Attentional and Oculomotor Components of Multiple Location Inhibition of Return

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Abstract

People engage in visual search during everyday tasks such as looking for a friend in a crowd.

Inhibition of return (IOR) facilitates visual search by inhibiting attention from returning to

previously inspected locations. IOR is believed to be mediated both by attention and eye

movements (i.e., oculomotor). The aim of the present research was to determine whether

oculomotor IOR is operating when multiple locations are searched. In this study, participants

were instructed to keep their eyes at central fixation to measure attentional IOR or move their

eyes to peripheral locations to measure oculomotor IOR. Results suggest a trend for oculomotor

IOR to develop more slowly than attentional IOR, with no differences in magnitude between the

two forms of IOR.

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Introduction

When we try to find our car in the parking lot, our misplaced keys on a counter, a friend in the crowd, or the latest version of our thesis on a cluttered desktop, we are engaging in visual search. There is little wonder that visual search is considered an essential task because we engage in it multiple times a day. Attentional processes including orienting to and detecting environmental signals and events are necessary in almost all everyday tasks such as crossing the street, driving a car, as well as in social interactions such as talking to a friend.. These attentional processes have also been found to facilitate visual search, thereby increasing the efficiency of our searches (Eriksen & Hoffman, 1973; Posner, 1980; Posner, Snyder, & Davidson, 1980). Specifically, when attention is allocated to a stimulus in the environment, response time (RT) for orienting to and detecting that stimulus is generally faster and visual search becomes more efficient. In this way, attention allows us to operate efficiently in our complex environment.

Importantly, attention can be allocated to a stimulus in different ways. First, attention can be deployed either overtly or covertly. Overt attentional orienting is accomplished by physically orienting the receptors to a stimulus via eye, head, or body movements. It is at play when we move our head, and hence our eyes and attention, in search of our car in the parking lot. In contrast, covert attentional orienting is accomplished without physically orienting the receptors to the stimulus. It is at play when a flash of lightening captures our attention "out of the corner of the eye" while driving, as we keep our eyes focused on the road ahead.

Second, attention can be deployed either endogenously or exogenously. Endogenous attentional orienting is under the control of the observer and involves voluntarily directing attention to a particular stimulus. It is at play overtly when we look both ways before crossing

the street to prevent a potential disaster. It is at play covertly when we keep our eyes focused straight ahead on the basketball court but monitor the position and movement of other players "out of the corner of the eye". Exogenous attentional orienting is not under the control of the observer and involves the involuntary capture of attention by salient features of an object or an abrupt onset in the peripheral visual field. It is at play overtly when our attention is involuntarily captured by a fast-approaching car in the periphery as we cross the street and we then align our eyes and attention with the car to determine its position and speed. It is at play covertly when our attention is involuntarily captured as we notice a parent waving to us as we proceed down the aisle at convocation, while keeping our eyes fixed straight ahead at the stage.

Studying Attentional Orienting

Attentional orienting is typically studied in a laboratory setting using either an endogenous or exogenous attentional orienting paradigm (Posner, 1980). In both versions, a central fixation stimulus is flanked by two boxes. In the endogenous version, as observers keep their eyes focused on the fixation stimulus, a second stimulus (i.e., the cue), such as an arrow that points to the left or right box replaces the fixation stimulus, and following a delay, a target (e.g., an asterisk) appears in one of the two boxes. This cue is predictive of target location as it directs the observer's attention to the likely location of the upcoming target – approximately 80% of the time it will occur at the pointed at (i.e., the cued) location and approximately 20% of the time it will occur at the other (i.e., the uncued) location. Overt attention is engaged if the experimental procedure requires an eye movement to be executed to the predicted location and then back to the central stimulus prior to target onset. However, covert attention is engaged if the experimental procedure requires that eyes remain at the central stimulus for the duration of the trial. Regardless of whether endogenous attention is deployed overtly or covertly to one of the

two peripheral locations, RT for subsequent target detection is faster at the cued than the uncued location – the facilitation effect.

In the exogenous version of the attentional orienting paradigm (Posner, Rafal, & Cohen, 1982), again, a central fixation stimulus is flanked by two boxes. But here, as participants keep their eyes focused on the central fixation stimulus, an abrupt onset in the periphery (i.e., the cue), such as the brief brightening of one of the boxes, occurs and following a brief delay, a target appears. Although the cue draws the observer's attention to the location of the cue, it does not predict the likely location of the target – as it will occur equally often at the cued and the uncued location. Overt exogenous attention is engaged if an eye movement is executed to the brightened box and then returned to central fixation. Covert exogenous attention is engaged if the eyes remain at central fixation throughout the trial. Again, regardless of whether endogenous attention is deployed overtly or covertly, a facilitation effect is observed with RT for subsequent target detection at the cued location (Posner, 1980).

Critically, although this facilitation effect is long-lasting with the endogenous deployment of attention, it is relatively short-lived with the exogenous deployment of attention – only occurring at short cue-target intervals (i.e., less than 100 ms). However, at long cue-target intervals (i.e., exceeding 300 ms), RT for subsequent target detection is slower at the cued location than at the uncued location (Posner & Cohen, 1984). This slowing in RT at the cued location was hypothesized to result from attention being inhibited from returning to the previously attended location, and was later termed *inhibition of return* (IOR; Posner, Rafal, Choate, & Vaughan, 1985). As with the facilitation effect, IOR occurs with the exogenous deployment of attention when observers orient to the cue either overtly or covertly, but it only occurs with the endogenous deployment of attention when observers orient overtly to the cue

(Posner & Cohen, 1984; Maylor, 1985). Specifically, when using a predictive endogenous central cue to orient attention, IOR will occur if an eye movement is made to the cued location and returned to central fixation, but not if the eyes remain at fixation.

IOR and Its Importance in Visual Search

Early on, IOR was hypothesized to facilitate visual search by inhibiting attention from returning to previously inspected locations (Klein, 1988; Posner & Cohen, 1984). Klein (1988) found that IOR was generated as a result of attention being allocated to distractor locations when searching for a target in conjunction search. And importantly, it was not found not in feature search, where attention was not allocated to distractor locations. Further evidence that IOR helps in everyday search comes from findings that IOR: can occur in discrimination tasks (Pratt & Abrams, 1995; Pratt, Kingstone, & Khoe, 1997) as well as simple detection tasks; is coded in environmental rather than retinotopic coordinates (Maylor & Hockey, 1985; Posner & Cohen, 1984); and occurs for both static and moving objects (Tipper, Driver, & Weaver, 1991). These findings demonstrate that IOR occurs in a variety of settings (see Klein, 2000; and Lupiáñez, Klein, & Bartolomeo, 2006 for reviews), supporting the hypothesis that IOR is important for efficient visual search.

However, if IOR is useful in visual search, one would expect to find it at more than one location in a search, as was demonstrated in Klein's (1988) study following conjunction search. Yet, initially there was substantial debate regarding the number of locations that could be concurrently inhibited by IOR. For instance, when Pratt and Abrams (1995) cued two locations in succession, IOR was observed only at the most recently cued location. Tipper, Weaver, and Watson (1996) re-examined this issue by cueing three of the four locations in succession and found IOR at all three cued locations, with the largest IOR effect observed at the most recently

cued location. In a follow-up study, Abrams and Pratt (1996) cued three of six locations in succession and failed to replicate Tipper et al.'s (1996) finding of multiple location IOR. Importantly, in Abrams and Pratt's (1996) study, the cued locations were non-adjacent, and therefore the authors suggested that multiple location IOR only occurs when the cued locations can be spatially grouped.

And finally, Danziger, Kingstone, and Snyder (1998) suggested that paradigms using a fixed number of cues and re-cueing the central fixation stimulus prior to target onset might allow observers to predict when the target would occur and that the temporal predictability of target onset might be a critical factor in whether multiple-location IOR is obtained. To test this hypothesis, they designed a five-location paradigm where either zero, one, two, or three peripheral cues could occur before target onset, thereby reducing temporal predictiveness of target onset. And indeed, IOR was found at all three cued locations, with the largest IOR effect at the most recently cued location as previously established by Tipper et al. (1996). Building on Danziger et al.'s (1998) findings, Snyder and Kingstone (2000) determined that IOR can be observed at five locations concurrently. Again, their data supported previous findings that IOR has the greatest magnitude at the most recently cued location and smaller magnitudes at less recently cued locations (see also Snyder & Kingstone, 2001, 2007).

Having established that multiple locations can be concurrently inhibited, much of the recent research has focused on multiple locations IOR and its utility in visual search. For instance, using "Where's Waldo?[®]" scenes in a search task, Klein and MacInnes (1999) were the first to demonstrate that IOR operates as a foraging factor in an ecologically valid orienting paradigm. Eye movements were tracked as observers searched for Waldo. After several eye movements were made, a target probe to which the observer made an eye movement was

presented at previously inspected or uninspected locations. Slower eye movements were made to probes presented at previously inspected locations, which indicated the presence of IOR. More recently, Thomas et al. (2006) used a 3-D virtual foraging task to mimic visual search employed by real life search tasks. In this simulation, leaves on a tree served as the stimuli that participants could flip up to see if a piece of fruit was underneath by pointing a virtual wand at a leaf. If the fruit was not found after a specified number of attempts, one of the leaves flickered (i.e., the probe) and participants were required to detect this event with a key press. The probe could be at one of the previously inspected leaves/locations or one of the uninspected leaves/locations. And indeed, IOR was observed at two of the previously inspected locations concurrently in this ecologically valid virtual foraging task, providing evidence that IOR can serve as a foraging factor as proposed by Klein & MacInnes (1999).

Further research conducted by Snyder and Kingstone (2007) investigated the role of attention on the magnitude of IOR in visual search using a combined visual search and multiple-location IOR paradigm. Here, four cues preceded onset of an eight-item visual search display that contained one of two target letters. In the feature search display, the seven distractor letters were identical, whereas in the conjunction search display, the seven distractor letters were all unique. And while they found multiple-location IOR for both feature and conjunction search, IOR was greater and more robust in conjunction than in feature search, corresponding to the higher attentional demands of conjunction search. And most recently, a study by Dodd, Van der Stigchel, and Hollingworth (2009) confirmed that IOR is specific to visual search and does not extrapolate to general visual (i.e., non-search) behaviour. Specifically, the authors found that participants exhibited IOR when they were required to search for a target item in a display (i.e.,

in a visual search task), but not for tasks requiring pleasantness ratings, subsequent memory recall, or simply free viewing of a scene.

Attentional IOR

Early on, there were two opposing explanations regarding how IOR was generated. Initially, it was proposed that IOR was an attentional effect (Posner & Cohen, 1984). Shortly thereafter, this proposal was countered by the suggestion that IOR was an oculomotor effect (Rafal, Calabresi, Brennan, & Sciolto, 1989). The evidence supporting an attentional component of IOR will be examined first followed by evidence supporting an oculomotor component of IOR. When it was discovered, the inhibitory effect at long cue-target intervals (i.e., IOR) was described as a function of attention that was similar to the previously described facilitation effect observed at short cue-target intervals. Specifically, IOR was postulated to occur as a result of covert attentional orienting (Posner et al., 1985) – when attention is reflexively captured by a peripheral cue and subsequently disengaged, attention is then inhibited from returning to the previously attended location (Posner & Cohen, 1984). Importantly, although attention has been linked to eye movements, both the facilitatory and inhibitory effects can occur when the eyes remain fixated at centre, in the absence of eye movements (Posner, 1980).

Klein (1988) was the first to demonstrate that IOR is an attentional effect by having observers perform two visual search tasks where they searched for a target amongst distractor items. In a conjunction search task, two features define the target (e.g., shape and colour) and attention must be systematically allocated to items in the display to for successful target detection. In a feature search task, a single feature defines the target (e.g., shape) and attention is not required for successful target detection as the target "pops out." On half of the trials, after observers completed the search task, a probe dot requiring detection was presented in a location

previously occupied by a distractor. Klein posited that IOR would be found following

conjunction search as the result of attention being allocated to distractor locations, but not

following feature search where attention was not allocated to distractor locations. And that is

exactly what he found, concluding that IOR facilitates complex search (see also Müller & von

Mühlenen, 2000; Takeda & Yagi, 2000).

Direct evidence for the attentional component of IOR comes from a study by Reuter-

Lorenz, Jha, and Rosenquist (1996). In a series of experiments, manipulation of factors known

to influence attentional processes were applied to IOR paradigm to establish the underlying

mechanisms and attentional contribution to IOR. These factors included target modality (i.e.,

visual and auditory) and target intensity (i.e., dim and bright). Importantly, the factor of

response modality (i.e., manual and oculomotor), should not affect IOR as it is a motor, rather

than an attentional, factor. The previous findings from the attention studies held true for IOR.

That is, the magnitude of the IOR effect did not differ for manual and oculomotor responses but

it was greater for visual than auditory targets and it was greater for dim than bright targets.

Because IOR was affected by the same factors and in the same way that attentional processes

were affected, Reuter-Lorenz et al. concluded that IOR is primarily an attentional effect..

And finally, indirect evidence for an attentional account of IOR was demonstrated by

Lupiáñez, Milán, Tornay, Madrid, and Tudela (1997). They examined accuracy and RT in a

target detection task and in a target discrimination task. As expected, IOR was found

consistently in both detection and discrimination tasks. Additionally, IOR was found in

measures of response accuracy with greater accuracy at cued than uncued locations. Attention is

known to affect accuracy rates in exactly that manner. Thus, the authors argued that if IOR was

not an attentional effect, accuracy would not have been affected, but because it was, IOR must have an attentional component.

Taken together, these findings demonstrate the existence of a strong attentional basis of exogenously-produced IOR. It follows that both facilitation and inhibition can be described as functions of covert attentional orienting as put forward by Posner and Cohen (1984).

Oculomotor IOR

In an early review of the cognitive inhibition of attention, Klein and Taylor (1994) questioned the view that IOR was primarily an attentional effect. An important piece of evidence for this challenge came from a study by Posner et al. (1985) that failed to find IOR in patients with lesions of the superior colliculus (SC), a midbrain oculomotor structure responsible for the generation of reflexive eye movements. Further evidence came from Rafal et al.'s (1989) investigation of IOR where: (1) the eyes remained at fixation throughout the trial; (2) eye movements were executed to a peripheral cue and back to centre; and (3) eye movements were prepared to the cued location but not executed. When exogenous cues (i.e., abrupt onsets in the periphery) were used, IOR was found with both overt and covert attentional orienting, but when endogenous cues (i.e., directional arrows at fixation) were used, IOR was found with overt but not covert attentional orienting. This finding held true even when an eye movement was prepared but not executed. The authors concluded that the activation of the oculomotor system is not only necessary, but it is sufficient to generate IOR. Once generated by the oculomotor system, IOR may then operate by biasing covert attentional orienting away from the inspected location. They concluded that in endogenous versions of the paradigms covert attentional orienting does not activate the oculomotor system, and thus IOR cannot be found.

However, a recent study by Chica, Klein, Rafal, and Hopfinger (2009) failed to replicate Rafal et al.'s (1989) finding that eye movement preparation is necessary and sufficient to generate IOR. In this modification of Rafal et al.'s (1989) earlier experiment, participants had to make an eye movement to the "prepared" location, even when the target did not appear at that location. Failure to replicate Rafal et al.'s (1989) findings suggested that endogenous saccade preparation is not sufficient for the generation of oculomotor IOR, and supported Klein and Taylor's (1994) proposal that different mechanisms underlie different manifestations of IOR. Specifically, Chica et al. (2009) suggest that the mechanisms differ for attentional and oculomotor IOR.

More direct evidence for oculomotor IOR comes from a study of a patient who had suffered a hemorrhagic lesion to the right SC leaving the left SC intact, which allowed for a comparison of IOR generated by the right and left SC, respectively (Sapir, Soroker, Berger, & Henik, 1999). Using a modified version of the attentional orienting paradigm, stimuli were presented monocularly to the patient to measure IOR in the temporal and nasal visual hemifields of each eye, separately. In this patient, the damaged right SC received projections from the temporal hemifield of the left eye and the nasal hemifield of the right eye, whereas the intact left SC received projections from the temporal hemifield of the right eye and nasal hemifield of the left eye. The authors predicted that IOR would not be generated by the damaged right SC to stimuli presented to the temporal hemifield of the left eye and nasal hemifield of the right eye, but that it would be generated in a typical fashion by the intact left SC to stimuli presented to the temporal hemifield of the right eye and nasal hemifield of the left eye. Indeed, this is what they found, supporting the involvement of the SC in the generation of IOR and confirming an oculomotor component of IOR.

Towards a Combined View of Attentional and Oculomotor Contributions

While early research suggested that IOR was either an attentional effect (e.g., Posner & Cohen, 1984; Reuter-Lorenz et al., 1996), or an oculomotor effect (e.g., Klein & Taylor, 1994; Rafal et al., 1989), recent research converges on the joint contributions of attentional and oculomotor components to IOR (e.g., Hunt & Kingstone, 2003; Chica, Taylor, Lupiáñez, & Klein, 2010; Klein & Taylor, 1994). Specifically, it is now proposed that different mechanisms may underlie different manifestations of IOR.

When examining the attentional component of IOR and its relation to eye movements, Abrams and Dobkin (1994) demonstrated that attentional IOR but not oculomotor IOR moves with the attended-to object. This finding suggests that attention precedes eye movements in IOR, and has since been replicated (Abrams & Pratt, 2000; Hoffman & Subramaniam, 1995). More recently, Hunt and Kingstone (2003) advocated the view that different response modalities (i.e., manual and oculomotor) generate different forms of IOR, rather than being merely an attentional effect as Reuter-Lorenz et al. (1996) posited. Hunt and Kingstone (2003) suggested that manual responses, which engage covert attentional orienting because eyes remain at central fixation, should produce attentional IOR. On the other hand, oculomotor responses, which engage overt attentional orienting because an eye movement to the target is executed, should produce oculomotor IOR. This hypothesis was supported by the successful replication of Reuter-Lorenz et al.'s (1996) finding that target intensity interacted with IOR only with manual but not oculomotor responses. In addition, in an attempt to replicate Abrams and Dobkin's (1994) finding that the fixation offset effect (FOE), which is an effect related to the SC, Hunt and Kingstone (2003) found that the FOE interacts with oculomotor but not manual responses. Thus, these authors successfully demonstrated a double dissociation between the attentional and

oculomotor components of IOR. That is, while oculomotor effects interacted with oculomotor IOR, attentional effects interacted with attentional IOR, but not vice versa. This dissociation of IOR according to response modality suggests that attentional and oculomotor IOR occur under different circumstances and reconciles the two explanations of IOR.

Moreover, when Briand, Larrison, and Sereno (2000) examined the time course of manual and oculomotor responses, they found greater facilitation for manual responses than for oculomotor responses. That is, facilitation effects lasted longer for manual responses, whereas IOR was generated faster for oculomotor responses. Further, the authors found an overlap in the time course of IOR generation where manual responses were facilitated, while oculomotor responses were inhibited. This finding strongly suggests that IOR has both an attentional and an oculomotor component and that they can operate somewhat independently.

And lastly, Chica et al. (2010) investigated the attentional and oculomotor components of IOR in a spatial detection task and in a non-spatial discrimination task. Specifically, they compared detection and discrimination tasks in which eye movements were either required – to assess oculomotor IOR – or prevented – to assess attentional IOR. Robust IOR was found in the spatial detection tasks regardless of whether or not the eyes moved. Robust IOR was also found in the non-spatial discrimination task when the eyes did not move. However, when the eyes moved, although IOR appeared to be evident in RT (i.e., slower RT at cued than uncued locations), a facilitation effect was observed in accuracy (i.e., greater accuracy for cued than uncued locations) which revealed that a shift in criterion, rather than IOR, was underlying the effect. Indeed, when this speed-accuracy trade-off was controlled for, oculomotor IOR was absent in the discrimination task. Importantly, when oculomotor IOR was generated, there was no deficit in attentional IOR, supporting the view of independent contributions of the attentional

and oculomotor components to IOR. Preventing eye movements generated attentional, but not oculomotor IOR, while requiring eye movements generated oculomotor, but not attentional IOR. Therefore, the authors suggest that either oculomotor or attentional IOR is at play depending on the activation or inhibition of the oculomotor system.

Research Question

While attentional and oculomotor components of IOR have been examined in studies employing the typical attentional orienting paradigm with two locations, only the attentional component of IOR has been established and confirmed in multiple location IOR paradigms (Danziger et al., 1998; Snyder & Kingstone, 2000, 2001). The goal of this experiment was to establish whether there is also an oculomotor component to IOR when multiple locations are cued in succession. And if there is an oculomotor component, whether it co-occurs at all cued locations, or only at the most recently cued location. It may be the case that oculomotor IOR only occurs at the most recently cued location, because the SC, which is responsible for the control of reflexive eye movements is believed to be capable of coding for a single eye movement (Posner et al., 1985; Rafal et al., 1989). These questions will be investigated using a six-location paradigm where three successive exogenous cues are followed by a central re-fixation event prior to target onset. First, attentional IOR will be measured via covert orienting to the cues (i.e., participants will keep their eyes at a central fixation stimulus). Second, oculomotor IOR will be measured via overt orienting to the cues (i.e., participants will make an eye movement to each cued location). Oculomotor IOR will be determined by subtracting the attentional IOR generated via covert orienting from the oculomotor and attentional IOR generated via overt orienting. Participants' eyes will be monitored to ensure that eyes remain at fixation – covert orienting, and that eyes moved to each of the cued locations – overt orienting.

Finally, given that eye movements have never been monitored in a multiple location paradigm, it may be the case that previous assessments of attentional multiple location IOR may have been inflated IOR effects as a result of inadvertent eye movements. Thus, eye movement monitoring will allow for such an assessment.

Finding oculomotor IOR for multiple locations would contribute to the evidence asserting the importance and utility of IOR in visual search. When we search our environment, not only attention, but also eye movements are deployed. If there is an oculomotor component to IOR, the question remains whether oculomotor and attentional components are additive, because both attentional and oculomotor IOR are at play during overt attentional orienting (Hoffman & Subramaniam, 1995), or whether attentional and oculomotor components are mutually exclusive, depending on the activation or inhibition of the oculomotor system (Chica et al., 2010).

Firstly, given that overt orienting to an exogenous cue would produce an additive effect of the attentional and oculomotor components, a greater IOR effect should be found for overt than for covert attentional orienting. Specifically, if there is an oculomotor component to multiple location IOR, and if it is evident at all cued locations, the IOR effect would be expected to be greater for overt orienting than for covert orienting for all cued locations. If the oculomotor component is only evident at the most recently cued location, as suggested by the limited capacity of the SC, the IOR effect would be expected to be greater for overt orienting than for covert orienting only at the most recently cued location, but equal for all other cued locations at which only attentional IOR is generated.

Secondly, if the attentional and oculomotor components are mutually exclusive, IOR effects of a similar size should be found for overt orienting and covert orienting. If oculomotor IOR is evident at all cued locations, IOR effects for overt orienting and covert orienting should

be equal across all cued locations. Again, if oculomotor IOR is evident at the most recently cued location only, the IOR effect for overt orienting would be smaller than for covert orienting at the most recently cued location, and equal across all other cued locations. However, given that attention precedes eye movements (Hoffman & Subramaniam, 1995), a delay in the generation of oculomotor IOR should be found. That is, oculomotor IOR should be smaller than attentional IOR at the most recently cued location, and comparable in size to the previous cued location of the attentional IOR effect.

Method

Participants. Forty-one experimentally naïve undergraduate university students (30 female, 11 male; mean age 19 years, *SD* = 1.83) participated for course credit. All participants had normal or corrected-to-normal vision.

Apparatus and stimuli. The stimulus display was presented on a 43 cm computer screen. On a black background, six rectangular, grey figure eights measuring .5° × 1° of visual angle (va) were arranged in an imaginary circle (8.5° va radius) around a central figure eight. Cueing was achieved by superimposing a white figure eight over the grey figure eight, which created a brightening effect. The target stimulus was a white square (.3° va × .3° va). A video camera was affixed to the top or bottom of the computer screen to ensure participants' compliance regarding eye position.

Procedure. Participants were seated at a distance of 57 cm in front of a computer screen. At the start of a trial, participants were instructed to fixate the central figure eight. A 100 ms warning tone indicated the start of a trial. At 1000 after the onset of the tone, three different peripheral figure eights and then the central figure eight were brightened in succession. Following the final central cue, a target appeared in any of the six peripheral figure eights until a

response was executed via a key press or for 1000 ms, whichever came first. On catch trials, where there was no target, the trial timed out after 1000 ms. All cue durations were 500 ms and all stimulus onset asynchronies (SOAs) between successive cues and the final central cue and the target were 1250 ms (see Figure 1).
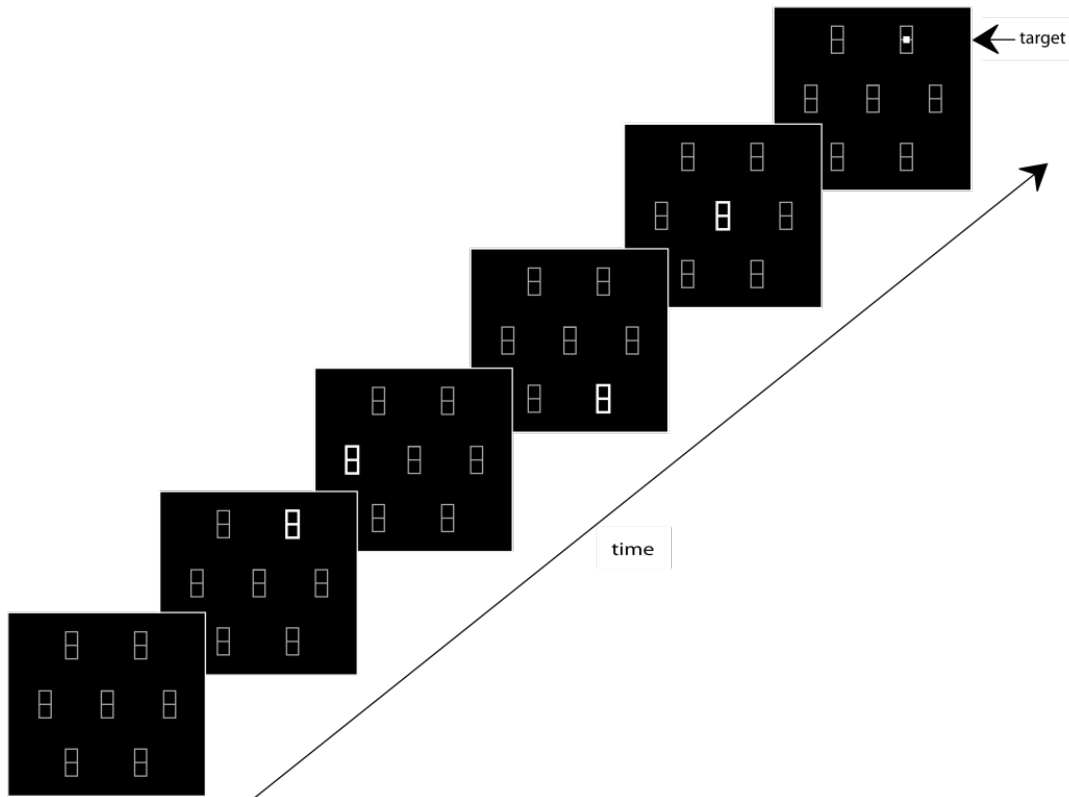

Figure 1. Sequence of events on a trial. In this example, the target appears at the first location that was cued. See text for timing details.

In the overt orienting trials, participants were instructed to move their eyes to each peripheral cue as quickly as possible and keep their eyes there until the next cue appeared. When the next cue occurred, they were to move their eyes to that cue and so on until finally returning their eyes to the central figure eight. In the covert orienting trials, they were instructed to keep their eyes fixated on the central figure eight throughout each trial. For both orienting

instructions, participants were informed that the peripheral cues were not predictive of target location. Finally, they were instructed to press the space bar on the keyboard in front of them as quickly and as accurately as possible upon target detection. A brief error tone, distinct from the warning tone, sounded when an error occurred. All participants received both overt and covert orienting instructions in separate blocks of trials.

Design. Both types of orienting (i.e., overt and covert) were completed during the same one-hour session and were counterbalanced across participants. For each type of orienting, participants received 15 practice trials followed by five blocks of 35 trials, resulting in a total of 175 trials. In each block, there were 25 trials in which the target occurred at each of the 1st, 2nd, and 3rd cued locations, 75 trials in which the target occurred randomly at one of the uncued locations, and 25 catch trials in which the target was absent. Cue locations were randomly selected with the caveat that each location could only be cued once on the same trial. The inter-trial interval was 1000 ms. Participants were instructed to take a break between blocks of trials as desired.

Results

Of the 41 participants in this study, eight were tested without video monitoring. Data from three participants were excluded due to a response accuracy of less than 90%. Overall accuracy was 96.1%. Errors were false alarms (responding before target appearance; 2.5%), misses (failure to respond to the target; 1.6%), or anticipatory responses (responding within 150 ms of target appearance; < 1%).

Before proceeding with the analyses, it is crucial to clarify the terminology used for describing target location. If the target appeared at the most recently cued location, it was a cued 1-back trial, because it occurred at the location that was one cue back from target onset. If the

target appeared at the second cued location, it was a cued 2-back trial, because it occurred two cues back from target onset. If the target appeared at the first cued location, it was a cued 3-back trial, because it occurred three cues back from target onset. Finally, if the target appeared at one of the locations that had not been cued, it was an uncued trial.

RT data. A mixed analysis of variance (ANOVA) was conducted on mean correct RT with video monitoring (present, absent), order (overt first-covert second, covert first-overt second) as between-subjects factors, and target location (cued 1-back, cued 2-back, cued 3-back, uncued) and orienting (overt, covert) as the within-subjects factors to determine whether there were any RT differences as a function of video monitoring. The analysis revealed no statistically significant main effect or interactions involving video monitoring (all Fs < 3.73, all ps > .06). Therefore, this factor was collapsed across and a second mixed ANOVA was conducted on mean correct RT to determine whether the order in which the overt and covert orienting instructions was administered mattered.

Although there was no statistically significant main effect of order on RT, all of the interactions involving order were statistically significant: order × orienting, order × target location, and order × orienting × target location (all Fs > 2.73, all ps < .05). The interactions revealed that the RT data across target location varied as a function of order as illustrated in Figure 2[1]. Specifically, when overt orienting was administered first, the RT pattern was atypical, with no statistically significant differences in RT at any of the target locations and hence, no IOR. When covert orienting was administered first, RTs followed a more typical pattern with reliable IOR found at the cued 1- and 2-back locations but not found at the cued 3-back location.

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[1] These findings are consistent with participants' unsolicited reports that moving from the overt orienting trials to the covert orienting trials was difficult. They are further supported by an analysis of the accuracy data that revealed that participants who completed overt orienting first responded significantly more accurately on overt than the covert trials, $t(94) = 2.55, p < .05$. In contrast, participants who completed covert orienting first responded equivalently on overt than the covert trials, $t(94) = -1.98, p > .05$.

Because of these order effects, it was necessary to conduct a mixed ANOVA with orienting as a between-subjects factor and target location as a within-subjects factor. Thus, only the data collected with the first set of orienting instructions was analyzed. Results showed a statistically significant main effect of target location, $F(3, 108) = 8.41$, $p < .001$, with planned contrasts revealing IOR at the cued 1- and 2-back locations (all Fs > 16 2 decimal places needed, all ps < .001) but not at the cued 3-back location, $F(1, 108) = 2.61$, $p > .1$.
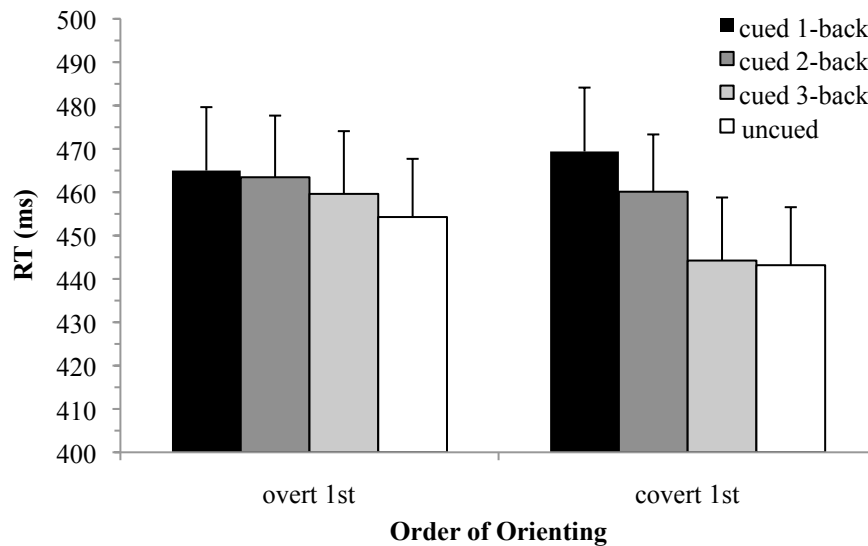

Figure 2. Mean correct RT as a function of target location and order of orienting.

IOR data. A second mixed ANOVA on IOR effects (e.g., cued 1-back – uncued) with orienting as between-subjects factor and target location as within-subjects factor also revealed a statistically significant main effect of target location, $F(2, 72) = 3.95$, $p < .05$. Planned contrasts revealed no statistically significant differences in IOR between the cued 1- and 2-back locations, $F(1, 72) = .04$, $p = .9$. However, IOR was statistically significantly greater for the cued 1- and 2-back locations than for the cued 3-back location, $F(1, 72) = 7.87$, $p < .01$. Neither the main effect of orienting nor the target location × orienting interaction were statistically significant (all

*F*s < 2, all *p*s > .2) indicating that IOR did not vary as a function of orienting. A visual

inspection of the data hints at the possibility of an alternative story (see Figure 3).
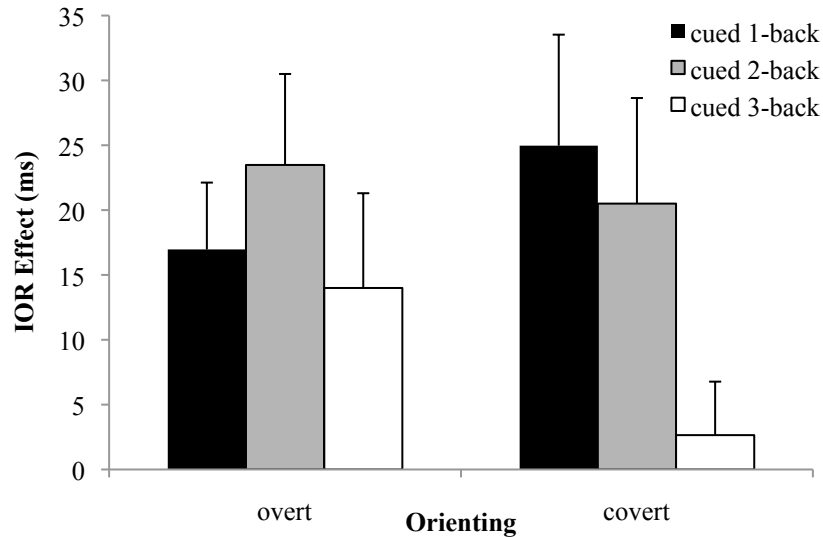

Figure 3. Mean IOR effects as a function of target location and
type of orienting.

Accuracy data. A mixed design ANOVA was conducted on the accuracy data with

orienting (overt, covert) as a between-subjects factor and trial type (cued 1-, 2-, 3-back, uncued,

catch) as factors. This analysis revealed no statistically significant main effects or interactions

(all *F*s < 1.2, all *p*s > .33).

Discussion

The purpose of this experiment was to determine whether there is an attentional and an

oculomotor component to IOR when multiple locations are cued in succession, and if so, whether

IOR co-occurs at all cued locations or only at the most recently cued location and whether the

attentional and oculomotor components are additive or mutually exclusive. Although IOR did

not statistically differ across orienting instructions, the conclusion that oculomotor IOR does not

exist in a multiple location paradigm cannot be drawn for several reasons. First, although there were no statistically significant differences in IOR across orienting, visual inspection of the data in Figure 3 is suggestive that IOR effects arising from overt and covert orienting may in fact be different and that perhaps with more statistical power, these differences would emerge. Specifically, with overt orienting, the IOR effects follow an atypical pattern of results with the greatest magnitude of IOR found at the cued 2-back rather than at the cued 1-back location with the smallest effect at the more typical cued 3-back location. This finding suggests that IOR may take longer to develop when eye movements must be executed to the cue. Indeed, under covert orienting, attention may leave the cued location faster, while under overt orienting, the eyes and presumably attention remain at the cued location until the next cue occurs – more than a full second later. Therefore, rather than being greater than attentional IOR, oculomotor IOR may merely develop more slowly.

This finding is in line with the proposition that attentional and oculomotor IOR are mutually exclusive, rather than additive. In agreement with Chica et al.'s (2010) finding, it appears that oculomotor IOR did not impair attentional IOR. The data revealed that oculomotor IOR at the cued 2-back location was greater than attentional IOR at that same location when directly comparing the two. However, if there is simply a lag in the development of oculomotor IOR, the cued 2-back location for oculomotor IOR should be comparable to the cued 1-back location for attentional IOR. Indeed, this seems to be the case ($M = 24$ ms for cued 2-back oculomotor vs. 25 ms for cued 1-back attentional). Further, if oculomotor IOR develops more slowly, it may be the case that it is still building at the cued 2-back location, and the mean may approach the mean for cued 1-back attentional IOR even more closely. As previous research has demonstrated, attention precedes eye movements (Abrams & Dobkin, 1994; Hoffman &

Subramaniam, 1995), and attentional IOR precedes oculomotor IOR (Rafal et al., 1994).

Additionally, for covert orienting, despite following a typical pattern, the IOR effect at the cued

3-back location was almost eliminated.

Second, there was a trend for greater IOR effects for overt orienting, suggesting that

oculomotor IOR occurs when the multiple location IOR paradigm is used and that the attentional

and oculomotor components may be additive. Third, a major limitation to this experiment was

that eye position was only monitored via video cameras and eye position could not be observed

in real-time. That is, there was no way of ensuring that participants followed the orienting

instructions either overtly – moving to and staying at the cued location until the next cue

appeared – or covertly – fixating centre throughout the trial. This uncertainty with respect to eye

position does not allow for a definite conclusion with respect to oculomotor IOR.

Surprisingly, the data revealed an atypical pattern of attentional IOR. Although previous

research has repeatedly shown that IOR robustly occurs at up to five locations in an exogenous

attentional orienting paradigm (Snyder & Kingstone, 2000; 2001), this was not the case in the

present study, as IOR was not observed at the cued 3-back location when eyes remained at

fixation. However, it may be the case that SOAs were simply too long for IOR to still be present

at the cued 3-back location. With 1250 ms SOAs, the cued 3-back location occurred 5000 ms

before target onset – well beyond the tested limits of multiple location IOR using a short cue

duration. Thus, this time period may simply be too long to maintain IOR. Moreover, again, it is

possible that participants did not follow orienting instructions, and did not keep their eyes at

fixation, or perhaps they did and attentional IOR does not co-occur for more than two locations –

only further research will tell.

Conclusion and Future Directions

Overall, a trend towards a statistically significant difference between oculomotor and attentional IOR emerged in this experiment. In particular, this trend manifested as a delayed development of oculomotor IOR as compared to attentional IOR. Modifications to the experimental design are necessary in order to confirm this trend. Specifically, this design revealed two major limitations that suggest a basis for modification. First, and most importantly, to make valid conclusions about the oculomotor component of IOR, there is a need to replicate this experiment using an eye tracker to ensure that orienting instructions are followed. Second, it seems advisable to implement the experiment as a between-subjects rather than a repeated measures design to eliminate order effects.

References

Abrams, R. A., & Dobkin, R. S. (1994). Inhibition of return: Effects of attentional cuing on eye movement latencies. *Journal of Experimental Psychology: Human Perception and Performance, 20*(3), 467-477. doi: 10.1037/0096-1523.20.3.467

Abrams, R. A., & Pratt, J. (1996). Spatially diffuse inhibition affects multiple locations: A reply to Tipper, Weaver, and Watson (1996). *Journal of Experimental Psychology: Human Perception and Performance, 22*(5), 1294-1298. doi: 10.1037/0096-1523.22.5.1294

Abrams, R. A., & Pratt, J. (2000). Oculocentric coding of inhibited eye movements to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance, 26*(2), 776-788. doi: 10.1037//0096-1523.26.2.776

Briand, K. A., Larrison, A. L., & Sereno, A. B. (2000). Inhibition of return in manual and saccadic response systems. *Perception & Psychophysics, 62*(8), 1512-1524. Retrieved from http://app.psychonomic-journals.org/

Chica, A. B., Klein, R. M., Rafal, R. D., & Hopfinger, J. B. (2009). Endogenous saccade preparation does not produce inhibition of return: Failure to replicate Rafal, Calabresi, Brennan, & Sciolto (1989). Manuscript submitted for publication.

Chica, A. B., Taylor, T. L., Lupiáñez, J., & Klein, R. M. (2010). Two mechanisms underlying inhibition of return. *Experimental Brain Research, 201*, 25-35. doi: 100.1007/s00221-009-2004-1

Danziger, S., Kingstone, A., & Snyder, J. J. (1998). Inhibition of return to successively stimulated locations in a sequential visual search paradigm. *Journal of Experimental Psychology: Human Perception and Performance, 24*(5), 1467-1475. doi: 10.1037/0096-1523.24.5.1467

Dodd, M. D., Van der Stigchel, S., & Hollingworth, A. (2009). Novelty is not always the best policy. *Psychological Science, 20*(3), 333-339. doi: 10.1111/j.1467-9280.2009.02294.x

Eriksen, C. W., & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics, 14*(1), 155-160. Retrieved from http://app.psychonomic-journals.org/

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics, 57*(6), 787-795. Retrieved from http://app.psychonomic-journals.org/

Hunt, A. R., & Kingstone, A. (2003). Inhibition of return: Dissociating attentional and oculomotor components. *Journal of Experimental Psychology: Human Perception and Performance, 29*(5), 1068-1074. doi: 10.1037/0096-1523.29.5.1068

Kingstone, A., & Pratt, J. (1999). Inhibition of return is composed of attentional and oculomotor processes. *Perception & Psychophysics, 61*(6), 1046-1054. Retrieved from http://app.psychonomic-journals.org/

Klein, R. M. (1988). Inhibitory tagging system facilitates visual search. *Nature, 334*(4), 430-431. doi: 10.1038/334430a0

Klein, R. M. (2000). Inhibition of return. *Trends in cognitive Sciences, 4*(4), 138-147. doi: 10.1016/S1364-6613(00)01452-2

Klein, R. M., & MacInnes, W. J. (1999). Inhibition of return is a foraging facilitator in visual search. *Psychological Science, 10*(4), 346-352. doi: 10.1111/1467-9280.00166

Klein, R. M., & Taylor, T. L. (1994). Categories of cognitive inhibition with reference to attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory, and language* (pp. 113-150). San Diego, CA: Academic Press.

Lupiáñez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics, 59*(8), 1241-1254. Retrieved from http://app.psychonomic-journals.org/

Lupiáñez, J., Klein, R. M., & Bartolomeo, P. (2006). Inhibition of return: Twenty years after. *Cognitive Neuropsychology, 23*(7), 1003-1014. doi: 10.1080/02643290600588095

Maylor, E. A. (1985). Facilitatory and inhibitory components of orienting in visual space. In M. I. Posner & O. S. M. Marin (Eds.), *Attention & performance XI* (pp.189-204). Hillsdale, N.J.: Erlbaum.

Maylor, E. A., & Hockey, R. (1985). Inhibitory component of externally controlled covert orienting in visual space. *Journal of Experimental Psychology: Human Perception and Performance, 11*(6), 777-787. doi: 10.1037/0096-1523.11.6.777

Müller, H. J., & von Mühlenen, A. (2000). Probing distractor inhibition in visual search: Inhibition of return. *Journal of Experimental Psychology: Human Perception and Performance, 26*(5), 1591-1605. doi: 10.1037/0096-1523.26.5.1591

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3-25. doi: 10.1080/00335558008248231Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. Bouwhuis (Eds.), *Attention & performance X* (pp. 531-556). Hillsdale, N.J.: Erlbaum.

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology, 2*(3), 211-228. doi: 10.1080/02643298508252866

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109*(2), 160-174. doi: 10.1037/0096-3445.109.2.160

Pratt, J., & Abrams, R. A. (1995). Inhibition of return to successively cued spatial locations. *Journal of Experimental Psychology: Human Perception and Performance, 21*(6), 1343-1353. doi: 10.1037/0096-1523.21.6.1343

Pratt, J., Kingstone, A., & Khoe, W. (1997). Inhibition of return in location- and identity-based choice decision tasks. *Perception & Psychophysics, 59*(6), 964-971. Retrieved from http://app.psychonomic-journals.org/

Rafal, R. D., Calabresi, P. A., Brennan, C. W., & Sciolto, T. K. (1989). Saccade preparation inhibits reorienting to recently attended locations. *Journal of Experimental Psychology: Human Perception and Performance, 15*(4), 673-685. doi: 10.1037/0096-1523.15.4.673

Reuter-Lorenz, P. A., Jha, A. P., & Rosenquist, J. N. (1996). What is inhibited in inhibition of return? *Journal of Experimental Psychology: Human Perception and Performance, 22*(2), 367-378. doi: 10.1037/0096-1523.22.2.367

Sapir, A., Soroker, N., Berger, A., & Henik, A. (1999). Inhibition of return in spatial attention: direct evidence for collicular generation. *Nature Neuroscience, 2*(12), 1053-1054. doi: 10.1038/15977

Snyder, J. J., & Kingstone, A. (2000). Inhibition of return and visual search: How many separate loci are inhibited? *Perception & Psychophysics, 62*(3), 452-458. Retrieved from http://app.psychonomic-journals.org/

Snyder, J. J., & Kingstone, A. (2001). Inhibition of return at multiple locations in visual search: When you see it and when you don't. *The Quarterly Journal of Experimental Psychology, 54A*(4), 1221-1237. doi: 10.1080/02724980143000154

Snyder, J. J., & Kingstone, A. (2007). Inhibition of return at multiple locations and its impact on visual search. *Visual Cognition, 15*(2), 238-256. doi: 10.10.80/13506280600724892

Takeda, Y., & Yagi, A. (2000). Inhibitory tagging in visual search can be found if search stimuli remain visible. *Perception & Psychophysics, 62*(5), 927-934. Retrieved from http://app.psychonomic-journals.org/

Thomas, L. E., Ambinder, M. S., Hsieh, B., Levinthal, B., Crowell, J. A., Irwin, D. E., ... Wang, R. F. (2006). Fruitful visual search: Inhibition of return in a virtual foraging task. *Psychonomic Bulletin & Review, 13*(5), 891-895. Retrieved from http://pbr.psychonomic-journals.org/

Tipper, S. P., Driver, J., & Weaver, B. (1991). Object-centred inhibition of return of visual attention. *The Quarterly Journal of Experimental Psychology, 43A*(2), 289-298. doi: 10.1080/14640749108400971

Tipper, S. P., Weaver, B., & Watson, F. L. (1996). Inhibition of return to successively cued spatial locations: Commentary on Pratt and Abrams (1995). *Journal of Experimental Psychology: Human Perception and Performance, 22*(5), 1289-1293. doi: 10.1037/0096-1523.22.5.1289