Inhibition of Return for Endogenous Colour Cues

by

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

at

Dalhousie University
Halifax, Nova Scotia
November 2017

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ABSTRACT

Inhibition of Return (IOR) is a phenomenon of attention where responses are slower toward a recently attended location, compared with novel locations. There are two types: sensory IOR, produced by peripheral onset cues, and motor IOR, produced by centrally-appearing endogenous signals. Recently, coloured signals have been used endogenously (MacInnes, Kruger & Hunt, 2015) although their ability to produce IOR in a similar manner to arrow signals has not been investigated. The aim of the present study was to compare colour and arrow signals in their ability to generate IOR given that both can provide endogenous information. Experiment 1 contained two conditions: arrow signals, and colour signals. In both conditions the participant made three consecutive saccades in response to signals (first target, return to center, second target). In the colour condition targets were signaled by the fixation stimulus changing colour to match one of the two outer targets, whereas in the arrow condition uncoloured targets were indicated by the direction of the arrow. In half of the trials in the colour condition, on a random basis, the colours of the outer targets switched places after the first signal breaking the correlation between colour and location. The results showed robust IOR (i.e., greater reaction time for repeated target locations compared to opposite target locations) for the arrow condition, which was also true for the colour condition on trials where the target colours did not change location. No IOR was found for trials in which the coloured targets changed location. In experiment 2, the arrow condition was repeated, along with a new condition in which arrows were used to signal targets but the targets had (irrelevant) colours that changed location on 50% of the trials on a random basis. The results showed robust IOR for both arrow conditions despite the fact that the peripheral targets switched positions. This suggests that the cancellation of IOR in Experiment 1 did not occur *simply* because the targets changed locations, but presumably because the colours were relevant to the endogenous information and a change in their position required attentional monitoring by the participant. In conclusion, the IOR generated by endogenous colour signals did not seem to be of the same nature as that produced by arrow signals although further research is required to determine if this is a property of the use of coloured signals *per se* or instead the use of central signals that require analysis of features in the peripheral field to provide meaning.

List of Abbreviations and Symbols Used

Δ	Prism Diopters
ANOVA	Analysis of Variance
APCT	Alternate Prism Cover Test
CTOA	Cue-Target Onset Asynchrony
E	Esophoria
FEFsac	Saccadic Region of the Frontal Eye Fields
IOR	Inhibition of Return
LGN	Lateral Geniculate Nucleus
MLF	Medial Longitudinal Fasciculus
Ortho	Orthophoria
PEF	Parietal Eye Fields
PPRF	Paramedian Pontine Reticular Formation
RT	Reaction Time
SC	Superior Colliculus
SD	Standard Deviation
SE	Standard Error of The Mean
SPSS	Statistical Package for Social Sciences
V1	Primary Visual Cortex
V4	Visual Area 4
X	Exophoria

Acknowledgments

The completion of this thesis would not have been possible without the support of several individuals. Firstly, I would like to thank my supervisor, Dr. David Westwood, for the time and effort he has put into this project. I also appreciate all the patience required to answer my questions, especially in the beginning when the questions were innumerable.

I would also like to thank my supervisory committee members, Heather Fennell-Al Sayed and Dr. Heather Neyedli for all the much-needed advice and support. Thanks to Leah Walsh for taking on the role of my external examiner. I appreciate your time and willingness to be involved.

Thank you to all the students that participated in this study. This research would not have been possible without the generous donation of their time. A special thanks to Lianne Esmores for her many "test drives" of the experiments while I fine-tuned them.

Finally, I would like to thank my parents for always encouraging me, and for listening every time I called home to chatter about the project. I am forever thankful to have had so many people supporting this project from beginning to end.

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Orienting and attention are functions that have evolved in humans to make interaction with the visual environment more effective. While foraging for food was probably the main evolutionary driver, searching tasks are still very common in modern times (Klein & MacInnes, 1999). From searching a crowd for a friend, to looking for a lost object, it is imperative that searching is done efficiently.

Searching depends upon the ability to shift spatial attention throughout an area of interest. Spatial attention is defined as the enhancement of processing at a location (Posner, 1980). This leads to orienting, where spatial attention is moved toward the location of interest.

The study of orienting is challenging because attention itself can only be measured indirectly via changes in performance or brain activity. Measurement of reaction time is one commonly used method, whether it is the reaction time of a key press, arm movement or eye movement. Reaction time is thought to encompass the amount of time to plan and execute a movement, making it sensitive to any delays in processing of these functions.

Humans continually shift attention during searching tasks, using it to determine if a target has been located, and if not, moving it to a new location. One mechanism that alters the way attention is shifted is inhibition of return (IOR). Inhibition of return acts to bias attention away from locations that have been recently attended, thus encouraging orienting towards new locations. Quantitatively, IOR is inferred when the reaction time to detect a target is greater when it appears at a previously attended location in

comparison to a new location (Klein, 2000). Often, IOR is measured using a "cue-target task". This consists of a display containing a central fixation point with placeholders that will be the locations of the cue and target. While maintaining fixation at the central fixation point, a cue appears in one of the placeholders. After a time delay, the target appears in either the same, or different placeholder. While the cue does not require a response, the appearance of the target does. The purpose is to determine how the previous cue location affects the reaction time to the target.

Both the type of cue, and the type of response made to the subsequent target can affect the presence and magnitude of IOR. It has been proposed that IOR can arise from both sensory and motor components and that these components work differently. Sensory IOR is thought to be caused by an event peripheral to fixation (an exogenous cue) that captures attention and presumably engages oculomotor programming intended to generate a saccade bringing the target onto the fovea. Experimentally, several different cue types have been used to study sensory IOR (Klein, 2000). In a typical paradigm, the eyes are fixed in a central location while cues are presented peripherally inside marked locations, and responses to targets are made either via manual keypresses or saccades.

Unlike sensory IOR, motor IOR is thought to arise from the preparation and/or execution of responses to consecutive targets. To isolate motor IOR from sensory IOR (which also necessarily involves a movement of some type in response to the target), consecutive motor responses are signaled using centrally presented information so that attention and oculomotor preparation are not automatically drawn to a peripheral

location. Commonly arrows are used as these convey information about target location without the requirement for participants to learn arbitrary associations between a stimulus and a target location.

The purpose of this study is to examine whether colours can be used as endogenous signals to create motor IOR, by comparing responses to colour signals and the traditional arrow signals.

1.2 INHIBITION OF RETURN

Inhibition of return refers to the impaired detection or response toward stimuli that have recently been the focus of attention, compared to stimuli that have not been recently attended (Klein, 2000). Posner and Cohen (1984) observed this in a series of experiments featuring both manual responses and eye movements in response to targets. In those without eye movements, the participants were shown an array of three boxes. While the eyes stayed fixed on the center box, a brightening of the box outline then cued one of the peripheral boxes. Participants were told that the cue did not predict where the target would appear. After a small time delay, the target (a small bright square) would randomly appear in one of the boxes, which was to be responded to as quickly as possible by a key press. This was repeated several times using a variety of time intervals between the cue and target. The results showed that for short cue-target intervals (<150 ms), there was a facilitation effect for cued location: participants had a faster reaction time when the target was in the same box as the previous cue. However, when intervals of greater than 300 ms were used, an inhibitory effect was

seen (faster reaction times occurred when the target appeared in the uncued location). This inhibitory effect was named "inhibition of return" in a later publication (Posner, Rafal, Choate, & Vaughan, 1985).

Another variation of the original experiment (Posner & Cohen, 1984) used predictive arrows as central cues, with key pressing as the response. This meant that the cue and target locations were correlated, and not random as before. Under these conditions facilitation was observed but not inhibition. From this, it was concluded that inhibition likely arises from the withdrawal of attention from a location; following uninformative peripheral cues, attention must be withdrawn from the cue's location to return to central fixation given the knowledge that targets could appear to either the left or right side of that location. With informative central arrow cues, there is no reason to withdraw attention from the cued location since the participant knows that the target is likely to appear there most of the time; hence, inhibition is not created when central or endogenous cues are used. Later it was found that central signals can generate IOR, but only when a response is made to the signal (i.e., if it is the first of two targets, rather than a cue followed by a target) (Rafal, Calabresi, Brennan, & Sciolto, 1989).

Inhibition of return occurs after attention is shifted towards, and then removed from, a location in space. This shift in attention could be reflexive such as when a peripheral cue is presented, or could be voluntary, such as during visual search. After removal of attention from an area, IOR delays both motor responses and the return of attention to the area (Klein, 2000). This occurs by way of an "inhibitory tag" that is

attached to the same location at which attention had been removed. This tag biases attention away from the location, and has been shown to remain with a recently attended object, even if its location in space changes. In this way, orienting toward novel items is encouraged and searching can occur more efficiently; hence, IOR is commonly referred to as a 'foraging facilitator' given its presumed value in promoting efficient visual search, even though the tasks in which it is studied often do not involve searching for a target amongst distractors.

1.3 SIGNAL TYPES

Inhibition of return has been studied using a variety of different signals. Each of these can be categorized based upon their relation to the two types of visual orienting. Peripheral cues cause reflexive orienting. To elicit 'pure' reflexive orienting, the location of the cue must not be probabilistically connected to the location of a future target; thus, any effects on subsequent performance arising from the cue can be attributed with confidence to reflexive rather than voluntary mechanisms. As the name implies, reflexive orienting is not voluntarily controlled, and attention is captured as opposed to being shifted as the result of an explicit decision. Central cues fall under the voluntary orienting category: orienting is controlled and generated internally, because the signal is believed to provide useful information about the location of a future event (Berger, Henik & Rafal, 2005). Often cues are used that are mixed in nature, in the sense that the cue itself is peripheral in nature, and thus engages reflexive orienting, but its location predicts the likely location of a subsequent target, and thus could also engage voluntary

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orienting.

For spatial IOR to occur, a location in space must be attended, then have attention removed from it. Peripheral cues cause reflexive orienting regardless of whether they are responded to or not. When a peripheral event occurs, attention is reflexively brought to the area then removed, contributing to the inhibitory effect later seen in that area. For central cues, orienting is voluntary, meaning that attention is neither brought to nor removed from the peripheral area indicated by the cue unless it is necessary for the participant to prepare a motor response. By using non-predictive cues, attention is removed from the cued location and brought back to center, because either location has equal probability of containing the target. For predictive cues, the cued location is more likely to be the location of the target, meaning the participant is more likely to continue attending to that location. This failure to remove attention would prevent IOR from occurring.

1.4 SACCADIC IOR

While IOR has been found among several modalities including saccades, reaching movements, and manual key presses, it shares some neural substrate with saccade systems (Klein, 2000). Saccades are generated in the midbrain after receiving programming input from the superior colliculus (SC) and frontal eye fields (Wong, 2008). A lesion to the SC causes defects in both saccade generation and IOR. Saccades will be hypometric and/or delayed, while IOR will be reduced or absent (Klein, 2000). Although SC damage attenuates IOR, it has been shown that during tasks that elicit IOR, the

ipsilateral SC receives reduced input from other areas of the brain (potentially the parietal cortex). This shows that the SC cannot solely be implicated as the site of IOR generation, as upstream areas are involved.

Despite this, the existence of IOR has been hypothesized as having evolved to make visual search more effective (Klein & MacInnes, 1999). In a searching task, several saccades will be made around the area of interest. Inhibitory "tags" will be left in the locations at which the object of interest was not found. Saccades are biased against returning to these areas, making the search process more efficient.

1.5 COLOUR AS A SIGNAL

The use of coloured stimuli is not a new development in the study of visual attention. Researchers have used colours in various ways to explore many different aspects of orienting and attention (Chica, Taylor, Lupianez, & Klein, 2010; Gersch, Kowler, Schnitzer & Dosher, 2009; Zhang, Shao, Zhou & Martens, 2010). However, the use of colour as an endogenous cue is a relatively new concept.

Although IOR is typically considered a spatial phenomenon, inhibitory effects caused by non-spatial features have been argued to fit the definition of IOR, although this has been debated (Dukewich & Klein, 2015). One of the first instances of the use of colour to study IOR was Law, Pratt & Abrams (1995), who sought to determine whether colour changes could cause IOR without any spatial interference. Importantly, unlike spatial IOR tasks, all stimuli appeared at the same central location so there was no movement of attention to new locations. The results showed a small (5ms) inhibitory

effect when colours were repeated. Taylor and Klein (1998) later replicated this experiment and found similar results; however, when the timing between targets was shortened to 150ms, an inhibitory effect was still seen. As shown in Posner and Cohen's (1984) original work, if this effect were IOR, a facilitatory effect would be seen at this shorter time interval. Taylor and Klein used this to argue that the inhibitory effect was repetition blindness, an entirely different phenomenon from IOR. Fox and de Fockert (2001) also argued that the effect was repetition blindness, and found that the effect disappeared if stimuli appeared peripherally. These results infer that colours themselves are not susceptible to IOR, and should not affect the magnitude of IOR observed within a target-target paradigm, although this has not been explicitly studied.

1.6 PURPOSE AND HYPOTHESIS

Studies of motor IOR have relied heavily on the use of arrows as signals. This is a limitation, as it becomes difficult to determine whether motor IOR effects are a function of movement, or of the arrow signal. Secondly, arrows have been shown to cause some reflexive orienting, signifying that they may not be an ideal endogenous signal. The use of a different endogenous signal could allow for motor IOR to be examined independently of the effects of arrows. The purpose of the present research is to examine whether a new type of signal can produce IOR comparable to that of arrow signals.

Colour is a potential candidate for use as an endogenous signal in IOR studies. A recent study by MacInnes, Kruger and Hunt (2015) utilized coloured stimuli in an

endogenous target-target paradigm. The aim of the research was to determine whether

sequential saccades were as susceptible to IOR as independently planned saccades. The

authors used a paradigm consisting of six circles placed around a central fixation point

(Figure 1.1). During each trial, three circles were blacked out, and each of the remaining

three was assigned a colour: red, green or blue. The participant was verbally instructed

the colours to which saccades would be made before any saccades were initiated. The

participant then planned and executed two saccades. This is an example of a non-

traditional paradigm that would not have been possible if directional arrows were used.

However, the research was performed without consideration of whether coloured

signals are valid endogenous signals.
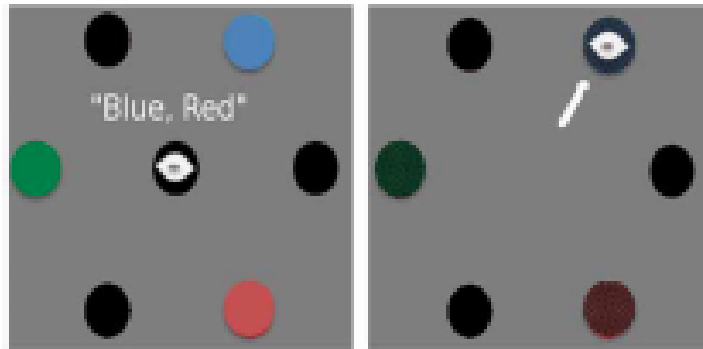
Figure 1.1. Representation of the display used in MacInnes et al. (2015). Participants endogenously prepared saccades which were directed by auditory cues. After the initiation of a saccade, the colours dimmed by 50%. Results showed no IOR for intermediate locations (ie blue, in this example). Taken from MacInnes et al. (2015).

Although several types of endogenous signal are currently used in IOR research they are all useful only in reference to central fixation. An advantage of using colours as stimuli is that they can be used to identify specific targets without any requirement to specify a spatial frame of reference. For example, if there is a red target on a computer screen, a red cue can be used to flag the target no matter where the participant is currently fixating or where the cue appears; contrast this to the ambiguity of flagging the same target using an arrow which would require a specific and different arrow for each place the participant might be fixating when the arrow is presented. When appearing at fixation, the word "left" or an arrow pointing upwards are both endogenous signals. The problem is that they are only useful relative to the current location: an arrow, for example, instructs the participant to saccade exactly one space in one direction. This is a limitation that can easily be circumvented by using a signal that is not dependent upon directing saccades relative to fixation. This could be especially advantageous in paradigms that require multiple saccades to be planned while still at fixation (as used by MacInnes et al., 2014). Signals could direct eye movements to targets anywhere within the viewing area, not necessarily to the targets directly adjacent to fixation.

A second advantage is that arrows have been shown to cause some reflexive orienting. The use of colour signals seeks to avoid this, as there are no predetermined connotations regarding the relationship between colour and location (i.e. a left arrow always means left, but a green circle is not associated with any particular location). In

this way, colours can be thought of as a purely voluntary cue, something that arrows have been shown not to be (Hommel, Pratt, Colzato & Godijn, 2001; Tipples, 2002).

These advantages converge on the idea that coloured stimuli are potentially an alternative method of studying motor IOR. Colour signals provide a different avenue for directing eye movements, and should have the ability to isolate motor IOR from sensory IOR. The aim of this research is to examine whether this type of signal is comparable to arrows, a signal already in use.

Previous research has examined colour-based IOR and found it to be non-existent, so it was predicted that endogenous colour signals would behave the same way as arrow signals. Because both signals direct eye movements endogenously, the signal type should not matter. Therefore, it was hypothesized that both arrow signals and colour signals would produce equivalent motor IOR. In the event that no IOR was found during the colour condition, it would indicate that some aspect of the paradigm is interfering with IOR. More specifically, the use of colours would be implicated as the potential cause.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION

Although humans possess many senses, vision is one of the most prominently used when interacting with the environment. To view and recognize things within an environment, we must have the ability to focus on certain things while ignoring others. Attention serves as the method of doing so by acting as a filter. At any given moment, there are dozens of things that could be made the focus of attention, therefore; mechanisms must exist to regulate which things are attended and which are not. One mechanism to ensure this happens is inhibition of return (IOR), which biases attention from returning to an area recently attended. Attention is especially important during visual search, which is a part of our everyday lives. Whether trying to find a friend in a crowd, or searching a store shelf for a snack, searching must be done efficiently. IOR makes search efficient by preventing the same area from being searched repeatedly.

Searching tasks also depend on the proper functioning of the visual system. Objects must be seen, recognized and fixated with the fovea for search to be successful. In this way, oculomotor IOR is dependent on the proper functioning of several interconnected neural structures: from the optic nerves, to the frontal cortex to the superior colliculi.

2.2 ATTENTION

The brain receives a constantly inflow of information from all the body's senses. Taking the time to consider every single sound, smell, or object seen in our environment

would be incredibly inefficient. Hence, attention exists. Attention is defined as the process of selectively concentrating on specific pieces of information while ignoring others (Rizzolatti et al., 1987). The premotor theory of attention states that oculomotor attention does not have its own system within the brain, it uses pre-existing sensory and motor systems. Thus, there are not separate mechanisms for attention and action, they are integrated together within other neural substrates.

Shifts of attention can be classified as endogenous or exogenous (Posner, 1980). Exogenous cues occur outside of fixation and are considered reflexive: orienting occurs involuntarily. Even if an individual is aware that a peripheral cue is not predictive of future events, the signal will still capture attention. Endogenous cues differ in that orienting is voluntary and intentional. Signals must be perceived, and acted upon intentionally for shifts of attention to occur.

Attention can also be overt or covert (Posner, 1980). Overt attention occurs when a location or object of interest is attended by motor response, such as a saccade. Overt attention can be easily measured by recording eye movements, as the area being foveated is the focus of overt attention. In contrast, covert attention does not involve a measurable action. Attention is shifted mentally, but there is no detectable motor response. For example, while driving a car, a driver's eyes may be fixating on road while his or her covert attention is on the speedometer.

Orienting refers to shifting attention to an object or location. This occurs in three stages (Posner & Petersen, 1990). First attention must be disengaged from the current location, then switched to the new location, then attention is engaged to the new

location. This process occurs constantly in humans as we sample our environment voluntarily and as our attention is captured involuntarily.

2.3 SPATIAL IOR

Within theories of attention is the necessity that mechanisms exist to influence the areas and objects that are deemed worthy of attention. Inhibition of return (IOR) is one of these mechanisms. It was first discovered by Posner and Cohen (1984). This experiment had five parts where IOR was found, and further characterized. The first experiment (Figure 2.1) was responded by button press and involved peripheral cues that could appear at either side of fixation. It was hypothesized that reaction times (RTs) would be faster when the target was in the recently cued location, and this was true, but only when the cue and target occurred in quick succession. At cue-target onset asynchronies (CTOAs) of 0ms, 50ms and 100ms, RTs were faster at the cued location. When 200ms elapsed between the cue and target, RTs were approximately equal for the cued and uncued location, and at longer CTOAs (300ms and 500ms) RT was faster at the uncued location (Figure 2.2)
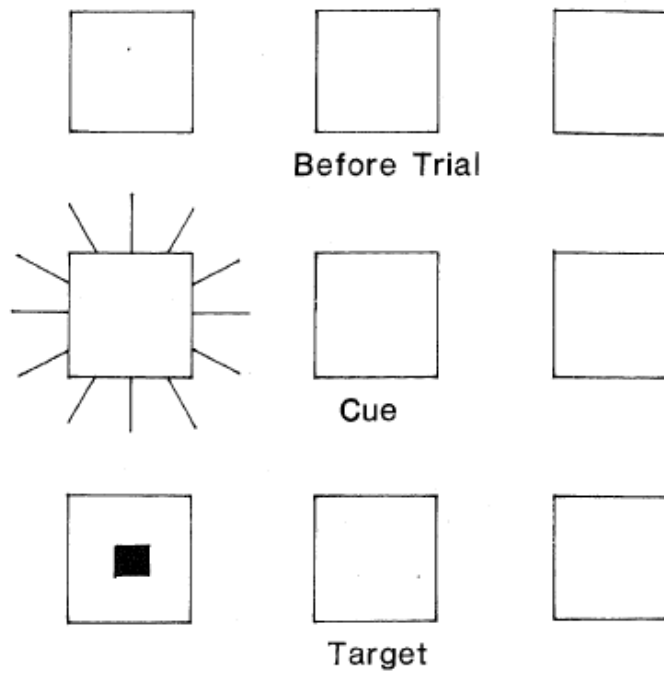
Figure 2.1. Sequence of events in Posner & Cohen's original IOR experiment (1984). The participants' eyes stayed fixated on the central square, while cues and targets appeared in peripheral squares. Taken from Posner and Cohen (1984).
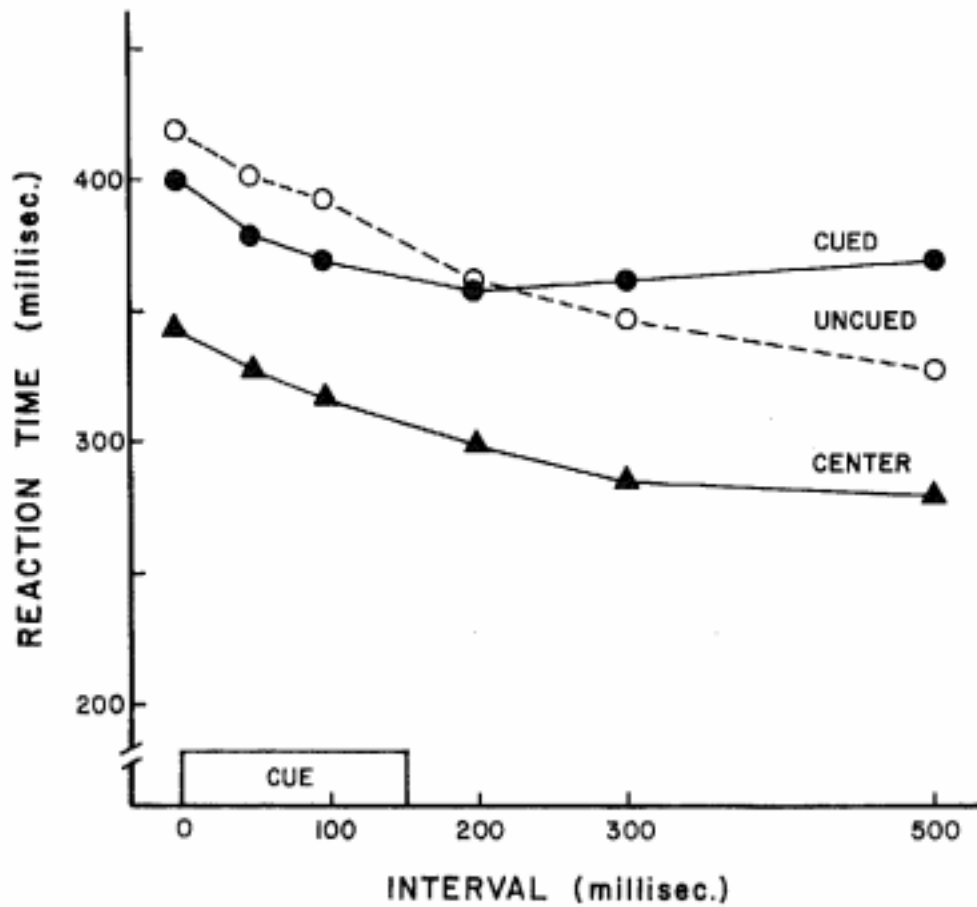
Figure 2.2. Representation of the IOR effect found by Posner and Cohen (1984). Reaction times were faster for cued locations (black circles) at short CTOA, but slower for cued locations at longer CTOAs. Taken from Posner and Cohen (1984)

Posner and Cohen (1984) also tried several variations on their paradigm to further explore the results. One experiment involved using 4 targets (above, below, left, and right) of fixation. Results showed that only the cued location was inhibited, with the other three target locations being equally fast. This showed that IOR also occurs with multiple targets, and that it isn't occurring simply because the targets of the first experiment were mirror images in the visual field. Another variation used dimming (as opposed to brightening) as a cue, and found no difference in results. A fourth experiment involved cueing both targets, and found that RTs were even slower than when only one side was cued. This implies that attention was on both cues, which contrasted with Posner's (1980) previous work that found attention cannot be split to two locations.

Further experiments (Posner & Cohen, 1984) using saccades made the important discovery that IOR is mapped within the visual environment and not retinotopically. This paradigm involved the participant making saccades to multiple targets, so that later targets appeared in spatial locations that had been attended, but not by the same area of the retina. These experiments were the precursor to the idea that IOR creates an "inhibitory tag" at a location as opposed to inhibiting one area of the retina.

2.3.1 SIGNAL TYPES

As mentioned above, there are two types of attention: exogenous and endogenous. Many of Posner and Cohen's (1984) experiments used peripheral exogenous cues. One experiment did use endogenous arrows, but no effect of IOR was

found. This was revisited by Rafal et al. (1989), who found that endogenous cues did generate IOR when saccades were programmed (regardless of whether the saccades occurred) but not when manual responses were made to stimuli. As studies of IOR became more numerous and complex, a theme emerged: the cue, target, and method to which the target were responded all contributed to the presence or absence of IOR.

Taylor and Klein (2000) tested various combinations of cue, target and response method to determine whether IOR represented a sensory or motor inhibition. Using a sequential stimulus paradigm for both central and peripheral signals, the first signal was either responded manually (by button press), saccade, or not responded, while the second was responded manually or by saccade. The oculomotor readiness hypothesis predicted that IOR was generated in any situation that an eye movement was programmed. This included conditions where both the first and second signal were peripheral, responded by saccade, or both.

The results showed that all conditions predicted to show IOR did; however, some conditions that were not predicted to show IOR also showed an effect (Figure 2.3). This lead to the proposal that there are two distinct forms of IOR: sensory and motor, and that they are generated and elicited in different ways. Motor IOR occurs when there is a saccade response, while sensory IOR occurs in conditions without saccadic responses.
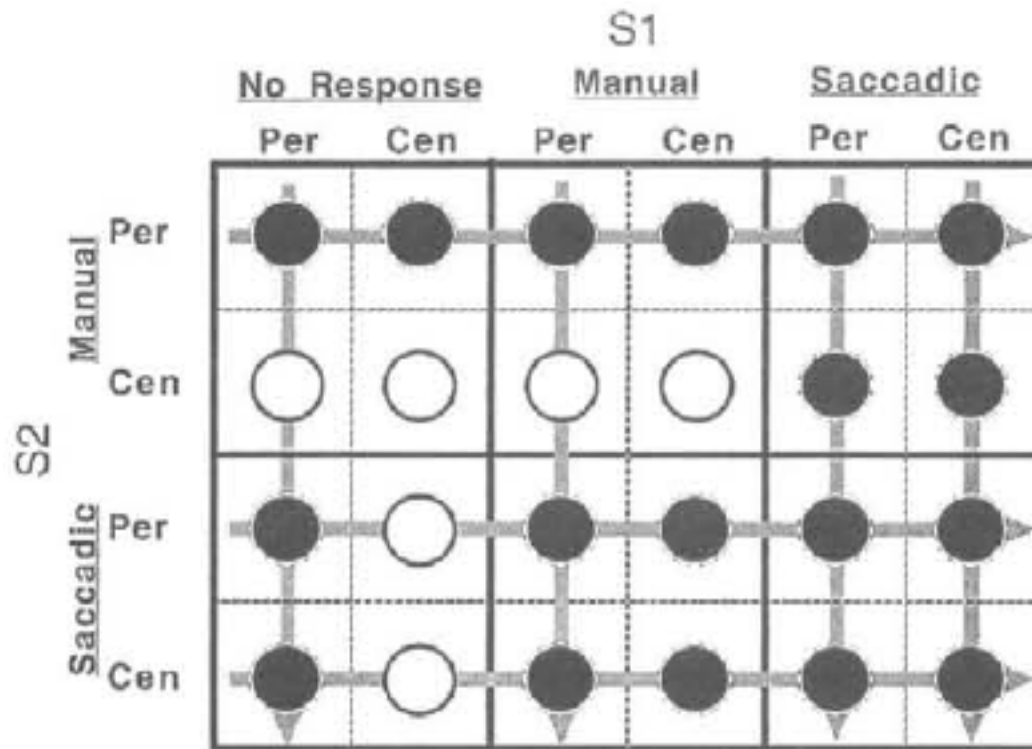
Figure 2.3. A diagram of the results of Taylor and Klein (2000). Black dots indicate conditions where IOR was found, while white dots indicate absent IOR. Intersections of grey arrows show conditions where IOR was hypothesized to occur. Taken from Taylor and Klein (2000).

This division of sensory and motor effects of IOR has persisted in the literature. Visual cues are typically categorized as either exogenous or endogenous. This assumes that all the cues within a category are equivalent in the way generate and elicit IOR: peripheral onsets of any type produce sensory IOR (when not responded motorically), while central cues produce motor IOR. However, recent studies have questioned whether this is true. Endogenous signals have classically been thought to cause voluntary orienting only. Tipples (2001) found that arrow signals do produce some level of involuntary capture of attention. In his experiment, participants did not respond to a pair of arrow cues, and responded manually to a peripheral target (Figure 2.4). If arrow cues are purely voluntary, then they should have no effect on reaction time, but this was not seen. Although participants were told that arrows were not predictive of target, they were still attended and affected RT of responses to the target. This lead to the idea that arrows, which are seen and learned from a young age, cause some level of involuntary orienting. The same result was seen in Taylor and Klein's (2000) study. This also agrees with studies that proposed that endogenous gaze cues cause involuntary orienting (Friesen & Kingstone, 1998).
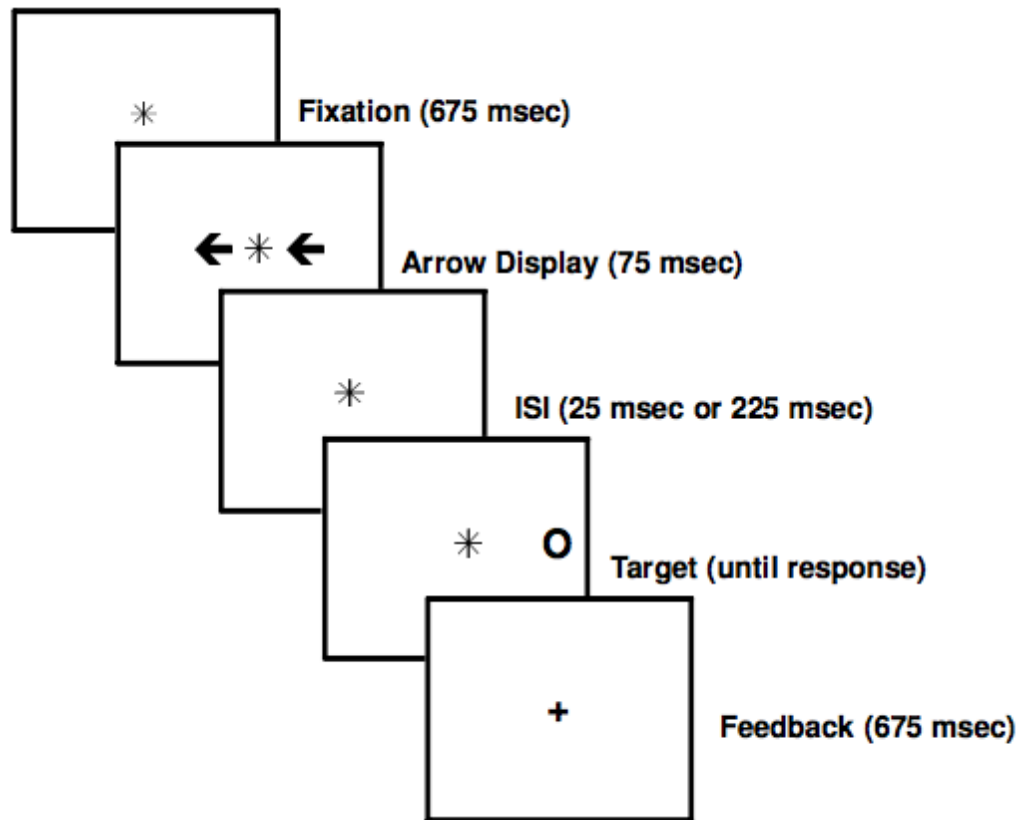
Figure 2.4. Sequence of events in Tipples (2001). Participants were presented with non-predictive arrows just adjacent to fixation and responded with a button press. Reaction times were affected by these arrows despite them being considered an endogenous cue. Taken from Tipples (2001).

Another clear difference between sensory and motor forms of IOR is the spatial distribution of inhibitory effects that follow the first response. Sensory IOR has a monotonic spatial distribution, while motor IOR has a non-monotonic distribution. Bennett and Pratt (2001) characterized the distribution of sensory IOR by peripherally cueing one of four locations around a central fixation point, then having the target appear in any of 441 locations around the visual field. The results showed the greatest inhibitory effect closest to the cued location, with this effect diminishing as the targets appeared farther away. As the cues were peripheral and non-predictive, it can be inferred that effects on subsequent manual responses arose from sensory rather than motor IOR.

Recent research has sought to compare the spatial distributions of sensory and motor IOR using eye movement recordings (Cowper-Smith, Harris, Eskes, & Westwood, 2013). This was done using a display of four circular placeholders around a central fixation point. Targets were located at 0° (same location), offset by 90° or -90°, or 180° (in the opposite location). In conditions where peripheral onsets were used to signal target locations, and thus where it is likely that sensory IOR was being created, reaction times were slowest at 0°, faster at 90° and -90°, and fastest at 180°, which agrees with Bennett and Pratt's (2001) notion of a monotonic pattern of inhibitory effects. In conditions where targets were signaled by central arrows, and which thus eliminated a sensory contribution to IOR, the results showed a non-monotonic distribution: reaction times were slowest at 0° and 180° and fastest at +90° and -90° offsets (i.e., a 'U-shaped' rather than monotonic distribution of inhibitory effects).

The proposed mechanisms for oculomotor sensory and motor IOR are different, although they involve similar structures. Sensory IOR is thought to arise from habituation-like processes in the superior colliculus (SC). Single neuron recordings in monkeys undergoing a cue-target task show that neuron activity is reduced for previously cued targets. Thus, visual input to the SC will be reduced following attention to a location (Satel, Wang, Trappenberg, & Klein, 2011). Motor IOR occurs when the SC "remaps" the visual environment after each saccade. This causes asymmetric activation of the intermediate layers of the SC and leads to encouragement of forward saccades and inhibition of saccades in the opposite direction, thus contributing to the IOR effect (Wang, Satel, Trappenberg, & Klein, 2011).

To test whether these separate effects could occur simultaneously, Wang, Satel, and Klein (2012) designed an experiment using three different paradigms. The sensory task used a peripheral cue and target, with the target being responded by saccade. The motor task used central arrows, both of which were responded with a saccade. The sensory-motor task used peripheral targets, both of which were responded, but also included a central arrow between the two, to direct saccades back to center. The results showed IOR for all conditions; however, the magnitude of IOR for the sensory-motor condition was almost exactly the addition of the IOR found in each of the sensory and motor conditions. This shows that sensory and motor IOR have additive effects when generated simultaneously, which supports the theory that they occur at two different stages of oculomotor processing, by two different processes.

2.3.2 NEURAL SUBSTRATE

Like attention, IOR is a mechanism integrated within several other existing

systems. Thus, it is rational that IOR cannot be conclusively correlated with a single area

of the brain. Early studies implicated the superior colliculus (SC) as the site of IOR, as

patients with damage to this area have reduced or absent IOR, and because IOR is also

present in infants, before cortical development has been completed (Klein, 2000).

However, single-cell recordings in monkeys showed reduced input to the SC, meaning

that while the SC must be intact for IOR to occur, it receives reduced signals from other

upstream structures (Dorris & Munoz, 1999). Further fMRI studies implicate the parietal

cortex, areas of the primary visual cortex (V1), and motor control areas of the brain as

potential upstream sites (Klein, 2000; Müller & Kleinschmidt, 2007; Pastötter,

Hanslmayr, & Bauml, 2008). The parietal lobe has been revealed to be another

associated area, as patients with parietal lobe lesions have shown intact retinotopic IOR,

but an inability to generate environmental or object-based IOR (Sapir, Hayes, Henik,

Danziger, & Rafal, 2004). Because IOR has been found for several modalities and actions

(i.e. auditory cues, reaching movements) it is reasonable to expect IOR to be generated

in areas of the brain that are not specifically oculomotor-based.

2.3.3 EVOLUTIONARY BASIS

Inhibition of return has been shown to exist for several body movements and

under many different circumstances. The reason humans developed IOR has been

speculated. The generally accepted theory is that IOR evolved as a foraging facilitator, to

help humans search for food. Posner and Cohen's (1984) original studies of IOR contained evidence of this: IOR is mapped within the visual environment and not retinotopically. It would be incredibly inefficient to have an inhibitory mechanism that worked based on retinal inhibition, as the eyes move constantly during visual search.

The next piece of evidence came from Klein (1988), who proposed that IOR is based on a tagging system. Related to this was research by Klein and MacInnes (1999) that showed IOR is contingent upon maintaining the scene. Participants were required to search for Waldo in a scene from a Where's Waldo™ book. Partway through the search, a probe appeared, and the participant was instructed to abandon the search and to saccade to the probe target as quickly as possible. While this occurred, the background visual environment either remained or disappeared. For trials where the background remained, RT was fastest when the probe was in the same direction as the previous saccade, and slowest when saccading in the opposite direction as the previous saccade. This is consistent with IOR. During trials where the background disappeared, there was no significant effect of saccade direction: there was no IOR. Thus, IOR is apparent during searching tasks, but is encoded in the visual environment. Klein and MacInnes (1999) used this as evidence to suggest IOR evolved to facilitate foraging behaviours.

2.4 NON-SPATIAL IOR

Searching tasks occur often in our everyday lives. However, not all searching tasks are equal. Searching a grocery store for cookies will be very different from

searching a grocery store for a friend: one involves static targets only, the other has a

mix of static and moving potential targets. Thus, if IOR exists to aid in the search of our

visual environment, it is reasonable to assume that it would include some method of

tracking targets in motion. This is the foundation of non-spatial IOR, which involves

attributes other than spatial location. Shortly after the discovery of IOR, the notion

emerged that IOR could have non-spatial effects. However, some researchers have been

hesitant to adopt this idea. In a recent study by Dukewich and Klein (2015), experts in

IOR were surveyed, and 32% of respondents believed non-spatial IORs have the same

mechanisms as spatial IOR. Slightly more respondents (51%) felt that non-spatial IORs

have the same cause as spatial IOR. There have also been cases of non-IOR effects being

attributed to IOR (Taylor & Klein, 1998). So, while inhibitory cueing effects are seen for

some non-spatial attributes there is no consensus on whether these are truly IOR.

2.4.1 OBJECT-BASED IOR

The first evidence of object-based IOR came from Tipper, Driver and Weaver

(1991). In their study, object-based IOR was discovered using a dynamic display that did

not permit the correlation of objects and spatial locations. Participants viewed a central

fixation target while two placeholders were placed equidistant from it (Figure 2.5). After

the beginning of the trial, one placeholder was cued, then both placeholders moved

clockwise, either 90° or 180° for one experiment, and 180° or 270° for a second

experiment. For all conditions, slower RTs were seen for the cued target, showing IOR.

This is especially interesting for the 180° rotation condition. If the cued box started to

the left of fixation, it ended on the right. If IOR were only location based, RT should be

slower when responding to targets on the left, because that is the location of the cue.

However, responses were slower to right, the location of the cued object, exactly

opposite of the cued location. This showed that IOR was based in the object, not the

location of the object. The amount of IOR was also not significantly different among the

90°, 180°, or 270° conditions, implying that no location-based effects existed during the

experiment.
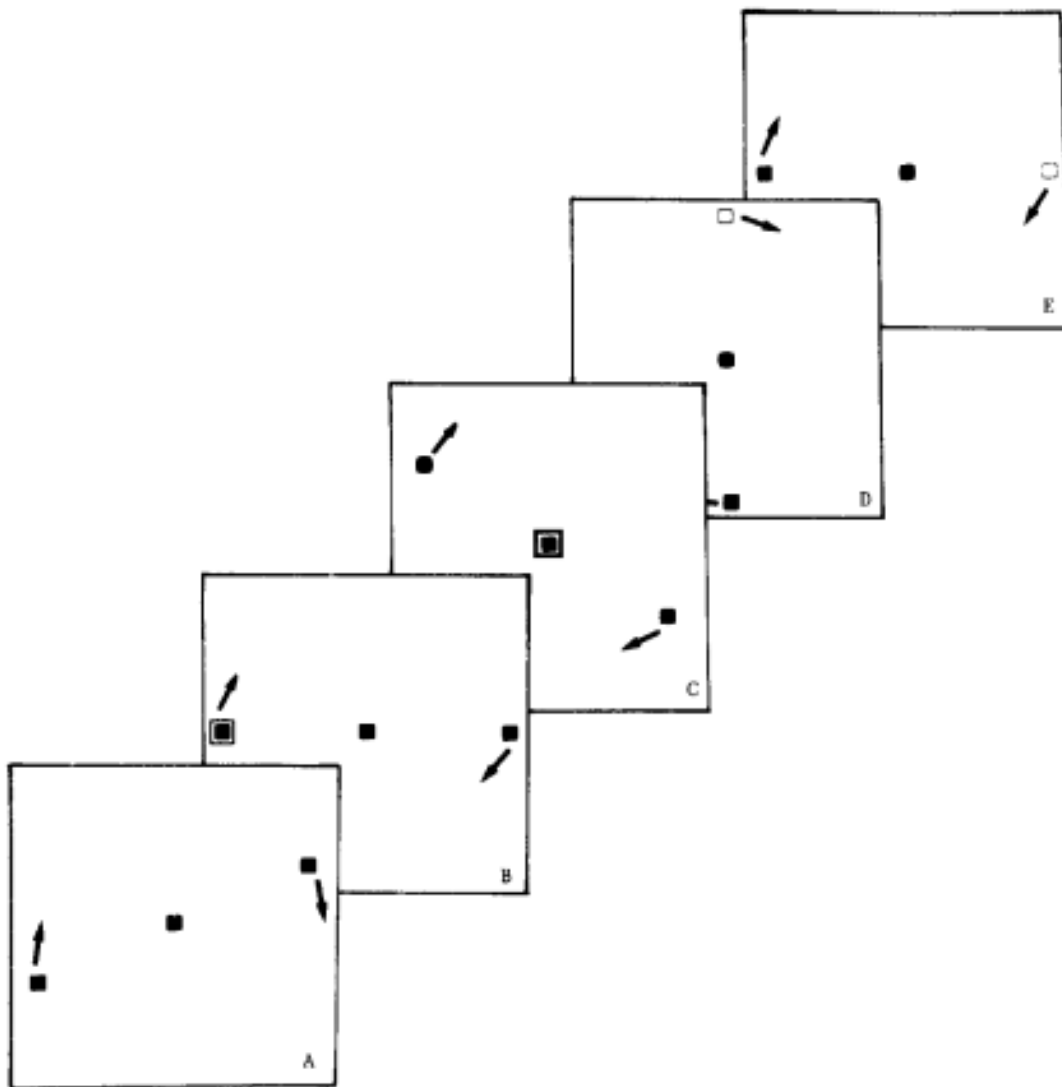
Figure 2.5. Experimental design of Tipper, Driver and Weaver (1991). Participants fixated on the center square while cue and target appeared. During the trial, both boxes moved 90°, 180°, or 270°. Responses were slower to the cued target, not the cued location. Taken from Tipper et al. (1991).

Tipper, Weaver, Jerreat and Burak (1994) later replicated and extended this study to address several questions. Firstly, Tipper, Driver and Weaver's (1991) finding that rotations of 90°, 180°, and 270° showed equal IOR was not replicated. The amount of inhibition at 180° was smaller, suggesting that both location-based and object-based processes were occurring simultaneously and contradictorily when placed 180° from one another. Secondly, it was found that inhibition was found at the location of the cue, even when the object was elsewhere and there was no object at the cued location. Thus, the object is clearly being inhibited, but the former location of the object remains inhibited even after the object leaves. This is a solid indication that object- and location-based IOR are two separate entities that can be additive, subtractive or interact with each other.

2.4.2 IOR FOR OTHER ATTRIBUTES

While object-based IOR has been proven repeatedly, the literature for IOR based in other object attributes (such as colour and shape) is more ambiguous. Early in the IOR's history, several researchers sought to determine whether colour alone could be considered a source of IOR. The first study to examine colour-based IOR found no effect of colour (Kwak & Egeth, 1992). The paradigm required manual responses to the appearance of a peripheral coloured square. IOR was found for repetition of location, but not repetition of colour. The first study to find an effect of colour repetition used slightly different methods (Law, Pratt & Abrams, 1995). Participants were shown a sequence of colours at fixation. The first colour acted as the cue, requiring no response.

The second was called the "neutral attractor", whose function was to ensure attention

was removed from the cue. The neutral attractor was always the same colour, and was

not the same colour as the cue and target colours. The third colour presented was the

target, which required a manual response (Figure 2.6). All stimuli occurred at fixation, so

that any inhibitory effect could be purely attributed to colour change, without having

spatial IOR effects intermixed. The results showed that responses were approximately

5ms slower when the same colour was used as cue and target. A second experiment

used the same paradigm, but without the neutral attractor, and no effect of colour

repetition was seen. The authors concluded that colours could induce and IOR effect,

but only when a neutral colour was used to ensure that attention was removed from the

cue before the presentation of the target.
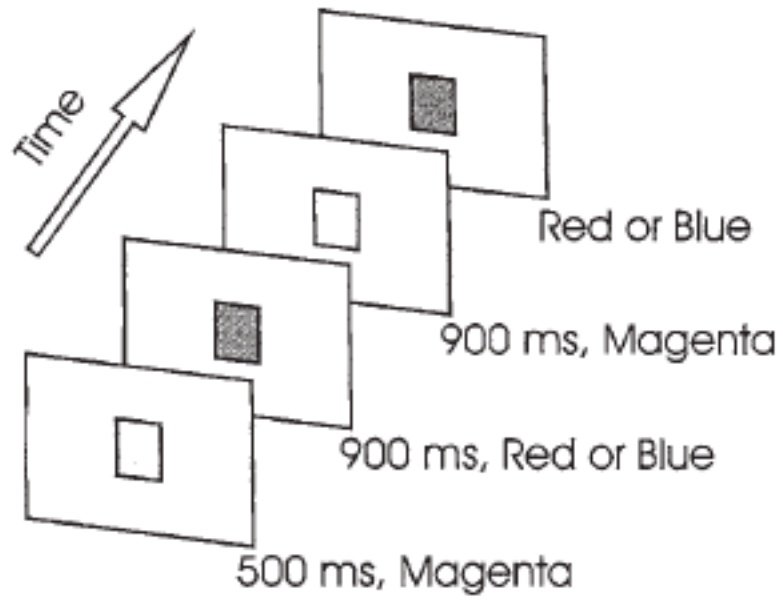
Figure 2.6. Sequence of events in Law et al. (1995). Participants were shown a series of colours at fixation. The cue (red or blue square) was preceded and followed by a "neutral attractor" (magenta square) to ensure attention was removed from the cue. The red or blue target then appeared, requiring a response. Taken from Law et al. (1995).

This study was replicated twice. The first of these, by Taylor and Klein (1998) used a variety of CTOAs to determine whether the inhibitory effect followed the same pattern as IOR. The results agreed with that of Law et al., (1995); however, the pattern did not follow that of IOR (Figure 2.7). Spatial IOR is shown when the time between cue and target is 300ms or more. At shorter intervals, responses are faster when responding to the previously cued location. Taylor and Klein (1998) reasoned that if the colour-based IOR effect was truly IOR, it should follow the same pattern. The results did not support this. An inhibitory effect was found when colour was repeated, but it was seen at all six CTOAs (from 150ms to 900ms) including those that would not have shown spatial IOR. This lead the authors to conclude that the colour-based inhibitory effect is not truly IOR, and is instead repetition blindness.
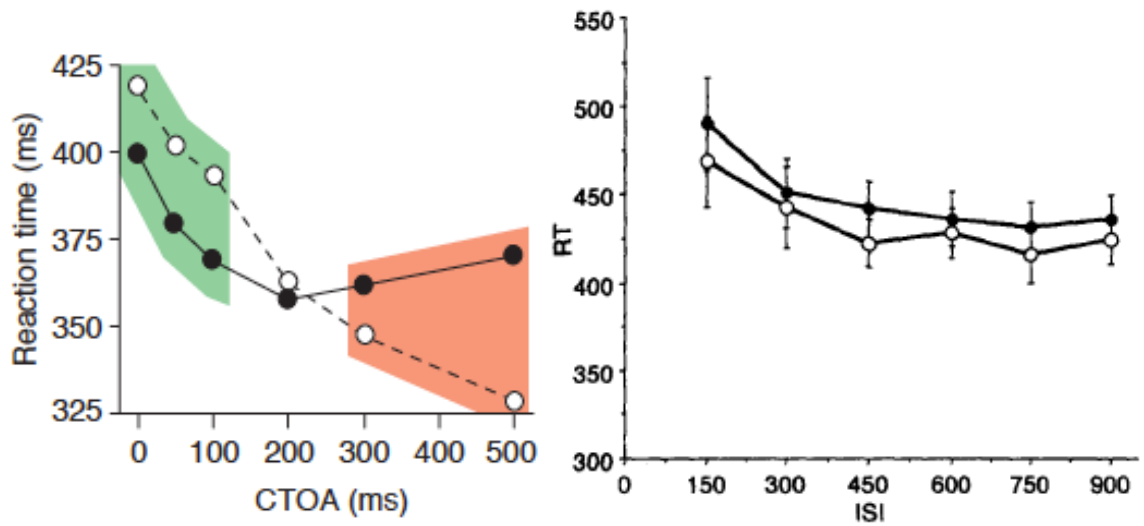
Figure 2.7. A comparison of Posner and Cohen (1984) to Taylor and Klein (1998). Spatial IOR has been shown to exist at CTOAs of 300ms or more (left). Conversely, shorter CTOAs show faster responses to targets in the previously cued location. This pattern was not shown for colour repetition (right). Taken from Klein (2000) and Taylor and Klein (1998).

The second replication of Law et al. (1995) came from Fox and de Fockert (2001) who sought to produce the colour-based inhibitory effect and determine whether it existed for the repetition of shapes. The results of several experiments showed an inhibitory effect of repeating shape, and that the effects of repeating shape or colour were not apparent when the stimuli were presented peripherally. Alteration of the CTOA showed the same results as Taylor and Klein (1998): the pattern did not fit that of spatial IOR. Fox and de Fockert (2001) agreed that the inhibitory effects produced by repeating a non-spatial attribute were repetition blindness, and not IOR.

2.5 THE HUMAN VISUAL SYSTEM

While IOR and attention exist within several pre-existing neural systems, the most essential of these is the visual system. To search for something within the environment, we must see potential targets, and move our eyes to these targets. Eye movements are crucial to visual search, and are commonly used as a method of studying shifts of attention. This is because many experiments studying overt attention have the advantage that eye position is synonymous with the focus of attention, meaning that attention can be measured by eye movement tracking.

The human central nervous system can be broadly categorized into two parts, the afferent system and the efferent system. The same categorization applies to the human visual system. Both halves work together so that we can function visually. The afferent system allows us to see an object, while the efferent system allows us to direct our eyes toward that object. While this is occurring, so is visual processing, so that an

35

object's attributes (shape, pattern, colour, etc.) can be integrated to a single recognizable object.

2.5.1 AFFERENT VISUAL SYSTEM

The afferent visual system consists of the eyes, optic nerves, and several areas of the brain. The pathway starts with rays of visible light entering the eye anteriorly and being absorbed by the photosensitive retina. This is converted to electric signals which move within the retina to the optic nerves. At the optic chiasm, approximately half the nerve fibers from each eye decussate, so that the left optic tract transmits information about the right visual field of both eyes, and vice versa. From here, nerve fibers travel to the lateral geniculate nucleus (LGN) with a small subsection going to superior colliculus (SC). The optic radiations bring the information to the visual cortex where it is integrated. The primary visual cortex (V1) then sends this information to extrastriate areas for higher processing of features such as colour, pattern and orientation (Strominger et al., 2012).

The processing of visual information is thought to occur through two separate but related pathways: dorsal and ventral. This is referred to as the two-streams hypothesis (Goodale & Milner, 1992). The dorsal stream extends from V1 into the parietal lobe. It is known as the "where" pathway and contains a map of the visual field for spatial recognition and for the detection of moving objects. Much of the input comes from the magnocellular layers of the LGN. The ventral stream runs parallel to the dorsal stream, and is connected to the medial temporal lobe. In contrast to the dorsal stream,

the ventral stream is referred to as the "what" pathway. It is involved in object

recognition and receives input mainly from the parvocellular layers of the LGN.

2.5.2 COLOUR PERCEPTION

Although objects possess many attributes, colour is arguably the most easily

distinguishable. There were probably several early evolutionary advantages of colour

perception including differentiating similarly shaped but different coloured objects, like

berries or plants. While humans still use colours for survival it is also often used as an

identifying feature in visual search (finding a red car in a parking lot full of cars, for

example). This makes perception of colour especially important.

Colour perception is dependent upon an intact visual system. The human retina

is equipped to absorb light waves from 400 to 700nm (Cassin, 1995). A normal human is

considered a trichromat, and has retinas containing three types of cones. Each type of

cone (red, blue and green) has a specific spectrum at which it absorbs light. Colours

other than these three primary colours are made of combinations of the primary colours

and therefore activate more than one cone. When a cone is activated, signals are sent

to the "hue center" of the brain, where information is integrated so that a colour is

recognized. The hue center is located within visual area 4 (V4), in the visual cortex, and

receives information from two intermediate locations: the R-G (red-green) and B-Y

(blue-yellow) centers. Information from both centers is integrated to form a single

colour (Gault & Vander, 2007)

2.5.3 EFFERENT VISUAL SYSTEM

Eye movements occur by way of the six extraocular muscles of each eye. The extraocular muscles are controlled by three pairs of cranial nerves. These cranial nerves originate at nerve nuclei within the midbrain, and extend from the brain into the orbit to innervate the extraocular muscles. In contrast to the perceptual nature of the afferent system, the efferent visual system is motor based. It allows us to make both voluntary and involuntary eye movements, so that we can look at an object or location of interest.

There are six types of eye movements (Wong, 2008). Three types are used to hold images on the retina (fixation, vestibular and optokinetic), while the others are used to direct the fovea toward an object (pursuit, vergence, and saccades), and are more relevant to visual search. Pursuit movements occur involuntarily in response to viewing a slow-moving object, while vergence movements are disjunctive, in that the eyes move in opposite directions to view things that are closer or farther from fixation. Saccades are much faster than the other types (velocities of more than 700°/sec) and are the primary eye movement used in visual search.

The initiation of saccades requires higher orders of processing that includes several intact cortical structures (Purves et al., 2001). The first step occurs with information from the afferent visual system. Volitional saccades use information in the saccadic region of the frontal eye fields (FEFsac) and superior colliculus (SC), which is projected to structures in the brainstem. A lesion to either of these areas will cause delayed or hypometric saccades, while lesions to both will not allow saccades to be

generated. Reflexive saccades are generated in the same way, but with added input

from parietal eye field (PEF) to the brainstem (Wong, 2008).

These structures project to areas in the brainstem. Control of horizontal

saccades occurs within the paramedian pontine reticular formation (PPRF). To initiate a

horizontal saccade, the PPRF innervates the abducens nucleus (Purves et al., 2001).

From here, innervation is sent to two locations: the ipsilateral abducens nerve, which

causes the lateral rectus to contract, and to the medial longitudinal fasciculus (MLF). The

MLF ascends to the contralateral oculomotor nerve nucleus, so that the medial rectus of

the other eye contracts, causing both eyes to move. At the same time, there are

projections to other brainstem areas to ensure that the other horizontal muscles remain

relaxed, and do not oppose the direction of the saccade. In this way, the PPRF

coordinates all four horizontal extraocular muscles so that both eyes saccade the same

distance, in the same direction (Figure 2.8).
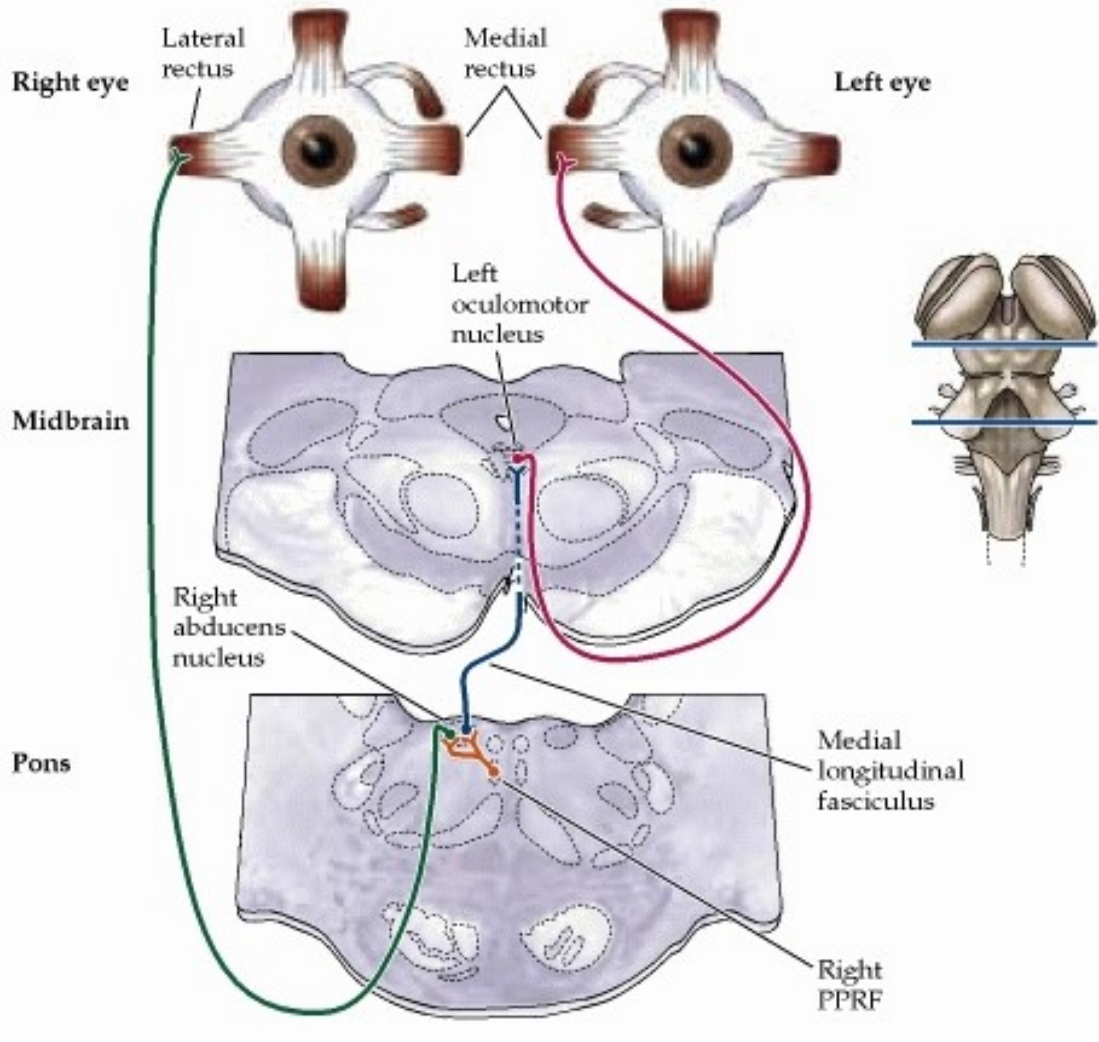
Figure 2.8. Representation of neural pathway to initiate a horizontal (rightward) saccade. Saccades are mediated by the PPRF in the pons, and are carried out by the horizontal recti muscles, in this case the right lateral rectus and left medial rectus. Taken from Purves et al. (2001).

CHAPTER 3 EXPERIMENT 1

3.1 METHODOLOGY

The first experiment investigated whether a target-target paradigm using colour changes as endogenous signals produced comparable IOR to a paradigm using arrows as endogenous signals.

3.1.1 PARTICIPANTS

Twenty participants (4 male, 16 female) were recruited for experiment 1. Six were recruited by word of mouth and 14 were from the SONA undergraduate participant pool. Participants recruited through SONA received one credit point for participating. Ages ranged from 18- 33 with a mean age of 22.3 (SD=3.91) (Table 3.1).

Participant	Gender	Age	Ocular Alignment		Near Visual Acuity		Colour Vision	
			Near	Dist	Right	Left	Right	Left
P01	F	21	ortho	X1$^\Delta$	6/6	6/4.8	20	20
P02	F	26	ortho	X1$^\Delta$	6/4.8	6/6	21	21
P03	F	24	X2$^\Delta$	X2$^\Delta$	6/4.8	6/4.8	20	21
P04	M	33	X4$^\Delta$	ortho	6/4.8	6/6	20	21
P05	F	20	X6$^\Delta$	ortho	6/4.8	6/6	21	21
P06	F	20	ortho	ortho	6/4.8	6/6	21	21
P07	F	20	X2$^\Delta$	X2$^\Delta$	6/4.8	6/4.8	20	20
P08	F	29	X10$^\Delta$	X6$^\Delta$	6/6	6/6	21	19
P09	F	25	X4$^\Delta$	X2$^\Delta$	6/6	6/6	21	21
P10	M	18	X8$^\Delta$	X2$^\Delta$	6/6	6/4.8	21	21
P11	F	22	X6$^\Delta$	X2$^\Delta$	6/6	6/6	21	21
P12	F	23	X2$^\Delta$	ortho	6/6	6/6	20	21
P13	M	26	X6$^\Delta$	ortho	6/6	6/6	21	21
P14	F	21	ortho	ortho	6/6	6/6	21	21
P15	F	18	X10$^\Delta$	X4$^\Delta$	6/4.8	6/4.8	21	21
P16	F	22	E4$^\Delta$	ortho	6/4.8	6/4.8	21	21
P17	F	19	X4$^\Delta$	ortho	6/6	6/6	20	21
P18	F	18	E6$^\Delta$	E2$^\Delta$	6/4.8	6/6	21	21
P19	M	20	X2$^\Delta$	X1$^\Delta$	6/6	6/6	20	20
P20	F	21	ortho	ortho	6/4.8	6/6	20	20

Table 3.1 Participant characteristics for experiment 1. Orthophoria is indicated by "ortho", esophoria by E and exophoria by X. All strabismus measurements are in prism diopters ($^\Delta$). Colour vision scores given are the number of correct plates out of 21.

Inclusion criteria included normal or corrected-to normal visual acuity, normal

colour vision, ocular motility and alignment. Participants were also required to be at

least 18 years of age, as this is the age required to give informed consent, as well as the

age the brain is considered fully developed. Exclusion criteria for the experiment

included the presence of any known ocular or neurological disease, as these could affect

visual processing or eye movements. This was determined by a self-screening form

(Appendix A).

3.1.2 OCULAR TESTING

All testing was done to ensure that the participants had normal visual

functioning, and all participants were required to meet all ocular criteria. Visual acuity

was tested monocularly using the Sloan near card (Good-Lite, Illinois, USA), with $6/6^{-2}$ or

better being considered normal vision. Colour vision was tested monocularly using

Ishihara's Tests for Colour Deficiency, 38-plate edition (Kanehara Shuppan Co., Ltd.,

Tokyo). Participants were required to correctly identify at least 17/21 of the screening

plates.

Ocular alignment was measured by alternate prism cover test (APCT) at near and

distance fixation, to determine the presence and size of any strabismus. APCT is

considered the gold standard for measuring strabismus (Choi et al., 1998). Participants

were required to have no manifest strabismus. Participants with vertical strabismus,

whether manifest or phoric, were excluded. Participants with horizontal phorias were

included if the phoria was less than 10^{Δ} of esophoria (Pratt-Johnson & Tillson, 1994) or less than 12^{Δ} of exophoria (Parks, 1975).

Ocular motility was examined by having the participant fixate in the field of each extraocular muscle (i.e., right gaze is the field of the right lateral rectus and left medial rectus) and grading each muscle on a scale of +4 (for overaction) to -4 (for underaction). Any perceived abnormality was confirmed by APCT in the field of action of the affected muscle. If the size of the phoria changed compared to primary position, it was considered a true abnormality. Any participants with true over- or underaction of any extraocular muscle were excluded.

3.1.3 ETHICS

Ethical approval was obtained from the Dalhousie University Research Ethics Board (Appendix B). All participants provided informed consent before beginning the experiment (Appendix C).

3.1.4 APPARATUS

The EyeLink 1000 plus (SR Research) was used to track participants' saccades. This apparatus consists of an infrared camera (850 to 940 nm), which is used to track corneal reflectance and pupil location with an accuracy of 0.5^{o} and a spatial resolution of 0.01^{o}. The camera was positioned directly in front of and below a 24" BenQ computer monitor, which was used to display the stimuli (Figure 3.1). Experiment builder software

(SR Research) was run on a Dell computer, while the display was controlled by a

separate Asus computer.
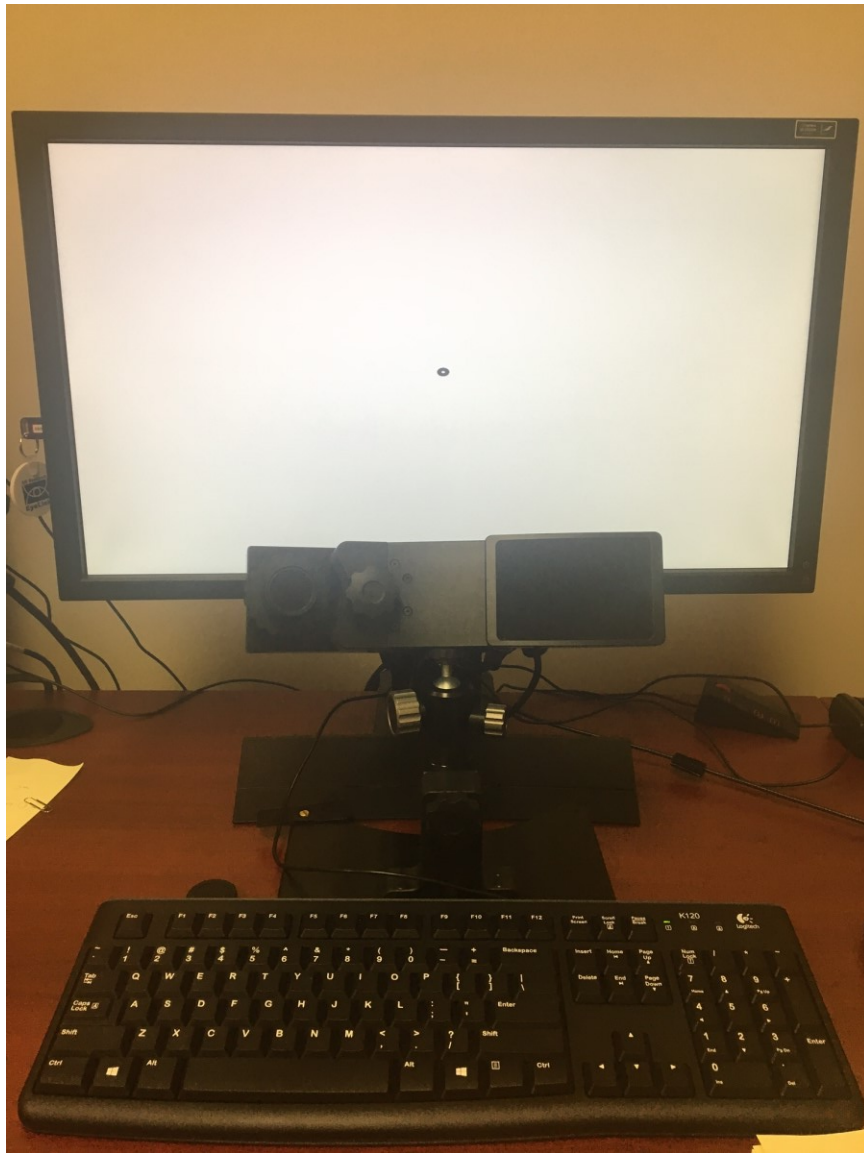
Figure 3.1. Experimental setup as viewed by the participant, including the keyboard, drift correct screen and EyeLink 1000 plus camera.

3.1.5 PROCEDURE

The experiment was conducted in the Interprofessional Centre for Attention in Real Environments (iCare) lab in the Forrest Building at Dalhousie University. After the participant's agreement to participate, they were asked to read and sign the consent form and then to voluntarily complete the screening questionnaire. If free of sensory and motor deficits, each participant was tested for abnormalities of colour vision, near visual acuity, ocular alignment and ocular motility using the methods described above.

After ensuring normal ocular conditions, the participant was asked to place a small bullseye-shaped sticker on his or her forehead so the system could monitor and account for head movements during the experiment. The participant then sat at a computer screen with his or her eyes approximately 57 cm from the screen. The EyeLink 1000 plus was calibrated by asking participants to sequentially fixate three locations on the screen to ensure that the system could record eye position at all areas of the screen, and so that the camera's frame of reference matched that of the display screen. The calibration was validated by having the participant repeat the calibration once more (Figure 3.2).
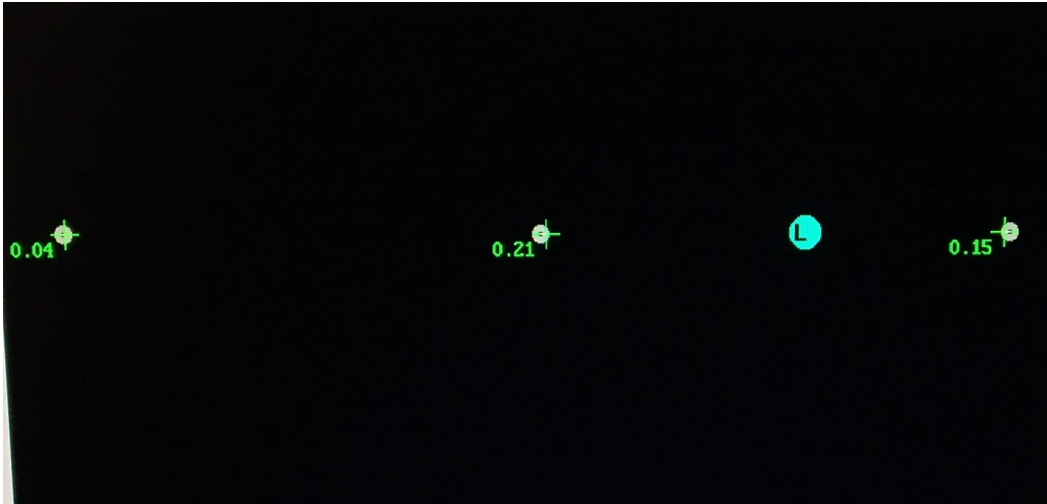
Figure 3.2. EyeLink validation screen. The participant's current eye position is given by the blue dot. Participants were required to sequentially fixate all three targets to calibrate, and again to validate. The numbers in green indicate the amount of drift between calibration and validation. Drift of more than 0.5° at any target indicated a failure of validation, requiring the participant to recalibrate before continuing.

There were two conditions in this experiment: one using arrow signals, the other using coloured signals. All participants completed both conditions, with half completing the arrow condition first, and half completing the colour condition first. Participants were given optional 5-10 minute breaks midway through the colour condition, and before starting the second condition. Each trial began with a drift correct, where the participant was required to fixate on a circular target and tap the space bar, which would account for any instability of the participant's head (Figure 3.3). This would also start the trial, which consisted of three eye movements. For both conditions, the display consisted of a cross between two circular targets. The cross and targets each subtended $2.1°$ of visual angle in diameter, and both targets were placed $7.8°$ from the center cross.
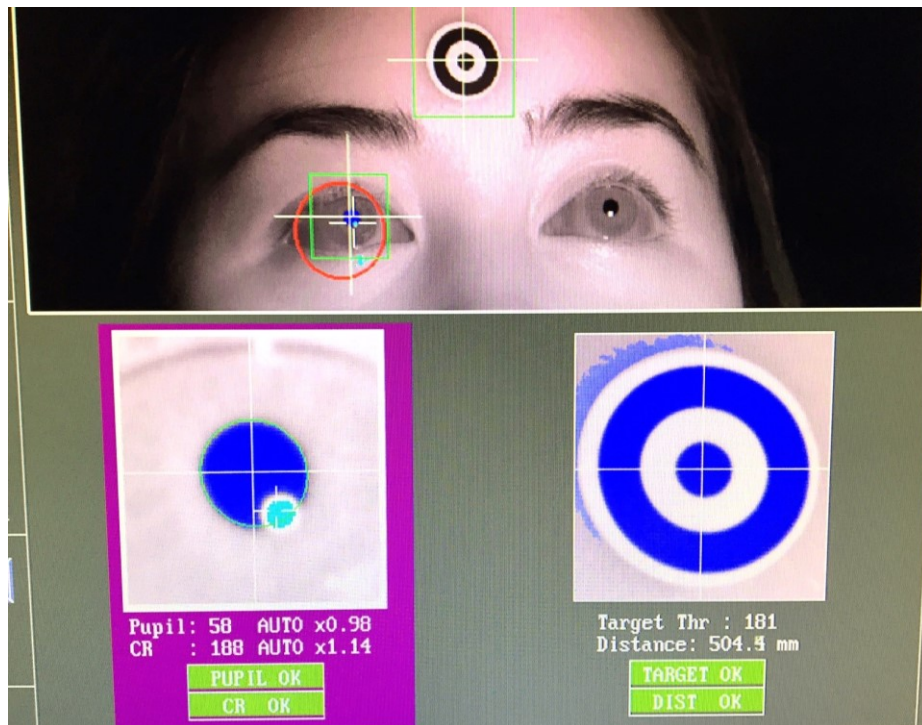
Figure 3.3. View of the participant. The view of the iris (left) ensured both the pupil and corneal reflection were being tracked. The target sticker (right) ensured that eye movements were tracked relative to head position, and that the participant's head had not drifted too close or far from the EyeLink camera.

The arrow condition (Figure 3.4) consisted of 40 trials. This allowed for 10

repetitions of each arrow direction combination (RR, RL, LR, LL). Participants were

presented with a stimulus array consisting of a cross situated between two circular

targets. Participants were instructed to fixate on the center cross until an arrow

appeared, at which time they were to saccade to the target that was indicated by the

arrow, and immediately saccade back to center fixation until another arrow appeared.

The first arrow appeared 2000ms after the beginning of the trial, and switched back to a

cross after 500ms so that that the participant's second saccade was toward a cross

instead of an arrow. The participant then waited (3000ms) for the cross to change to an

arrow a second time, at which point he or she made another saccade to one of the

outer targets. All arrows pointed either left or right, each direction appearing with equal

probability. Therefore, half of trials involved two saccades to the same target, while the

other half had two saccades to two different targets. After three saccades, (from center

to a target, back to center, from center to a target) the trial ended. At the end of the

trial, the participant returned their gaze to center and pressed the space bar for a drift

correction, starting the next trial.
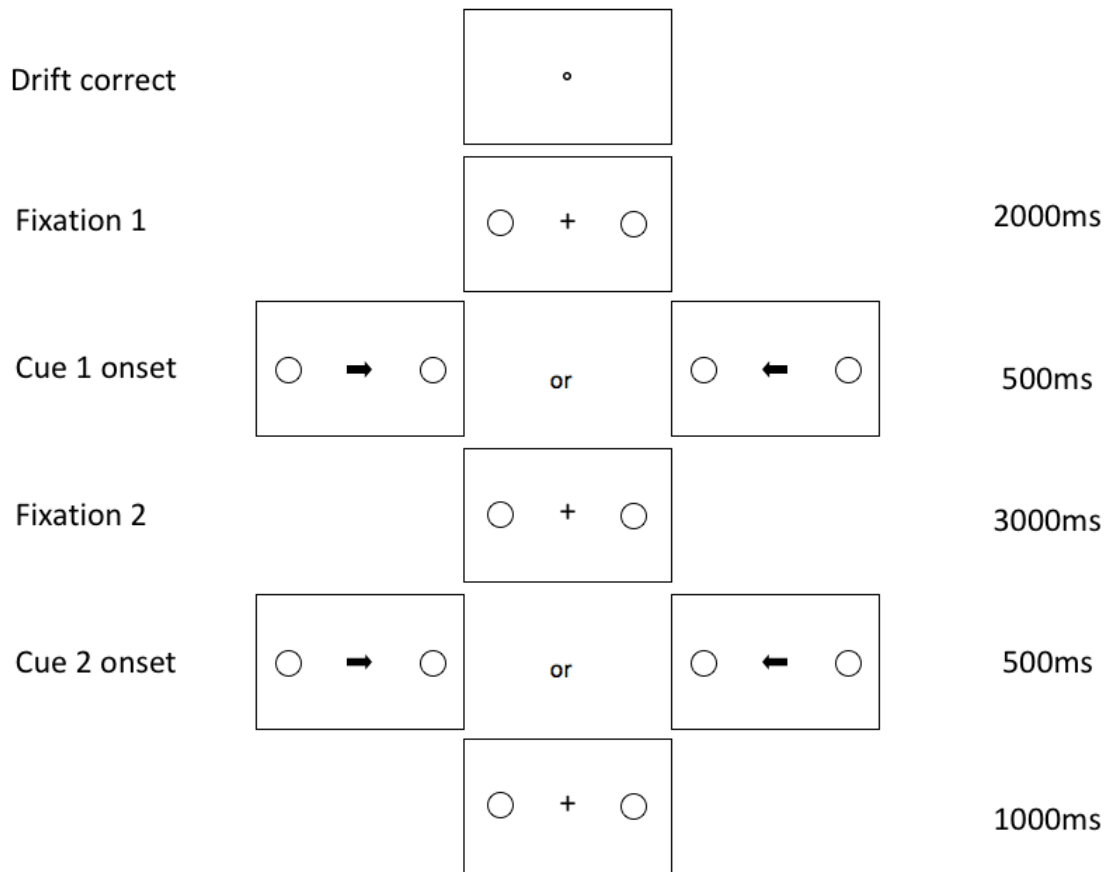
Figure 3.4. Sequence of events during one trial of the arrow condition. After pressing the space bar for a drift correct, the participant fixated on the center cross for 2000ms. The first signal directed a saccade either left or right (p=0.5), after which the participant refixated on the center cross for 3000ms. The second signal then directed a saccade to either the same or opposite side (p=0.5).

For the coloured signals condition (Figure 3.5; Figure 3.6), the process and display were much the same. After a drift correction, the display showed a black center cross with a coloured circle on either side (one red and the other green, randomly assigned). The participant was signaled by the center cross changing to either red or green, indicating the target to which the participant should saccade. As with the arrow condition, the participant was told beforehand to always saccade back to the center cross after saccading to a target. By the time the participant looked back to the center cross, it had switched back to black (500ms after changing colour). The third saccade in the trial was signaled by another colour change of the central cross to match either of the side targets (50% probability for each colour). In addition to this, half of all trials were "colour switch" trials where the red and green targets switched sides after the first two saccades so that colour and location are not correlated for the entire trial (Figure 3.6). This change occurred while participants were looking at the center cross, 1000ms after the onset of the first signal and 2000ms before the second signal. Participants were also told to continue fixating on the cross and not to look at either of the targets when the switch occurred. Because of the additional factor of a colour-switch between the first and second signals, twice as many trials (80) were needed for this condition.
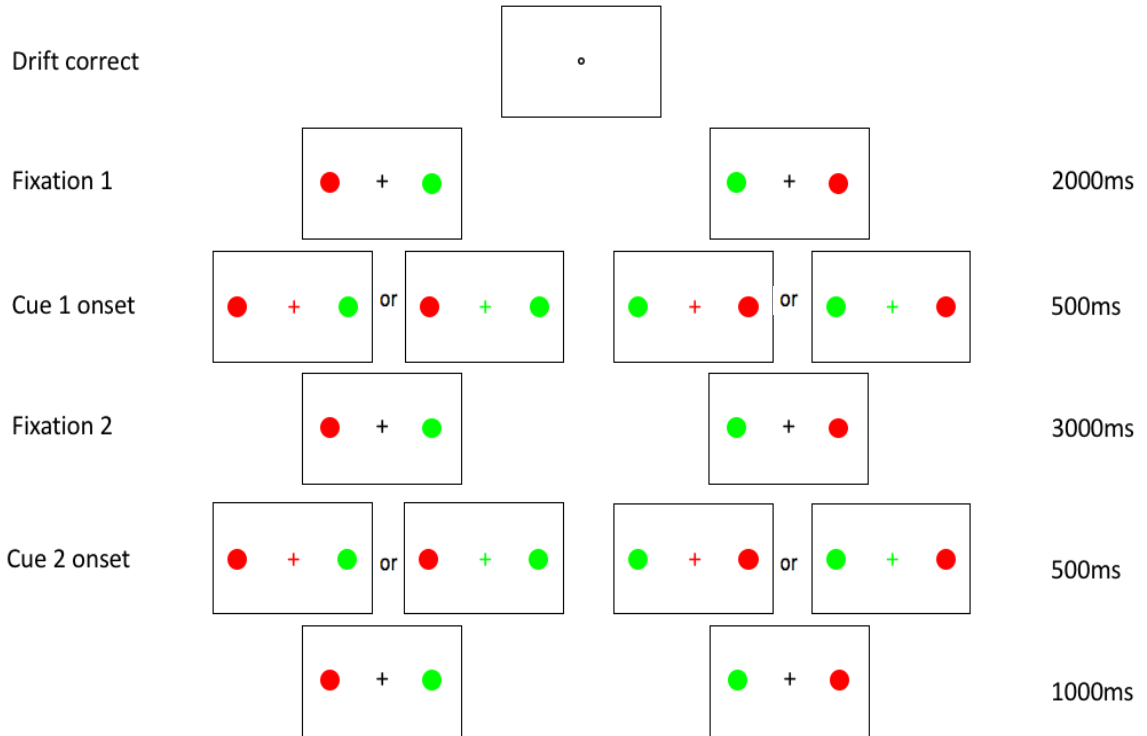
Figure 3.5. Sequence of events during one colour static trial. Half of the trials within the colour signal condition were colour static, meaning the target colours did not change (i.e. red was on the left and stayed on the left during the duration of the trial). The first fixation screen involved red and green targets, one on the left, one on the right (p=0.5). After 2000ms of fixation the center cross changed to either red or green (p=0.5) indicating the target to which the participant saccaded. After 3000ms of refixation, the second signal appeared, directing the saccade to either of the targets (p=0.5). Colour static and colour switch trials were mixed so that the participant did not know which type of trial was occurring at the beginning of the trial.

Figure 3.6. Sequence of events during one colour switch trial. Half of the trials within the colour signal condition were colour switch, meaning the target colours changed partway through the trial (i.e. red was on the left but switched to the right 1500ms after the onset of the first signal). The first fixation screen involved red and green targets, one on the left, one on the right (p=0.5). After 2000ms of fixation the center cross changed to either red or green (p=0.5) indicating the target to which the participant saccaded. After 1000ms of refixation, the coloured targets switched sides (i.e. if red was on the left, red was now on the right). 2000ms after the colour switch, the second signal appeared, directing a saccade to either of the targets (p=0.5). Colour static and colour switch trials were mixed so that the participant did not know which type of trial was occurring at the beginning of the trial.

After the participant completed both conditions (a total of 120 trials), he or she was given the debriefing form (Appendix D) and the opportunity to ask any questions before leaving the lab.

3.1.6 STATISTICAL ANALYSIS

Data were obtained by using Data Viewer (SR research) to extract the reaction time of the third saccade of each trial. Reaction time (RT) is defined as the time between the onset of the second signal and the beginning of the participant's saccade. Reaction times were only generated if the saccade was more than 2°. Before analysis, error trials were removed. Errors were categorized as either a failure to generate a saccade of more than 2°, or because a saccade was made in a direction other than toward the correct target. Outlier data were also removed by removing any RT that was more than 2 SD from the participant's own mean RT.

Data analysis was performed using SPSS Statistics (v24, IBM). Each condition was analyzed separately using a repeated measures ANOVA. For the arrow condition, the factors included final saccade direction (left vs right) and relationship between first and third saccade (same vs different direction). Data from the coloured signal condition were examined in the same way, but with the added factor of target colour switch (colour switch vs colour static). The presence of IOR was determined by the presence of a significant effect of relative direction. All analyses were tested for significance at an alpha level of 0.05.

3.2 RESULTS

Experiment 1 consisted of 800 total trials (across all participants) in the arrow signal condition and 1600 in the colour signal condition. Fifty-six trials were lost to error (7.0%) in the arrow condition. Reasons included a saccade in the wrong direction (2.1%), insufficient saccade size (0.3%), and z-score exclusion (4.6%). Of the 108 trials (6.8%) excluded from the colour signals condition, 2.6% were due to saccade direction error, 0.06% to insufficient saccade size, and 4.2% to z score exclusion (Appendix E).

3.2.1 ARROW SIGNAL CONDITION

The dependent measure was reaction time of the saccade after the second signal (the third saccade of the trial). This was analyzed using repeated measures analysis of variance (ANOVA) with factors final saccade direction (right or left), direction relative to the first saccade (same or different). Variability is indicated by standard error of the mean.

A significant main effect was seen for final saccade direction (left or right), $F(1, 19)=12.17$, $p=0.002$ and relative direction (same or different side), $F(1, 19) =8.75$, $p=0.008$. The effect of final saccade direction indicates that leftward saccades (252 ± 1.84 ms) were initiated faster than rightward saccades (262 ± 1.82 ms). The effect of relative direction indicates a faster mean reaction time for saccades in a different direction (249 ± 1.80 ms) versus the same direction (265 ± 1.85 ms) as the first saccade (Figure 3.7). There was no significant interaction between final saccade direction and relative direction $F(1, 19)=0.243$, $p=0.628$.
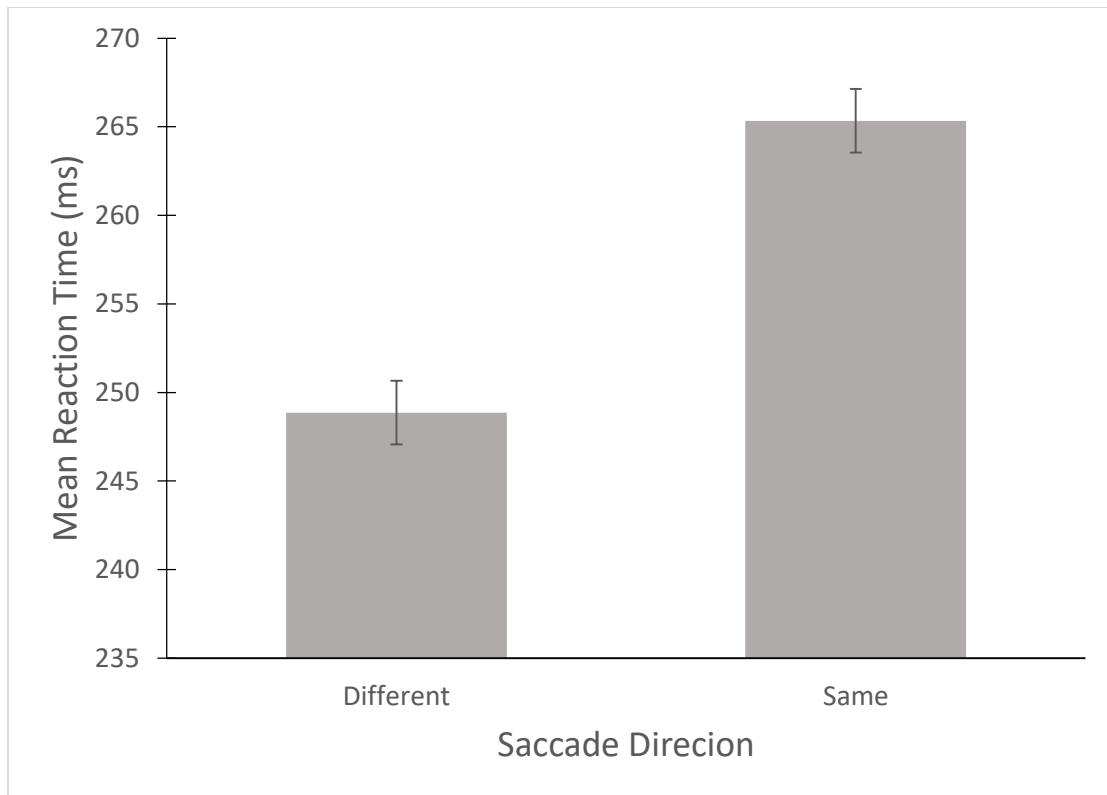
Figure 3.7. Mean saccadic reaction time (in milliseconds) of the arrow signal condition, split by direction of the third saccade relative to the first (different vs same). A significant difference was found between the two, indicating the presence of IOR. Error bars represent standard error of the mean.

3.2.2 COLOUR SIGNAL CONDITION

The colour signal condition was analyzed in the same way as the arrow condition, but with the added factor of colour switch (colour switch vs colour static). A significant main effect was seen for relative direction (same or different side), $F(1, 19)=5.80$, $p=0.026$. This indicates that mean RT was faster for different direction (316 ± 1.9 ms) versus the same direction (324 ± 1.9 ms) as the first saccade. A significant main effect of colour switch was also seen $F(1, 19)=6.38$, $p=0.021$, where mean RT was faster when the colours switched mid trial (317 ± 1.9 ms) versus when the colours were static (323 ± 1.9 ms). A significant interaction also existed, $F(1, 19)=6.85$, $p=0.017$. Simple effects analysis revealed that the effect of relative direction was only significant during colour static trials $F(1, 19)=14.80$ $p=0.001$, while there was no significant effect of relative direction within the colour switch trials $F(1,19)=1.30$, $p=0.269$ (Figure 3.8).
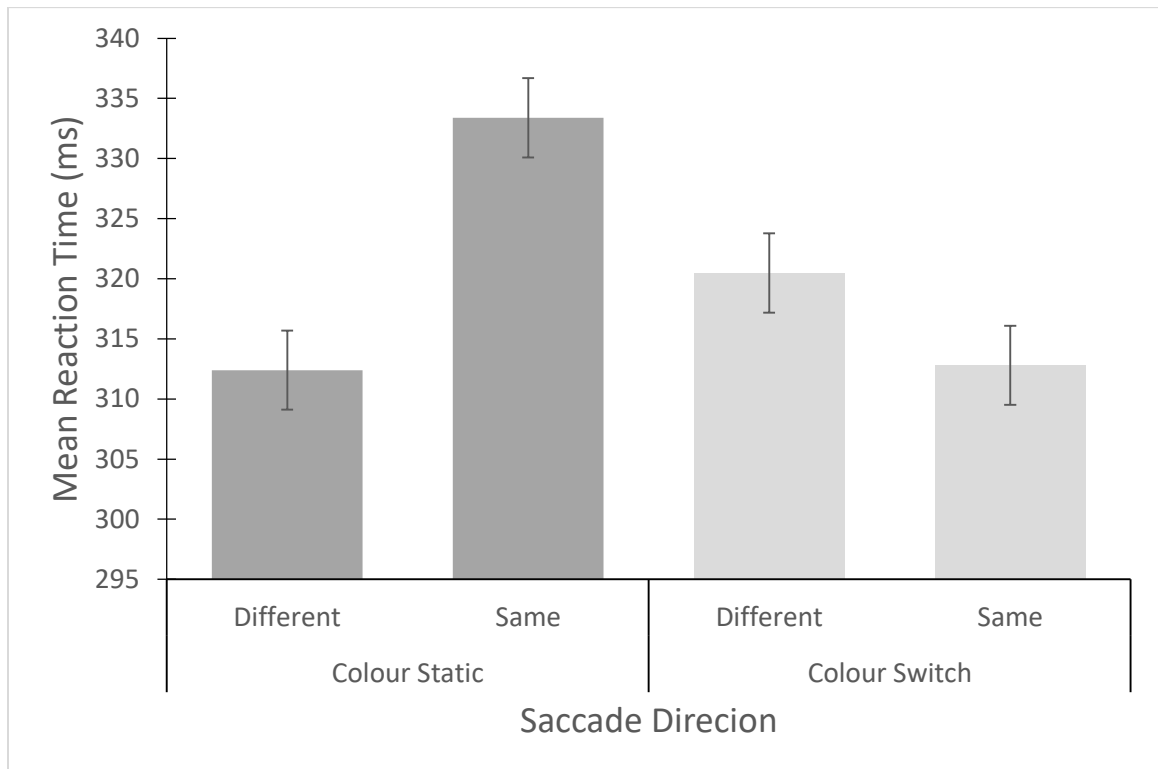
Figure 3.8. Mean saccadic reaction time (in milliseconds) of the colour signal condition, split by the presence of a target colour change (colour static vs colour switch) and by direction of the third saccade relative to the first (different vs same). For the colour static trials, a significant difference was found between same and different locations, indicating the presence of IOR. For the colour switch trials, there was no significant difference. Error bars represent standard error of the mean.

3.3 DISCUSSION

The results of experiment 1 showed a significant effect of spatial IOR for the arrow signal condition, as predicted. Mean RT was 16ms faster when saccades were in a different direction (vs same direction) than the first saccade. In comparison, the colour signal condition showed 8ms of IOR. While this seems comparable to the IOR generated by arrows signals, interactions showed that this is not the case. The difference occurs in the interaction between relative direction and whether the trial was colour static or colour switch. For colour static trials, 21ms of IOR was seen. During colour switch trials, no significant IOR effect was seen. In fact, saccades were 8ms slower when in a different direction compared to the same direction, but this effect was not statistically significant. Of 20 participants, 17 showed faster RT to the same direction, with only 3 showing the expected IOR effect. Therefore, coloured signals did not elicit IOR comparable to that of arrow signals.

Two explanations became apparent to justify the results after the completion of experiment 1. Firstly, it is possible that spatial IOR is occurring in conjunction with object-based IOR during colour switch trials. The other option is that IOR does not exist at all during these trials, due to changes of the visual environment.

The first explanation is the presence of an object-based IOR. As mentioned above, a possible explanation for the discrepancy in IOR within the colour switch trials is the presence of more than one inhibitory effect. In this case, the switching targets may have been treated as switching objects by participants.

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Tipper, Driver & Weaver (1991) first discovered object-based IOR effects using a paradigm that contained moving placeholders. After cueing one placeholder, both placeholders (placed horizontally, equidistant from fixation) rotated clockwise. Even after rotating 180°, so that the cued target appeared in an uncued location, inhibition was seen at the cued target, not at the cued location.

The difference between the experiment by Tipper et al. (1991) and the present experiment is the perceptible movement of the placeholders. When studying object-based IOR, Tipper et al. used targets whose movement was purposely obvious to the participants so that they covertly attended the location of the placeholders as they moved. In the present experiment, the colour switch was designed to be noticeable to the participant to avoid confusion. However, the colours simply disappeared and reappeared in a different location instantaneously, without any trackable movement around the display. This makes it difficult to assume that the switching colours were treated as continuous objects.

However, if participants were treating the coloured targets as separate objects, both spatial and object-based inhibitory effects would be seen. When the previously signaled location and object are in opposite locations, both may be inhibited, causing reduced or absent IOR. When the object and location remain static, these effects are additive (Leek, Reppa & Tipper, 2002). The effect of IOR in the colour static trials (21ms) is larger than that of the arrow condition (16ms), which supports the idea that two types of IOR may be occurring during the colour signal condition.

The second potential explanation is that the colour switch effectively "resets" the visual environment. Studies of visual attention assume that the visual environment within a trial does not affect the next trial: any inhibitory "tags" that existed have been effectively removed between trials by the disappearance of the display. This also assumes that the visual environment is treated as continuous within a trial. Experiment 1 was designed with this in mind: the fixation target never disappeared during the trial, even when colours switched. However, the colour switch was visible to the participant during the trials it occurred. While the colour switch was instantaneous and there was never a time that the placeholders disappeared completely, it is still possible that this effectively "reset" any existing inhibitory effects. Instead of having a recently attended, inhibited location, it is possible there was simply no inhibition for either target.

Additionally, the RT of each condition lends evidence to this explanation. Mean RT of same and different location trials within the colour switch condition (313ms and 320ms, respectively) were both faster than that of the same location (inhibited) trials of the colour static condition (333ms). If no locations were being inhibited, it is expected that RTs be generally faster, which is the case. This supports the idea that inhibition is occurring in neither location, as opposed to having inhibition in both.

CHAPTER 4 EXPERIMENT 2

4.1 INTRODUCTION

After the completion of experiment 1, the results were analyzed. Because two explanations for the results were apparent, experiment 2 was devised to resolve this by refuting one of these explanations. Experiment 2 sought to replicate the arrows condition from Experiment 1 while adding a new condition in which the peripheral targets were red or green and either stayed static or switched positions like the colour condition in Experiment 1. Critically, however, black coloured central arrows instructed participants which target to look toward.

The purpose of this was to determine if the colour switch negates IOR. If this were the case, IOR should be absent when the colours switch, regardless of the signal. The more likely explanation is that the negation of IOR is dependent on colour being relevant to the task. In experiment 2, the colour locations are never relevant, making it likely that the colour switch will not affect IOR, as the participants are not required to continually monitor their placement. Therefore, the hypothesis of the second experiment was that motor IOR would be equivalent for the black target and coloured target conditions, with both colour static and colour switch trials showing IOR.

4.2 METHODOLOGY

Experiment 2 had similar methodology to experiment 1. The experimental setup was identical, in the same lab with the same equipment, the only difference being the stimuli on the display screen.

4.2.1 PARTICIPANTS

Twenty new participants (5 male, 15 Female) were recruited, with none of them having participated in experiment 1 (Table 4.1). Eight were recruited by word of mouth and 12 were from the SONA undergraduate participant pool. Participants recruited through SONA received one credit point for participating. Ages ranged from 19-34 with a mean age of 24.4 (SD=4.21). Inclusion and exclusion criteria remained the same.

Participant	Gender	Age	Ocular Motility	Ocular Alignment		Near Visual Acuity		Colour Vision	
				Near	Dist	Right	Left	Right	Left
P21	F	21	Full	ortho	ortho	6/6	6/6	19	20
P22	F	34	Full	$E6^{\Delta}$	$E2^{\Delta}$	6/6	6/6	21	21
P23	F	21	Full	ortho	ortho	6/6	6/6	20	20
P24	M	34	Full	ortho	$E2^{\Delta}$	6/6	6/4.8	21	21
P25	F	19	Full	ortho	ortho	6/4.8	6/4.8	21	21
P26	M	26	Full	$X8^{\Delta}$	ortho	6/6	6/6	21	21
P27	F	26	Full	ortho	ortho	6/4.8	6/6	21	21
P28	F	20	Full	$E4^{\Delta}$	ortho	6/6	6/6	21	21
P29	M	26	Full	$X2^{\Delta}$	ortho	6/4.8	6/4.8	21	21
P30	M	27	Full	ortho	$X1^{\Delta}$	6/6	6/4.8	20	21
P31	F	21	Full	ortho	ortho	6/4.8	6/4.8	21	21
P32	F	22	Full	ortho	ortho	6/6	6/6	21	21
P33	F	26	Full	$X8^{\Delta}$	$X6^{\Delta}$	6/6	6/6	21	21
P34	F	25	Full	$X1^{\Delta}$	$X1^{\Delta}$	6/6	6/6	20	20
P35	F	23	Full	$X2^{\Delta}$	ortho	6/6	6/4.8	21	21
P36	F	20	Full	ortho	ortho	6/6	6/6	21	21
P37	F	26	Full	ortho	ortho	6/4.8	6/4.8	20	20
P38	F	26	Full	$X4^{\Delta}$	ortho	6/6	6/6	19	20
P39	F	20	Full	$X8^{\Delta}$	ortho	6/6	6/6	21	20
P40	M	24	Full	$X6^{\Delta}$	$E1^{\Delta}$	6/4.8	6/4.8	21	21

Table 4.1 Participant characteristics for experiment 2. Orthophoria is indicated by "ortho", esophoria by E and exophoria by X. All strabismus measurements are in prism diopters ($^{\Delta}$). Colour vision scores given are the number of correct plates out of 21.

4.2.2 ETHICS

Ethical approval was obtained from the Dalhousie University Research Ethics Board (Appendix B). All participants provided informed consent before beginning the study (Appendix F).

4.2.3 PROCEDURE

This experiment was performed as previously described in experiment 1. After providing informed consent, viewing the screening form and completing tests of visual acuity, colour vision, ocular motility and ocular alignment, the participant began the experiment. The two conditions were done in random order, with 120 total trials and optional 5-10 minute breaks scheduled between conditions, and halfway through the coloured target condition. The black target condition was a replication of the arrow condition seen in experiment 1 (Figure 3.3).

The coloured target condition (Figure 4.1) consisted of 80 trials and used the same timing of events as the coloured signal condition of experiment 1. After calibration and validation, the participant pressed the space bar to drift correct. The trial began with a black cross horizontally situated between two circular targets, one red and one green, randomly assigned left and right. The participant fixated on the center cross for 2000ms, and was again instructed to saccade to the target indicated by the black arrow as soon as it appeared, and then to immediately saccade back. Two arrows appeared during the duration of the trial, with the participant fixating on the black center cross before and after each signal. The red and green target switched places after the first

signal in half of the trials (Figure 4.2). The signal was always a black arrow, and only the

targets were coloured red and green. Timing remained identical to that of the coloured

signals condition of experiment 1. At the completion of both conditions, the participant

was given the debriefing form (Appendix D) and allowed to ask any questions before

leaving the lab.
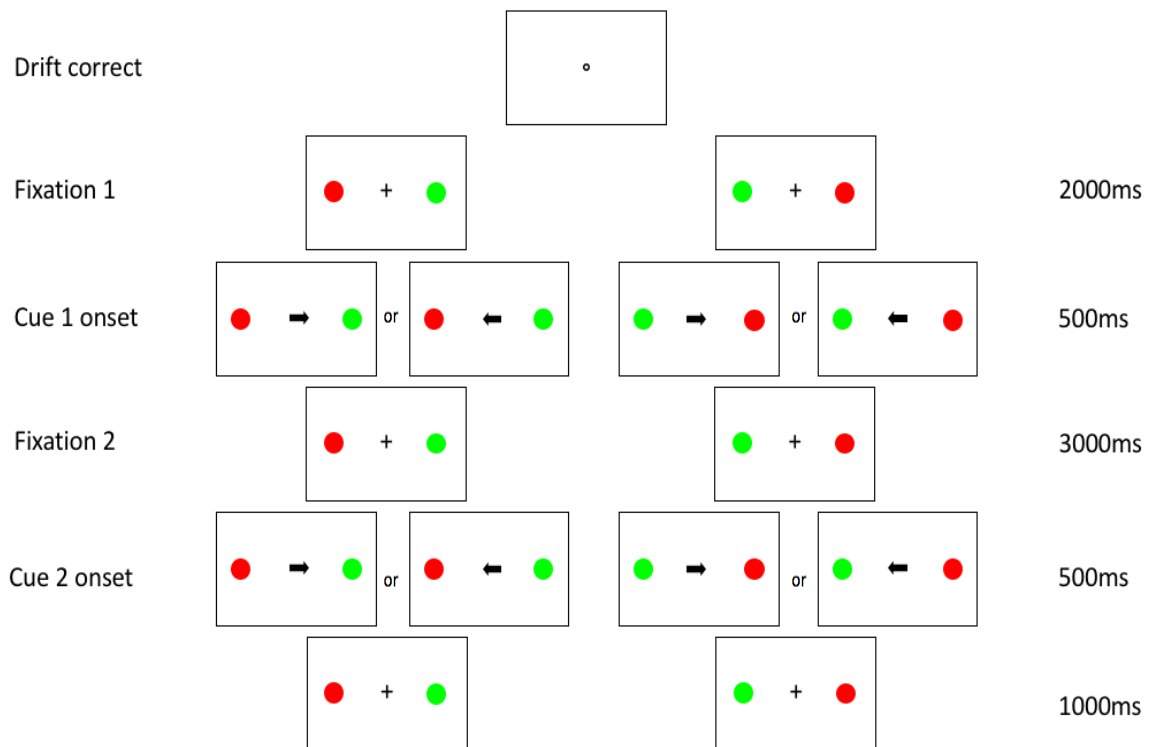
Figure 4.1. Sequence of events during one colour static trial. Half of the trials within the colour target condition were colour static, meaning the target colours did not change (i.e. red was on the left and stayed on the left during the duration of the trial). The first fixation screen involved red and green targets, one on the left, one on the right (p=0.5). After 2000ms of fixation a black arrow appeared pointing left or right (p=0.5) indicating the target to which the participant saccaded. After 3000ms of refixation, the second signal appeared, directing the saccade to either of the targets (p=0.5). Colour static and colour switch trials were mixed so that the participant did not know which type of trial was occurring at the beginning of the trial.
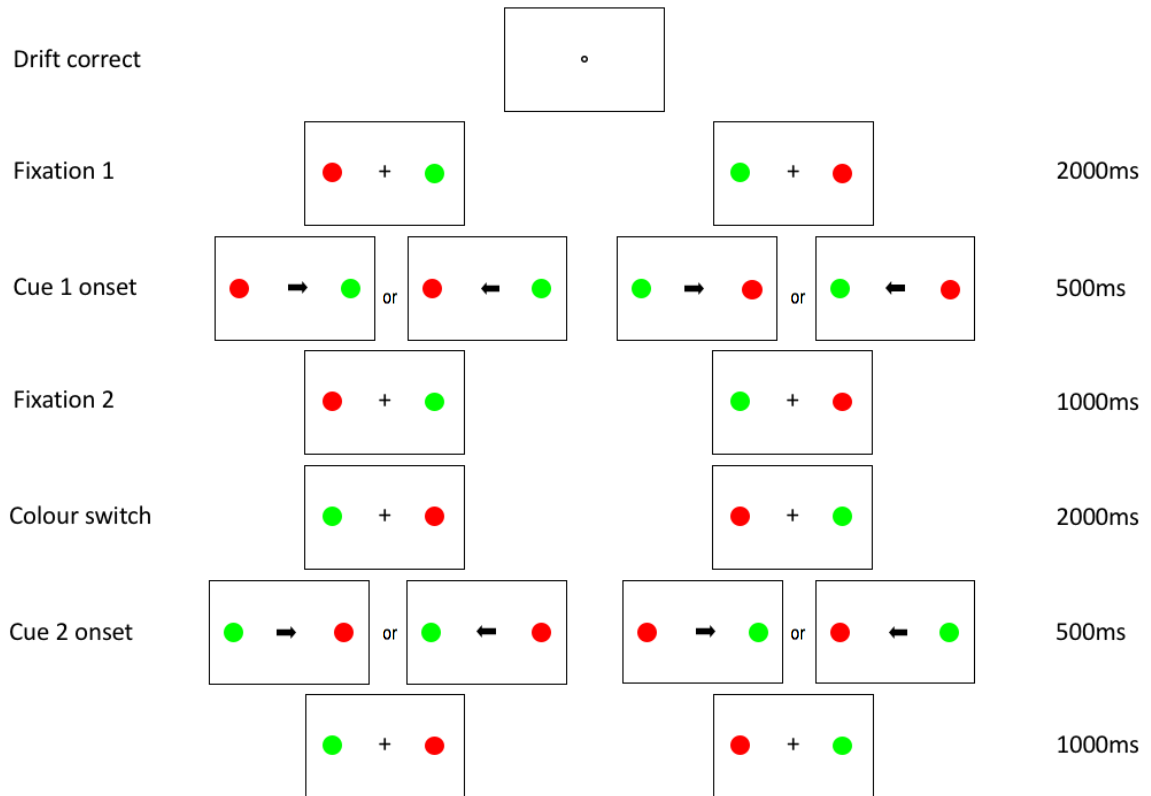
Figure 4.2 Sequence of events during one colour switch trial. Half of the trials within the colour target condition were colour switch, meaning the target colours changed partway through the trial (i.e. red was on the left but switched to the right 1500ms after the onset of the first signal). The first fixation screen involved red and green targets, one on the left, one on the right (p=0.5). After 2000ms of fixation the center cross changed to an arrow indicating the target to which the participant saccaded. After 1000ms of refixation, the coloured targets switched sides (i.e. if red was on the left, red was now on the right). 2000ms after the colour switch, the second arrow appeared, directing a saccade to either of the targets (p=0.5). Colour static and colour switch trials were mixed so that the participant did not know which type of trial was occurring at the beginning of the trial.

4.2.4 STATISTICAL ANALYSIS

Data were obtained using Data Viewer (SR Research) using the same method as experiment 1. The two conditions were examined separately using SPSS (v24, IBM). For both conditions, a repeated measures ANOVA was performed with the factors final saccade direction (left vs right), and relationship between first and final saccades (same location vs different location). The coloured target condition had the added factor of colour switch (switch vs static target colours). All analyses were tested for significance at an alpha level of 0.05. Variability is indicated by standard error of the mean.

4.3 RESULTS

Experiment 2 consisted of 800 total trials in the black target condition and 1600 in the colour target condition. In the black target condition, 1.8% of trials were excluded because of a saccade in the wrong direction, 1.1% due to insufficient saccade size, and 4.1% from z-score exclusion. A total of 55 trials (6.9%) were excluded from this condition. Of the 97 trials (6.1%) excluded from the colour targets condition, 0.9% were due to saccade director error, 0.8% to insufficient saccade size, and 4.4% to z score exclusion (Appendix G).

4.3.1 BLACK TARGET CONDITION

The dependent measure was reaction time of the saccade after the second signal (the third saccade of the trial). This was analyzed using repeated measures analysis of variance (ANOVA) with factors final saccade direction (right or left), direction relative to

the first saccade (same or different). Reaction time is the time measured between the

presentation of the signal and the onset of the saccade.

A significant main effect for relative direction (same or different side), $F_{(1,19)}$

=11.85, p=0.003 was found, indicating a shorter mean reaction time for objects located

in a different direction (265 ± 3.2 ms) versus the same direction (288 ± 3.2 ms) as the

first movement (Figure 4.3).
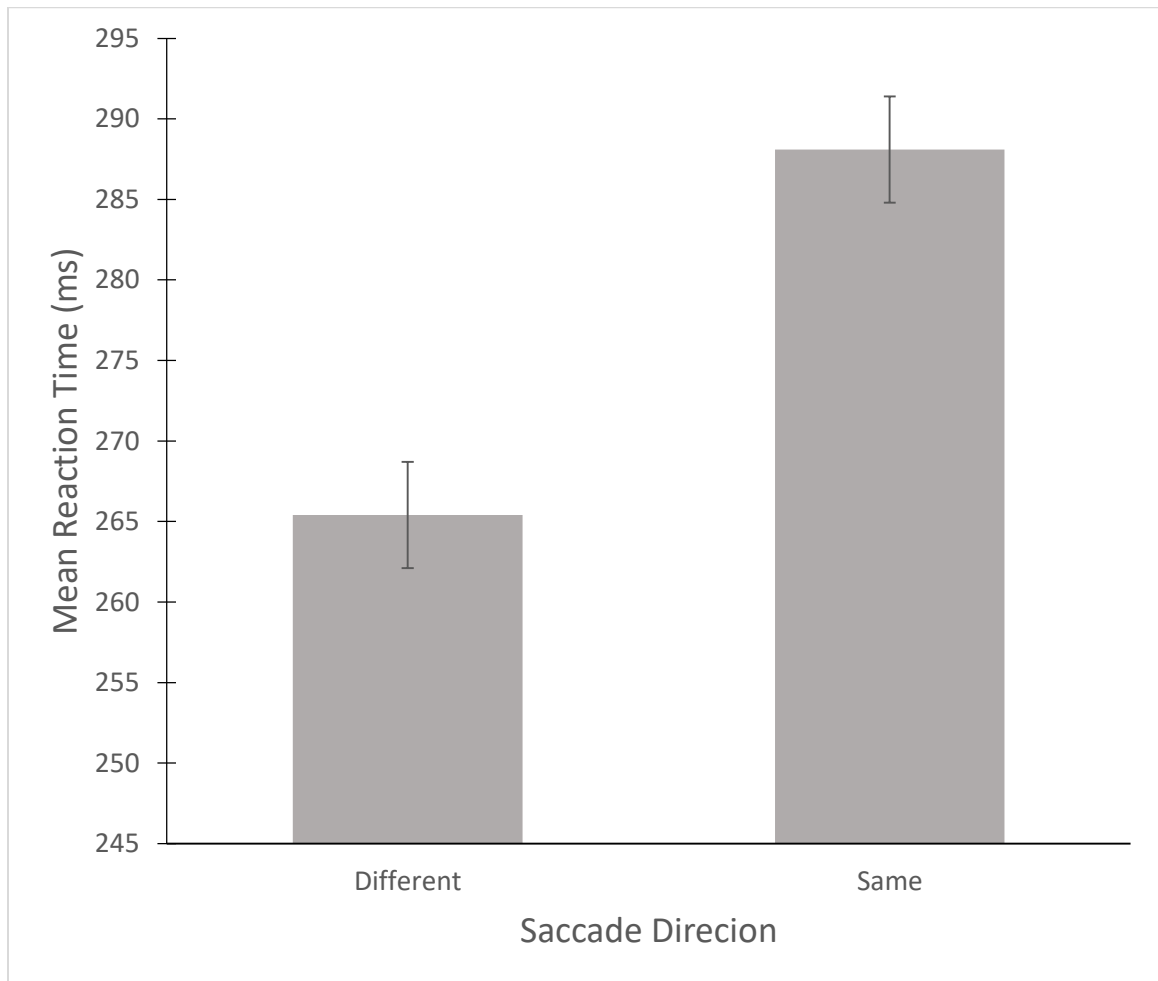
Figure 4.3 Mean saccadic reaction time (in milliseconds) of the black target condition, split by direction of the third saccade relative to the first (different vs same). A significant difference was found between the two, indicating the presence of IOR. Error bars represent standard error of the mean.

4.3.2 COLOUR TARGET CONDITION

A significant main effect of relative direction (same or different side), $F(1,19)=$ 16.10, $p=0.001$ was found, indicating a faster mean reaction time for objects located in a different direction (262 ± 2.1 ms) versus the same direction (283 ± 2.2 ms) as the first movement (Figure 4.4). No significant effect of colour change $F(1, 19)=0.821$, $p=0.376$ was found, nor did colour change interact with the relative direction of the saccade $F(1, 19)=2.50$ $p=0.131$.
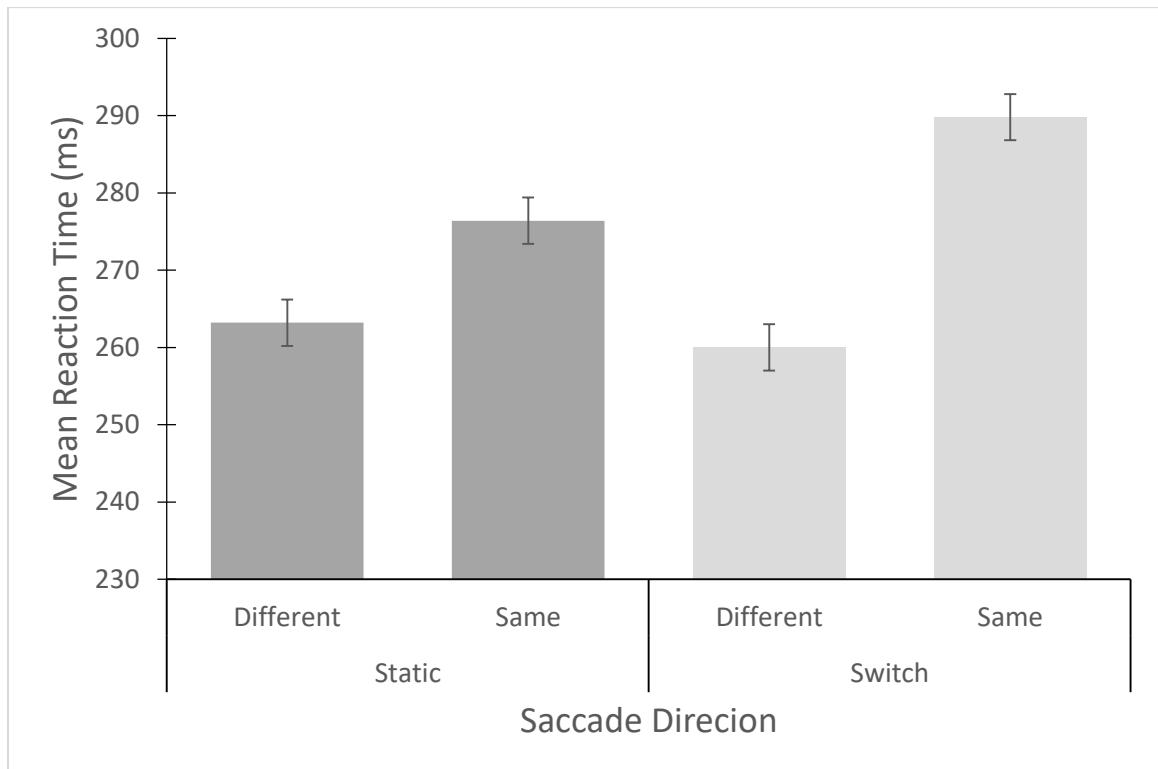
Figure 4.4. Mean saccadic reaction time (in milliseconds) of the colour target condition, split by the presence of a target colour change (colour static vs colour switch) and by direction of the third saccade relative to the first (different vs same). In both colour static and colour switch trials, a significant difference was found between same and different locations, indicating the presence of IOR. Error bars represent standard error of the mean.

4.4 Discussion

Experiment 2 was designed to determine whether the colour switch was causing a cancellation of IOR. Before beginning experiment 2, it was hypothesized that the black target and coloured target conditions would show equivalent IOR. More importantly, it was hypothesized that colour static and colour switch trials would both show significant IOR. The results showed that when arrows were used as signals in combination with coloured targets, IOR was seen in all conditions.

For the black target condition, mean RT was 23ms faster for different direction, compared to same direction, showing an effect of spatial IOR. For the coloured target condition, 21ms of IOR was found. Unlike experiment 1, IOR was apparent when the coloured targets were static (13ms), and when they switched (29ms). The difference in IOR between the two conditions was not statistically significant. IOR was absent in experiment 1 when the colours switched, but was still apparent in experiment 2 when the colours switched. This implies that the colour switch alone was not responsible for cancelling IOR. These results allow for the reexamination of the proposed explanations after experiment 1.

The first explanation involved the concurrent presence of object-based IOR with location-based IOR. The results of experiment 2 neither confirm nor refute this, as this experiment was designed mainly to determine whether the colour switch cancelled IOR.

The second explanation for these results was that the colour switch interfered with the continuity of the perceived visual environment, effectively resetting it. This was not seen in experiment 2. If changes in the visual environment caused a cancellation of

IOR, it should have been apparent in both experiments. As this was not the case, this is no longer a valid explanation.

However, a third explanation challenges the idea of object-based IOR: the colour switch effect may have been a unique feature associated with using a central signal that was matched to a peripheral target. During the colour signals condition of experiment 1, participants were required to track the locations of the colours so that they could be matched with the signals. In experiment 2, the targets were signaled by arrows, eliminating the necessity of covertly orienting the locations of the placeholders. The paradigm in experiment 1 relies on the participant to use both covert and overt attention. There is overt orienting when responding to the signals with saccades, but also covert orienting when tracking the placement of the colours. In this way, coloured signals are dependent on attentional control settings, where arrows are not.

Research by Folk, Remington and Johnston (1992) found that visual attention is dependent upon attentional control settings. In two similar experiments, they used abrupt onset white and red circles as peripheral cues and looked at reaction time of a button press response. Reaction times were slower when both the cue and target were red as opposed to when only one of the two were red, the other white. Thus, there is inhibition of red objects, but only when the participant knew to look for a red object. This implies that the attentional system must be set to respond to a colour for shifts of attention to colour to occur.

In experiment 1, the signal and target did share the same colour, meaning the participants' attentional control was set to colour. Participants were required to

monitor both the central signal, and the peripheral placeholders. In experiment 2, the

signal was never a colour, so attentional control was not set to colour. This difference

could be the reason endogenous colour signals do not behave the same way as arrows.

CHAPTER 5 CONCLUSION

5.1 Summary of Results

The purpose of the present experiments was to determine whether endogenous colour signals produce spatial IOR comparable to directional arrows. Previous studies of motor IOR have relied heavily on the use of arrow signals. However, some researchers have used coloured signals endogenously although they have not been compared to classic arrow signals (MacInnes et al., 2015). Because arrows and endogenous colour signals both serve the same function, it was hypothesized that the signals would create motor IOR in the same way.

In experiment 1, participants were required to saccade in response to endogenous signals. The arrow signal condition used arrows to direct eye movements, while the colour signal condition required the participant to match a colour appearing at fixation to the colour of a target before saccading to the target. Each trial consisted of three saccades, with the RT of the third saccade being measured. Mean RT was compared by relative direction: IOR was present if RT was slower when the first and third saccade were in the same direction, compared to when the saccades were in opposite directions.

In experiment 2, participants completed a modified version of experiment 1. Black target and colour target conditions were compared to determine whether the targets affected IOR. Otherwise, these conditions were the same: both used a black arrow as the signal. The results showed no IOR during colour switch trials in experiment 1, but IOR was apparent for all conditions in experiment 2.

After both experiments, two explanations remain: both location-based and object-based IOR is occurring for colour signals, or the process of matching a central colour signal to a peripheral colour target interferes with attentional control settings. Neither of these explanations can be conclusively accepted or refuted. However, it is conclusive that endogenous colour signals do not elicit motor IOR same way as arrow signals, in contrast to the original hypothesis that the two are equivalent.

5.2 LIMITATIONS AND FUTURE DIRECTIONS

Because a single explanation cannot be used to conclusively rationalize the results of these experiments, it opens several avenues for future experiments. Firstly, an experiment could be devised to further examine the object-based IOR theory. During experiment 1, the red target either appeared in the same location it was signaled (colour static trials), or at the location where the green target had been (colour switch trials). If the placeholders instead moved to new locations (i.e. vertically, with one above and one below fixation) location-based and object-based effects could be separated, allowing a determination of whether they are both in existence.

Another option is to use colour switch with another attribute that shows the participant that the targets are not continuous objects. If the colours not only switched, but also changed shape (from a circle to a square, for example) it would be interesting to see if participants viewed the targets as different objects, negating any potential object-based effect.

To further examine the effects of the colour switch, the timing and manner of the stimuli could be examined. The colour switch occurred 1500ms after the first signal, and 2000ms before the second. This was so participants noted the colour switch. If the colour switch instead occurred during the saccade back to center after the first signal, it would be imperceptible to the participant, thus potentially altering or negating motor IOR.

Red and green stimuli were used for several reasons: Ishihara's tests for colour deficiency has been shown to be extremely accurate in screening for colour vision deficits, and is specific to red-green deficiencies (Birch, 2010). Red and green are also opposites on the colour wheel, and not likely to be confused (unlike red and orange, for example). However, there are several reasons to use other colours. Firstly, to ensure that the above results are not exclusive to red and green, and are applicable to all visible hues. Additionally, there are connotations associated with red and green stimuli that may affect reaction time. While neither red or green are associated with a direction, from a young age we learn that red mean stop and green means go. Although this did not seem to affect the results of the current experiments, future experiments should take this into account when choosing colours.

In real-world situations, objects have many visual attributes including colour, shape, pattern, orientation and size. This experiment examined only one of these attributes. In the future, it would be worth examining whether similar results are seen when other object attributes are used as stimuli, or whether colour is a special case.

5.3 ORTHOPTIC SIGNIFICANCE

The basis of an orthoptic exam involves determining whether the afferent and efferent visual systems are functioning correctly. In very young children, visual acuity is often approximated using forced choice tests, which are a form of visual search. These tests involve the assessment of the afferent visual system by observing the efferent visual system. One example of this is Teller acuity cards, where the patient looks to the side of the card that contains a black and white grating pattern, if they have sufficient acuity to see the pattern (Cassin, 1995). One of the major assumptions made in forced-choice testing is that all the choices given to the patient are equally likely to be chosen if the patient cannot distinguish among them. The presence of motor IOR contradicts this assumption. Because IOR acts to bias the motor system against locations previously attended, it can be hypothesized that this could affect saccades that are made in response to environmental stimuli during clinical testing.

Additionally, the results obtained in experiment 1 showed that an object attribute, colour, influenced the observed IOR. This is an example of a motor bias that would affect a normal patient but presumably would not affect a colourblind patient, as he or she could not see the difference in stimuli. Colour blindness is thought of as a defect of the afferent visual system. Clinicians and patients alike may fail to realize that this visual defect can lead to changes in motor interactions with the environment.

5.4 CONCLUSION

This study is the first to determine whether colour can be used as an endogenous signal to generate IOR. It was hypothesized that coloured signals would generate IOR equivalently to a more common endogenous signal: a directional arrow. This was not supported by the results. Using an endogenous target-target paradigm, it was found that coloured signals did not generate significant spatial IOR when the target colours switched mid-trial. Two explanations remain: firstly, object-based effects may exist in tandem with spatial IOR effects. This supports previous findings of object-based IOR (Tipper et al., 1991). A second explanation is that attentional control settings interfere with the task, where monitoring both the signal and placeholders affects the observed IOR. Further research must be undertaken to conclusively determine the cause of the current results.

This study also gives us insight into how we visually process objects. Although most IOR research focuses on objects' spatial location, these results support the idea that an object's attribute, colour, also affects saccades. In this way, we've learned more about the features that affect the way our oculomotor system behaves.

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APPENDIX A – PARTICIPANT SCREENING FORM
SCREENING FORM:

If the answer to any of these questions is "**YES**", you are not eligible to participate in this study.
It is not necessary to disclose which of the questions or conditions applies to you.

- Please inform the investigator you are unable to participate.
- If you have any questions regarding the question or any of the conditions listed below, please ask the investigator.

1. **Are you under the age of 18?**

2. **Have you ever been diagnosed with any form of visual disorder?**

   Possible examples may include (but are not limited to):
   - Amblyopia
   - Colour Blindness
   - Glaucoma
   - Monocular deprivation for an extended period (e.g. eye patching)
   - Strabismus
   - Uncorrected near- or far-sightedness
   - Corneal or Retinal disease
   - Cataracts

3. **Have you ever been diagnosed with any form of neurological challenge or diagnosis which has affected your ability for coordinated eye movements, visual and cognitive processing skills, head and neck control in a seated position, or upper limb fine motor coordination?**

   Possible examples may include (but are not limited to):
   - Acquired Brain Injury as a result of: Trauma, Cerebral palsy, Encephalitis, Hydrocephalus, Meningitis, Stroke, Tumour, etc.
   - Developmental Coordinator Disorder
   - Learning Disability
   - Movement Challenges such as: athetosis, chorea, dystonia, spasticity, rigidity, etc.
   - Peripheral neuropathy
   - Seizure disorder
   - Vestibular disorder
   - Progressive conditions such as: Amyotrophic Lateral Sclerosis (ALS), Huntington's, Multiple sclerosis, Parkinson's disease, etc.

APPENDIX B – ETHICAL APPROVAL

Social Sciences & Humanities Research Ethics Board
Letter of Approval

December 08, 2016

Jessica Wood
Health Professions\Clinical Vision Science

Dear Jessica,

REB #:   2016-3983
Project Title: Inhibition of return for endogenous colour cues

Effective Date: December 08, 2016
Expiry Date: December 08, 2017

The Social Sciences & Humanities Research Ethics Board has reviewed your application for research involving humans and found the proposed research to be in accordance with the Tri-Council Policy Statement on *Ethical Conduct for Research Involving Humans.* This approval will be in effect for 12 months as indicated above. This approval is subject to the conditions listed below which constitute your on-going responsibilities with respect to the ethical conduct of this research.

Sincerely,

Dr. Karen Beazley, Chair

Post REB Approval: On-going Responsibilities of Researchers

After receiving ethical approval for the conduct of research involving humans, there are several ongoing responsibilities that researchers must meet to remain in compliance with University and Tri-Council policies.

1. Additional Research Ethics approval
Prior to conducting any research, researchers must ensure that all required research ethics approvals are secured (in addition to this one). This includes, but is not limited to, securing appropriate research ethics approvals from: other institutions with whom the PI is affiliated; the research institutions of research team members; the institution at which participants may be recruited or from which data may be collected; organizations

or groups (e.g. school boards, Aboriginal communities, correctional services, long-term care facilities, service agencies and community groups) and from any other responsible review body or bodies at the research site

2. Reporting adverse events

Any significant adverse events experienced by research participants must be reported **in writing** to Research Ethics **within 24 hours** of their occurrence. Examples of what might be considered "significant" include: an emotional breakdown of a participant during an interview, a negative physical reaction by a participant (e.g. fainting, nausea, unexpected pain, allergic reaction), report by a participant of some sort of negative repercussion from their participation (e.g. reaction of spouse or employer) or complaint by a participant with respect to their participation. The above list is indicative but not all-inclusive. The written report must include details of the adverse event and actions taken by the researcher in response to the incident.

3. Seeking approval for protocol / consent form changes

Prior to implementing any changes to your research plan, whether to the protocol or consent form, researchers must submit a description of the proposed changes to the Research Ethics Board for review and approval. This is done by completing an Amendment Request (available on the website). Please note that no reviews are conducted in August.

4. Submitting annual reports

Ethics approvals are valid for up to 12 months. Prior to the end of the project's approval deadline, the researcher must complete an Annual Report (available on the website) and return it to Research Ethics for review and approval before the approval end date in order to prevent a lapse of ethics approval for the research. Researchers should note that no research involving humans may be conducted in the absence of a valid ethical approval and that allowing REB approval to lapse is a violation of University policy, inconsistent with the TCPS (article 6.14) and may result in suspension of research and research funding, as required by the funding agency.

5. Submitting final reports

When the researcher is confident that no further data collection or participant contact will be required, a Final Report (available on the website) must be submitted to Research Ethics. After review and approval of the Final Report, the Research Ethics file will be closed.

6. Retaining records in a secure manner

Researchers must ensure that both during and after the research project, data is securely retained and/or disposed of in such a manner as to comply with confidentiality provisions specified in the protocol and consent forms. This may involve destruction of the data, or continued arrangements for secure storage. Casual storage of old data is not acceptable.

It is the Principal Investigator's responsibility to keep a copy of the REB approval letters. This can be important to demonstrate that research was undertaken with Board approval, which can be a requirement to publish (and is required by the Faculty of Graduate Studies if you are using this research for your thesis).

Please note that the University will securely store your REB project file for 5 years after the study closure date at which point the file records may be permanently destroyed.

7. Current contact information and university affiliation
The Principal Investigator must inform the Research Ethics office of any changes to contact information for the PI (and supervisor, if appropriate), especially the electronic mail address, for the duration of the REB approval. The PI must inform Research Ethics if there is a termination or interruption of his or her affiliation with Dalhousie University.

8. Legal Counsel
The Principal Investigator agrees to comply with all legislative and regulatory requirements that apply to the project. The Principal Investigator agrees to notify the University Legal Counsel office in the event that he or she receives a notice of non-compliance, complaint or other proceeding relating to such requirements.

9. Supervision of students
Faculty must ensure that students conducting research under their supervision are aware of their responsibilities as described above, and have adequate support to conduct their research in a safe and ethical manner.

APPENDIX C
EXPERIMENT 1 CONSENT DOCUMENTS

Title of Study: Inhibition of return for endogenous colour cues
SSHREB Approval #: 2016-3983

Who is in charge of this study?	Who is involved with this study?
Jessica Wood MSc Student, Clinical Vision Science program Dalhousie University jessica.wood@dal.ca	Dr. David A. Westwood Professor Division of Kinesiology Dalhousie University Email: dwestwood@dal.ca Phone: 494-1164

Introduction:
We invite you to take part in a research study run by Jessica Wood, a Vision Science Masters student. You do not have to take part in this study if you do not want to. It is entirely your choice. Your grades will not be affected if you choose not to take part. Even if you do take part, you may leave the study at any time for any reason. The study is described below. You will learn about the risks, inconveniences, or discomforts that might go along with taking part in the study. There probably will not be a benefit to you from taking part, but what we learn might help other people in the future.
Please ask as many questions as you want from the person running the study today. If you have any questions after you leave feel free to email the principal investigator.

Why are we doing this study?
We want to learn more about how people make eye movements in response to what they see. Right now we know very little about how the brain makes this happen. In particular, we want to know how your past eye movements affect the eye movements you make next. This study will help us understand eye movement planning better.

What type of study is this?
Everyone in the study will do the same tasks. We will compare how you do the task in slightly different conditions to see which conditions matter.

Who can take part in this study?
Males and females over the age of 18, who have good visual acuity and colour vision. You can use glasses or contact lenses if you need to. You cannot take part if you have had any ocular anomalies, neurological disorder, or a history of movement difficulty.

Who is running the study?
This study is being run by Jessica Wood, a Masters student in the Clinical Vision Science program at Dalhousie University, in conjunction with Dr. David Westwood, a professor of Kinesiology at Dalhousie University.

How many people are taking part in the study?
Overall, we hope to have 20 people take part.

Where is the study being done?
Right here! This is the Eyelink Laboratory in the Forrest building.

What you will be asked to do:
You will be asked to volunteer in a single session study. Prior to the start of the study you will be screened for any motor, visual, or neurological problems that would prevent you from being able to complete the experiment through use of a questionnaire. After you are cleared to participate, you will be asked to wear an eye tracking system that will track where you are looking on a computer screen (the Eyelink 1000plus, eye tracking device). The device uses infrared light to measure eye movements. Once the Eyelink is calibrated, you will start the experiment. The experiment contains two parts, one with black arrows and one with arrows and coloured targets. You will do both parts; one part will be chosen randomly to be first. The black arrow part involves eye movements directed by arrows. You will be looking at a cross with one circle on either side. You will start at the cross, then an arrow will appear directing you to look to one of the side circles. After you have moved your eyes to the circle, you will look back to the centre cross. A second arrow will direct your eye movements again to a side circle. This process is repeated until you have done it 40 times. At this time you will be given the option to have a five to ten minute break. After your optional break the next part of the experiment will begin. This part follows the same procedure as the first only this time there are red and green targets. This part has 80 trials with an optional break in the middle.

Possible Benefits, Risks and Discomforts:
There are no major risks to taking part in this study. There is nothing that should hurt you. Nothing will touch your eyes. There is no real benefit to you for taking part in this study, but you might learn a bit about eye movements. Plus you get to see interesting research equipment.

What will I receive for taking part?
There is no payment for taking part in this study, and we cannot pay for any expenses. If you signed up for this study using the Department of Psychology Participant System (SONA), you will receive one course credit for taking part in this study.

How will my information be protected?

Your information will be kept safe. We will use a code number, instead of your name, to keep track of your information. This means your name cannot be connected to your information. Only the researchers will know your name and your code number. Your results in the study will be put together with other people who take part. Only this 'group' information will be shared with other scientists. Your personal information will not be shared. These 'group' results might be published in a scientific article. All information from this study will be protected with a code key on computers in our laboratory. We will keep all information for at least five years after the study has been published as a scientific article. Then, we will shred all paper information and erase all computer information. You can choose to remove your information from the study, just let us know. Keep this consent form to help you remember taking part in this study.

Can I find out the results of the study?

We cannot give your individual results. But if you are interested, please write your email address on this consent form. We can send you a summary of the results. We can also explain what the study was about, and help you find more to read about the topic if you find it interesting.

What if I start the study but decide not to keep going?

That is no problem at all! You can leave the study at any time, for any reason. There won't be any negative effects from doing this. It will not affect your compensation either.

Questions and Contact Information:

Please keep this letter so you can remember the name of the study and who to contact later if you need to. At any time you can ask questions to the person running the study today. Later you can email Jessica Wood if you have any more questions. If you know someone who might want to take part in this study, you are welcome to share Jessica Wood's email address with him or her (Jessica.Wood@dal.ca).

Who makes sure this study is run safely?

This research study has been reviewed and approved by the Social Sciences and Humanities Research Ethics Board (SSHREB) at Dalhousie University. It is your choice to take part in the study, or not. You can drop out of the study at any time for any reason. There won't be any negative consequences to you for dropping out of the study.
If you have difficulties with, or wish to voice your concerns about, any aspect of your participation in this study, you may contact the Director, Research Ethics, Dalhousie University, Catherine Connors (ethics@dal.ca, or phone 902-494-1462)

Quick summary of the study:
- This study is about eye movements.
- It is your choice to take part in this study, or not.
- The study will last 60 minutes.
- You can withdraw from the study at any time, for any reason.
- Ask as many questions as you need to.
- You will make eye movements in response to what you see on a computer screen.
- You can take breaks whenever you need to.
- An eye movement tracking system will track your eye movements.
- There is no payment for taking part in the study.
- Your information will be protected: no one can find out your name and your information.

Title of Study: Inhibition of Return for Endogenous Colour Cues

Principal Investigator:
Jessica Wood, Clinical Vision Science Masters Student, Dalhousie University,
(jessica.wood@dal.ca)

Research Supervisor:
Dr. David Westwood, Division of Kinesiology, Dalhousie University
(david.westwood@dal.ca, phone# 902-494-1164).

I have read the information consent letter. I meet the requirements to take part in the study as outlined earlier. I have had the opportunity to ask all the questions I needed to. I understand that I can withdraw from the study at any time, for any reason. I understand that I can contact the person in charge of the study even after I leave the laboratory, using the contact information provided above. I understand that this study has been reviewed and approved by the Social Sciences and Humanities Research Ethics Board (SSHREB) at Dalhousie University. If I have any concerns or comments as a result of my participation in this study I may contact Catherine Connors, Director, Research Ethics, Dalhousie University, ph. 494-1462 email: ethics@dal.ca

I agree to participate in this study.

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

I wish to take part as a PARTICIPANT (use my data for the study): _____

I wish to take part as an OBSERVER (do not use my data for the study): _____

I would like to receive group results from this study: (provide email address if YES):

_____

Assigned Participant Code Number: _____

Date of birth: _____

Gender: _____

DEBRIEFING FORM

<u>Project title:</u> Inhibition of return for endogenous colour cues

<u>Principal investigator:</u>
>Jessica Wood, Clinical Vision Science Masters Student, Dalhousie University, (jessica.wood@dal.ca)

<u>Supervisor</u>
>Dr. David Westwood, Division of Kinesiology, Dalhousie University
>(david.westwood@dal.ca, phone# 902-494-1164)

Thank you for your participation in this research study. If you have any questions or comments about this experiment, please feel free to communicate them to us.

What is inhibition of return? You walk into a party, ready to meet your friend, but the room is crowded and you can't easily pick them out. From the level above you begin to scan the room looking for them. Your brain is wired with certain mechanisms to help make this search more efficient (so you can find your friend quicker). In particular, inhibition of return is a mechanism that results in slower responses to stimuli presented in locations that we have already paid attention to. This mechanism helps to guide our search behavior, creating a penalty of sorts for searching in places you have already looked. So, if you have already searched one part of the room for your friend and they weren't there, inhibition of return guides your behavior that you would be less likely to search there a second time. In this way, you optimize your search behavior and do not waste time searching where you have already looked.

Why would this mechanism have developed? As hunters and gathers long ago, our survival would have depended on our ability to not only search for the things we needed (e.g. food), but also to pay attention to events around us (e.g. predators or prey). Inhibition of return is thought to facilitate efficient search and response behavior and would have been one mechanism that may have guaranteed that we survived another day. When searching for food sources, energy would have been greatly depleted if we searched the same unsuccessful location over and over again. Further, searching the same location repeatedly may have allowed a predator to sneak up on us from behind.

<u>Further reading:</u>
Klein, R.M. (2000). Inhibition of return. *Trends in Cognitive Neurosciences*, *4*(4):138-147.

APPENDIX E - EXPERIMENT 1 ELIMENINATED TRIALS

Arrow signal condition

Participant	Trials lost to incorrect movement direction	Trials lost to insufficient saccade size	Outliers	Trials included in analysis	Total number of trials
P1	0	0	2	38	40
P2	4	0	1	35	40
P3	1	0	1	38	40
P4	0	0	1	39	40
P5	1	0	2	37	40
P6	0	0	4	36	40
P7	1	0	2	37	40
P8	1	0	3	36	40
P9	0	0	4	36	40
P10	2	0	3	35	40
P11	0	0	2	38	40
P12	0	1	1	38	40
P13	2	0	0	38	40
P14	1	0	1	38	40
P15	0	0	1	39	40
P16	1	0	2	37	40
P17	0	1	3	36	40
P18	0	0	2	38	40
P19	3	0	1	36	40
P20	0	0	1	39	40

EXPERIMENT 1 ELIMENINATED TRIALS

colour signal condition

Participant	Trials lost to incorrect movement direction	Trials lost to insufficient saccade size	Outliers	Trials included in analysis	Total number of trials
P1	3	0	5	72	80
P2	3	0	2	75	80
P3	3	0	3	74	80
P4	5	0	3	72	80
P5	3	0	5	72	80
P6	0	0	1	79	80
P7	1	0	3	76	80
P8	2	0	4	74	80
P9	3	0	4	73	80
P10	2	0	3	75	80
P11	1	0	3	76	80
P12	1	1	5	73	80
P13	2	0	3	75	80
P14	4	0	3	73	80
P15	0	0	4	76	80
P16	1	0	4	75	80
P17	1	0	2	77	80
P18	2	0	4	74	80
P19	3	0	2	75	80
P20	1	0	3	76	80

Title of Study: Inhibition of return for endogenous colour cues
SSHREB Approval #: 2016-3983

Who is in charge of this study?	Who is involved with this study?
Jessica Wood MSc Student, Clinical Vision Science program Dalhousie University jessica.wood@dal.ca	Dr. David A. Westwood Professor Division of Kinesiology Dalhousie University Email: dwestwood@dal.ca Phone: 494-1164

Introduction:
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Please ask as many questions as you want from the person running the study today. If you have any questions after you leave feel free to email the principal investigator.

Why are we doing this study?
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What type of study is this?
Everyone in the study will do the same tasks. We will compare how you do the task in slightly different conditions to see which conditions matter.

Who can take part in this study?

Males and females over the age of 18, who have good visual acuity and colour vision. You can use glasses or contact lenses if you need to. You cannot take part if you have had any ocular anomalies, neurological disorder, or a history of movement difficulty.

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Overall, we hope to have 20 people take part.

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Right here! This is the Eyelink Laboratory in the Forrest building.

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You will be asked to volunteer in a single session study. Prior to the start of the study you will be screened for any motor, visual, or neurological problems that would prevent you from being able to complete the experiment through use of a questionnaire. After you are cleared to participate, you will be asked to wear an eye tracking system that will track where you are looking on a computer screen (the Eyelink 1000plus, eye tracking device). The device uses infrared light to measure eye movements. Once the Eyelink is calibrated, you will start the experiment. The experiment contains two parts, one with black arrows and one with arrows and coloured targets. You will do both parts; one part will be chosen randomly to be first. The black arrow part involves eye movements directed by arrows. You will be looking at a cross with one circle on either side. You will start at the cross, then an arrow will appear directing you to look to one of the side circles. After you have moved your eyes to the circle, you will look back to the centre cross. A second arrow will direct your eye movements again to a side circle. This process is repeated until you have done it 40 times. At this time you will be given the option to have a five to ten minute break. After your optional break the next part of the experiment will begin. This part follows the same procedure as the first only this time there are red and green targets. This part has 80 trials with an optional break in the middle.

Possible Benefits, Risks and Discomforts:
There are no major risks to taking part in this study. There is nothing that should hurt you. Nothing will touch your eyes. There is no real benefit to you for taking part in this study, but you might learn a bit about eye movements. Plus you get to see interesting research equipment.

What will I receive for taking part?
There is no payment for taking part in this study, and we cannot pay for any expenses. If you signed up for this study using the Department of Psychology Participant System

(SONA), you will receive one course credit for taking part in this study.

How will my information be protected?
Your information will be kept safe. We will use a code number, instead of your name, to keep track of your information. This means your name cannot be connected to your information. Only the researchers will know your name and your code number. Your results in the study will be put together with other people who take part. Only this 'group' information will be shared with other scientists. Your personal information will not be shared. These 'group' results might be published in a scientific article. All information from this study will be protected with a code key on computers in our laboratory. We will keep all information for at least five years after the study has been published as a scientific article. Then, we will shred all paper information and erase all computer information. You can choose to remove your information from the study, just let us know. Keep this consent form to help you remember taking part in this study.

Can I find out the results of the study?
We cannot give your individual results. But if you are interested, please write your email address on this consent form. We can send you a summary of the results. We can also explain what the study was about, and help you find more to read about the topic if you find it interesting.

What if I start the study but decide not to keep going?
That is no problem at all! You can leave the study at any time, for any reason. There won't be any negative effects from doing this. It will not affect your compensation either.

Questions and Contact Information:
Please keep this letter so you can remember the name of the study and who to contact later if you need to. At any time you can ask questions to the person running the study today. Later you can email Jessica Wood if you have any more questions. If you know someone who might want to take part in this study, you are welcome to share Jessica Wood's email address with him or her (Jessica.Wood@dal.ca).

Who makes sure this study is run safely?
This research study has been reviewed and approved by the Social Sciences and Humanities Research Ethics Board (SSHREB) at Dalhousie University. It is your choice to take part in the study, or not. You can drop out of the study at any time for any reason. There won't be any negative consequences to you for dropping out of the study.
If you have difficulties with, or wish to voice your concerns about, any aspect of your participation in this study, you may contact the Director, Research Ethics, Dalhousie University, Catherine Connors (ethics@dal.ca, or phone 902-494-1462)

Quick summary of the study:
- This study is about eye movements.
- It is your choice to take part in this study, or not.
- The study will last 60 minutes.
- You can withdraw from the study at any time, for any reason.
- Ask as many questions as you need to.
- You will make eye movements in response to what you see on a computer screen.
- You can take breaks whenever you need to.
- An eye movement tracking system will track your eye movements.
- There is no payment for taking part in the study.
- Your information will be protected: no one can find out your name and your information.

APPENDIX G - EXPERIMENT 2 ELIMINATED TRIALS

Black target condition

Participant	Trials lost to incorrect movement direction	Trials lost to insufficient saccade size	Outliers	Trials included in analysis	Total number of trials
P21	2	2	4	32	40
P22	1	0	1	38	40
P23	0	0	1	39	40
P24	0	5	2	33	40
P25	0	0	1	39	40
P26	0	0	2	38	40
P27	1	0	1	38	40
P28	1	0	3	36	40
P29	1	1	1	37	40
P30	1	0	1	38	40
P31	1	0	1	38	40
P32	0	0	3	37	40
P33	0	0	1	39	40
P34	3	1	0	36	40
P35	0	0	2	38	40
P36	2	0	1	37	40
P37	0	0	1	39	40
P38	1	0	2	37	40
P39	0	0	2	38	40
P40	0	0	2	38	40

EXPERIMENT 2 ELIMINATED TRIALS

Colour target condition

Participant	Trials lost to incorrect movement direction	Trials lost to insufficient saccade size	Outliers	Trials included in analysis	Total number of trials
P21	1	5	5	69	80
P22	1	0	3	76	80
P23	1	0	3	76	80
P24	1	3	6	70	80
P25	1	0	3	76	80
P26	2	0	2	76	80
P27	2	0	1	77	80
P28	0	1	5	74	80
P29	1	0	4	75	80
P30	1	0	4	75	80
P31	4	1	4	71	80
P32	0	0	4	76	80
P33	0	0	1	79	80
P34	0	0	2	78	80
P35	0	0	4	76	80
P36	0	0	2	78	80
P37	0	0	3	77	80
P38	0	0	5	75	80
P39	0	0	5	75	80
P40	0	2	4	74	80