which IOR is demonstrated experimentally. This reluctance to return to previously attended regions provided by IOR is thought to bias the direction of attention to novel locations in order to maximize the efficiency of visual search (Klein, 1988). Interestingly, the presence or absence of IOR during attention shifts seems to depend on the reason for the attention shift. IOR tends to be observed in cases where participants are explicitly told to search for an item, but not in cases where they are simply instructed to inspect an item or array without any intention of finding an item of interest (Dodd, Van der Stigchel & Hollingworth, 2009). This observation strengthens the previously-proposed notion that IOR acts as a "foraging facilitator" (Klein, 1988), as IOR appears only to be present in cases of foraging-type behaviour.

1.5 IOR, Overt and Covert Orienting of Attention

IOR has been shown to affect both overt and covert shifts of attention (Posner et al., 1985; Taylor & Klein, 2000). Given the previously described debate on the potential dissociation between overt and covert orienting (de Haan et al., 2008; Fairhall et al., 2009), it seems reasonable to ask similar questions in the context of IOR. That is, since IOR seems to affect both overt and covert orienting, one may wonder if IOR in these cases is the same, or if there are distinct forms of IOR operating for overt and covert orienting. Researchers curious about the degree of functional and anatomical similarity between IOR in overt and covert orienting have set out to compare and contrast IOR in each of saccadic response tasks (which require overt orienting; herein referred to as overt orienting tasks) and manual response tasks (which require covert orienting; herein referred to as covert orienting tasks). An appreciable number of studies from this line of research seem to indicate that the IOR observed for covert and overt orienting is at least functionally distinct (Taylor & Klein, 2000; Chica, Taylor, Lupiáñez & Klein, 2010). That is, covert and overt IOR appear to display some different characteristics at the behavioural level. For example, whether IOR affects attentional/perceptual or motoric processes appears to depend whether IOR is generated using overt or covert orienting. This "Two Flavors" account of IOR was first presented by Taylor and Klein (2000) after examining IOR in a number of different circumstances. Here, it was observed that IOR affected manual responses to peripheral targets in trials for which the eyes were prevented from moving to either the cue or target (covert shifts of attention). Conversely, IOR was seen to affect saccadic and manual responses to peripheral and central arrow targets when the eyes were permitted to move to either the cue or the target (overt shifts of attention) (Taylor & Klein, 2000). These results were interpreted as demonstrating the existence of two flavours of IOR – one that affected attentional/perceptual processes when the eyes remained fixed and one that affected motoric processes when the eyes were permitted to move (Taylor & Klein, 2000).

In a recent behavioural study, Chica et al. (2010) provided further evidence for the "two flavours of IOR" account. Here, the motoric flavour of IOR was generated by requiring a saccadic response to an initial peripheral cue and then back to centre prior to target presentation. Following this initial cue, participants completed either spatial detection task or a non-spatial discrimination tasks (between-subjects factor) as target reaction times were monitored. The detection task required participants to keep gaze fixed at centre and make a simple keypress response to the appearance of a target presented in either the cued location or the uncued location. The discrimination task required a separate set of participants to correctly identify the color (red or green) of a target presented in the cued or uncued location by pressing one of two keys (counterbalanced across participants). Importantly, although both the detection and discrimination tasks could be described as perceptual, the detection task required the extraction of spatial information about the target, whereas the discrimination response task did not. The authors reasoned that if the motoric flavour of IOR resulted in a general deficit in perceptual processing, then reaction times in the target discrimination task would be slower when the target appeared in the cued location than when this target appeared in the uncued location. Conversely, if the motoric flavour of IOR affected only spatial tasks, then no IOR should be observed in the discrimination task, as it had no spatial component. In summary, results demonstrated that IOR affected detection responses but not discrimination responses. These results were interpreted as offering support to the notion that motoric IOR (generated by eye movements) affects spatial responses but not non-spatial perceptual tasks (whereas both tasks are affected when IOR is generated by covert shifts of visual attention).

While these pieces of research are suggestive of the different *effects* of the two flavours of IOR, other research has demonstrated an apparent distinction between cortical and collicular brain pathways responsible for *generating* different forms of IOR (Sumner, Nachev, Vora, Husain & Kennard, 2004). Sumner et al. (2004) demonstrated that Short-wave (S-wave) stimuli invisible to the superior colliculus were capable of generating IOR for manual responses (requiring covert shifts of attention) but not for saccadic responses (overt shifts of attention). These results suggest that the motoric flavour of IOR is intrinsically linked to the function of the superior colliculus, whereas the perceptual/attentional flavour of IOR may be more tightly coupled with the functions of cortical areas – for example, posterior parietal cortex (Sumner et al., 2004).

Taken together, the results of the studies described above seem to suggest that IOR observed in tasks requiring overt orienting of attention show may some anatomical and functional differences from the IOR observed in tasks requiring the covert orienting of attention. That is, overt IOR differs from covert IOR. A comparison of two recent behavioural studies appears to provide additional evidence for two unique flavours of IOR in overt (Harris, Cowper-Smith & Westwood, 2009) and covert (Spalek & Hammad, 2004) orienting tasks. Specifically, Harris et al. (2009) showed that for an overt orienting task, IOR differed in magnitude depending on the locations of the cues and targets used to reveal IOR (IOR anisotropy). Interestingly, upon conducting what we felt to be a more appropriate analysis of Spalek and Hammad's (2004) results (They analyzed their results by cue location when, because RTs are to targets (and cues are not task-relevant), it is more appropriate to analyze by target location; Klein, personal communication), our analyses showed that this variation in IOR magnitude as a function of target location (IOR anisotropy) was not present in Spalek and Hammad's (2004) covert orienting task. Unfortunately, a direct comparison of IOR anisotropy between studies cannot be made due to numerous methodological differences between studies. Thus, the primary goal of the current study was to replicate and extend (to overlapping conditions) the key conditions in these two studies, while controlling for methodological differences in an attempt to convincingly determine whether there are differences in IOR anisotropy for overt (saccadic response) vs. covert orienting (manual response) tasks. What follows is a detailed account of each of the two studies upon which the rationale for the current study is based.

The first study of interest was conducted by Harris et al. (2009). Here, we were interested in characterizing IOR in the vertical and horizontal axes separately and in determining the potential influence of target location on the magnitude of inhibition of return. The experiment required participants to make two successive target-directed saccades (separated by a return-saccade to a central fixation region in response to a stimulus). Each of these saccades was directed to one of two possible cue and target locations and was always made in response to either a central arrow or in response to a peripheral contrast change in the location of the target. Within a given trial, all cues and targets presented were either central arrows or peripheral contrast changes. There were four possible target locations in the experiment (up, down, left and right from the central fixation region), but within a given trial, participants were presented with only two possible target locations occupying opposite positions in either the horizontal axis or in the vertical axis (two peripheral placeholders and a central fixation placeholder were presented simultaneously). In the context of the current discussion, the key result of this study was that IOR had a larger magnitude for trials in which the target was located down from the central placeholder than in trials where the target was located up from the central placeholder. In fact, the IOR effect appeared to be absent in this latter case. No IOR anisotropies were noted in the horizontal axis. That is, IOR was present and appeared to be equal in magnitude for targets presented to the left and the right of the central placeholder.

The second study whose design included stimulus location as a factor, thus allowing for the examination of potential IOR anisotropy, used covert shifts of attention in a standard cue-target paradigm requiring manual keypress responses made in towards exogenous visual stimuli (Spalek & Hammad, 2004). In this study, participants were presented with an initial cue at one of four possible peripheral locations, followed by a peripheral target at one of four possible locations. Trials were characterized by the location of the cue (left, down, right or up from centre) and the spatial relationship between the cue and target (same location, adjacent locations or opposite locations).

Participants were required to ignore the cue and then to respond to the appearance of the target by pressing the spacebar on a computer keyboard. Importantly, subjects were required to keep their gaze fixed at centre for the duration of the trial so that any shifts in attention in response to the cue or target were covert in nature. Results indicated that target detection reaction times were significantly longer when the target occupied the same location as the cue than when the target occupied a location different from the cue. This is the standard IOR effect. However, it was shown in this study that IOR was larger in magnitude for trials in which the cue was presented to the left of centre than for trials in which the cue was presented to the right of centre. Similarly, IOR magnitude seemed to depend on the initially cued location in the vertical axis as well. Here, trials in which the up location was cued showed greater IOR than trials in which the down target location was cued. Although these results are of interest, the use of cued location rather than target location as a factor in the statistical analysis seemed counterintuitive and was a result of the author's interest in attentional momentum (Pratt, Spalek & Bradshaw 1999); a theory against which conflicting evidence has been accumulating (Snyder, Schmidt & Kingstone, 2009). Thus, in order to make a more direct comparison between these results and those reported by Harris et al. (2009), we reorganized Spalek and Hammad's data, replacing the "cued location" factor with a "target location" factor and made non-statistical observations of these data. When examined in this manner, Spalek and Hammad's (2004) results showed no appreciable IOR anisotropy; IOR magnitude (as the reaction time difference between 0 and 180 degree angular S1-S2 distance conditions for a given location) did not vary with the location of the target. IOR magnitudes were 41ms, 43ms, 41ms and 45ms for left, right, down and up target locations, respectively.

Although we were unable to perform a statistical analysis on these values, it seems unlikely that they should have differed significantly from one another. Unless otherwise noted, for the remainder of the paper, I will refer to the "by-target" analysis of Spalek and Hammad's (2004) results, which, to remind the reader, revealed no IOR anisotropy for a cue-target manual response (covert orienting) paradigm.

To summarize, the results of the two studies just described (Harris et al., 2009; Spalek & Hammad, 2004) illustrate seemingly clear differences in the pattern of IOR observed between covert and overt orienting tasks. Harris et al. employed a target-target overt orienting paradigm reported IOR anisotropy only in the vertical axis, where IOR had a larger magnitude for trials in which the target was located down from the central placeholder than in trials where the target was located up from the central placeholder. In contrast, Spalek and Hammad's 2004 (when examined as a function of target rather than cue location) results showed no such IOR anisotropy. A comparison of the by-target analyses of both Harris et al. (2009) and Spalek and Hammad (2004) is shown in Figure 1 below.

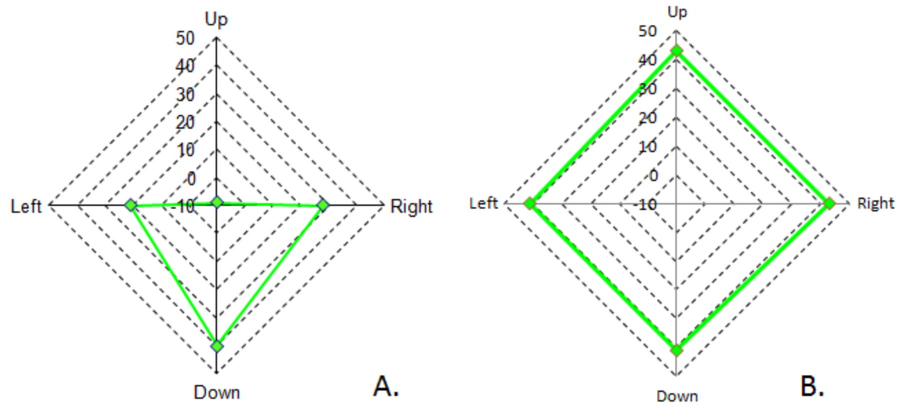

Figure 1: Polar coordinate plots of the IOR effect (as the difference between 0 and 180-degree S1-S2 distance conditions) as a function of location in (A) Harris et al. 2009 (target-target overt orienting paradigm) and (B) Spalek and Hammad, 2004 (cue-target covert orienting paradigm). IOR magnitude (in milliseconds) is displayed on the radial axes. Figure 1A clearly demonstrates IOR anisotropy, where IOR is absent for targets presented in the "up" location. Conversely, Figure1B shows the same IOR magnitude of approximately 41-42ms independent of target location.

There are a number of reasons why this difference in IOR anisotropy between the two studies may have been observed. Given the debate on the degree of functional and anatomical similarity between overt and covert orienting (Fairhall et al., 2009; Posner & Petersen, 1990) and past research suggesting functional differences between IOR in overt and covert orienting tasks (Chica et al., 2010; Sumner et al., 2004; Taylor & Klein, 2000), it would be most interesting to conclude that the difference in directional IOR anisotropy between studies results from the different methods of orienting required (that is, overt vs. covert orienting). If it were the case that these distinct modes of orienting yield distinct patterns of IOR anisotropy, this would offer additional evidence that overt and covert orienting are functionally (and possibly anatomically) distinct. However, there are a number of other differences between the two studies which may reasonably be expected to have produced this difference in IOR anisotropy (these differences will be fully characterized in the section which follows).

Thus, the goal of the current study was to systematically manipulate differences in methodology between studies in an attempt to reconcile whether it was indeed the different methods of orienting which yielded the aforementioned differences in IOR anisotropy.

1.6 Why Might IOR Anisotropy Be Observed?

Past research seems to suggest that IOR observed for overt orienting is dependent upon pathways involving the superior colliculus, whereas IOR observed for covert orienting does not appear to rely on these same pathways, and instead is thought to rely more heavily on cortical projections (Fairhall et al., 2009; Sumner et al., 2004). Thus, from a neuroanatomical standpoint, differences in directional IOR anisotropy between overt and covert orienting tasks could reflect differences in the way upper, lower, right and left visual space are represented in the superior colliculus versus cortex. For example, the posterior parietal cortex appears to receive a greater number of inputs from the lower visual field than the upper visual field. Consequently, there appears to be a lower visual field advantage for cuing in peripersonal space (Losier & Klein, 2004). In addition to such field biases for sensory processing, related location-dependent differences within the vertical axis have been suggested for attentional processes (Previc, 1990). Given that different regions of the brain appear to be involved in overt and covert IOR and these different brain regions may have different preferences for upper, lower, left and right visual fields, it may be expected that these field biases for basic sensory and attentional processing could yield differences in IOR magnitude when comparing the upper, lower, left and right visual fields between overt and covert orienting tasks.

1.7 Current Study

The purpose of the current study was twofold. First, it was our intention to replicate the results of two past studies (Harris et al., 2009; Spalek & Hammad, 2004). Second, we intended to determine which differences in methodology were responsible for differences in directional IOR anisotropy observed between the two studies. We hypothesized that differences in IOR anisotropy observed between studies were most likely due to either: i.) The different modes of orienting used in each case (overt orienting in Harris et al. and covert orienting in Spalek and Hammad), or ii.) the number of responses required (two in the target-target task presented by Harris et al. and one response in the cue-target task presented by Spalek and Hammad). If this hypothesis were correct, then we would expect to see that manipulating either the type of orienting required or the number of responses required lead to changes in the nature of the IOR anisotropy observed, where IOR is defined as longer reaction times to targets presented in previously attended locations and IOR anisotropy is defined as an interaction between target location and IOR (a two-way interaction between S1-S2 distance and cued location). Additional differences in methodology between studies included differences in the number of placeholder locations presented simultaneously and differences in the requirements for time-out errors. We felt that the aforementioned differences in orienting type and/or the number of responses required were most likely to have yielded differences in IOR anisotropy. Thus, to avoid unnecessary complexity in our research design, we decided to manipulate these factors (orienting type and number of responses) rather than other methodological differences. A general summary of experimental methods is presented below.

To address our research goals, we used exogenous (peripheral) cueing in a standard IOR task. In all trials, two stimuli (S1 and S2) were presented. Four possible target locations (left, right, up and down from a central fixation location) were used. Reaction times for detecting the onset or making a saccade to the location of the second target were measured as the difference in time between the onset of the target and the initiation of an eye movement greater than 2.0 degrees of visual angle in magnitude (overt orienting response block) or the keypress response (covert orienting block). Ultimately, we were interested in determining whether this difference in IOR anisotropy between overt and covert orienting tasks persisted with other factors (number of on-screen placeholders, time-out error length) held constant. Although the number of placeholders present on screen simultaneously differed between studies (with two presented simultaneously in the Harris et al. (2009) study and four targets present simultaneously in the Spalek and Hammad (2004) study), we decided to present only four targets simultaneously in the current study. That is, we did not manipulate the number of on-screen targets as a factor as past studies have shown IOR using both two-target conditions and four-target conditions (Posner & Cohen, 1984). Similarly, the rules governing time-out errors in the Spalek and Hammad study differed from those presented to participants by Harris et al. Specifically, time-out errors were recorded if no response was generated 1000ms after the presentation of the target in Spalek and Hammad (2004) study, but 500ms after the presentation of the target in the Harris et al. (2009) study. In the current study, we decided not to manipulate time-out error length as a factor, since both 500ms and 1000ms allow sufficient time for the generation of IOR (Posner & Cohen, 1984). Instead, we used a constant time-out error length of 500ms, which was consistent with Harris et al. (2009). Additionally, we did not manipulate cue type (exogenous vs. endogenous as a factor), as only exogenous cues were presented to participants by Spalek and Hammad (2004), and since the IOR anisotropy noted by Harris et al. (2009) did not vary as a function of cue type. Overall, the design included conditions which independently manipulated the nature of the task (cue-target or target-target) and the mode of orienting required (covert orienting in a manual response task or overt orienting in a saccadic response task) to determine which of these factors was responsible for the differences in IOR anisotropy observed. We felt that these two factors were most likely to have yielded the differences in IOR anisotropy noted between studies, and that equating the other factors should have no effect on IOR anisotropy observed previously for the reasons noted above.

CHAPTER 2: METHODS

2.1 Participants

Thirty-seven undergraduate students (13 Male and 24 Female) at Dalhousie University participated in the current study in exchange for course credit. This project received ethical approval from the Dalhousie University Research Ethics Board. All participants reported normal or corrected-to-normal vision.

2.2 Apparatus

The SR Research Experiment Builder (SREB) was used in combination with EyeLink®II (SR Research Ltd., Mississauga, ON) eye tracking system to create and carry out this study. The flow of the experiment and eye movements of the participants were measured using the EyeLink®II (SR Research Ltd., Mississauga, ON) video-based eye-tracking device (sampling rate = 500 Hz; spatial precision <0.01°; spatial accuracy <0.8° RMS error). Calibration of the EyeLink®II was carried out in the same picture-plane used to display the experimental stimuli. EyeLink DataViewer™ software (SR Research Ltd., Mississauga, ON) digitizes the pupil in order to describe the location of the visual gaze fixations. Respondents' eye movement data (saccadic reaction times) and key presses (manual reaction times) were recorded to a text file which was exported into an excel file and ultimately uploaded to SPSS v.15.0™ for further statistical analysis.

2.3 Design Summary

In summary, the current study has a 2 (cue-target or target-target; between subjects) by 2 (covert orienting or overt orienting; blocked and counterbalanced within subjects) by 4 (First stimulus location; random within subjects) by 4 (S1-S2 distance; random within subjects) design (Refer to Figure 2B). Reaction time to the second stimulus was defined as the time elapsing between the presentation of the second stimulus and the time to either the initiation of the saccade or the pressing of the spacebar and represented the sole dependent variable for our main analyses. Each participant was assigned to either the target-target group (N = 18) or the cue-target group (N = 19) and completed two separate blocks of trials (one covert orienting block and one overt orienting block). Thus, there were four blocks in total (2 modes of orienting (overt or covert) by 2 groups (cue target or target-target)), with each participant contributing to data for two blocks. The order of mode of orienting blocks was counterbalanced across participants.

Within each block, all possible combinations of S1 location and S2 location were presented ten times each, for a total of 160 trials (4 possible S1 locations x 4 possible S2 locations x 10 repetitions). Catch trials (for S2) were added as ten percent of experimental trials (16 catch trials), bringing the total number of trials per block to 176. Thus, each participant completed 354 total experimental trials (176 for each of the covert orienting and overt orienting blocks). Participants completed an additional 30 practice trials (15 manual response and 15 saccadic response trials) prior to initiating the first experimental block. These practice trials were randomly selected from among all possible combinations of S2 location and S1-S2 distance factors and required a response only to S2 (cue-target group) or to both S1 and S2 (target-target group). Subjects were given ten-minute breaks halfway through each block and between blocks. Experimental procedure for individual trials is summarized in Figure 2A.

2.4 PROCEDURE

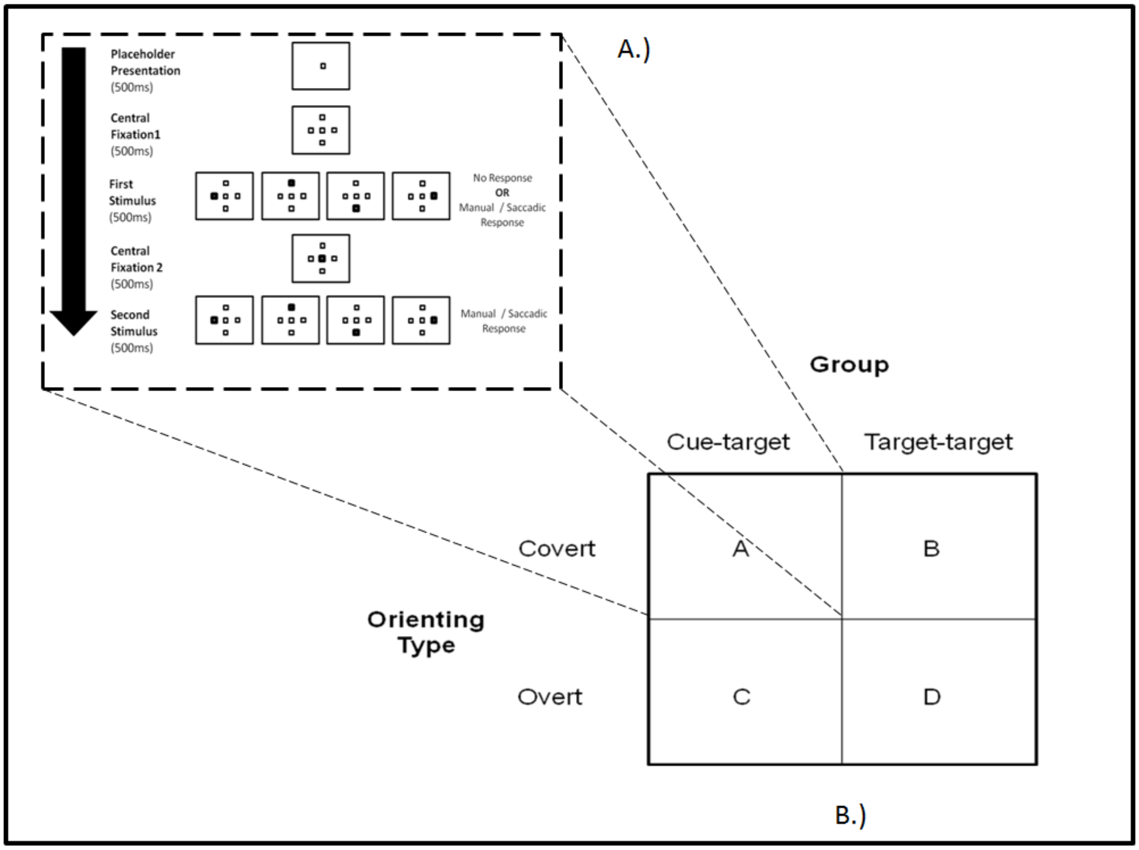

Figure 2: Summary of experimental procedure. Figure 2A.) illustrates the experimental procedure for all trials. Both the first and second stimulus could appear in any of the four placeholder locations. That is, the first stimulus was not predictive of the location of the second stimulus. Figure 2B.) Depicts the four possible combinations of the Group factor (Cue-Target or Target-Target) and Orienting Type factor (Covert or Overt). Cells A, B, C and D in this figure represent cue-target covert, target-target covert, cue-target overt and target-target overt conditions, respectively. Cell A is the condition which replicates the work of Spalek and Hammad (2004) and cell D is the condition which replicates the work of Harris et al. (2009).

Each experimental trial included a “central fixation 1”, “S1 presentation”, “central fixation 2” and “S2 presentation”, phase. These four distinct phases are described in detail below and depicted in Figure 2A.

2.4.1 Central Fixation 1

For the duration of the experiment, participants were seated 56 cm from a computer monitor upon which all experimental stimuli were presented. Participants were presented with a central square (with dimensions of 3.57 degrees of visual angle) and four peripheral squares, all equal in size to the central square and S1-S2 distance from this square by 12.2 degrees of visual angle, one above and one below the horizontal meridian and one to the right and one to the left of the vertical meridian. Thus, the 5-square placeholder arrangement formed a "+".Target dimensions and relative orientation remained the same for all trials. Participants were required to maintain gaze at centre position for the duration of this central fixation period (the central fixation array was presented for a total of 500ms). Failure to comply with this instruction resulted in the presentation of an error screen. The offending trial was recorded as an error (error trials were not recycled).

2.4.2 First Stimulus (S1) Presentation

Following the 500ms central fixation period, in all trials, a darkening of one of the four possible peripheral target locations occurred. In the cue-target group, for both covert orienting (manual response) and overt orienting (saccadic response) blocks, this initial stimulus represented a cue, and participants made no overt response to its appearance. Instead, they maintained fixation on the central target (they did not move their eyes to the target location, nor did they respond manually to the appearance of the target). In the target-target group, participants made either a saccade to the location of this first stimulus (overt orienting block), or responded via non-discriminatory manual key press with the right hand (covert orienting block) to acknowledge the appearance of this first stimulus.

In all trials, S1 was presented for a fixed 500ms period. For subjects taking part in the target-target overt and target-target covert conditions, failure to respond to the first stimulus within 500ms resulted in the presentation of a timeout error.

2.4.3 Central Fixation 2

Following the 500ms S1 presentation, in all trials, a boldening of the central placeholder square returned participants overt or covert attention to this location. During the overt orienting block in the target-target group, participants were required to make a saccade back to this central location. Failure to do so within 500ms resulted in the trial being recorded as an error. In both cue-target conditions and in the target-target covert orienting block, the eyes remained at centre and the boldening of the target in this location presumably served to return covert attention from its peripheral location to the centre of the display. For subjects taking part in the target-target saccadic condition, failure to return gaze to the central region within 500ms of the onset of the signal resulted in the presentation of a timeout error.

2.4.4 Second Stimulus (S2) Presentation

One-thousand milliseconds following the presentation of S1 (S1 was presented for 500ms and central fixation 2 was presented for 500ms), a second peripheral stimulus (the boldening of one of the four peripheral placeholders) was presented for 500ms in one of the four possible target locations. This second stimulus was S1-S2 distance from the first by 0, -90, 90 or 180 degrees (all offsets occurred with equal probability). In both cue-target and target-target trials, participants responded to the appearance of this second target by making either an eye movement to its location (overt orienting block) or by acknowledging its appearance with a non-discriminatory keypress response made with the right hand (covert orienting block). In all trials, saccadic or manual reaction time to the onset of the second stimulus represented the dependent variable. In a given trial, any responses required were be made using either the eyes or the hands, but never a combination of the two. For example, there were no trials which required participants to make a manual response to the first target followed by a saccadic response to the second target or vice versa. Refer to Figure 2 for a summary of experimental procedure for cue-target and target-target groups, respectively.

2.4.5 Errors

All trials in which participants failed to respond to peripheral targets or centre fixation cues within the allotted time, made a saccadic response in the wrong direction, or looked away from centre when instructed to refrain from doing so were recorded as errors. Offending trials were not recycled. Based on the experimental design described above, four types of errors were possible. These errors are described in detail below. All errors resulted in a 3000ms penalty during which participants were unable to continue with the experimental trials. Reaction times from error trials were excluded from further analyses.

A central fixation 1 error was recorded if a participant failed to direct their gaze to the centre square within 500ms of its presentation or if gaze left this region at any time during the 500ms central fixation period.

An S1 error was recorded if a participant in the cue-target group made any type of response (either manual or saccadic) to the first stimulus, since they were explicitly instructed not to do so. In the target-target group, an error was recorded if a participant failed to make either a saccadic or manual response to this first stimulus within 500ms, or if a saccade was directed to any of the three non-target locations.

A central fixation 2 error was recorded if a participant failed to return gaze to centre within 500ms of central brightening (target-target group, saccadic response block), or if gaze left this central region at any time during the 500ms central fixation period.

An S2 error was recorded if participants in either the cue-target or target-target group failed to make the required response (manual or saccadic) to the second target within 500ms, or if a saccade was directed to any of the three non-target locations.

Any error resulted in the presentation of a screen detailing the nature of the error made. In all cases, participants were then given a fixed 3000ms penalty, after which the next scheduled trial commenced. Any data collected in error trials was not used in the analysis and these trials were not recycled.

2.5 Data Analysis

2.5.1 First Stimulus (S1) Reaction Times

Our design allowed us to assess reaction times to the first stimulus in both target-target saccadic and target-target manual factor combinations (as both conditions required a response to S1). These analyses were done using a 4(S1 Location; down, left right or up) by 2(Mode of orienting; manual or saccadic) repeated measures ANOVA with S1 reaction time as the dependent variable.

2.5.2 Second Stimulus (S2) Reaction Times

To reiterate, our primary concern was in determining whether the different IOR anisotropies observed in the two aforementioned studies was due to: i.) The different modes of orienting or the number of responses required in these studies, or ii.) other methodological differences between the studies. Our design manipulated First stimulus location (left, down, right or up), S1-S2 distance (-90, 0, 90 or 180 degrees), group (cue-target or target-target) and orienting type (covert or overt) to determine the effect of group and orienting type on IOR (defined as a main effect of S1-S2 distance on S2 reaction time) and IOR bias (defined as an interaction between S1-S2 distance and S2 location on S2 reaction time). To summarize, the second stimulus reaction time analysis was completed in two steps. We used an omnibus analysis followed by four separate analyses. Each of these analyses is summarized below.

2.5.3 Omnibus Analysis

We used a single mixed ANOVA which included all levels of all factors to establish a general sense of the relationships between and among these factors. This was a 2 (cue-target or target-target; between subjects) by 2 (manual response or saccadic response; blocked and counterbalanced within subjects) by 4 (Second stimulus location; random within subjects) by 4 (S1-S2 distance; random within subjects) ANOVA, with second stimulus reaction time as the dependent variable. If present, IOR would be revealed as a main effect of S1-S2 distance on S2 reaction time, with significantly longer S2RTs under the zero degree S1-S2 distance condition (where S1 and S2 occupied the same location). IOR anisotropy would be observed as a two-way interaction between first stimulus location and S1-S2 distance, where zero degree S1-S2 distance condition show significantly longer reaction times than the 180-degree S1-S2 distance condition and the difference between zero and 180-degree S1-S2 distance conditions varies as a function of the S2 location.

2.5.4 Additional Analyses

In addition the omnibus analysis, we completed four two-way (4 first stimulus location by 4 S1-S2 distance) repeated measures ANOVA – one for each of cue-target covert (condition A in Figure 1B), target-target covert (condition B in Figure 1B), cue-target overt (condition C in Figure 1B) and target-target overt (condition D in Figure 1B) combinations. Results from conditions A (cue-target covert) and D (target-target overt) in the figure above were used verify that we had replicated the results of the Spalek and Hammad (2004) and Harris et al. (2009) studies, respectively. We reasoned that if the previously described differences in IOR anisotropy persisted in examining these two conditions, then we could be safe in assuming that neither the number of simultaneously presented placeholder locations (which was four in the current study, but two in the Harris et al. paper) nor the difference in cue types (which were exogenous and endogenous for the Harris et al. (2009) study, but only exogenous for the Spalek and Hammad (2004) study) were responsible for the difference in IOR anisotropy between studies since these were now equated among the four conditions in this study. Next, we could examine how this IOR anisotropy changed as we manipulated the factors of "group" (cue-target or target-target) and mode of orienting (manual or saccadic), by including the remaining two combinations of group and mode of orienting variables (Cue-Target Saccadic and Target-Target Manual – conditions B and C, respectively).

2.5.5 Error Analysis

It has been suggested that IOR may in fact be a speed-accuracy tradeoff (Ivanoff & Klein, 2001). That is, participants can potentially respond more slowly but more accurately to targets appearing in the same location as a previous cue (a speed-accuracy trade-off). To verify that any supposed IOR effects observed in the current study were in fact inhibition of return and not simply a speed-accuracy trade-off, we analyzed trial error data and compared the results to those of the various reaction time analyses.

Due to the design of the experiment, we could not recover data concerning incorrect reactions to catch trials. Thus, we analyzed only S2 errors from saccadic response trials, as these errors could provide information concerning the presence or absence of a speed-accuracy trade-off. For each participant in the cue-target and target-target groups, we recorded the total number of S2 errors in saccadic response trials (overt orienting trials) for each of the sixteen factor combinations (4 S2 locations x 4 S1-S2 distances). To generate a percentage error for each participant for each of the sixteen factor combinations, we then divided the number of S2 errors for each factor combination by the total number of error-free trials in that factor combination plus the total number of S2 error trials for that factor combination. These error data were submitted to two separate 4 (S2 location – Left, Right, Down or Up) by 4 (S1-S2 offset – -90, 0, 90 or 180 degrees) repeated measures ANOVA.

We reasoned that if errors were significantly less in conditions where we noted significantly longer reaction times, this would represent a speed-accuracy trade-off rather than IOR (participants responding more slowly but more accurately under a particular set of experimental conditions).

CHAPTER 3: RESULTS

3.1 S1 Reaction Time Analysis

The analysis of S1 reaction time data involved an omnibus 2 (Mode of orienting; manual or saccadic) by 4 (First stimulus location; left, right down or up) repeated measures ANOVA. As was mentioned previously, this S1 reaction time analysis included only data from the target-target overt and target-target covert factor combinations as these were the only trials in which responses to the first stimulus (S1) were required.

The omnibus analysis showed a main effect of First stimulus location on the magnitude of S1 reaction times ($F(3, 51) = 13.52$; $MSE = 240.68$; $p < 0.01$). Both the main effect of mode of orienting ($F(1, 17) = 1.95$; $MSE = 4901.92$; $p=0.18$) and the interaction between S1 location and mode of orienting ($F(3, 51) = 0.75$; $MSE = 389.33$; $p=0.53$) failed to reach significance. Subsequent 2(Mode of orienting; manual or saccadic) by 2(S1 Location; left or right, or up or down) were conducted to further investigate the main effect of location in the omnibus analysis. For the analysis restricted to S1 locations in the vertical axis, there was a main effect of location ($F(1, 17) = 24.76$; $MSE = 259.06$; $p < 0.01$), where reaction times to down targets (297.1 ms) were significantly longer than reaction times to up targets (278.2 ms). Both the main effect of mode of orienting ($F(1, 17) = 0.9$; $MSE = 2951.05$; $p=0.36$) and the interaction between mode of orienting and S1 location ($F(1, 17) = 0.39$; $MSE = 579.16$; $p=0.54$) failed to reach significance.

For the analysis restricted to S1 locations in the horizontal axis, there was a main effect of location ($F(1, 17) = 14.56$; $MSE = 167.44$; $p= 0.001$), where reaction times to targets on the right (288.44ms) were significantly longer than reaction times to targets presented on the left (276.8ms). Both the main effect of mode of orienting (F(1, 17) = 3.33; MSE = 2265.04; p= 0.09) and the interaction between S1 location and mode of orienting (F(1, 17) = 0.05; MSE = 274.68; p= 0.82) failed to reach significance.

In summary, the results of these S1 reaction time analyses suggest that reaction times are faster to targets on the left than to targets on the right and faster to upward targets than to downward targets.

Table 1

S1 Reaction Times for S1 Location by Mode of Orienting Factor Combinations in Target-Target Conditions

S1 Location	Covert	Overt
Up	270.37	286.04
Down	292.81	301.37
Right	277.75	299.13
Left	267.01	286.59

3.2 S2 Reaction Time Analysis

The analysis of S2 reaction time data involved an omnibus analysis (a 4-way mixed ANOVA) and four separate two-way repeated measures ANOVA – one for each of the four possible combinations of group and mode of orienting factors. First, the omnibus analysis and associated simple effects analyses will be discussed. We will then turn our attention to the results of the subsequent four two-way ANOVAs.

The omnibus analysis included mode of orienting (covert or overt), group (cue-target or target-target; between subjects), S2 Location (down, left right or up from the central fixation location) and S1-S2 distance (0, 90, -90 or 180 degrees) factors, with reaction time to the second stimulus as the dependent variable. In this analysis, several important results were noted. First, mode of orienting affected the magnitude of reaction times ($F(1,32) = 95.9$; $MSE = 8257.3$; $P < 0.01$). On average, reaction times in covert orienting trials (Mean=236.2ms) were significantly longer than reaction times in overt orienting trials (Mean = 182.2ms). There was also a significant main effect of S2 location on the magnitude of second stimulus reaction times ($F(2.44, 78.14)=13.49$; $MSE = 907.89$; $p < 0.01$). To determine which locations differed significantly from one another, we completed a series of simple effects analyses including the same factors used in the omnibus analysis, but with the S2 location factor restricted to two levels. We then used a Bonferroni correction to control the familywise error rate for these multiple comparisons (The critical alpha was set at $0.05/6 = 0.0083$). Results showed that reaction times to down targets (217.47ms) differed significantly from reaction times to left (mean = 203.16ms; $F(1,32) = 24.9$; $MSE = 971.53$; $p<0.001$), right (mean = 209.9ms; $F(1,32) = 19.37$; $MSE = 401.59$; $p<0.001$) and up (mean = 205.3ms; $F(1,32) = 19.8$; $MSE = 1020.42$; $p<0.001$) targets. Results showed no significant difference between left and right ($F(1,33) =7.21$; $MSE = 684.6$; $p =0.01$), left and up ($F(1,33) =0.31$; $MSE = 667.61$; $p=0.58$) or right and up ($F(1,33) = 4.92$; $MSE = 634.2$; $p = 0.033$).

The main effect of S2 location in the omnibus analysis was qualified by an interaction with mode of orienting ($F(3, 96)=10.86$; $MSE = 738.15$; $p<0.01$). This interaction provided part of the rationale for conducting four separate two-way ANOVAs.

To summarize the interaction, the main effect of location on reaction time was only significant in cue-target overt response condition. Next, there was a significant main effect of S1-S2 distance on S2 reaction times in the omnibus analysis ($F(3,96) = 38.85$; $MSE = 547.82$; $p < 0.01$). Zero degree S1-S2 distances conditions yielded the greatest reaction times (222.36ms), whereas reaction times in the other three S1-S2 distance conditions were smaller in magnitude and similar to one another (204.2ms, 203.8ms and 206.4ms for each of -90, 90 and 180 degree conditions, respectively). This is the standard IOR effect. Again however, this main effect of S1-S2 distance was qualified by an interaction with mode of orienting ($F(3, 96) = 7.36$; $MSE = 446.26$; $p<0.01$). Thus, we completed a simple effects analysis with S1-S2 distance set at two levels (0 and 180). This simple effects analysis showed a main effect of S1-S2 distance which verified that mean reaction times for 0 (Mean=222.36ms) and 180 degree (Mean=206.41ms) conditions were significantly different from one another ($F(1, 32) = 57.99$; $MSE = 549.69$; $p<0.01$), and thus that IOR was being observed. However, the results of this simple effects analysis showed that the interaction between mode of orienting and S1-S2 distance was not significant ($F(1, 32) = 1.42$; MSE = ; $p=0.24$), which suggested that IOR did not differ in magnitude between covert and overt orienting trials. Importantly, the interaction between S1-S2 distance and S2 Location failed to reach significance in this simple effects analysis ($F(3, 96) = 0.39$; $MSE = 547.42$; $p = 0.76$) and in the omnibus analysis ($F(9, 288) = 0.8$; $MSE = 417.42$; $p=0.6$). Thus, IOR anisotropy was not observed; an outcome which conflicts with our original hypothesis. Finally, there was a main effect of the group factor on S2 reaction times in the omnibus analysis ($F(1,32) = 5.05$; $MSE = 19412.2$; $p=0.03$), where reaction times were longer in the cue-target group

(218.7ms) than in the target-target group (199.7ms). Reaction time data from the omnibus analysis are shown as a function of both S1-S2 distance and target location in Table 2.

Table 2

S2 Reaction Times as a Function of Both Target Location and S1-S2 Distance for the Omnibus Analysis of S2 Reaction Times

S2 Location	S1-S2 Distance (Degrees)	S2RT (ms)
Up	-90	198.88
	0	219.32
	90	197.99
	180	204.86
Down	-90	215.58
	0	227.81
	90	212.03
	180	214.46
Right	-90	205.2
	0	223.54
	90	206.14
	180	204.69
Left	-90	197.14
	0	218.77
	90	198.88
	180	201.64

Given that our initial research question was focused on characterizing any differences in IOR anisotropy (appearing as an interaction between S2 Location and S1-S2 distance) with changes in mode of orienting or group, we decided to complete four separate 4 (S2 location; Down, Left, Right, Up) X 4 (S1-S2 distance; -90, 0, 90, 180) repeated measure ANOVAs; one for each of the four possible combinations of group and mode of orienting factors. The results for each of the Cue-Target Covert (A), Target-Target Covert (B), Cue-Target Overt (C) and Target-Target Overt (D) conditions are discussed below and summarized in Figure 3 and Table 3.

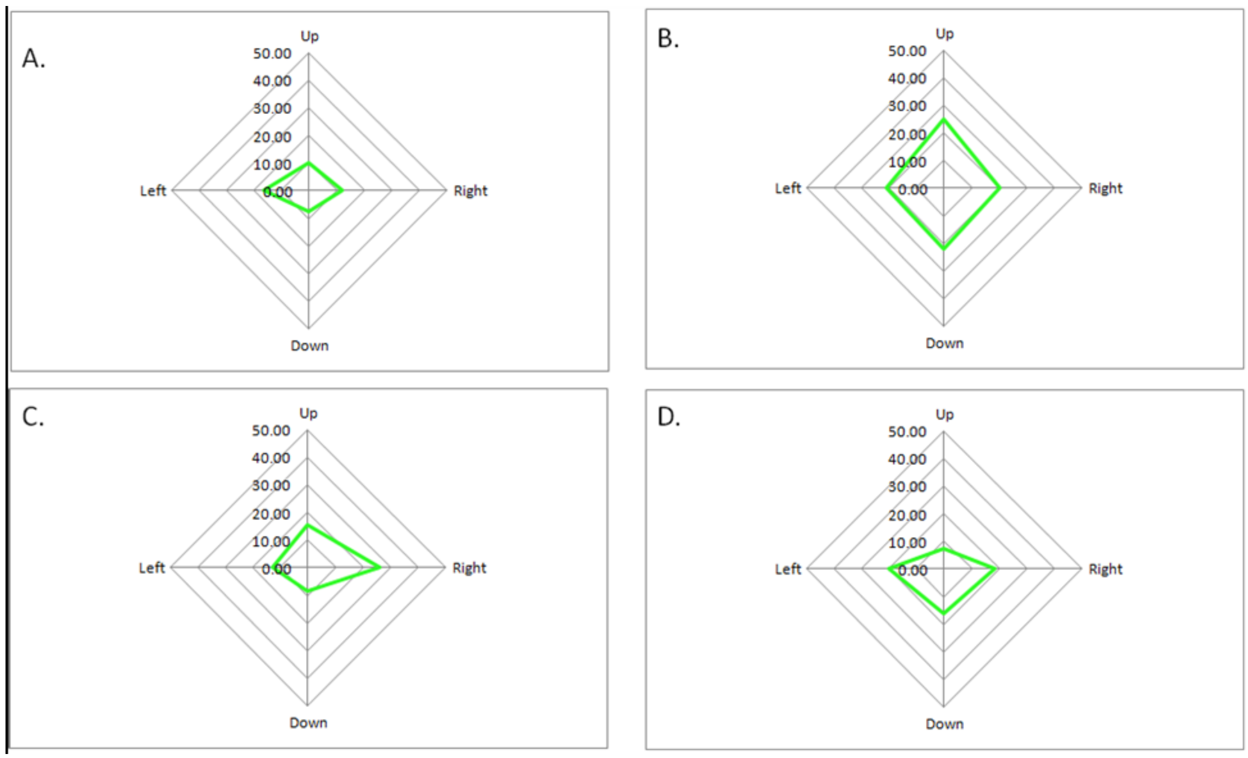

Figure 3: Polar coordinate plots of the IOR effect in cue-target covert, target-target covert, cue-target overt, and target-target overt orienting conditions. Graphs A-D show the lack of interaction between S2 location and S1-S2 distance factors for each of cue-target covert ($F(9,135) = 1.04$; $MSE = 608.7$; $p= 0.41$), target-target covert ($F(9, 153) = 1.03$; $MSE = 527.51$; $p= 0.42$), cue-target overt ($F(3.56, 53.45) = 0.96$; $MSE = 318.53$; $p=0.43$) and target-target overt ($F(9, 162) = 0.45$; $MSE = 162$; $p= 0.9$) response conditions, respectively. IOR is generally defined as a significant difference in S2 reaction time between 0 degree and 180 degree S1-S2 distance conditions. The difference in mean S2 reaction time between 0 and 180 degree conditions was significant for each of the Cue-Target Covert ($F(1, 15) = 6.66$; $MSE = 627.4$; $p=0.02$), Target-Target Covert ($F(1, 17) = 17.15$; $MSE = 512.73$; $p<0.01$), Cue-Target Overt ($F(1, 15) = 21.78$; $MSE = 702.15$; $p<0.01$) and Target-Target overt conditions ($F(1, 18) = 19.29$; $MSE = 470.11$; $p<0.01$).

Overall, several important patterns were evident as a result of these analyses. Firstly, IOR was present in each of the four factor combinations. That is, there was a main effect of S1-S2 distance on S2 reaction time for each of Cue-Target covert ($F(3, 45) = 3.7$; MSE = 605.18; $p=0.02$), Target-Target covert ($F(3, 51) = 5.0$; MSE = 667.07; $p<0.01$), Cue-Target overt ($F(3, 45) = 22.48$; MSE = 428.88; $p<0.01$) and Target-Target overt conditions ($F(2.24, 40.25) = 38.46$; MSE = 380.91; $p<0.01$). Further simple effects analyses for each of these conditions were used to compare 0 and 180 degree S1-S2 distance conditions to verify that reaction times were significantly different in these cases (IOR is generally defined as the difference in reaction times between 0 and 180 degree S1-S2 distances). The difference in mean S2 reaction time between 0 and 180 degree conditions was significant for each of the Cue-Target Covert ($F(1, 15) = 6.66$; MSE = 627.4; $p=0.02$), Target-Target Covert ($F(1, 17) = 17.15$; MSE = 512.73; $p<0.01$), Cue-Target Overt ($F(1, 15) = 21.78$; MSE = 702.15; $p<0.01$) and Target-Target overt conditions ($F(1, 18) = 19.29$; MSE = 470.11; $p<0.01$). IOR was defined as the difference in reaction times between 0 and 180 degree S1-S2 distance conditions and had magnitudes of 11.43ms, 15.63ms, 21.86ms, and 15.45ms for each of the Cue-Target Covert, Target-Target Covert, Cue-Target Overt and Target-Target overt conditions, respectively.

Importantly, there was no significant interaction between S2 Location and S1-S2 distance for any of the cue-target covert ($F(9,135) = 1.04$; MSE = 608.7; $p= 0.41$), target-target covert ($F(9, 153) = 1.03$; MSE = 527.51; $p= 0.42$), cue-target overt ($F(3.56, 53.45) = 0.96$; MSE = 318.53; $p=0.43$), or target-target overt conditions ($F(9, 162) = 0.45$; MSE = 162; $p= 0.9$). Thus, we may conclude that although IOR was present in each of these four factor combinations, IOR anisotropy was not statistically reliable under any conditions in the current experiment (Refer to Figure 3). These results were unexpected and will be covered in detail in the discussion section.

Finally, we observed a main effect of S2 location on S2 reaction times in both of the two analyses involving overt mode of orienting (but not those involving covert responses). That is, there was a significant main effect of S2 location on S2 reaction time for each of the cue-target overt ($F(1.87, 28.11) = 9.03$; MSE = ; 1248.93; $p<0.01$) and target-target overt groups ($F(3, 54) = 13.64$; MSE = 778.7; $p<0.01$). To determine the precise nature of this main effect in the cue-target overt condition, we completed a series of simple effects analyses with S2 location set at two levels and used a Bonferroni correction to control familywise error rate. These analyses indicated that downward reaction times differed from reaction times to left, right and up targets. No other significant main effects or interactions were noted. To determine the precise nature of this main effect in the target-target overt orienting condition, we used Tukey's HSD to make comparisons among the various levels of the S2 location factor. None of these comparisons yielded significant differences. Thus, the aforementioned interaction between S2 location and mode of orienting in the omnibus analysis was due to this directional reaction time asymmetry in cue-target overt trials, but not target-target overt or any of the covert trials. Table 3 shows second stimulus reaction times as a function of both target location and S1-S2 offset for each of the cue-target covert, target-target covert, cue-target overt and target-target overt orienting trials.

Table 3

S2 Reaction Times as a Function of Both Target Location and S1-S2 Distance for Cue-Target Covert, Target-Target Covert, Cue-Target Overt and Target-Target Overt Conditions

Cue-Target Covert			Target-Target Covert		
S2 Location	S1-S2 Distance (Degrees)	S2 RT (ms)	S2 Location	S1-S2 Distance (Degrees)	S2 RT (ms)
Up	-90	249.26	Up	-90	210.31
	0	255.84		0	234.75
	90	240.22		90	220.54
	180	245.79		180	219.22
Down	-90	250.20	Down	-90	227.24
	0	248.59		0	230.42
	90	248.48		90	222.90
	180	241.22		180	221.89
Right	-90	254.19	Right	-90	226.55
	0	262.13		0	235.95
	90	254.58		90	228.24
	180	250.21		180	210.19
Left	-90	237.75	Left	-90	216.98
	0	263.37		0	231.21
	90	233.53		90	221.35
	180	246.99		180	218.53

Cue-Target Overt			Target-Target Overt		
S2 Location	S1-S2 Distance (Degrees)	S2 RT (ms)	S2 Location	S1-S2 Distance (Degrees)	S2 RT (ms)
Up	-90	171.06	Up	-90	163.42
	0	204.20		0	180.57
	90	171.69		90	157.95
	180	179.21		180	173.00
Down	-90	200.00	Down	-90	184.25
	0	220.84		0	210.01
	90	196.00		90	179.22
	180	199.18		180	193.87
Right	-90	174.09	Right	-90	165.29
	0	205.05		0	190.13
	90	178.28		90	162.81
	180	185.08		180	171.95
Left	-90	174.86	Left	-90	157.95
	0	196.53		0	183.70
	90	183.90		90	156.40
	180	175.70		180	163.81

3.3 Error Analysis

To verify that any supposed IOR effects in the overt orienting trials were not simply the result of a speed-accuracy trade-off, we completed two separate 4 (S2 location – Left, Right, Down or Up) by 4 (S1-S2 offset – -90, 0, 90 or 180 degrees) repeated measures ANOVA.

For the analysis of error scores restricted to the overt orienting condition in the cue-target group, the main effect of S2 location was significant ($F(2, 30.07) = 3.84$; MSE

= 303.02; p = 0.03). Importantly, the main effect of S1-S2 offset (F(3, 45) = 1.94; MSE = 87.66; p = 0.14) failed to reach significance. The mean S2 error values for the various levels of S1-S2 offset was not indicative of a speed-accuracy tradeoff, as the largest mean error percentage (10.56%) was observed in the 0-degree offset condition, which when interpreted with the results of the S2 reaction time analysis suggest that 0-degree offsets yield both a relatively long reaction time and a relatively large number of errors. Finally, the interaction between S2 location and S1-S2 offset failed to reach significance (F(9, 135) =1.86; MSE = 94.39; p=0.06).

For the analysis of error scores restricted to the overt orienting condition in the target-target group, the main effect of S2 location was significant (F(2, 36.22) = 3.52; MSE = 298.33; p=0.04). Mean error percentages were 7.99, 5.11, 10.51 and 12.06 for targets located left, right, down and up from the central fixation location, respectively. Both the main effect of S1-S2 offset (F(3, 54) =1.1; MSE = 172.06; p=0.36) and the interaction between S2 location and S1-S2 offset (F(9, 162) =0.47; MSE = 132.8; p=0.9) failed to reach significance.

3.4 Order Analysis

Spalek and Hammad (2004) used an experimental paradigm which included only manual responses to peripheral targets. In the current study, participants responded with the eyes or with the hands (blocked) to peripheral targets. Thus, it is possible that our non-replication of Spalek and Hammad’s (2004) results was due to this difference in blocked presentation of mode of orienting. Specifically, half of those individuals who participated in the cue-target covert response condition in the current study had already participated in the cue-target saccadic response condition. It is possible that having responded using the eyes in the first (overt orienting) block may have influenced the results obtained in the subsequent cue-target covert response block for these participants. To make a more direct comparison between the results of Spalek and Hammad (2004) and our own data, we completed an analysis of S2 reaction times in the cue-target covert orienting condition in which the order of trials was included as a between subjects factor. This analysis was the same as the analysis of S2 reaction times from the cue-target overt orienting condition described above in that included S2 Location (down, left right or up from the central fixation location) and S1-S2 distance (0, 90, -90 or 180 degrees) as factors. The order analysis included one additional "order" (saccadic first or manual first) factor.

The results of this analysis indicated a significant interaction between the S2 location and first block factors ($F(3, 42) = 4.58$; $MSE = 636.87$; $p=0.01$) and a significant main effect of offset ($F(3, 42) = 3.7$; $MSE = 636.86$; $p=0.2$). No other main effects or interactions reached significance. Importantly, the two way interaction between offset and first block ($F(3, 42) = 0.25$; $MSE = 636.86$; $p=0.86$) and the three-way interaction among offset, S2 location and first block ($F(9, 126) = 0.54$; $MSE = 628.21$; $p=0.85$) failed to reach significance, which suggests that the order of presentation of blocks did not influence the characteristics of IOR (or IOR anisotropy) in the cue-target covert orienting block.

Similarly, the design employed by Harris et al. (2009) included only saccadic responses. Half of the participants in the target-target overt orienting block of the current study had already completed the target-target covert orienting block. Thus, it is possible that having responded using the hands in the first (covert orienting) block could have influenced the results obtained in the subsequent target-target overt orienting trials in these participants. Thus, we decided that it was important to complete an analysis of the target-target overt orienting block of the current study which included a "first block" factor.

The results of this analysis showed significant main effects of S2 location ($F(3, 51) = 13.49$; $MSE = 796.33$; $p<0.01$) and offset ($F(2.17, 36.88) = 39.48$; $MSE = 385.08$; $p<0.01$). Importantly, the two-way interaction between offset and first block ($F(2.17, 36.88) = 1.35$; $MSE = 385.08$; $p=27$) and the three-way interaction among offset, S2 location and first block ($F(9, 153) = 1.51$; $MSE = 275.44$; $p=0.15$) failed to reach significance. Thus, we can be confident that our non-replication of the IOR anisotropy observed by Harris et al. (2009) was not due to the blocked presentation of covert and overt orienting trials used in the current study.

3.5 Results Summary

For each of the cue-target covert, target-target covert, cue-target overt and target-target overt conditions, we observed IOR. That is, S2 reaction times were significantly longer when the second stimulus occupied the same location as the first (0 degree S1-S2 distance condition) than when this second stimulus occupied the location opposite the initial stimulus (180 degree S1-S2 distance condition).

Next, there was a main effect of S2 location on S2 reaction time for the cue-target overt conditions, but not for the other response conditions. Subsequent simple effects analyses showed that for cue-target overt condition, S2 reaction times were longest when the second stimulus was presented in the down location.

Importantly, IOR anisotropy was not observed in any of the four aforementioned conditions. That is, the interaction between S2 Location and S1-S2 distance failed to reach significance in each of these four separate analyses of cue-target covert, target-target covert, cue-target overt and target-target overt conditions. There was also no interaction between group and S1-S2 distance in the omnibus, suggesting that while IOR was present, it did not differ in magnitude between cue-target and target-target conditions. Also of interest is the fact that IOR did not differ in magnitude between overt and covert trials.

Finally, the error analyses completed suggested that speed accuracy trade-off was in no case responsible for an IOR-like effect. If a speed-accuracy trade-off were causing the longer reaction times, we would expect to see relatively few errors under conditions which generated more IOR/longer reaction times (suggesting that participants were slowing down and consequently producing fewer errors – a speed-accuracy trade-off). In general, we actually observed the opposite trend, where there tended to be more errors in conditions where IOR was greatest (for example, in the cue-target saccadic response condition).

CHAPTER 4: DISCUSSION

The primary aim of the present study was to demonstrate differences in IOR anisotropy for covert and overt orienting tasks. Such a finding would strengthen and extend the results of past literature which suggest functional differences between overt and covert IOR. We made three main predictions about the results of this study. First, we expected that Inhibition of return should be observed as significantly longer reaction times in trials where the second stimulus occupied the same location as the first (zero degree S1-S2 distance condition) than for any of the other S1-S2 distance conditions (particularly the 180-degree S1-S2 distance condition). This is the standard IOR effect. Second, we expected that the magnitude of IOR should depend on the location of the target (a significant interaction between S1-S2 distance and target location). This we termed IOR anisotropy. Third, we predicted that this IOR anisotropy should differ depending on the mode of orienting (covert or overt) or the number of responses (cue-target group vs. target-target group) required. This would manifest as a three-way interaction among S2 location, S1-S2 distance and mode of orienting, a three-way interaction among S2 Location, S1-S2 distance and group, or a four way interaction among S2 Location, Group, S1-S2 distance and Mode of orienting. In line with out hypothesis, we observed IOR in each of the cue-target covert, target-target covert, cue-target overt and target-target overt orienting conditions. Although we did not observe IOR anisotropies in the current study, there are a number of interesting reasons why this may be so. In the following discussion of experimental results, we have strayed from the format adhered to in the results section. Instead, we will discuss results from both sections of the analysis as they relate to specific hypotheses and outcomes.

4.1 Inhibition of Return

The omnibus analysis indicated a significant main effect of S1-S2 distance on the magnitude of S2 reaction times. Reaction times were longer when the first and second stimuli occupied the same location (0 degree S1-S2 distance condition; 222.36ms) than when these stimuli occupied opposite locations (180 degree S1-S2 distance condition; 206.41ms). This is the standard IOR effect.

In the current study, IOR was shown to have a magnitude of roughly 16ms (from the omnibus analysis), which is well within the range reported elsewhere (Taylor & Klein, 2000). As mentioned previously, IOR was observed as a main effect of S1-S2 distance in each of cue-target covert, target-target covert, cue-target overt and target-target overt conditions when each of these four separate 2-way ANOVAs were examined. Again, simple effects analysis verified that a significant difference in reaction time existed between 0 degree and 180 degree S1-S2 distance conditions in each case. The omnibus analysis and subsequent simple effects analysis revealed that IOR was equal in magnitude for overt and covert orienting trials. This outcome has sometimes been reported in past literature (Taylor & Klein, 2000; but see Pratt & Neggers, 2008).

Also, from the omnibus analysis of S2 reaction times (particularly apparent in Table 2), the magnitudes of reaction times are very similar in -90, 90 and 180 degree offset conditions for all S2 locations. This provides strong evidence against the attentional momentum account of IOR (Pratt, Spalek & Bradshaw, 1999).

4.2 IOR Anisotropy

In the omnibus analysis, the two-way interaction between S1-S2 distance and S2 location failed to reach significance ($F(9, 288) = 0.8$; $MSE = 417.42$; $p=0.6$). When interpreted in light of the main effect of S1-S2 distance (where zero degree S1-S2 distances yielded longer reaction times than 180 degree S1-S2 distances), this result suggests that although IOR was present, its magnitude did not differ with the location (left, right, down or up from centre) of the target. Further analyses for each of cue-target covert, target-target covert, cue-target overt and target-target overt conditions again indicated no significant IOR anisotropy within any of the four separate factor combinations investigated. As we had intended to replicate and extend the findings of Harris et al. (2009), whose results demonstrated IOR anisotropy, these results were unexpected. So, why did we not replicate the IOR anisotropies observed by these researchers under similar experimental conditions? Potential explanations for this non-replication are outlined below.

4.3 Non-Replication of Harris et al., 2009

To reiterate, Harris et al. (2009) had shown that in a target-target saccadic (overt) response paradigm, IOR had a larger magnitude for targets presented down from the central location point than those presented up from a central fixation point. In contrast, we found no such significant IOR anisotropy in our target-target condition. Although present, IOR magnitude was not modulated in a statistically significant way by target location in the current study. Our non-replication of the results of Harris et al. (2009) in the target-target overt orienting condition may have resulted from slight differences in experimental methodology which we had assumed to be unimportant in designing the current study. The largest and most obvious difference is related to the number of possible target locations presented simultaneously. In the Harris et al. (2009) study described previously, only two possible peripheral target locations were presented on screen at any given time. Conversely, in the current study, there were always four possible target locations present. In designing the current study, we decided that this difference in set size was unlikely to have elicited the differences in IOR anisotropy and to avoid having subjects complete a large number of trials, we opted not to manipulate set size as a factor. Instead, we used an experimental design which always included four possible target locations (as in the Spalek and Hammad (2004) paper). Thus, it is possible that the difference in set size between the Harris et al. (2009) paper and the current study was responsible our failure to observe this previously reported IOR anisotropy. This influence of set size on the characteristics of IOR observed would be in keeping with some previous and currently unpublished results from our laboratory (Cowper-Smith). Similarly, published research has shown that set size has the ability to affect the magnitude of IOR observed (Birmingham, Visser, Snyder & Kingstone, 2007), so it seems reasonable to expect that set size may affect other characteristics of IOR, including perhaps IOR anisotropy. It may be of interest to manipulate set size to determine if this difference may have caused the disappearance of IOR anisotropy in moving from a two-target to a four-target design.

4.4 Replication of Spalek and Hammad

To remind the reader, when analyzed by target location, Spalek and Hammad's (2004) data demonstrated no IOR anisotropy. Similarly, we found no indication of statistically significant IOR anisotropy in our cue-target manual condition (the condition which replicated the experimental design reported by Spalek and Hammad). Interestingly, the magnitude of the IOR effect was much smaller in cue-target manual response (covert orienting) condition in the current study (~11ms) than in the by-target location analysis of

Spalek and Hammad's data (~41ms). This may have resulted from slight differences in experimental methodology between that study and the current study. For example, the average reaction time in the Spalek and Hammad study was 357.5ms, whereas reaction times reported in the cue-target covert orienting condition of the current study had an average magnitude of 248.9ms. Reaction times in the Spalek and Hammad study were roughly 42% longer than those reported in the current study. It is possible that encouraging participants to respond more quickly (within 500ms) in the current study was enough to reduce the magnitude of the IOR effect observed. Speeded responses could be inherently more reflexive than responses that participants are allowed more time to generate. Thus, a difference in the way the participants approached the task in these two experiments could potentially explain the difference in IOR magnitude observed.

Luminance differences represent another potential source of the discrepancy between IOR magnitude in the current study and that conducted by Spalek and Hammad (2004). Spalek and Hammad presented white stimuli on a black background, whereas in the current study we presented black stimuli on a white background. Past research has demonstrated the potential for background luminance and possibly target-background polarity to affect the specific characteristics of IOR observed (Hunt & Kingstone, 2003; Reuter-Lorenz, Jha & Rosenquist 1996; Souto & Kerzel, 2009), so it is not unreasonable to expect that this may be the source of the difference in IOR magnitude observed. Overall then, both differences in time allowed for responses and/or differences in background luminance between studies could have resulted in our observing relatively small amount of IOR in the cue-target manual response condition in the current study.

We will now shift the focus of our discussion away from these two past studies, to consider the variations in reaction times noted within the current study.

4.5 Main Effect of Group

The first result worthy of consideration is the main effect of group in the omnibus analysis ($F(1,32) = 5.05$; $MSE = 19412.2$; $p=0.03$). Reaction times to the second stimulus were significantly shorter in the target-target group (218.7ms) than in the cue-target group (199.7ms). It seems that having previously made some response to a target facilitates subsequent target-directed responses; this result has been reported elsewhere in studies using similar tasks (Welsh & Pratt, 2006). However, some research has demonstrated the opposite effect, where S2 reaction times in trials requiring a response to the target only were in fact shorter than S2 reaction times in trials requiring a response to both the cue and target (Taylor & Klein, 2000; no-response manual vs. manual-manual response conditions). Thus, in light of these conflicting results, further research is needed to identify the factors which influence the pattern of reaction times in studies which include both cue-target and target-target tasks.

4.6 Group by S1-S2 Distance Interaction

Past research has shown that IOR is larger in magnitude for cue-target than for target-target conditions when a single non-discriminatory manual detection response is required, but that the magnitude of the IOR effect does not differ between cue-target and target-target conditions when participants are required to make one of two possible spatially-directed manual responses (Welsh & Pratt, 2006). In the current study, we found that IOR was not significantly different in magnitude between the cue-target and target-target conditions for our non-discriminatory manual response (covert orienting) condition. That is, we found no significant interaction between group and S1-S2 distance factors in the omnibus analysis ($F(3, 96) = 0.06$; $MSE = 547.82$; $p = 0.98$) and no significant interaction among response type, S1-S2 distance and group factors in the omnibus analysis with S1-S2 distance restricted to 0 and 180 degrees ($F(1,32) = 1.89$; $MSE = 558.5$; $p = 0.18$). These results are clearly at odds with the larger IOR magnitude for cue-target than for target-target conditions in a similar task reported by Welsh and Pratt (2006). The most obvious difference between that study and the current study is in the number of on-screen targets present concurrently. Welsh and Pratt presented participants with two possible on-screen target locations whereas participants in the current study were always presented with four possible on-screen target locations. Thus the differences in S1-S2 distance-group interactions observed between studies - with no difference in IOR magnitude between cue-target and target-target groups in the current study and larger IOR for cue-target than for target-target conditions reported by Welsh and Pratt - may offer additional evidence in support of the notion that set size can affect the precise characteristics of IOR observed, for example, differences in magnitude between response conditions.

4.7 Mode of Orienting

The next result worthy of consideration is the main effect of mode of orienting. In the omnibus analysis, we observed that participants took significantly longer to respond to a target during covert orienting trials (mean reaction time = 237.1ms) than during overt orienting trials (mean reaction time = 190.49ms). This pattern of results has been reported elsewhere (Pratt & Neggers, 2008; Sumner et al., 2004; Taylor & Klein, 2000).

4.8 Mode of Orienting By S2 Location Interaction

Next, we will discuss the observed interaction between mode of orienting and location. Results indicated that for cue-target overt orienting conditions, downward targets yielded longer reaction times than targets presented in the left, right or up positions. Similar results have been reported elsewhere (Pitzalis & Di Russo, 2001; Zhou & King, 2002) for overt orienting (saccadic responses). As identified in the introduction, past research has demonstrated a bias for motion segmentation in the lower visual field (Lakha & Humphreys, 2005). Thus, the finding of no directional asymmetries in manual reaction time in covert orienting trials time goes against those results reported by Losier and Klein (2004), who identified a lower visual field advantage for manual detection target reaction times in a go/no-go paradigm. Overall then, research results do not appear to converge on some common pattern for location-dependent differences in reaction time for covert response conditions.

4.9 Mode of Orienting By S1-S2 Distance Interaction

Also of interest was the lack of interaction between mode of orienting and S1-S2 distance in the omnibus and subsequent simple effects analysis. The magnitude of the IOR effect (as the difference in reaction times between 0 and 180-degree S1-S2 distance conditions) was not significantly different between overt and covert orienting trials. This has sometimes been reported in past literature (Taylor & Klein, 2000; but see Pratt & Neggers, 2008). In comparing the methods of the current study to those employed in past studies, it is not readily apparent why our results related to the magnitude of overt and covert IOR should diverge from some past research (Pratt & Neggers, 2008) but agree with other research (Taylor & Klein, 2000). Further research is needed to determine the nature of the relationship between IOR magnitude in covert and overt orienting tasks.

4.10 Practical Implications

It is important to note that IOR represents a general reluctance towards responding to stimuli in a recently attended location, thus biasing the direction of attention in favour of novel locations. Whereas IOR is often demonstrated experimentally as a slowing of reaction times for targets presented in a recently cued location, it is not difficult to imagine more ecologically valid scenarios in which IOR may influence the detection of sensory events. In general, the results of IOR studies are most readily applicable to the field of ergonomics.

Imagine the case of a helicopter pilot training for a particular emergency scenario. In this scenario, there are a number of variables which need to be monitored (for example, fuel level, proximity to the ground, proximity to other potentially dangerous obstacles, etc.). The current values of each of these variables are presented on a display located in front of the pilot. The values associated with each of these variables all change rapidly and all variables must be monitored simultaneously. Furthermore, when any of these variables takes on a potentially dangerous value, a warning is given and an appropriate response must be generated quickly.

If an individual were responsible for designing the display to be used by this helicopter pilot, it would be important to identify the most appropriate location in which to present important visual information (for example, the values of the aforementioned variables and any warning signals which indicate that a variable is about to take on a dangerous value). A poorly-designed display would limit the pilot`s ability to detect and respond to important changes in fuel level, altitude, etc. Given that IOR affects the allocation of visual attention, the individual designing such a display would do well to learn about the properties of IOR and to design the display with such factors in mind. For example, if two warning signals were to be presented in rapid succession (for example, separated by 1.5 seconds), these warnings should be presented at different locations in the display so that the inhibitory tag produced by orienting to the appearance of the first warning (and the subsequent removal of attention from this location) does not prevent the rapid detection of a second warning signal presented in this same location. Following the same reasoning, warning signals should be presented in locations well away from the locations in which the values of the aforementioned values are displayed.

4.11 CONCLUSION

Although we had originally aimed to show differences in IOR anisotropy between saccadic (overt orienting) and manual response (covert orienting) tasks, we did not. Interestingly though, we observed that IOR was equal in magnitude for covert orienting (manual responses) than for overt orienting (saccadic responses). This result has been reported previously (Taylor & Klein, 2000; but see Pratt & Neggers, 2008).

A careful comparison of the results of the current study to those reported by Harris et al. (2009) allows us to draw several important conclusions. Ultimately our non-replication of the previously observed IOR anisotropy speaks to the importance of considering all factors which have the potential to affect IOR in designing such studies. Interestingly, factors known to affect more general characteristics of IOR (for example, its magnitude) seem to have the potential to affect IOR anisotropy as well. For example, one of the key differences between Harris et al. (2009) and the current study was our inclusion of four, rather than two possible on screen target locations. Thus, it seems tempting to conclude that differences in set size have the ability to manipulate the specific characteristics of IOR observed, as changing this factor may have eliminated the previously observed IOR anisotropy. In light of this observation, it would be of interest to complete a study which manipulates the number of on-screen targets presented concurrently in a similar experimental paradigm to characterize the effect of set size on the magnitude of IOR.

From a theoretical standpoint, we feel that the fundamental distinction between two-target and four-target conditions may be related to participant strategy. In experimental paradigms which include two target placeholder locations, participants could potentially prepare both directional responses in advance and simply execute the one which turns out to be relevant to the location of the target. In contrast, when presented with four (or more) targets, it may no longer be possible to prepare all possible directional responses in advance given the larger number of locations in which the target could be presented. Thus, in this case, it may be more efficient to refrain from preparing any particular response and instead to wait and respond reflexively to the appearance of the target.

Overall, we are suggesting that the two target location scenario represents a special case in which a more cognitive/strategic method may be employed by participants to complete the task. On the other hand, in experimental paradigms including four or more potential target locations, responses may be made in a more reflexive manner, since the aforementioned strategic approach is no longer possible. It seems reasonable to suggest that the former cognitive/strategic method and the latter reflexive method of orienting in two and four target designs, respectively, may involve different regions of the brain, each potentially having different biases for left, right, upper and lower visual fields. Thus, the involvement of different brain regions may be responsible for the differences in IOR anisotropy when comparing the two-target results of Harris et al. (2009; where IOR anisotropy was observed) to those four-target results reported in the target-target overt orienting condition of the current study (where IOR anisotropy was absent). A study which included functional imaging (fMRI) using an IOR task which varied the number of potential target locations in both covert and overt orienting tasks would allow us to further explore these ideas. To overcome the limitations associated with the poor temporal resolution of fMRI, it would be advisable to couple these imaging methods with an electrophysiological method to elucidate the timecourse of activation.

Although the current study did not demonstrate differences between overt and covert IOR, we feel that additional research is needed to determine the possible neural underpinnings for the potentially different flavours of IOR in overt and covert orienting tasks, as the results of at least one behavioural study (Sumner et al., 2004) are suggestive of such differences. To remind the reader, Sumner et al. (2004) demonstrated that isoluminant blue stimuli invisible to the superior colliculus generated IOR in manual but not saccadic response tasks, suggesting that the superior colliculus may be necessary for the generation of overt, but not covert IOR.

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APPENDIX 1: LITERATURE REVIEW

Introduction

The visual system provides us with more incoming sensory information than can be processed simultaneously (Soto & Blanco, 2004). As a result, it is necessary to divert limited cognitive resources to facilitate the processing of only the most important aspects of the visual scene. The processes required to accomplish this goal are referred to as selective visual attention (Tassinari & Berlucchi, 1995). Past research has shown us that it is possible to direct attention to specific features, objects or locations in the visual scene (Soto & Blanco, 2004). For the duration of the current discussion, we will concern ourselves primarily with location-based attention (herein referred to as visual-spatial attention).

Ultimately, attention facilitates the processing of attended stimuli and as a consequence, unattended stimuli enjoy relatively poorer processing (Tassinari & Berlucchi, 1995). Thus, for everyday function, it is essential to direct spatial attention to those locations which are most likely to contain interesting or important stimuli. Such shifts in attention can be accomplished either overtly, with an eye movement to the location of interest, or covertly (Posner, Snyder & Davidson, 1980), when an individual attends to a stimulus in the peripheral visual field while the eyes remain fixed at centre (in common language, this is often described as "looking at something out of the corner of your eye").

Experimental paradigms examining attention have often used target-detection tasks (Posner, 1980). Usually, covert attention is drawn to a location in the visual scene using an abrupt-onset peripheral cue (participants are instructed to keep their eyes fixed at centre for the duration of the trial). Under everyday circumstances, such an abrupt peripheral onset would likely represent an important event to which attention should be directed, for example, an approaching object or organism to be avoided, so it is no surprise that attention should be captured by such a cue. Sometime after the presentation of this peripheral cue, a target is presented in either the cued location, or in a novel location. When the time elapsing between cue and target presentation is short (less than 200ms), participants are faster to detect stimuli appearing in the cued location than targets appearing in the uncued location. It is thought that the effect of the initial cue is to draw attention to the cued location. Since there is little time between cue and target presentation, the "spotlight" of attention remains at the cued location and speeds the detection of a target presented here (Wright & Ward, 2008).

Conversely, when the time elapsing between cue and target presentation is relatively long (greater than about 300ms), participants are now slower to detect targets appearing in the cued location than targets appearing in the uncued location. This latter situation reveals an interesting aspect of the allocation of spatial attention referred to as "Inhibition of Return" (IOR; Posner & Cohen, 1984). It is thought that once attention has been given time to leave the cued location (when more than 300ms elapse between cue and target presentation), an inhibitory tag is left at this recently-attended location. The effect of the tag is to discourage attention from being reoriented to this same location (Wright & Ward, 2008). Researchers have suggested that such a mechanism may increase the efficiency of visual search by helping us to avoid previously inspected and uninteresting locations (Klein, 2000). Reports in the literature have also identified object-based forms of IOR (Gibson & Egeth, 1994).

IOR has also been observed in overt orienting tasks, which by definition involve eye movements, rather than the non-discriminatory manual detection responses to targets required in covert orienting tasks. However, it remains unclear whether IOR is the same, in terms of functional characteristics and cortical control mechanisms, for overt and covert orienting tasks. There is some research to suggest that separate regions of cortex mediate shifts of overt and covert attention (de Haan, Morgan & Rorden, 2008), but this view is does not go unopposed (Fairhall, Indovina, Driver & Macaluso, 2009). For example, the premotor theory of attention suggests that the cortical control mechanisms for overt and covert orienting are the same (Rizzolatti, Riggio, Dascola & Umiltá, 1987).

Past behavioural IOR research offers some evidence to suggest that IOR for covert and overt orienting is functionally distinct. For example, some research has shown that IOR is directionally asymmetric (Harris, Westwood & Cowper-Smith, 2009; Spalek & Hammad, 2004). That is, the direction of the shift of attention required has an effect on the magnitude of the inhibitory effect observed. Past behavioural IOR research suggests that the directional bias observed for IOR in covert orienting tasks is different from that observed for covert orienting tasks; specifically, in overt orienting tasks, IOR has a larger magnitude for rightward saccades than for leftward saccades and for downward saccades than for upward saccades (Harris et al., 2009), whereas the converse appears to be true in the more traditionally studied covert orienting task (Spalek & Hammad, 2004. Note, however that this study analyzed data by cued location, rather than target location). However, differences in methodology between these past studies prevent researchers from directly attributing the difference in directional IOR bias between overt and covert orienting to the mode of attentional orienting (overt vs. covert) required in these studies.

That is, the differences in directional bias noted between studies may be caused by differences in methodology rather than differences in the mode of orienting required. Thus, additional research is required to determine the exact nature of the relationship between IOR for overt and covert orienting. Specifically, behavioural research, aimed at investigating the differences in directional IOR bias for overt and covert orienting tasks while eliminating past methodological differences between studies, must be conducted. The goal of this literature review is to describe in greater detail the methodology of such studies, and in particular, the differences in methodology between past overt and covert IOR studies involving directional IOR bias.

Exogenous Vs. Endogenous Orienting

Researchers often make a distinction between exogenous orienting, a bottom-up process made in response to a stimulus in the environment, and endogenous orienting which is a result of goal-driven behaviour on the part of the participant (Chica & Lupiáñez, 2009)). For example, imagine an individual watching for traffic as he/she waits to cross the street. The volitional left-to-right scanning of the visual scene would represent an example of endogenous orienting. Conversely, an exogenous orienting response (turning the head and/or eyes to a particular location) would be made when a person’s attention is reflexively attracted by a fast-approaching car which occupies the peripheral portion of the visual field. It is worth mentioning here that IOR is observed in response to both endogenous and exogenous cues (Taylor & Klein, 2000).

Inhibition of return for covert shifts of visual-spatial attention

We will now consider Inhibition of return (IOR) - a phenomenon observed in select cases of both overt and covert orienting tasks. IOR was first demonstrated using a task that required covert attention shifts and manual responses (Posner & Cohen, 1984). Here, it was shown that reaction times for non-discriminatory manual responses (where the same keyboard response was required regardless of which location the target occupied) were consistently longer when targets occupied the same region of space as a previously presented, non-predictive peripheral cue when the temporal delay between cue and target presentation was greater than about 200 ms (Posner & Cohen, 1984). Participants were presented with an initial peripheral cue and required to continue looking at a central target (so that covert, but not overt attention was drawn to the location of this peripheral cue). Following this cue, there was opportunity for covert attention to return to the centre, as the peripheral target disappeared. After some delay, a target was presented in the periphery, either in the same place as the preceding cue, or 180 degrees opposite this initial cue. When participants were asked to respond to the onset of this peripheral target using a manual keypress response (and while maintaining gaze at the central target position), it was observed that reaction times were significantly longer in conditions where the target occupied the same region of space as the preceding cue. Note that in the experiment just described, the eyes never strayed from the central target, and thus the orienting of attention required was covert in nature. These results were explained in the following way: the initial cue had the effect of summoning covert attention to the cued region of space. After the disappearance of the cue and after sufficient time had elapsed (roughly 300ms) attention presumably disengaged from this cued location and returned to the central region where the eyes had remained fixed. Detection of the subsequently presented target is in some way related to attention. Since reaction times to targets were longer for targets presented in recently cued space, it seems that covert attention is slower to return to a region of space to which it has recently been directed. This reluctance for attention to return to a recently cued location was later termed inhibition of return. Overall, this study demonstrated that inhibitory tagging, presumably generated by the initial shift and subsequent removal of covert attention, has the potential to affect subsequent shifts in covert attention.

Inhibition of return for overt shifts of visual-spatial attention

As was previously mentioned, IOR generated by overt shifts in attention has also been demonstrated to affect subsequent overt shifts in attention. It has been shown that saccadic reaction times to targets presented in a region of space which has recently been targeted by a saccade is longer than to targets presented in regions not recently targeted by a saccade.

In one such study (Taylor & Klein, 2000), participants were presented with an exogenous peripheral cue in one of two possible locations (right or left) and were required to generate a saccade to the location of this first target. Next, overt attention was returned to centre by the brightening of a central placeholder. Finally, overt attention was summoned again to one of the two peripheral target locations by an exogenous cue. It was determined that reaction times were significantly longer when the second target occupied the same location as the first target. These results are analogous to those reported in the cue-target covert attentional shift paradigm described above. The effect of a shift in overt attention to some region of space is to slow the generation of subsequent shifts in overt attention to this same region. Similar results were observed in this study for saccades initiated in response to endogenous cues (central arrows).

Premotor Theory of Attention

Next, it will be of use to outline the theoretical relationship between overt and covert orienting. The premotor theory of attention makes an attempt to link overt and covert attention and will be discussed herein. In 1987, Rizzolatti et al. performed a study in which participants completed a manual response cue-target covert orienting task. Based on the results of this and other studies, Rizzolatti et al. proposed the premotor theory of attention as the most parsimonious account of results reported in the literature. This theory suggests that covert attention occupies the region of visual space which is currently foveated and that usually, overt and covert attention move together. In circumstances where participants are instructed to maintain gaze at a central location as peripheral targets are presented, the eye movement that would normally be generated in response to this peripheral onset is suppressed, and in this case, there is a shift in covert attention only, while overt attention remains fixed at a central region. Importantly, the premotor theory of attention suggests that covert shifts of attention differ from overt shifts in attention only in that the final step (the eye movement) is inhibited, while all underlying neural computations (and the brain regions required to complete them)required remain identical.

Some human neuroimaging studies seem to support the premotor theory of attention, as they show that similar regions of cortex are activated in both overt and covert orienting tasks (de Haan et al., 2008). In this study, participants were required to perform either overt or covert shifts of visual attention to peripheral locations all in response to endogenous (central) cues. The areas of activation during central attention were subtracted from the brain regions activated during peripheral attention under both overt and covert attention conditions. In this way, authors attempted to produce a pure measure of the brain regions activated during covert and overt attention to peripheral locations in response to endogenous cues. Results indicated that very similar regions of cortex were activated in both overt and covert orienting tasks. Authors concluded that these results were most compatible with a premotor theory of attention (Rizzolatti et al., 1987). However, there seem to be several potential issues with this piece of research. Firstly, the pattern of brain activation was not examined. That is, no attempt was made to examine the order of activation of these cortical regions found to be the same between overt and covert orienting tasks. Secondly, no attempt was made to examine subcortical structures known to be involved in some forms of orienting. Also, from the diagrams provided in the text, it seems clear that there were in fact some small regions of cortex which were uniquely activated in overt and covert orienting tasks. More recent research has addressed these issues and is summarized below (Fairhall et al., 2009).

In contrast to the view that overt and covert orienting involve identical regions of cortex, it has also been suggested that overt and covert orienting are mediated by entirely separate regions of cortex (Posner & Petersen, 1990). Neuroimaging evidence also exists to support the views of Posner and Petersen (1990), as it suggests that some entirely separate cortical and subcortical regions are activated in covert and overt shifts of attention (Fairhall et al., 2009). In this study, participants were required to complete both overt and covert visual search tasks while brain activity was monitored using fMRI. Results indicated that although similar cortical regions were activated during both types of search, the order of activation in the dorsal fronto-parietal network differed as a function of search type (overt vs. covert). Also, it was observed that some subcortical structures (particularly the pulvinar and caudate nuclei) were activated preferentially during the covert search.

In contrast to the extreme views held by Rizzolatti et al. (1987) and Posner and Petersen (1990), some theorists suggest that the brain regions responsible for overt and covert orienting are somewhat distinct (Corbetta, 1998). Overall the results of neuroimaging research seem to support this view that overt and covert orienting activate some distinct and some overlapping regions of cortical and subcortical structures. If one accepts this intermediate view, it may not be surprising to observe that the same should be true of inhibition of return for overt and covert orienting tasks (that is, that overt and covert IOR are mediated by some separate and some overlapping regions of cortex). Consequently, some functional independence between IOR for overt and covert orienting (for example, differences in directional bias between overt and covert IOR) may be observed and could ultimately reflect these differences in cortical and subcortical activation for overt and covert IOR.

Attentional momentum as the cause of IOR

Proponents of an attentional momentum view suggest that IOR is caused by the tendency for attention to continue along a straight line once shifted in a particular direction (Pratt, Spalek & Bradshaw, 1999). For example, in the previously described cue-target paradigms, IOR would be explained in the following way: An initial rightward cue has the effect of drawing covert attention to the right. Once sufficient time has elapsed (i.e. greater than 300ms), attention moves in a straight line from the right back to centre (thus, attention is moving from right to left). Since attention would prefer to continue moving to the left, a subsequent rightward shift in attention, such as that required to detect a target presented on the right, is more difficult than a shift in attention further to the left, such as that required to detect a target presented 180 degrees opposite the initial cue. Thus, reaction times are longer to targets on the right than to targets on the left after and initial rightward cue. Although there is considerable evidence against this attentional momentum view (Snyder, Schmidt & Kingstone, 2009), the issue remains unresolved.

The initial evidence for this point of view came from a study which required participants to complete a standard cue-target non-discriminatory manual response paradigm. In all trials, a cue and a target were each presented at one of four possible peripheral locations, all equidistant from the central fixation point, with two aligned along a vertical meridian and two aligned along the horizontal meridian. An initial cue was presented at one of the four peripheral locations. After presentation of an initial peripheral cue, a boldening of the central fixation point returned covert attention to this location. Finally, a target was presented in one of the four possible peripheral locations and participants were required to press the spacebar as soon as they were aware of the appearance of the target. Results indicated that reaction times were fastest when the target appeared 180 degrees opposite the initial cue and slowest when the target occupied the same location as the cue. This is the standard IOR effect. Reaction times to targets presented at 90 degree offsets from the cued location showed reaction times intermediate of the 0 and 180-degree offsets. These results are consistent with the attentional momentum, the spreading inhibition hypothesis (where there is a gradient of inhibition that spreads from the inhibited location and drops off as a function of distance from this inhibited location) and an inhibited hemifield hypothesis, which suggests that inhibition spreads from the inhibited location, but only within the hemifield in which the cue was initially presented.

The results of a second and third experiment helped to determine which of the attentional momentum, spreading inhibition or inhibited hemifield hypotheses offered the most accurate account of the results. In the second experiment, there were four possible peripheral cue and target locations, but this time, two locations were aligned along one diagonal, 7.4 degrees of visual angle from the central fixation point, whereas the other two targets were aligned along the opposite diagonal, 4.3 degrees of visual angle from the central fixation point. This way, when a cue appeared in one of the near locations, the distance between the cued and opposite location was the same as the distance between the cued and both of the orthogonal locations.

The results of this second study showed that reaction times were longest when the target was presented in the same location as the previous cue. This result represents the standard IOR effect and is predicted by all three of the aforementioned models. Further analysis showed that reaction times were shorter for the short opposite conditions than for the orthogonal conditions. This result offers evidence against the spreading inhibition hypothesis, since in this experiment, the short opposite target and both of the orthogonal targets were equidistant from the initially cued location, and thus, would have shown identical amounts of inhibition if this theory were correct. Overall, these results were thought to be consistent with both the attentional momentum and inhibited hemifield hypothesis, so a third experiment was required to distinguish between these two remaining possibilities.

The third experiment introduced 8 possible cue-target locations, all equidistant from the central fixation point and from one another. The 8 placeholders formed a circle, with two placeholders in each of the four visual quadrants. Again, participants were presented with a cue and a target, separated by a central fixation cue, were required to keep eyes at centre for the duration of the trial and were required to press the spacebar as soon as they were aware of the appearance of the target.

Analysis of results showed that target detection reaction times were fastest to targets presented 180 degrees opposite the cue and slowest when the target was presented in the same location as the previous cue. A comparison of a given target location and the two adjacent target locations was used to determine which of attentional momentum or inhibited hemifield hypothesis offered the most accurate account of the results. Since one of the two adjacent placeholders occupied the same hemifield as the placeholder in question, the inhibited hemifiled hypothesis would predict that targets presented in the location adjacent to the initial cue and in the same hemifield should show longer reaction times than targets presented adjacent to the location of the initially presented cue but in the neighbouring hemifield. Results indicated that target reaction times did not differ between adjacent locations, and thus supported only the attentional momentum hypothesis (Pratt et al., 1999). A fourth experiment helped to provide additional evidence for the attentional momentum view. Also, some recent research has provided evidence in favour of the attentional momentum view (Spalek & Hammad, 2004). However, there is some disagreement as to whether attentional momentum is supported by research results.

Directional Biases

Although IOR is observed in both covert and overt orienting tasks, some evidence exists to suggest that these forms of IOR are functionally distinct. Of particular relevance to the current discussion is the difference between directional IOR biases for overt and covert orienting.

Past IOR research has largely ignored the potential for directional IOR asymmetries. In most cases, statistical analysis has been collapsed across the direction in which overt or covert attention has been drawn when IOR is revealed to increase the power of statistical tests. That is, whether the second shift in (overt or covert) attention was directed to the left or the right has been ignored, and trials are simply referred to on the basis of whether this shift in attention was directed towards the previously attended to location, or whether attention was directed to a novel location the second time. Also, the majority of IOR studies have focused only on saccades directed horizontally (with targets and cues to the right and left of the vertical meridian). Studies have much less frequently examined saccade directed vertically (with targets presented above and below the horizontal meridian).

Among those studies which have included the direction of attentional shift as a factor, two stand out as being particularly important to the current discussion, as they are suggestive not only of directional asymmetries for inhibition of return, but for task-dependent (overt vs. covert orienting) differences in directional bias. Importantly, these studies included targets above and below the horizontal meridian in addition to those targets located to the right and left of the vertical meridian. Together, these studies illustrate the potential for differences in IOR bias between overt and covert orienting tasks.

The first to be considered was conducted by Spalek and Hammad (2004). In this study, participants were presented with a peripheral cue at one of four locations (the four possible locations formed a “+”, with one placeholder located up, one left, one right and one down from a centre location). Participants were required to keep their gaze fixed on a central target during the presentation of this initial cue, so that covert, but not overt attention was drawn to the cued location. Next, the centre fixation point was highlighted so that participants were encouraged to return covert attention to this centre fixation point. Finally, participants were presented with a target in one of the four aforementioned locations and were required to make a non-discriminatory manual response as soon as they were aware of the appearance of this target. As with the first cue, participants were required maintain gaze at the central fixation point as the peripheral target was presented. Results indicated that non-discriminatory manual reaction times to targets were significantly longer when the target occupied the same location as the preceding cue. This is the standard IOR effect. The interesting observation was that IOR was more pronounced when the cue and target occupied the left placeholder than when the cue and target occupied the right placeholder and more pronounced when the cue and target occupied the upper placeholder than lower placeholder. This directional asymmetry for IOR generated by an initial shift in covert attention and revealed as a reluctance to generate subsequent shifts in covert attention is the key finding in this study and one that will be referred to again shortly. It is important to mention that this study included cue-target offsets of -90 and 90 degrees. This represents a methodological discrepancy between this study and the one about to be described and may be responsible for the differences in directional IOR bias between the two studies.

The second study of interest was conducted by Harris et al. (2009). Here, participants were presented with three horizontally or vertically-arranged placeholders (within a given trial, these placeholders were arranged either vertically or horizontally). Participants were then presented with an initial peripheral target as a boldening of one of these placeholders and were required to generate an eye movement to this placeholder. This eye movement would presumably have resulted in both a covert and overt shift in attention. Then, participants were cued to make an eye movement back to centre by the boldening of the central placeholder. Finally, participants were presented with a second peripheral target towards which they were required to generate a second eye movement (once again resulting in a shift of both overt and overt attention to this peripheral location). Results indicated that saccadic reaction times were slower to second targets occupying the same region of space as the first target. That is, IOR was present as a reluctance to generate a saccade to a region of space to which a saccade had recently been generated. Interestingly, a directional IOR bias was noted in this study as well. IOR was found to be greater when the second saccade was directed to the right than when it was directed to the left and greater when the second saccade was directed downward than when it was directed upward. Importantly, this directional bias is opposite to the one described by Spalek and Hammad (2004).

A comparison of the results of these two studies seems to lend support to an idea advanced by Taylor and Klein (2000), who concluded, based on the results of a number of related experiments, that IOR seemed to come in two distinct varieties; one that operated as a peripheral processing deficit when the eyes remained fixed (covert orienting) and a motor inhibition that was observed in cases where the eyes moved (overt orienting). The question raised here ("does overt IOR differ from covert IOR?") is reminiscent of the debate on the premotor theory of attention. Clearly, the idea that IOR differs between covert and overt orienting is consistent with the results of the two studies just described (Harris et al., 2009; Spalek & Hammad, 2004). The directional bias observed in a covert orienting task was opposite to that observed in an overt and covert orienting task.

However, direct comparison of the results of these two studies (Harris et al., 2009; Spalek & Hammad, 2004) is complicated by several factors. These factors prevent us from concluding directly that the opposite IOR biases noted for the two studies were a direct result of the different types of orienting used in the two studies. Firstly, the study conducted by Spalek and Hammad (2004) had participants make only one response (a standard cue-target paradigm), whereas Harris et al. (2009) had participants make two responses (A standard target-target paradigm). The results of Taylor and Klein (2000) seemed to suggest that there were differences between cue-target and target-target versions of IOR tasks, so this difference between the two studies could be responsible for the differences in directional IOR bias noted.

Secondly, the participants in the Harriset al. (2009) study were presented with two possible target locations at a time, whereas those who participated in the Spalek & Hammad (2004) study were presented with four possible target locations at a time. Thus, differences in participant strategy between the two studies may be responsible for the differences in IOR bias noted.

Thirdly, the participants in the Harris et al. (2009) study were presented with both central and peripheral targets, whereas those who participated in the Spalek and Hammad (2004) study were presented only with central targets. Again, this methodological difference may have allowed for differences in participant strategy, which may ultimately be responsible for the differences in directional IOR bias noted.

Finally, the cue and target in the Spalek and Hammad study were offset by 0, -90, 90 or 180 degrees, whereas the two targets in the Harris et al. (2009) study were only ever offset by 0 or 180 degrees. It is possible that this difference in possible target location could have led to the differences in directional bias noted between the two studies, again as a result of differences in participant strategy.

If a study were conducted in which these differences in methodology were eliminated, we could make a direct comparison of differences in directional IOR biases in covert orienting paradigms and those in overt orienting paradigms. Thus, the goal of the currently proposed research is to replicate the results of the two aforementioned studies while eliminating methodological differences. To do this, participants will be presented with four possible target locations, where all cues and targets are exogenous and where cues and targets can be offset by 0, 90, -90 or 180 degrees. We will then compare directional IOR biases between shifts in overt (eye movements) and covert (manual detection responses with eyes fixed at centre) attention. We will use both cue-target and target-target paradigms (between subjects) to determine whether any differences in directional IOR bias noted between overt and covert orienting differ between cue-target and target-target tasks. The results of this study will help us to determine whether, as Taylor and Klein (2000) had reasoned, separate forms of IOR exist for cases where the eyes move (overt orienting) vs. cases where the eyes do not move (covert orienting) and to determine how these separate forms of IOR may differ depending on specific task demands.

Also, due to the design of the study, we will be able to offer evidence in support of or against the attentional momentum view. If the account offered by Pratt et al. (1999) is accurate, we should expect to see that IOR is present as longer reaction times to targets presented in recently attended locations. Also, reaction times to targets presented at 90-degree offsets to initially attended locations should yield reaction times intermediate of those for cued and 180 degree opposite locations. This would be consistent with the idea that attention tends to continue along a straight line; it should be easier to perturb attention from this path (for example, when targets are presented at 90-degree offsets from the initially-attended location) than to completely reverse the direction of attention (as is required when the target occupies the initially-attended location).

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APPENDIX 2: INFORMED CONSENT FOR PSYCHOLOGY SUBJECT POOL PARTICIPANTS

September 2004, Rev. 1

DALHOUSIE UNIVERSITY
Inspiring Minds

Department of Psychology
INFORMED CONSENT FORM

Study Title *Differences in directional IOR bias for overt vs. covert orienting*

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Co-Investigators

Contact Person **(if different from PI)**

Feel free to address any questions you may have about the study to the Principal Investigator/Contact Person either now, or after you have participated.

Psychology Department Code Number **R04/05.**

1) To All Subjects

You are invited to take part in the research project that is described below. The Human Research Participants & Ethics Committee of the Department of Psychology has reviewed this project and found it to conform to current ethical guidelines. These guidelines require:

(1) That you be informed of the purpose of the research project and any attendant inconvenience, risk, or benefits.
(2) That the character of the task required be explained to you.
(3) That you be made aware that participation is voluntary and that you may decline to continue at any point during the course of the research project, without loss of expected compensation.
(4) That you be assured that all information assembled is entirely confidential.

2) Purpose of the Study

The purpose of this study is to explore how spatial attention is directed in healthy human participants. A more detailed explanation of the study purpose will be given upon completion of experimental trials.

3) Study Design

You will wear a light weight eye-tracking device (Eyelink II) on your head to monitor your eye-movements. You will be asked to move your eyes in response to visual cues on a computer screen. We will measure the accuracy and response time of your movements. This is a mixed design, which means that each participant will take part in a portion (half) of the tasks in which we are interested in.

4) Who can participate in the Study

You are eligible to participate in this study if you between the ages of 18 and 35, have no history of neurological illness and have normal or corrected-to-normal vision with contact lenses only (i.e. no glasses). You will be asked to complete a participant screening form before agreeing to participate in this study, to make sure that these requirements are satisfied

5) Who will be conducting the Research

Dr. David Westwood, a faculty member of the School of Health and Human Performance at Dalhousie University, will be supervising the study. The study will be carried out by Jonathan Harris, an M.Sc. Kinesiology student under Dr. Westwood's supervision.

6) What you will be asked to do

You will be asked to wear a head-mounted eye-tracking device that weighs about 500g. This device shines infra red light on your eyes and small cameras record the position of your pupil and cornea; from this information, the system can calculate where your eyes are looking. First we will calibrate the eye tracker, which will take about 5 minutes. Next, you will be asked to fixate your gaze on a target at the center of a computer screen. You will then be asked to complete a practice trial for about 5 minutes, followed by the experimental trials for about 110 minutes. Each trial requires either one or two successive hand or eye-movement responses to be made quickly. In each trial, you will be presented with two stimuli (S1 and S2). The responses generated to each of these stimuli will depend on the current experimental block and on which of the two groups (cue-target or target-target) to which you were assigned. You will be assigned to either the cue-target or the target-target group. Participants in each group will complete a manual and a saccadic response block. Each of these blocks will consist of 176 experimental trials, separated into sub-blocks consisting of 88 trials. Each of the sub-blocks will be separated by a 10-minute break.

Cue-Target Group

During the first stimulus presentation, a boldening of one of the four peripheral targets will occur. You will be required to make no response to this first stimulus, and instead, your eyes will remain fixed at centre. Next, a boldening of the central fixation square will occur and you will be expected to continue looking at the central location. Finally, a second stimulus will occur as a boldening of one of the peripheral targets. Your task will be to move your eyes to the location of the boldened peripheral target (saccadic response block), or to signal the appearance of this second stimulus by pressing spacebar while your eyes remain at centre (manual response block). We will measure the accuracy and response time of your movements. You will be allowed to take breaks during the experiment. Following the experiment, we will debrief you to inform you further about the nature and purpose of the experiment.

Target-Target Group

During the first stimulus presentation, a boldening of one of the four peripheral targets will occur. You will be expected either to make an eye movement to the location of this target (saccadic response block), or to signal the appearance of this second stimulus by pressing spacebar while your eyes remain at centre (manual response block). Next, a boldening of the central fixation square will occur and you will be expected to maintain gaze at this central fixation region (manual response block), or to return gaze to this location from the periphery (saccadic response block). Finally, a second stimulus will occur as a boldening of one of the peripheral targets. Your task will be to move your eyes to the location of the boldened peripheral target (saccadic response block), or to signal the appearance of this second stimulus by pressing spacebar while your eyes remain at centre (manual response block). We will measure the accuracy and response time of your movements. You will be allowed to take breaks during the experiment. Following the experiment, we will debrief you to inform you further about the nature and purpose of the experiment .

7) Possible Risks and Discomforts

You may experience slight discomfort from wearing the eye-tracking device. You will be allowed to take breaks, and you can choose to stop participating in the study at any time.

8) Possible Benefits

There are no benefits to you for your participation

9) Compensation / Expense Reimbursement

If you are an undergraduate psychology student, you may obtain credit points for participating in this study.

10) Confidentiality & Anonymity

You will be assigned a participant number after completing this form, so your name will not be included beside any information from this experiment. Your identity will not be revealed when the data from the study are reported in papers and presentations. All data from the study will be kept in a locked cabinet in Dr. David Westwood's faculty office in Dalplex 215F for 5 years after the publication of the results from the study, at which point all physical and electronic data from this study will be destroyed. No one will have direct access to your data except Dr. David Westwood and Jonathan Harris. You will be permitted to withdraw your data at any point, during or after completion of the study.

11) Questions

Feel free to address any questions you may have about the study to the Principal Investigator or Contact Person either now, or after you have participated.

12) Summary

For a maximum of two hours, you will perform a task in which you will be asked to respond to visual cues on a computer screen by moving your eyes. We will measure the accuracy and response time of your eye-movements. There is no serious risk of injury or discomfort (refer to above for potential risks).

13) Problems or Concerns

In the event that you have difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact a member of the Human Research Participants & Ethics Committee of the Department of Psychology, Tel: 494.1580, email beatrice@dal.ca, and/or Patricia Lindley, Director, Dalhousie University's Office of Human Research Ethics Administration, Tel: 494.1462, email patricia.lindley@dal.ca.

SIGNATURE PAGE *(this page must be printed on a separate sheet)*

- **Subjects Must Read And Sign This Form To Confirm That They Understand And Accept Conditions Before Experiment Can Begin**
- **Subjects Must Be Given A Copy Of This Form For Their Information And Records**

Feel free to address any questions you may have about the study to the Principal Investigator either now, or after you have participated.

Study Title Differences in directional IOR bias for overt vs. covert orienting
Name of Principal Investigator Jonathan Harris
Research Supervisor Dr. David Westwood
Contact Person **(if different from PI)**
University Address
School of Health and Human Performance
6230 South Street
Halifax NS, B3H 3J5
University Telephone 494-2066
Email jn653119@dal.ca

14) Psychology Department Subject Pool Policy

Individuals with specific ethical concerns should contact either the Research Supervisor or a member of the Human Research Participants & Ethics Committee of the Department of Psychology, Tel: 494.1580, email beatrice@dal.ca.

Please sign below to confirm that you have had your questions answered to your satisfaction, that you are aware that all records are entirely confidential and that you may discontinue participation at any point in the study.

If you anticipate receiving educational credit points for assisting in this research, you may choose to do so as either a research participant or as an observer.

If you choose to be a research **Participant**, the researcher will **keep your data** and use it in the research project.

If you choose to be an **Observer**, the researcher will **destroy any data** that you may have provided, after you complete the study.

Please check one box below to indicate whether you choose to be a research participant or an observer.

☐ **Research Participant (Use my data)**

☐ **Observer (Destroy my data)**

Participant's Signature: Date:

Principal Investigator's Signature: Date:

Department of Psychology
DEBRIEFING FORM

Project title: Differences in directional IOR bias for overt vs. covert orienting

Principal investigator:

Jonathan Harris
School of Health and Human Performance
Telephone: 902-494-2066
ccowpers@dal.ca

David A. Westwood, Ph.D. (School of Health and Human Performance & Dept. of Psychology)
Telephone: 902-494-1164
Email: David.Westwood@dal.ca

Thank you for your participation in this research study. This study was primarily concerned with something called inhibition of return (IOR), which is known to affect shifts of attention. When you shift attention either overtly (using eye movements) or covertly (by paying attention to a region of space without moving the eyes there, commonly referred to as “looking at something out of the corner of your eye”) to some location and then remove it from this location, IOR makes it easier to shift attention to a new location than back to the same location. That is, shifts of attention to a previously attended location are inhibited as compared to shifts of attention to new regions of space. We were interested in how IOR may differ between overt shifts of attention and covert shifts of attention

Some researcher suggests that overt and covert orienting are controlled by the same regions of the brain[3]. If this were true, we would expect something like IOR, which is related to the orienting of attention, to be very similar for overt and covert orienting. However, past research seems to indicate that the directional bias for IOR may differ between overt and covert orienting tasks[1 2]. The current study was designed to extend the results of these studies by eliminating methodological differences between them.

In each trial, we showed you two stimuli, each of which occupied one of four possible locations. The first and second stimuli occupied either the same location or different locations. We expect that both manual and saccadic reaction times to the second stimulus should be slower when this stimulus occupies the same location as the first than when this target occupies the same location as the first. This would be the standard IOR effect. We also expect that the location of the target (left, right, up or down from centre) should affect the amount of IOR we observe, and that this directional IOR bias should be different between manual and saccadic response blocks (which require covert and overt orienting of attention, respectively). Specifically, we expect that IOR should be greater for targets on the right than on the left and greater for down targets than for up targets in the saccadic response block. Conversely, in the manual response block, we expect that IOR should be greater for targets on the left than on the right and greater for up targets than for down targets. These results would extend the findings of past research that seem to suggest that directional IOR bias differs between overt and covert orienting tasks [1,2]. If IOR bias does differ between overt and covert orienting tasks, we could offer some evidence against the premotor theory of attention[3], which suggests that overt and covert orienting are controlled by the same regions of the brain.

If you have any questions or comments about this experiment, please feel free to communicate them to us.

Thanks again for your participation!

Jonathan Harris
Dalhousie University

Discussion Questions

1. Do you think reaction times should be relatively slower to targets presented in the same place as a preceding stimulus? If so, why?

2. Do you think that directional bias for inhibition of return should be the same or different when overt and covert orienting are compared?

APPENDIX 3: WORD OF MOUTH RECRUITMENT SCRIPT

Hello, my name is Jonathan Harris. I am a Master of Science student in the School of Health and Human Performance at Dalhousie University and am currently conducting a study entitled “Differences in Directional IOR bias for Overt vs. Covert orienting” examining visual attention in human participants as part of the requirements for completion of my degree. I am here today to ask you to participate in this study at a time of your choosing.

You may participate in this study if you have normal or corrected-to-normal vision and no history of neurological deficits. For a total duration of no longer than two hours, you will be required to make eye movements to a series of targets presented on a computer monitor as these eye movements are recorded using a lightweight head-mounted eye tracking system. This eye tracking equipment will not capture an image of you, but will instead record gaze position for the duration of each experimental trial. The experiment and the equipment used therein pose no more than minimal risk. During the course of the experiment, you may experience eye muscle fatigue. To help overcome this, frequent break periods will be provided. You will be permitted to withdraw from the study at any time prior to or during the completion of experimental trials. All research will be conducted by the principal investigator (Jonathan Harris) in Dalplex room 217 and 218b at Dalhousie University. Although you will not receive any compensation for participation in the study, the information gained as a result will contribute to our understanding of visual attention and may benefit others in the future.

Upon completion of the study, you will be provided with the exact nature of the research question being investigated. At this time, you will be encouraged to ask any questions you may have.

If you are interested in participating in this study, please contact me via email at Jn653119@dal.ca , or via telephone at 494-2066. Thank you for your time.

APPENDIX 4: CONSENT FORM FOR WORD OF MOUTH PARTICIPANTS

School of Health and Human Performance
CONSENT FORM

Title of Study: Differences in directional bias for inhibition of Return in overt and covert orienting

Principal Investigator & Contact Person:	**Supervisor:**
Jonathan Harris MSc Student School of Health and Human Performance Dalhousie University Phone: (902) 494-2066 Email: jn653119@dal.ca	David Westwood, Ph.D. Associate Professor School of Health and Human Performance & Dept. of Psychology Dalhousie University Phone: (902) 494-1164 Fax: (902) 494-5120 Email: david.westwood@dal.ca

Introduction:
We invite you to take part in a research study being conducted by Jonathan Harris who is graduate student at Dalhousie University, as part of the MSc programme. Your participation in this study is voluntary and you may withdraw from the study at any time. The study is described below. This description includes information about the risks, inconveniences, or discomforts that you might experience during participation in the study. Participating in the study might not benefit you, but we may learn things that could benefit others. You should discuss any questions you have about this study with Jonathan Harris.

Participation in this study is voluntary and if you have any questions about this study, please do not hesitate to contact Jonathan Harris, the Principal Investigator.

Purpose of the Study:
The purpose of this study is to learn more about visual attention in healthy human participants. The exact nature of the study question will be explained after you have participated in the study.

Participants in this Study:
We invite any individuals between the ages of 18 and 35 to participate in this study. You are eligible to participate in this study if you have normal or corrected-to-normal visual acuity wearing contact lenses, and you do not have a known visual or neurological condition which affects your ability to make eye movements, your visual and cognitive processing skills, your head and neck control in a seated position, or your ability to make hand movements.

Investigator Conducting the Study:
The study is being conducted by Jonathan Harris who is an MSc student in the School of Health and Human Performance, with supervision from Dr. David Westwood, Associate

Professor in the School of Health and Human Performance & Dept. of Psychology, Dalhousie University.

What you will be asked to do:

You will be asked to volunteer for a one time visit of a maximum of two hours. Before you come to the lab, you will be given a questionnaire to determine whether you meet the inclusion criteria for the study. The study will take place in the Actionlab in Dalplex rooms 217 and 218b, Dalhousie University. During your visit you will be asked to sit at an ergonomically adjustable computer station and complete a consent form. After completing the survey, you will be asked to respond either by pressing a key in response to a series of targets presented on a computer screen, or by moving your eyes in response to targets presented on a computer screen. The eye tracking system will record all your eye movements while you complete the study. To make sure that your eye movements can be tracked accurately, we will ask you to remove any eye makeup (e.g., eye-liner and mascara) before wearing the eye tracking system.

Possible Benefits, Risks and Discomforts:
The risks for this study are minimal. You may not benefit personally from your participation in this study, but the information gathered in this study will help us to better understand attention. The long term outcome of this line of research will help us to understand how people attend to events and objects in their surroundings.

Compensation / Expense Reimbursement
You will receive no compensation or reimbursement for participating in this study.

Confidentiality & Anonymity
After completing the informed consent signature page, you will be assigned a participant number for this study. The participant number will be used to link your data for all phases of this study. Your identity will not be revealed when the data from this experiment is reported. All data from this study will be kept in a locked cabinet in Dr. David Westwood's faculty office in Dalplex 215F for 5 years following the publication of the results from this study. After five years, all physical and electronic data from this study will be destroyed. No one will have direct access to your data except Jonathan Harris and Dr. David Westwood. You will be allowed to withdraw your data at any point during or after your participation in the study.

Questions and Contact Information:
Please keep this letter for your personal records. If you have questions about this study either now, or after you have participated, please contact the principal investigator, Jonathan Harris, at
Phone: (902) 494-2066 Email: jn653119@dal.ca

If you know of anyone else who may be interested in participating, please feel free to discuss this project with them and ask them to contact Jonathan Harris directly for further information.

Concerns about Your Participation:
This study has been reviewed by the office of Human Research Ethics Administration at Dalhousie University. However, the final decision to participate is yours. If you have any difficulties with or wish to express your concern about any aspect of your participation in

this study, you can contact Patricia Lindley Director of Dalhousie University's Office of Human Research Ethics Administration, for assistance (902) 494-1462, patricia.lindley@dal.ca

Summary:

Individuals who volunteer for this study will be asked to participate in a two hour session. During the session the participant would be asked to:

- Wear a lightweight eye tracking system while making eye and hand movements to targets on a computer screen

There is no serious risk or discomfort involved with this study. There is no reimbursement offered for participation in this study.

Please keep this letter for your personal records. If you know of anyone else who may be interested in participating, please feel free to discuss this project with them and ask them to contact Jonathan Harris directly for further information.

INFORMED CONSENT SIGNATURE PAGE

Title of Study: Differences in directional IOR bias for overt vs. covert orienting

I have read the information consent letter and meet the requirements for participation as outlined on the screening form for this study. I agree to participate in this study being conducted by Jonathan Harris, and MSc. Kinesiology student with School of Health and Human Performance, Dalhousie University. I have had the opportunity to ask any additional questions and understand that I may withdraw my consent from the study at any time, and/or refrain from answering any questions by contacting the principal investigator at any time without penalty.

I understand that this study has received ethics review though the office of Human Research Ethics Administration at Dalhousie University. If I have any concerns or comments as a result of my participation in this study I may contact Patricia Lindley, Director of Human Research Ethics Administration, at 494-1462.

I agree to participate in this study.

☐YES ☐NO

Participant Name (please print)	Participant Signature	Date:
Researcher Name (please print)	Researcher Signature	Date:

Participant Code: ____________

Appendix 5:

F-Tables

Omnibus S1 RT Analysis

Effect	df	MSE	F	p
S1 Location	3, 51	240.68	13.52	<0.01
Response Type	1, 17	4901.92	1.95	0.18
S1 Location * Response Type	3, 51	389.33	0.75	0.53

Vertical S1 RT Analysis

Effect	df	MSE	F	p
S1 Location	1, 17	259.06	24.76	<0.01
Response Type	1, 17	2951.05	0.9	0.36
S1 Location * Response Type	1, 17	579.16	0.39	0.54

Horizontal S1 RT Analysis

Effect	df	MSE	F	p
S1 Location	1, 17	167.44	14.56	<0.01
Response Type	1, 17	2265.04	3.33	0.09
S1 Location * Response Type	1, 17	274.68	0.05	0.82

Cue-Target Covert + Order
S2RT Analysis

Effect	df	MSE	F	p
S2 Location	3, 42	636.87	1.82	0.16
S2 Location * First Block	3, 42	636.87	4.58	0.01
S1-S2 Distance	3, 42	636.86	3.7	0.02
S1-S2 Distance * First Block	3, 42	636.86	0.25	0.86
S2 Location * S1-S2 Distance	9, 126	628.21	1	0.44
S2 Location * S1-S2 Distance * First Block	9, 126	628.21	0.54	0.85

Target-Target Overt + Order
S2RT Analysis

Effect	df	MSE	F	p
S2 Location	3, 51	796.33	13.49	<0.01
S2 Location * First Block	3, 51	796.33	0.6	0.62
S1-S2 Distance	2.17, 36.88	385.08	39.48	<0.01
S1-S2 Distance * First Block	2.17, 36.88	385.08	1.35	0.27
S2 Location * S1-S2 Distance	9, 153	275.44	0.45	0.9
S2 Location * S1-S2 Distance * First Block	9, 153	275.44	1.51	0.15

Omnibus S2 RT Analysis (Offset at 0 and 180)

Effect	df	MSE	F	p
Response Type	1, 32	4462.05	70.77	<0.01
Response Type * Group	1, 32	4462.05	1.84	0.19
S2 Location	3, 96	601.82	5.13	<0.01
S2 Location * Group	3, 96	601.82	1.13	0.34
S1-S2 Distance	1, 32	594.69	57.99	<0.01
S1-S2 Distance * Group	1, 32	594.69	0.11	0.74
Response Type * S2 Location	3, 96	822.66	7.48	<0.01
Response Type * S2 Location * Group	3, 96	822.66	0.22	0.88
Response Type * S1-S2 Distance	1, 32	558.58	1.42	0.24
Response Type * S1-S2 Distance * Group	1, 32	558.58	1.89	0.18
S2 Location * S1-S2 Distance	3, 96	547.42	0.39	0.76
S2 Location * S1-S2 Distance * Group	3, 96	547.42	0.4	75
Response Type * S2 Location * S1-S2 Distance	2.22, 71.14	703.14	0.33	0.74
Response Type * S2 Location * S1-S2 Distance * Group	2.22, 71.14	703.14	0.47	0.65

Cue-Target Covert S2 RT Analysis (Offset at 0 and 180)

Effect	df	MSE	F	p
S2 Location	3, 45	811.05	1.04	0.38
S1-S2 Distance	1, 15	627.4	6.66	0.02
S2 Location * S1-S2 Distance	3, 45	608.96	0.19	0.9

Target-Target Covert S2 RT Analysis (Offset at 0 and 180)

Effect	df	MSE	F	p
S2 Location	3, 51	639.45	0.16	0.92
S1-S2 Distance	1, 17	512.73	17.15	<0.01
S2 Location * S1-S2 Distance	2.12, 35.97	954.06	0.72	0.5

Cue-Target Overt S2 RT Analysis (Offset at 0 and 180)

Effect	df	MSE	F	p
S2 Location	3, 45	750.18	4.45	0.01
S1-S2 Distance	1, 15	702.15	21.78	<0.01
S2 Location * S1-S2 Distance	1.74, 26	710.2	0.09	0.89

Target-Target Overt S2 RT Analysis (Offset at 0 and 180)

Effect	df	MSE	F	p
S2 Location	3, 54	637.25	9.66	<0.01
S1-S2 Distance	1, 18	470.11	19.29	<0.01
S2 Location * S1-S2 Distance	3, 54	416.27	0.68	0.57

Cue-Target Covert S2 RT Analysis

Effect	df	MSE	F	p
S2 Location	3, 45	789.04	1.55	0.22
S1-S2 Distance	3, 45	605.18	3.7	0.02
S2 Location * S1-S2 Distance	9, 135	608.73	1.04	0.41

Target-Target Covert S2 RT Analysis

Effect	df	MSE	F	p
S2 Location	3, 51	588.04	0.61	0.61
S1-S2 Distance	3, 51	667.07	5	<0.01
S2 Location * S1-S2 Distance	9, 153	527.51	1.03	0.42

Cue-Target Overt S2 RT Analysis

Effect	df	MSE	F	p
S2 Location	1.87, 28.11	1248.93	9.03	<0.01
S1-S2 Distance	3, 45	428.88	22.48	<0.01
S2 Location * S1-S2 Distance	3.56, 53.45	804.57	0.96	0.47

Target-Target Overt S2 RT Analysis

Effect	df	MSE	F	p
S2 Location	3, 54	778.7	13.64	<0.01
S1-S2 Distance	2.24, 40.25	380.91	38.46	<0.01
S2 Location * S1-S2 Distance	9, 162	283.32	0.45	0.9

Omnibus S2 RT Analysis

Effect	df	MSE	F	p
Response Type	1, 32	8257.3	95.9	<0.01
Response Type * Group	1, 32	8257.3	1.33	0.26
S2 Location	2.44, 78.14	907.89	13.49	<0.01
S2 Location * Group	2.44, 78.14	907.89	0.41	0.71
S1-S2 Distance	3, 96	547.82	38.85	<0.01
S1-S2 Distance * Group	3, 96	547.82	0.06	0.98
Response Type * S2 Location	3, 96	738.15	10.86	<0.01
Response Type * S2 Location * Group	3, 96	738.15	0.56	0.65
Response Type * S1-S2 Distance	3, 96	446.26	7.36	<0.01
Response Type * S1-S2 Distance * Group	3, 96	446.26	2.2	0.09
S2 Location * S1-S2 Distance	9, 288	417.43	0.81	0.61
S2 Location * S1-S2 Distance * Group	9, 288	417.43	0.6	0.8
Response Type * S2 Location * S1-S2 Distance	9, 288	455.65	1.25	0.27
Response Type * S2 Location * S1-S2 Distance * Group	9, 288	455.65	1	0.44

Cue-Target Overt Error Analysis

Effect	df	MSE	F	p
S2 Location	2, 30.07	303.02	3.84	0.03
S1-S2 Distance	3, 45	87.66	1.94	0.14
S2 Location * S1-S2 Distance	9, 135	94.39	1.86	0.06

Target-Target Overt Error Analysis

Effect	df	MSE	F	p
S2 Location	2, 36.22	298.33	3.52	0.04
S1-S2 Distance	3, 54	172.06	1.1	0.36
S2 Location * S1-S2 Distance	9, 162	132.8	0.47	0.9