

Exploring the Dissociations between Overt and Covert Mechanisms of Spatial Attention
and Inhibition of Return

by

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ABSTRACT

Prompted by oculomotor theories of attention, the present experiments explore the role of saccade activation in the generation of two cueing effects: exogenous capture (Experiment 1) and inhibition of return (IOR; Experiment 2). Exogenous capture is short-lived and marked by faster responding toward recently stimulated locations, whereas the longer-lasting IOR manifests as slower responding toward those locations. Within each experiment, Group A performed in a dual-task in which on most trials a peripheral target had to be identified but infrequently a central arrow probe called for an eye movement instead, while for Group B the tasks were the same except saccade trials were frequent and target identification trials were infrequent.

In Experiment 1, for group A uninformative cues captured attention as measured by faster digit identification at the cued location, an effect not accompanied by saccade activation. For group B, cues generated saccade activation without capturing attention. Thus saccade activation need not accompany exogenous covert capture, and covert capture need not accompany saccade activation.

In Experiment 2, group A exhibited IOR which slowed digit identification, but did not affect saccadic responding, while Group B exhibited no IOR in either digit identification or eye movement trials. This finding provides converging evidence that IOR can be dichotomized into two forms; one which delays motor production itself (Evidenced amply elsewhere, e.g., Taylor & Klein, 2000) and another which delays responding by applying inhibition at a perceptual-motor interface which can operate in independence from its motoric cousin.

LIST OF ABBREVIATIONS USED

ACS	Attentional Control Setting
CTOA	Cue-Target Onset Asynchrony
EM	Eye Movement
IOR	Inhibition of Return
ISI	Inter-Stimulus Interval
MDiff	Mean Difference
ms	Millisecond
OMRH	Oculomotor Readiness Hypothesis
RT	Response Time
S#	Stimulus Number (within a sequence)
S-R	Stimulus-Response
SOA	Stimulus Onset Asynchrony
SRT	SRT
VEP	Visually Evoked Potential

GLOSSARY

Attentional Control Settings (ACSs): Many of the attentional phenomena that we study we assume to be both caused and measured within a single trial (e.g., cue generated response facilitation). However, many strategies will persist throughout the experiment and can modulate our observed effects. Participants will narrow their attentional window to task relevant space (i.e., where the targets can appear) and cued capture will be weaker outside of that region (Ishigami et al, 2012), or they might prioritize one task over another resulting in dispreparation to perform their secondary task (e.g., the mean SRT differences between E1 and E2 in this study). In method, the relevance of different region os task-space is varied to create a measurable difference in the theoretical ACS. Since an ACS is an expected consequence rather than a design manipulation, in methods and results we discuss the relevant vs. irrelevant regions, but in the discussion we interpret the differences between these two regions in the context of an ACS.

Inhibition of Return: Broadly, Inhibition of Return is the phenomenon of slowed processing at previously stimulated locations. It is well accepted that there are at least two forms of IOR; one which impairs target processing at a previously processed region (an input flavor) and another that seems to inhibit responding toward previously processed regions (an output flavor).

The Modes of Attention: Shifts in attention can occur either endogenously or exogenously. Shifts voluntarily made toward a region of interest or importance are under endogenous control whereas those made reflexively to external stimulation are under exogenous control. When I am looking for a taxi, the attentional shifts I make along the street to find one are endogenously driven. While focussing on my search I might hear a horn and shift with a start to attend a nearby car; an exogenously driven shift.

The Modalities of Attention: We can improve sensory inputs via overt or covert means. One way is to shift a sensory organ toward the source of stimulation; for instance we might shift our eyes or our head to bring an object in line with our field of best vision. Alternatively, we can bring an object into awareness without an overt shift. When you attend to a visual object without looking directly at it, you have an obvious sensation that it is being drawn into sharper relief.

Oculomotor Readiness Hypothesis (OMRH): According to the this efference hypothesis of attention, covert spatial attention and eye movement preparation are unconditionally linked. Under one interpretation, the same systems that activate when we move our eyes in space might activate to a lesser degree to achieve covert orienting. This hypothesis makes two explicit predictions: (1) if you attend a location, eye movements to that location should be facilitated, and (2) if you prepare to move your eyes to a location, the detection of events there should be facilitated.

Chapter 1 Introduction

Visuospatial attention can be operationalized as the differential allocation of perceptual resources to areas of salience or interest to the observer. In some instances a shift is driven reflexively by your response to an unexpected stimulus (i.e., a loud noise), this is referred to as an exogenous (from without) shift in attention. In other instances attention might be intentionally and purposefully allocated to something that could otherwise easily be ignored in order to achieve some goal, like attending to the streetlight so as to continue on your way when it turns green; this is referred to as endogenous (from within) attention. Further, orienting in space can be accomplished either overtly or covertly. An overt shift involves the orienting of the body like the eyes or head to optimize perceptual input, whereas a covert shift is defined by the absence of the bodily shift and might be best exemplified by the saying “to look out of the corner of one’s eye”. These two dichotomies can be crossed together to form four relatively unique ways of attending to space.

Klein and Lawrence (2011) have proposed a complimentary model (Figure 1, below) where in addition to separating shifts of attention by whether they are accomplished via exogenous or endogenous modes, they further distinguish at least four domains; space, time, sense, and task, upon which these modes of control might be operating (Klein & Lawrence, 2011). These four domains are described below. Overt and covert attentional shifts might be seen as a third dimension on this figure (Klein & Lawrence, 2012).

		Mode of allocation	
		Exogenous	Endogenous
Domain of allocation	Space		
	Time		
	Sense		
	Task		

Figure 1. A framework of attention proposed by Klein & Lawrence (2012).

Much of what we understand today about selective attention we came to understand through the lens of spatial attention. Posner’s original cue-target paradigms for exploring the nature of attention were primarily designed to tap into spatial processes, though they inevitably reflect the effects of the allocation of attention in time as well. In these paradigms the presentation of a cue results in the establishment of a restricted region of enhanced attentional processing, the effect of which is measured by comparing the speed and accuracy of responses to targets subsequently presented within and outside of that region. The effects observed crucially depend upon whether participants can predict the location of the upcoming target (exogenous vs. endogenous cues) and the time between the cue and the target (CTOA). When the cue generates exogenous activation response times are faster for targets presented at the location of the cue, but this effect is short-lived. After this facilitation dissipates the pattern actually reverses, showing comparatively slower response times at cued locations (Posner & Cohen, 1984). On the other hand, when the cue predicts the location of impending relevant information,

typically a participant will endogenously engage that location and facilitation persists into much longer CTOAs.

Temporal selection is a related process by which one's selective mechanisms can be brought to bare at a particular point in time more effectively than in others. Selection can once again be characterized by exogenously driven bursts in activation (i.e., a loud noise rapidly rouses an unwitting person to an active state) or endogenous "preparation" to attend stimuli appearing at crucial time points (i.e., using a light change on the other street to prepare for your own green light). These two modes of temporal attention have different effects that have been experimentally separated. Temporal selection wrought by endogenous preparation results in a true performance advantage: faster and more accurate responding at the time that a signal is expected (Lawrence & Klein, 2012). However, the effect of exogenous activation is largely dependent upon endogenous factors. When participants are endogenously using a stimulus to predict the onset of a target, additional exogenous stimulation tends to result in a lowered response criterion rather than a genuine performance advantage at the time of the shift, manifested as faster but more error-prone responding at and immediately following the time of exogenous stimulation. On the other hand, when participants are not preparing to attend the stimulus endogenously, the exogenous activation it causes can result in a real performance advantage.

Sensory attentional selection has been observed in the fencer, who, when placed in a context wherein visual and kinesthetic sources of information are perfectly married is strongly biased to use visual feedback to direct their behaviour even when they could

benefit by using kinesthetic feedback (or both!) instead (Jordan, 1972 as cited in Posner, Nissen, & Klein, 1976). A sensory selection *error* can be observed in the fake hand paradigm, where participants view a model of a hand in close proximity to their concealed hand and misidentify the location of their real hand as being closer to the fake hand than it actually is, a finding that might be categorized more broadly under phenomenon of visual dominance. Such findings have precipitated into what is now understood to be a probabilistic linkage between sensory modalities resulting in a powerful and largely automatic linkage between selection systems across sensory modalities that are regardless dissociable (Armel & Ramachandran, 2003).

The effect of attention to task can be made evident by observing how participants' performance changes as a consequence of whether different trial types are included in a single block ("mixing") or separated into discrete blocks ("blocking"). It was ambiguous whether the aforementioned human tendency for visual dominance was a hard-wired property or an artifact of the choice of the participant in a given task. However, by separating visual, kinesthetic, and combined stimulation targets to discrete trials, then mixing them within a single block (and thus making the predictive value of either sense alone insufficient) Klein (1974) revealed that participants adopted a hybrid response strategy wherein visual dominance was eliminated and the input from both visual and kinesthetic sensory streams more closely resembled a horse-race model¹ than the effect of

¹ Under a horse-race model, two mental operations "race" to transmit content regarding the same decision to the observer. This can be conceptualized as though there were two theoretical RT distributions simultaneously randomly sampled, with the faster of the two samples becoming the observed behavioural value.

overshadowing. In this way the choice to block or mix two or more trial types can avail an experimenter of information about the interactions and linkages of systems used in those tasks. These experiments show that manipulations on the task domain are valuable as they can be leveraged to better understand the other modes and domains of attention.

1.1 Attentional Capture & Attentional Control Settings

Although it was once believed that irrelevant abrupt onset cues invariably capture attention (Yantis & Jonides, 1984; Jonides & Yantis, 1988), it is now known that when observers can forecast where their target will appear, they can often prevent capture by objects outside of that region (Yantis & Jonides, 1984; Theeuwes, 1991; Ishigami, Klein & Christie, 2009). For example, Yantis and Jonides (1990) showed that when spatial cues forecast the location of upcoming targets, participants can ignore onset distractors that appear elsewhere in space. When people begin to automatically prioritize some sensory inputs and filter others based upon what they know about their given task, the mechanism by which this is accomplished is usually referred to as a “Attentional Control Setting” (ACS).

An ACS can also be measured by comparing the degree to which uninformative cues capture covert attention when participants are performing a target task. This can be done by comparing capture when the cue is presented within task-relevant space to capture when it is presented outside of task space. Ishigami et al (2009; their display shown in Figure 2) demonstrated that when the vast majority of task-relevant objects are presented within a subregion of a visual scene, uninformative cues presented outside that region were less likely to capture attention (as measured by slower and/or less accurate

responding to of subsequent targets) than those presented within the attended region. Rather than being caused by endogenous cues on the present trial, this was caused by the spatial expectancies of the participant developed over the course of the entire experiment. This is demonstrable by the fact that the participants' ability to filter the irrelevant cues increased as they progressed through the blocks of the experiment.

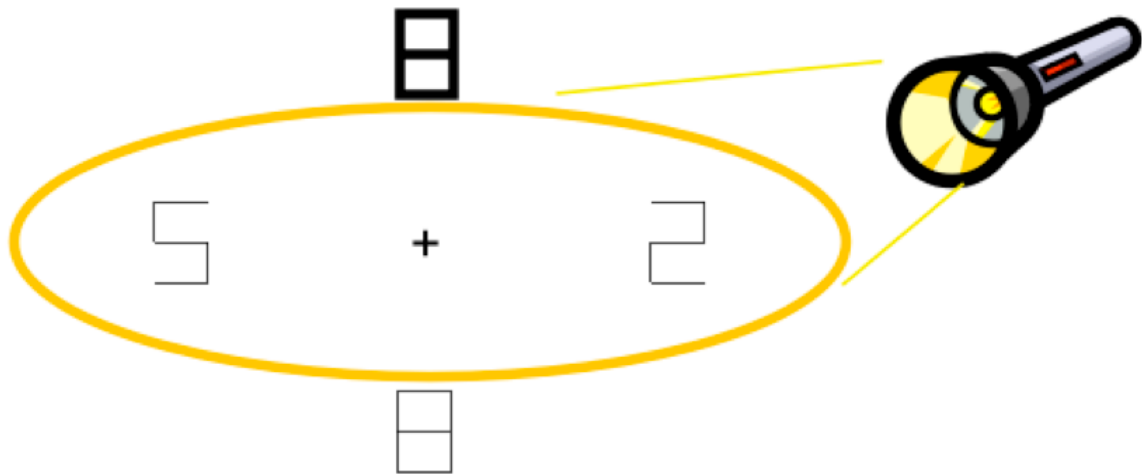


Figure 2. The window of attention. Digit identification targets only appear in one region of the display. Participants tend to narrow their window of attention to this region. This is why cues such as the one shown above are expected to capture attention less reliably and less strongly than those presented within the window.

In another experiment using a similar stimulus array, Ishigami, Hamm, Satel and Klein (2012) found converging neurophysiological evidence that the irrelevant cues were differentially affecting attention. Again, cues presented in irrelevant region generated weaker capture effects than those presented in the relevant region as indicated by comparatively faster RT following irrelevant mismatching cues. This effect was also accompanied by a reduction in cue-generated Visually Evoked Potentials (VEPs) specifically for irrelevant cues. A VEP is a waveform generated in the visual cortex in response to briefly presented visual stimuli and the amplitude of this waveform is

typically larger when relevant stimuli are presented than when irrelevant ones are, making it a likely neural correlate of covert attention. Unfortunately without a no cue condition as a baseline it is difficult to infer in a relatively meaningful way *how* filtered the irrelevant cue was, but the VEP was found to be to some degree modulated by the ACS.

1.2 The Present Study

The experiments presented here are modeled on an experiment from Ishigami et al (2009). In their third experiment, by manipulating the spatial probability of targets such that 80% of task-relevant stimuli occurred within one region, Ishigami et al (2009) demonstrated that the strategies adopted by their participants enabled them to resist involuntary attentional capture from cues presented outside of that region. One key difference between the Ishigami et al. experiment and the present experiments; the "line" probes used by Ishigami et al. to explore the effects of endogenous and exogenous attention on the experience of illusory line motion by arrow probes that called for endogenously activated saccades. The purpose was to explore the state of activation of the oculomotor system as a joint function of uninformative peripheral stimulation (exogenous) and attentional control settings (endogenous) put in place because targets in the primary task only occurred at some locations. The second difference was that, in two different experiments, the interval between the uninformative peripheral stimulation and either the primary task target or oculomotor probe was manipulated with a short interval (as in Ishigami et al) used in Experiment 1 and a long interval used in Experiment 2.

At the start of each trial four figure-8s were presented above, below, to the left, and right of a central fixation stimulus. Peripheral cues were equiprobable at all locations across all trials. In 80% of trials, participants were required to identify a peripheral target (an 8 turned into either a 2 or a 5; requiring participants to press ‘z’ or ‘/’, respectively). In 20% of trials, subjects were required to respond to centrally presented arrows by executing a saccade to the placeholder indicated by the arrow. These two tasks were randomly inter-mixed. Arrow targets directed eye movements equiprobably both inside and outside of the region of target presentation, and as such provided a measure of saccade activation inside and outside of the hypothetical “window” of attention (See Figure 3 for a breakdown of all trial types). The time-course of stimulus presentation is shown in Figure 4, p.17.

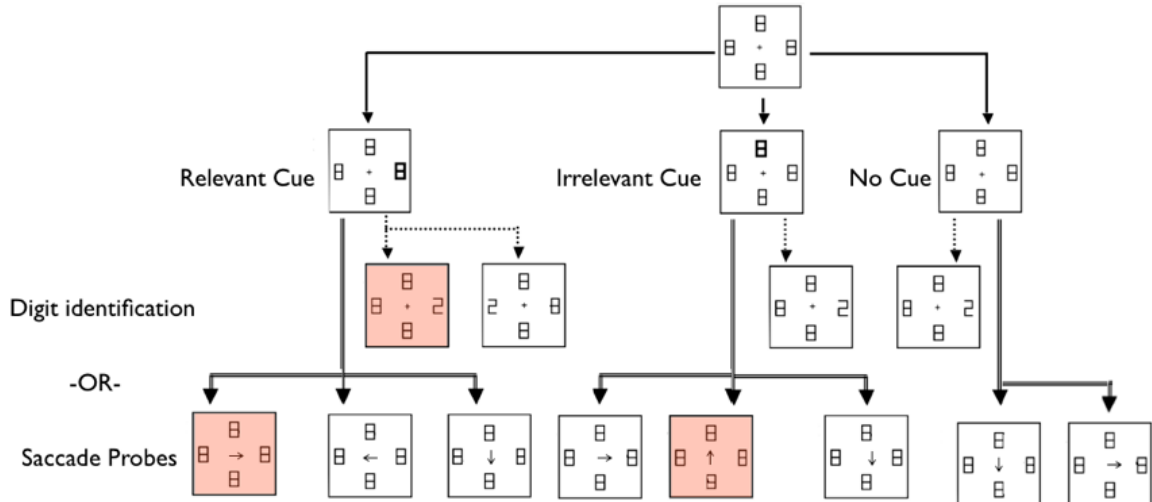


Figure 3. A flow Chart of Possible Trials in the present four experiments. Separated by cued region, targeted or probed region, and cue-target location matching or cue-arrow direction agreement. Note that identification targets are only ever presented in one region (on one axis). Shown in red are the cells in which the direct effects of attentional capture (E1) or IOR (E2) might be observed. The bottom row illustrates each of the eight combinations of cue and saccade probe, and the row above it illustrates each of the four combinations constituting a digit identification trial.

Chapter 2 The Oculomotor Readiness Hypothesis and Two Modes of Attention

2.1 Oculomotor Readiness Hypothesis of Attention

Given the everyday overlap between what one is attending to and what one is foveating, it might seem reasonable to imagine that the same brain system which underlies shifts in attention also controls the execution of eye movements. One may further note that one can, *with some care*, focus one's attention in the peripheral visual field without shifting one's eyes. This phenomenon is often referred to as “looking out of the corner of your eye”. It could be that even these covert shifts of attention result from preparedness of the same system that generates eye movements. The proposal that endogenous shifts of covert spatial attention results from sub-threshold preparation of an eye movement, which was first put forward by Klein (1980), has been dubbed the Oculomotor Readiness Hypothesis of Attention (OMRH).

From this proposal comes two testable predictions. If a subject is attending to a region of space, eye movements should be facilitated toward that region. The opposite must also be true, the preparation to move their eyes to a region of space should always be accompanied by improved target detection at that region. Klein (1980; Klein & Pontefract, 1994) tested these two predictions, and somewhat regretfully rejected the OMRH when both predictions were repeatedly disconfirmed (see also Hunt & Kingstone, 2003).

In his first experiment Klein (1980) instructed his participants to perform in a dual task wherein the primary task strongly encouraged saccade preparation and the secondary task was used to determine whether participants were covertly attending to the

probable saccade location. When participants were presented with an asterisk target either left or right of fixation, they were to move their eyes in a predetermined direction. When instead they detected a flash at a peripheral placeholder they were to release a depressed keyboard button as quickly as possible. The majority of trials (75%, catch trials excluded) called for saccadic responses. Importantly, participants were no faster to detect a peripheral flash when it appeared at the probable saccade location than when it did not, reflecting the fact that focal oculomotor readiness was uncoupled with covert attention at the cued location.

In a second experiment arrow cues provided advance knowledge of the likely location of detection onsets but not saccade onsets and most trials required the detection of peripheral onsets, participants responded faster when the target location matched the cued location than when they didn't. Despite this, performance in a concomitant saccade task was, statistically speaking, unaffected by the cue. Preparation to process one visual region (endogenous orienting) was not accompanied by facilitation of saccades to that same region. The endogenous maintenance of attention and saccade preparation had been double-dissociated through the manipulation of task demands.

In 1987, Rizzolatti, Riggio, Dascola and Umiltà asserted that if the OMRH were true, then participants in Experiment one of Klein, 1980, would not have been able to prepare their saccade before the onset of the probe stimulus because the probe stimulus was equally likely to appear left or right of fixation (recall that participants would always saccade toward the same location regardless of probe location). *If* onsets could not be processed without first shifting the attentional beam to their location, then participants

would have to first prepare their oculomotor system to move the eyes from center to the probe, then to the location of response on every trial. This would result in the observed pattern of results; no effect of attentional facilitation and a seeming cost to additional reorienting of the saccadic system. It is important to note that in Klein's 1980 paper two separate experiments rejected the OMRH and no challenge was offered by Rizzolatti et al. against experiment two, but on the basis of this criticism and their causal interpretation of the meridian effect the authors argued in support of the oculomotor readiness hypothesis referring to it as a "premotor theory of attention".

In Klein and Pontefract (1994), two further experiments again ruled out the OMRH and provided converging evidence that endogenous attention and saccade preparation were not the same thing. In experiment one, participants were asked to perform a dual-task wherein most trials required eye movement responses commanded by a computer-generated voice ("Right" or "Left") and the remaining 20% of trials required manual detection responses. Preceding the probe which signaled and demanded the required response, auditory cues (A computer-generated "Right", "Left", or spatially non-informative "Ready") were presented. These cues were predictive of the probable location of upcoming saccade "targets" (87.5% predictive) but were uninformative of peripheral detection targets. It was found that participants showed definite cue match effects for saccadic responses, while simultaneously showing no facilitation of target detection in the region of saccade preparation. In the second experiment most trials required manual responses while the remainder required saccadic responses, and cues only predicted the upcoming location of detection targets. The results showed that

detection was facilitated by precues but saccades were slower in the attended region. While participants were covertly attending the cued location in advance of the target, overt and covert attention systems were actually spatially contra-prepared.

Klein and Pontefract (1994) inferred that the observed loss of cueing effects in their secondary tasks was owing to differences in the preparatory states of covert and overt attentional systems. However, participants might have sacrificed their overall response speed in the secondary task to prepare their response for the primary task and this response conflict might have masked existing cueing effects in the secondary task. To test this, Hunt and Kingstone (2003) dropped the speeded task used in 1994 in favor of an unspeeded masked discrimination (line orientation: Vertical v. Horizontal) task. Now participants were only required to make a speeded saccade, and no response conflict should arise. In their experiment wherein saccade trials were more frequent than discrimination trials, participants' eye movements were facilitated toward the cued location, but participants were actually slower to discriminate targets at the cued location. When the discrimination task was made frequent, participants made fewer discrimination errors at cue matched locations and this perceptual advantage was not accompanied by saccade facilitation. Even when response competition was accounted for, performance in the saccade and detection tasks dissociated completely.

2.2 Tests of the OMRH within the Exogenous Mode of Attention

The previously discussed experiments explored the OMRH in an endogenous context because participants could spatially prepare themselves in advance of the target stimulus (Klein 1980; Klein & Pontefract 1994; Rizzolatti, 1987; Hunt & Kingstone,

2003)). However, limited evidence has also been marshaled to determine whether oculomotor preparation must accompany covert shifts of exogenous attention. In fact, the more recently collected and still somewhat limited evidence for a linkage between exogenous covert attention and motor preparation is on the whole quite strong. In one study Belopolsky and Theeuwes (2012) presented participants with an array which had one of its four place holders absent at random. Five hundred ms after presentation of the array, all four locations were replaced with block characters, three of which were letters and one of which was a number that informed the participant to execute a saccade. The number was presented at random at one of any of the four locations. If the number was “1” they were to saccade to the top left placeholder, if 2 then the top right placeholder, and so on. Their analysis revealed two effects: 1. responses were faster when the number appeared at a placeholder-absent location than at a placeholder-present location (presumably because onset targets can exogenously capture attention), and 2. responses were faster when the target number matched the location of the saccadic response. Since saccadic eye movements were facilitated toward the locus of covert attention, the authors proposed this as evidence for a premotor theory of attention. Though this evidence is consistent with the OMRH, it might also be a saccadic S-R compatibility effect like the one observed in experiment one of Klein (1980); he found that saccades were faster when they were directed toward the “go” stimulus than when they were directed away from it but saccade preparation was not inferred from this result. If this were the case Belopolsky and Theeuwes’ finding would have little to do with the preparatory state of overt attentional systems.

However, recently Smith, Schenk, and Rorden (2012) provided convincing evidence that the exogenous orienting of attention is mediated by sub-threshold activation of a saccade program using a standard three placeholder 150ms CTOA detection target paradigm. Importantly, in different blocks of trials they had participants either shift their head at a 40° angle offset from the monitor, or sit such that they would be facing it head-on. Regardless their head's angle, participants were always required to foveate the central placeholder. All participants wore an eye patch over their non-dominant eye, and when their head was angled it was done such that their eye was near its point of maximum abduction; thus, they could not physically direct their eye further into their temporal hemifield. If shifts in covert attention require the programming of a saccade, the spatial “range” of the covert beam should be limited to the range of motion of the eye and participants should not show any cueing effects in the temporal hemifield. It was found that when participants were facing the screen head-on, non-predictive cues always produced typical exogenous capture of attention. However, when their eyes were abducted, cues no longer affected RTs to targets presented in their temporal hemifield. In other words, consistent with the OMRH stimuli need to be within the eye's range of movement to exogenously capture attention. In contrast, in an otherwise identical experiment where the peripheral pre-cues were made 75% predictive of the upcoming target location a cueing effect was observed in the temporal hemifield. These findings suggest that saccade activation is a necessary trait of exogenous but not endogenous covert attention.

Though there is some need to solidify the findings of Smith, Schenk and Rorden (2012)², theirs might be considered the strongest evidence to date that saccade preparation is necessary for exogenous shifts of attention (and not for endogenous ones). Indeed, it seems reasonable that the system that responds rapidly and reflexively to environmental change would take command of both orienting systems simultaneously so often that there would be little necessity to neurally uncouple the mechanisms. However, their experiment can be interpreted as consistent with a limited version of the OMRH which only necessitates saccade preparation at the instant of a shift in covert attention after which the two systems may uncouple. Indeed, Smith et al. (2012) favor this “shifting” account of the oculomotor readiness hypothesis (See footnote #6 in Klein & Pontefract 1994 for the proposition of a “shifting” account, and Smith and Schenk, 2012 for a review of neuropsychological evidence on the subject).

The first experiments presented in my thesis will test exogenous cueing effects in a paradigm that probes for evidence of a *sustained* linkage between covert exogenous attention and saccade preparation. Further, an endogenous attentional window akin to that of Ishigami et al (2009) will be established in order to observe the effects and interactions

² The findings of Smith, Schenk and Rorden (2012) are in some ways challenging to interpret. For example, shifts of attention in this paradigm are defined by cue-generated capture effects and exogenous attention was inferred not to have shifted in the temporal hemifield by lack of cue location match effects, yet the calculation of exogenous capture in the nasal hemifield indicates two effects, 1. responding was facilitated on match trials and, 2. responding was delayed on mismatch trials. The latter effect indicates that exogenous attention shifts were occurring following cues in the temporal hemifield. Specifically, the cue match condition should have differed from the neutral cue condition to the same degree that it differed from the mismatch cue condition; it did not.

of endogenous and exogenous attention upon saccadic eye movements. Ishigami et al (2009 & 2012) have shown that exogenous cueing effects can be modulated by attentional set, and that cues presented within a task-relevant region are processed more or differently from those presented outside the relevant region. Given that Klein and Pontefract (1994) found that eye movements were inhibited to enter covertly attended regions, it may be that this endogenous inhibitory effect will interact with any exogenous effects observed.. Specifically, in the present experiments, Ishigami's method was redesigned with their illusory line movement trials replaced by endogenously commanded (via central arrows) eye movement trials. In such an experiment one might find covert exogenous attentional facilitation coupled with oculomotor inhibition in the relevant region. Further, if exogenous effects can only be observed in an uninhibited region, then cue-generated oculomotor facilitation may be present in the unattended region but absent in the attended region.

Experiment 1A and 1B will be presented here sequentially before any discussion because they are highly complimentary. The only difference between these two experiments is that in E1A most of their target (S2, as compared to S1, the cue) stimuli are digit targets requiring manual discrimination responses and in E1B most S2 stimuli are arrow targets requiring saccadic eye movements.

2.3 Experiment 1A

2.3.1 Methods

Participants. Thirty (nine male, 21 female) undergraduate students volunteered to participate in the present study in exchange for course credit. Ages ranged from 17 to 35,

with a mean age of 21. Three participants reported themselves to be left-handed, the remaining 27 reported as being right-handed. All participants reported normal or corrected-to-normal vision, and were informed not to wear eyeliner in order to improve calibration quality.

Stimulus and Apparatus. Stimulus presentation and response collection was performed using a Mac Mini computer operating with OSX Snow Leopard. Stimuli were displayed on a CRT monitor with a 4:3 aspect ratio and 50cm diagonal screen width, and responses were made using an Apple Extended Keyboard (Model No. M0115). An S-R Research Eyelink II head mounted eye tracking system monitored and recorded eye movements.

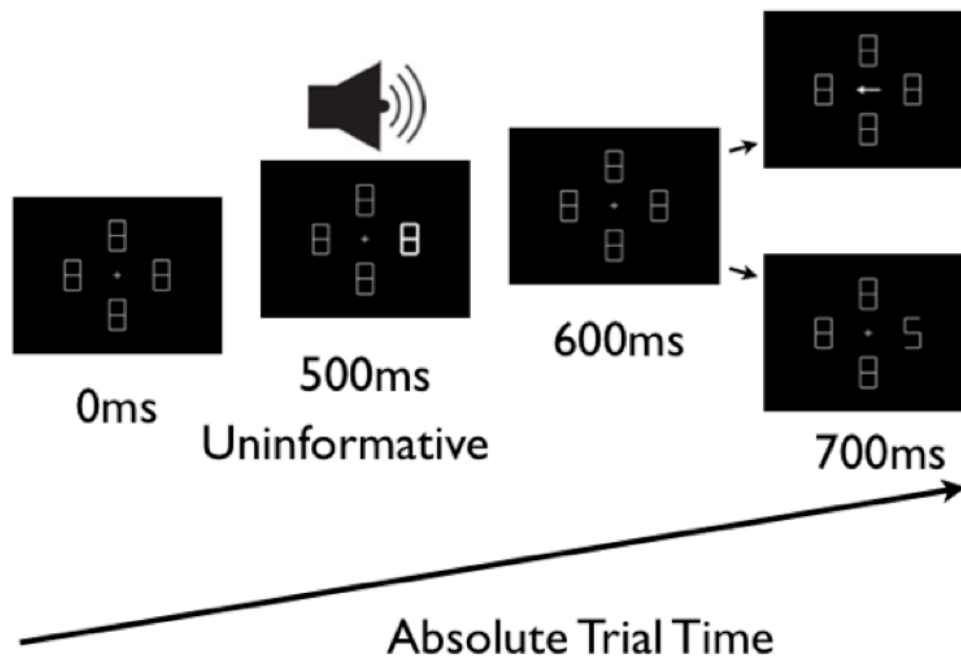


Figure 4. The time-course of Stimulus Presentation in a given trial.

The static stimulus array consisted of four placeholders (block-letter eights) presented at 2.5° offset above, below, left and right of a central fixation cross (See Figure

3). These eights were 1.45° high and 0.65° wide. The central fixation cross was formed of two lines which were 0.65° in length. The visual cues were produced by changing the brightness of one of the eights from gray to white for 100ms, with a 200ms stimulus onset asynchrony (SOA) between cue and target. In order to provide a warning signal about the upcoming digit identification and eye movement stimuli a 500 Hz tone was presented on all trials, also 200ms prior to the appearance of either imperative stimulus. The tone's purpose was to remove any incentive for participants to endogenously attend the peripheral cues for temporal information pertaining to the time of target presentation. Central arrow probes were 1 degree in length, 0.5 degrees in width and were always gray. Peripheral numeric targets were identical to the block-letter eight stimuli, but with two lines removed to create the "2" and "5" shapes.

Procedure. Participants were seated in front of the screen at 57cm viewing distance. They were instructed to foveate the central fixation cross, and not to look away lest the trial be terminated and recycled. Only those trials where an eye-movement error was made before the appearance of the target (193 trials) were recycled. At the same time, subjects were told that the twos and fives that they were looking for would only appear on one axis, at which point they were shown which axis they would appear on by beginning the practice trials. Before beginning, participants were made aware that peripheral targets were more likely to appear than central arrows. The experimenter also explained that the flashes (cues) were uninformative and did not predict the location or identity of the upcoming S2.

Eye movements were monitored and recorded using an Eyelink II eye tracking system (SR Research). Drift correction was performed by asking participants to press the space bar once foveating a red central fixation cross on a black background; if the position of the eye as calculated by the eyetracker overlapped the cross, it turned white permitting continuation of the task. If the estimated position did not overlap the fixation cross, simultaneously the mac mini generated an audible beep, and their current gaze position was recalibrated to the center of the cross, then the test was repeated. This drift correction was performed at the beginning of each block. During trials, if the eye tracker could not locate the participant's pupil or their gaze was not calculated as being within one degree of the fixation cross before appearance of the response stimulus (either due to need for recalibration or a real fixation failure) an error message appeared. If participants received either a gaze or saccade error successively, they were told to press a button on their table to summon an experimenter who entered the room and re-calibrated the eyetracker to within one degree before continuation of the task. While foveating center fixation, participants pressed the space bar to begin each trial. The 100 ms warning tone was presented 500 ms after the commencement of a trial, usually accompanied by a peripheral cue (See Figure 3) and after a 200ms CTOA the peripheral target or arrow probe was presented. The 5 possible cue conditions (left, right, above, below, or no cue) occurred at random with equal probability. Cues were spatially non-informative about the upcoming target location or probe direction.

Subjects performed in 700 trials (7 blocks). The first block was a practice block and was excluded from analyses. Within a block of 100 trials, each of the five possible

cue conditions were orthogonally and evenly combined within 80 peripheral digit identification trials demanding a manual response and 20 central arrow trials demanding a saccadic response (a 5*2 factor structure). While peripheral (digit) targets appeared only in the participant's "task relevant" region, central arrows directed responses to any of the four placeholders. On manual response trials, participants were required to identify a digit (2 or 5), responding with the 'Z' key if the target was a "2" and the "/" key if the target was a "5". On saccadic response trials, an arrow appearing at fixation called participants to move their eyes to the figure-8 pointed to by the arrow.

There was one between-subjects variable included only for balancing reasons: orientation of the relevant region (horizontal and vertical). In the horizontal condition, digit targets appeared only to the right and left of the fixation cross. In the vertical condition, digit targets appeared only above and below the fixation cross. The region within which the digit targets could appear will be referred to as the "relevant" region whereas the regions on the adjacent axis are referred to as "irrelevant" regions; these titles reflect the spatial relationship between the stimuli and the location of target presentation.

The experiment typically lasted about 45 – 60 minutes.

2.3.2 Predictions & Data Analysis

Digit Identification Task

It was expected that exogenous cues within the relevant region would capture attention resulting in a response benefit when they overlapped the target location (cue-target location "match") and a cost when they did not. It was also expected that cues

presented outside of the endogenous ACS (which will always mismatch the digit target's location) would slow response times in the primary task to a lesser degree than would mismatching cues presented within the ACS, consistent with the Spatial ACS findings of Ishigami et al (2008). This is because invalid cues further delay responding when they capture attention, which they should be more capable of doing within the ACS. These predictions were directly tested by the use of two paired t-tests, one comparing performance between trials where targets matched the cued location and those targets mismatched cues in the relevant region, and the other comparing performance between mismatch trials where the cue appeared in the relevant region and mismatch trials where cues appeared in the irrelevant regions. Further, protected Fisher's Least Significant Difference (FLSD) comparisons and their corresponding ANOVA are included for the reader to make simple comparisons between levels of cueing that are not directly related to our predictions. All RT ANOVAs linked to our hypotheses were paired with log-odds transformed error rate analyses, the nature of and logic behind the use of this transform is described in Appendix A.

Saccade Task

It was expected that the relatively greater proportion of peripheral digit identification trials would result in saccadic inhibition within the ACS (See Figure 5; blue). While this expectation was partially wrought from the findings of Klein and Pontefract (1994) and Hunt and Kingstone (2003), in the present experiments exogenous cues were presented rather than endogenous ones leaving the possibility that our findings would differ from theirs. Of primary interest is whether saccadic RT is affected by cued

covert capture or alternatively whether saccade inhibition might prevent this capture as the OMRH would predict. This would manifest as either an equivalent or inhibitory saccade cueing effect when the required saccade location as indicated by the central arrow “agrees” with the cued location (e.g., a left cue followed by an arrow commanding a leftward saccade). In the non-attended region it was expected that the reduced requirement to withhold eye movements owing to the lack of target stimuli presented in that region would result in faster saccades overall, and the possible appearance of cue-saccade agreement effects reflecting oculomotor activation generated by the cue (See Figure 5; red). These hypotheses were tested using one 2x2 ANOVA with region of response entered as one factor and cue-arrow direction agreement as the second factor. Facilitation of target identification in the absence of facilitation of eye movements would extend the rejection of OMRH to the exogenous domain.

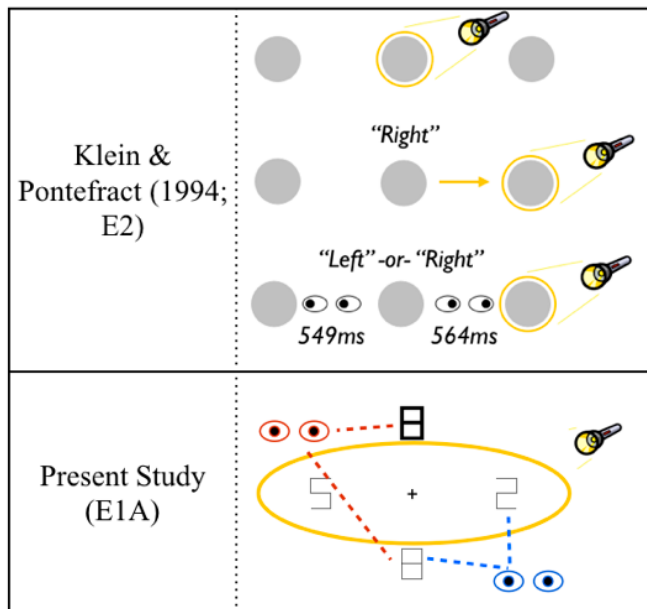


Figure 5.

Oculomotor readiness and ACS effects

Top panel: When participants were given advance knowledge of the likely location of a detection target, saccade inhibition was observed at the locus of covert endogenous attention.

Bottom Panel: a) A similar inhibitory effect to that illustrated in the Top Panel may be observed here. b) The effect of exogenous cues upon saccades made outside the attended region (red conditions) could reveal exogenous capture of eye movements.

2.3.3 Results

Digit identification responses faster than 200ms or slower than 1000ms, and saccadic responses faster than 300ms or slower than 660 were removed from all analyses as outliers³. A total of 352 (3%) digit trials and 375 (1%) saccade trials were removed for exceeding these RT cutoff criteria across all 30 participants. In the analysis of digit task RT, trials that contained either an eye-movement or keypress error were removed, these error rates are compared later in their respective results sections. In the analysis of SRT, 850 (~23%) of the remaining trials were coded as errors and removed from SRT analysis because the eye landed at a distance greater than 1.5 degrees visual angle from the saccade placeholder⁴. This criteria was set to avoid contaminating RT analyses with trials where participants were not directing saccades to the hypothetically affected region; the OMRH specifies that the locus of attention should be the locus of oculomotor activation,

³ These cutoffs were generated by examination of the error rates (defined as incorrect button pressed in the digit task and saccades >1.5 degrees from center of the saccade target in the saccade task) when responses were sorted into 20 ms bins. The lower bounds for data inclusion were determined by identifying the first point where participant accuracy rose above 50%, the upper bound was determined by identifying the primary rise in accuracy over time and the ensuing dip in response accuracy was taken as the cutoff to prevent the inclusion of trials reflecting untoward processes not related to S2.

⁴ While categorizing 23% of saccades as errors is seemingly high, investigators are interested in a focal effect of the cue and saccade landing distance might modulate that effect (see the saccade accuracy analyses), and the probability of a saccade landing within 1.5 degrees of a target location on 77% of trials by chance is absurdly low. Saccade endpoints were not recorded when eye movements were made before target presentation.

so only saccades that are directed toward the location of the placeholder proper are analytic of the hypothesis. For condition means from this experiment, see Table 1 below.

Digit Task Results

Discrimination RT was submitted to two t-tests, one of cue-target location matching (matching cue v. mismatching cue) and another of ACS effects (irrelevant mismatching cue v. relevant mismatching cue). RT in the match condition was significantly faster than RT in the mismatch condition, $t(29) = -2.4367$, $p < 0.05$ ($M_{diff} = 13.6$ ms, See Figure 6). Responses to digits following mismatching cues inside and outside of the relevant region did not differ significantly, $t(29) = 1.0765$, $p > 0.05$, $M_{diff} = 2.96$ ms. Protected FLSD bars were computed treating all four conditions shown in Figure 6 as levels of one factor (Corresponding ANOVA: $F(1,29) = 7.89$, $p < .01$, $MSe = 13595.7$) for the reader to make comparisons not addressed here.

Table 1

Means from Experiment 1A. See saccade error comparison below⁵

Condition	Cuing	Mean RT (ms)	SD	Digit Identification Error Rate (Log-odds)	Cued - Uncued RT
Manual	Match	557.9	60.7	-2.81	<u>-13.8</u>
	Rel. Mismatch	571.8	57.4	-2.96	
	Irrel. Mismatch	568.5	61.4	-2.96	
	No Cue	553.2	60.9	-3.17	
Read as.....	“Cue:Target Agreement”			> 1.5 Deg (log-odds)	
Saccade	Rel:Rel Agree	512.0	42.9	-1.18	-0.4
	Rel:Rel Disagree	512.4	51.8	-1.18	
	Irrel:Rel Disagree	489.6	43.9	-1.26	
	No Cue:Rel	502.7	53.1	-1.29	
	No Cue:Irrel	489.6	56.2	-1.43	
	Rel:Irrel Disagree	498.7	48.2	-1.34	
	Irrel:Irrel Agree	482.5	53.9	-1.43	1.8
	Irrel:Irrel Disagree	480.7	54.4	-1.09	

⁵ Saccade accuracy was not of primary theoretical interest in this study, however because it was added as an exclusion parameter it behooves me to test whether it may have compromised the essential effects reported. To that end, two linear models of saccade errors (>1.5°) were compared for each dataset using the “anova” function in R; one with subjects entered as a random effect and other with both the levels of cueing as a fixed effect and subject number as a random effect. The two linear models did not differ significantly ($\chi^2(7, N = 30) = 5.72, p > .05$).

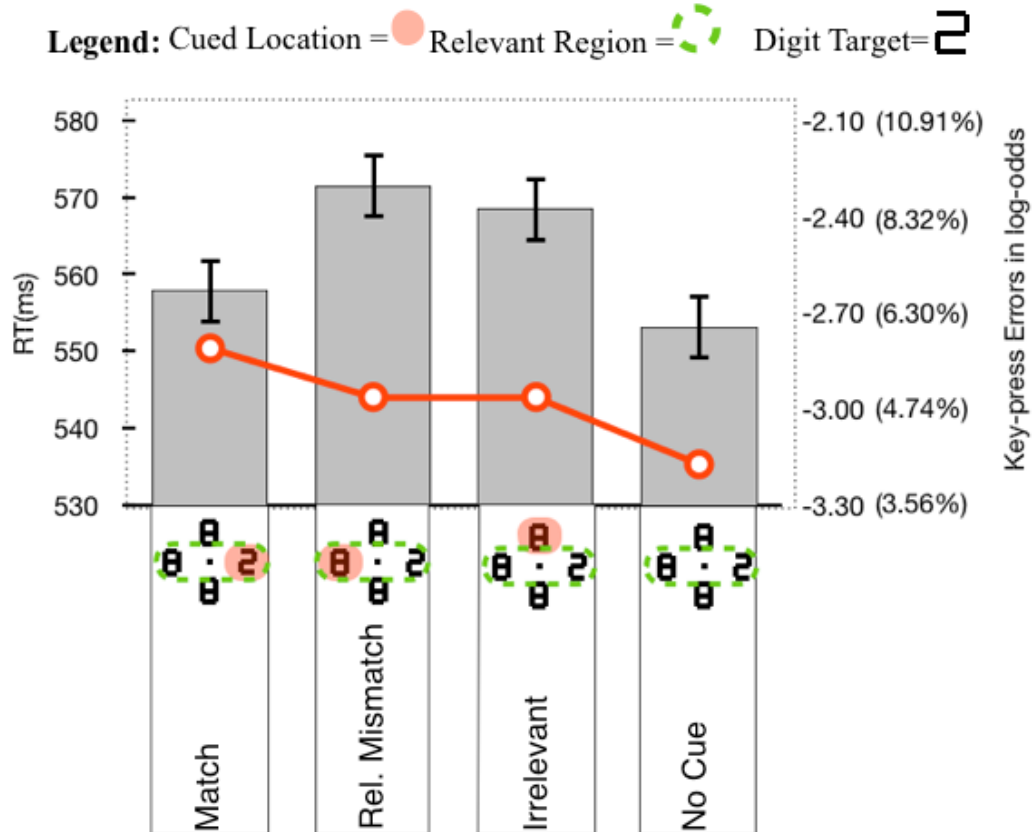


Figure 6. Response times from the digit task in EIA, revealing cue-target matching effects within the task-relevant region. Error bars are 1/2 FLSD. Errors are shown in log-odds (See Appendix A for a primer) and equivalent percentages (in parentheses). Grey bars are measures of RT differences whereas red lines are error rate differences.

Identification error rates were converted to log-odds and analyzed using two linear mixed models with subject ID entered as a random effect⁶. Error rates in the match condition did not significantly differ from error rates in the mismatch condition, $z = -1.412$, $p > .05$, $M_{diff} = 0.1656$. Error rates in the irrelevant condition also did not differ from error rates in the relevant mismatch condition, $z = -0.003$, $p > .05$, $M_{diff} = 0.00032$. However, when trials without cues were compared to trials with cues, participants were

⁶ All z values are Walds' test statistics extracted from LMER outputs created using the lme4 package in the R Environment of Statistical Computing (R Development Core Team, 2011).

more accurate on trials where no cue had appeared, $z = -2.434$, $p < .05$, $M_{diff} = 0.2486$; this is briefly addressed in the discussion.

Saccade Results

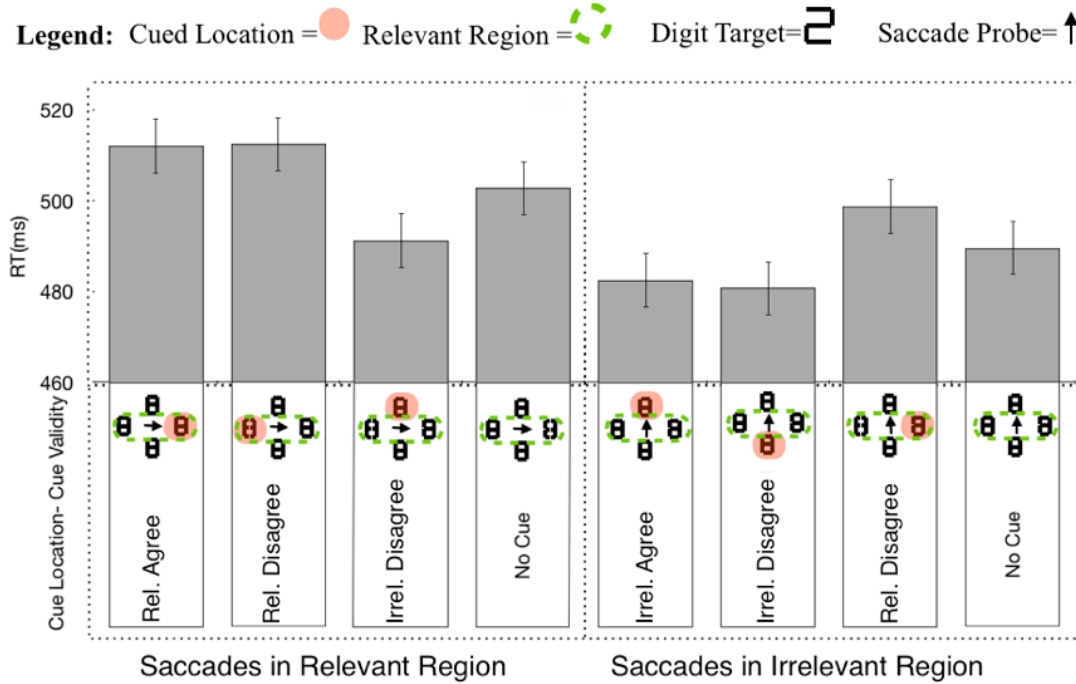


Figure 7. SRTs in arrow probe trials in E1A.

Protected Fisher’s Least Significant Difference bars used in Figure 7 were computed including all eight combinations of cued region, target region, and saccade cueing (agreement vs. disagreement) as levels of one factor (Corresponding ANOVA: $F(7,203) = 8.1$, $p < .01$, $MSe = 16702.5$) for the interested reader to make comparisons which are not directly treated below ⁷. SRTs were submitted to two 2x2 repeated measures ANOVAs to test the effects of cue agreement and region of saccade (ANOVA 1) and region of cue presentation and region of saccade (ANOVA 2) on SRT. All means that were used in these comparisons can be viewed in Figure 7, with ANOVA 1 comparing the

⁷ Saccade errors were also compared, see the footnote beneath Table 1.

leftmost two values of each panel and ANOVA 2 comparing the two central values in each panel⁸. ANOVA 1, for which the cued region and the targeted region were always the same, was used to assess the two IVs of cue agreement (agreement v. disagreement) and region of cue and response (relevant v. irrelevant) on RT. The main effect of cue agreement was not significant ($F(1,29) < 1$) showing that cues did not affect the saccade system. However, the region into which the saccade was directed had a strong effect on SRT ($F(1,29) = 4.2, p < .01, MSe = 8345.61$, for means and SDs see Table 1) such that saccades were much slower when directed into the relevant region than when they were directed into the irrelevant one. The interaction did not reach significance ($F(1,29) < 1$).

To test the effects that cue-arrow direction agreement had upon participant performance, response times as a function of both the cue and saccadic response's relationship to the relevant region were entered into a 2*2 repeated measures ANOVA. Trials that did not contain a cue were excluded, and trials collapsed into a single condition based on the region of cue presentation regardless as to whether the cue agreed or disagreed with the location of the subsequent saccade, this decision was made based upon both the statistical non-difference mathematical similarity of the cue-arrow directed agreement and disagreement conditions. The main effect of the cued region revealed that SRT was delayed following cues presented in the relevant region, ($F(1, 29) = 34.17, p < .05, MSe = 7798.91$), and the main effect of response location revealed that eye

⁸ This was done over two ANOVAs rather than one because cue agreement is no longer fully orthogonal when trials where cues and targets appear in opposing regions (never spatially match) are mixed with those where they occur within one region type (sometimes match), and because the results of 2 level ANOVAs are more inferentially useful.

movements were also slower when commanded into the relevant region, ($F(1, 29) = 8.13, p < .05, MSe = 7798.91$). The interaction between these effects was non-significant, ($F(1, 29) < 1, p > .05, MSe = 7798.91$), the cue's location relative to the relevant region affected response times irrespective of the location of the response (see Figure 8).

Effects of Intertrial Priming on Cue-Target Location

Matching & Regional Effects

Since more trials were immediately preceded by discrimination targets than saccadic response targets, and since an exogenous cueing effect was found only in the discrimination task, it is important to test whether this was an effect of endogenous task preparation or of task priming. If the former, covert capture effects should be observed regardless whether the previous trial was a saccade trial. If the latter, covert capture would only occur after discrimination trials. An analysis task priming can be performed on data from the primary task due to the greater quantity of observations in each condition. Response time data from the digit task were submitted to a 2*2 repeated measures ANOVA with cue-target matching (Match-Relevant vs. Mismatch-Relevant) entered as one variable and the response type required on the previous trial (Saccade vs. Digit identification) as the

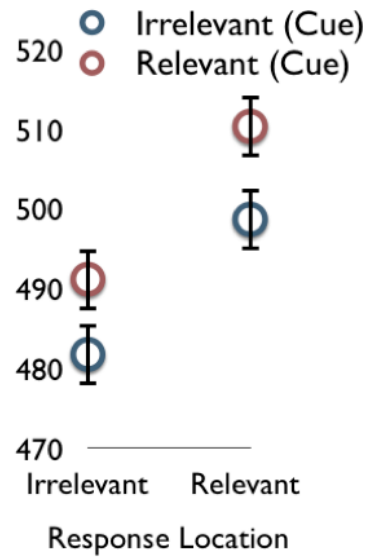


Figure 8. SRT by region relevance in EIA. Saccades were executed more slowly into the relevant region than out, and more slowly following cues presented into the relevant region than out.

other⁹. A significant main effect of cue-target matching revealed that responses were significantly faster following match cues than mismatch cues in the relevant region, $M_{diff} = 13.6\text{ms}$, $F(1, 29) = 9.65$, $p < .05$, $MSe = 12427.12$. However, there was no effect of previous trial type ($F(1, 29) = 1.01$, $p > .05$, $MSe = 12427.12$) and the two variables did not have an interactive effect on response time ($F(1, 29) = 1.76$, $p > .05$, $MSe = 12427.12$). The same 2*2 design was utilized in a linear mixed effects model for digit identification error rate analysis. The estimate of the intercept was -2.88062, the SE 0.11805. There was no significant effect of cue-target matching ($z = 1.520$, $p > .05$, $SE = 0.077$), nor previous trial type ($z = 1.322$, $p > .05$, $SE = 0.077$), and an interaction was not observed ($z = -0.743$, $p > .05$, $SE = 0.077$).

Table 2

Digit Task Performance as a function of task in the previous trial, matching effects

Previous Trial	Matching	Mean RT(ms)	SD	Errors (Log-Odds)
Identification	Match	560.0	61.3	-2.72
	Mismatch	571.5	60.2	-2.84
Saccade	Match	550.1	64.2	-2.81
	Mismatch	572.5	53.9	-3.16

A similar 2*2 ANOVA compared the two mismatch conditions (irrelevant vs. relevant), since it seems reasonable that having just performed a manual response trial might increase the participant's ability to filter irrelevant cues more effectively. However,

⁹ The effects of intertrial priming were only tested for the primary response task because dividing the secondary task (which contains many fewer observed values) would reduce statistical power to an unsatisfactory level, and because priming of cueing effects is of central interest, and cueing effects were only found in the primary task.

neither the effect of previous trial type, mismatch cue relevance, nor the interaction were significant ($F < 1$). The same 2*2 design was utilized in a linear mixed effects model for digit identification error rate analysis. The estimate of the intercept was -3.05487, the SE 0.13977. There was no significant effect of cued region ($z = 0.703$, $p > .05$, $SE = 0.06864$), nor previous trial type ($z = -1.225$, $p > .05$, $SE = 0.06867$), and an interaction was not observed ($z = 1.154$, $p > .05$, $SE = 0.06866$).

Table 3

Digit Task Performance as a function of task in the previous trial, relevance effects

Previous Trial	Cued Region	Mean RT(ms)	SD	Errors (Log-Odds)
Identification	Relevant	571.5	60.2	-2.94
	Irrelevant	566.0	61.6	-3.00
Saccade	Relevant	572.5	53.9	-3.27
	Irrelevant	578.5	63.5	-3.01

General Design of “B” Experiments

The equipment and software used in the following experiment was identical to the preceding one, with the exception that 80% of trials contained arrow probes which

commanded saccadic responses, and 20% of trials contained peripheral digits requiring identification and a manual button press (Figure 9, Right). These probabilities represent a reversal of the original experiments.

2.4 Experiment 1B

2.4.1 Methods

Participants. Thirty (11 male, 19 female) undergraduate students volunteered to participate in the present study in exchange for course credit. Ages ranged from 18 to 30, with a mean age of 20. Five participants reported themselves to be left-handed, the remaining 25 reported as being right-handed.

2.4.2 Predictions & Data Analysis

All data analysis methods used in E1B were identical to its twin experiment E1A except that inter-trial effects analyses were performed on SRT with an additional factor added to each one to account for saccade directed both inside and outside of the digit task relevant region. The purpose of this experiment was to determine whether the pattern of exogenous capture results would reverse as did the endogenous effects in Klein and Pontefract (1994) as a consequence of inversion of task probabilities. That is, the OMRH makes two clear predictions that were tested for the endogenous domain in (Klein) 1980 and must each be tested for the exogenous domain in the present paper; eye movements will be facilitated toward the locus of covert attention and covert attention must accompany eye movement facilitation. The first was directly tested in E1A and the

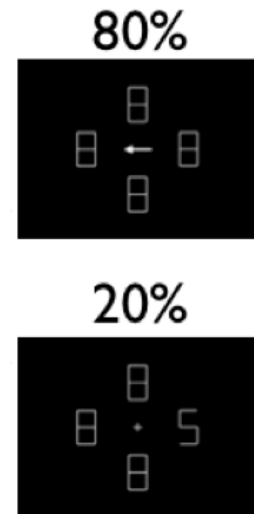


Figure 9. Condition Reversal in E1B and E2B. The proportion of trials was reversed in E1B.

second was tested in E1B. It was not expected that ACS effects would be as dramatic in E1B because identification targets were presented less frequently on the relevant axis; a manipulation shown by Ishigami et al (2010) to weaken observed ACS effects.

2.4.3 Results

All trials that contained either an anticipatory eye-movement or digit identification error were removed from analysis. Further, digit identification responses faster than 400ms and slower than 1050ms, and SRTs faster than 100ms and slower than 800ms were removed from analyses as outliers. A total of 221 (7%) digit response trials and 374 (2.6%) saccade trials were removed via this procedure, and 2980 (~21%) eye movement trials where the eye landed at a distance greater than 1.5 degrees visual angle from the placeholder indicated by the arrow probe were removed from RT analysis and coded as errors. For all mean RT and error data from this experiment, see Table 4 on the following page.

Table 4

Means from Experiment 1B. see saccade error comparison below¹⁰

Condition	Cuing	Mean RT (ms)	SD	Digit Identification Error Rate (Log-odds)	Cued - Uncued RT
Manual	Match	654.5	73.5	-2.77	-2.4
	Rel. Mismatch	656.9	79.9	-2.82	
	Irrel. Mismatch	646.8	71.1	-2.90	
	No Cue	668.3	73.3	-2.88	
Read as.....	“Cue:Target Agreement”			% > 1.5 Deg	
Saccade	Rel:Rel Agree	362.0	45.8	-1.63	<u>-14.4</u>
	Rel:Rel Disagree	376.4	46.4	-1.30	
	Irrel:Rel Disagree	350.2	40.9	-1.52	
	No Cue:Rel	346.9	31.1	-1.64	
	No Cue:Irrel	337.5	27.1	-1.37	
	Rel:Irrel Disagree	367.9	41.2	-1.14	
	Irrel:Irrel Agree	322.3	37.8	-1.72	<u>-21.1</u>
	Irrel:Irrel Disagree	343.3	37.2	-1.21	

¹⁰ The linear model of which included cueing levels as a fixed effect fit the dataset substantially better than the model which did not ($\chi^2(7, N = 30) = 91.62, p < .05, \Delta AIC = 77$). A follow-up 2x2 LMER comparing cueing and saccade region revealed a main effect of cue-arrow direction agreement ($z = 6.082, p < .05, SE = .035$). Neither the main effect of saccade region nor the interaction reached significance ($p > .1$). Thus, participants were both faster and more accurate at the cued location in this experiment.

Manual Results

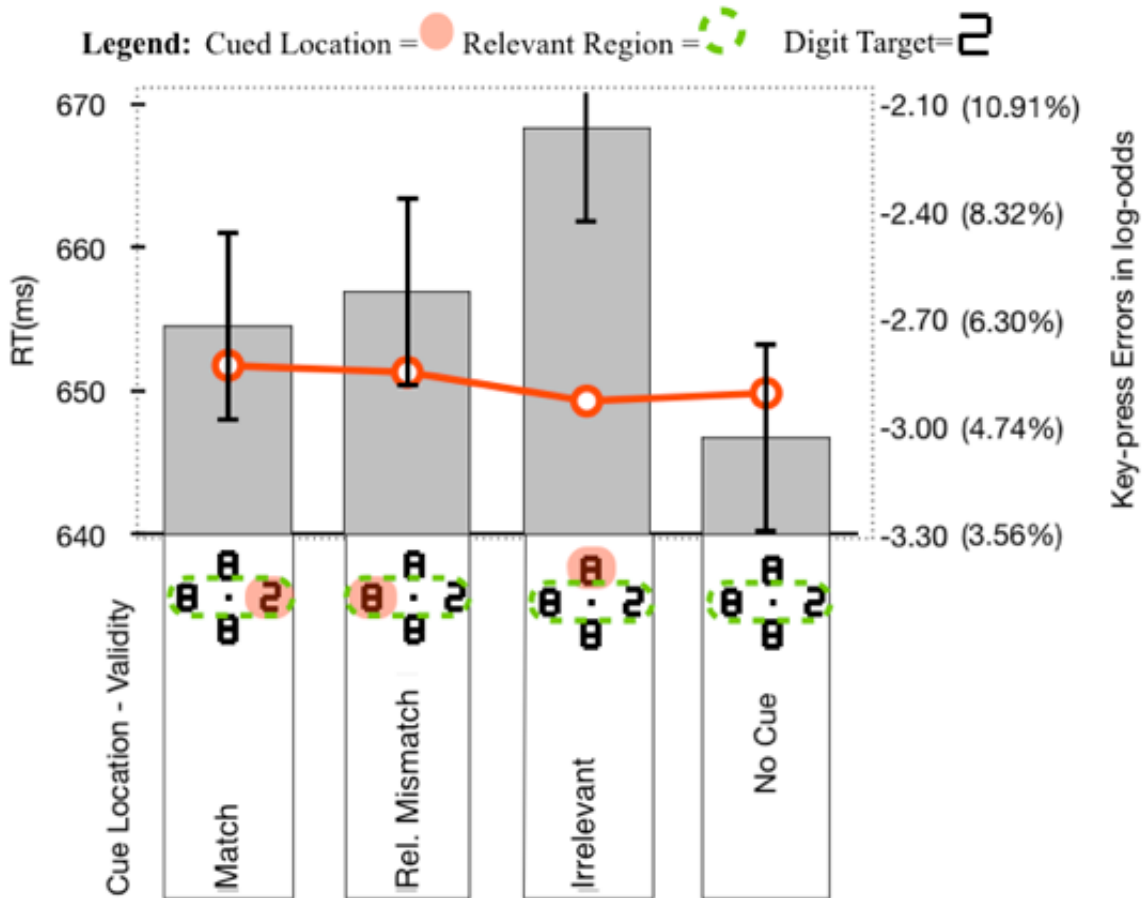


Figure 10. Discrimination RT in E1B. No comparisons of present interest were significant in the digit task.

Digit identification error rates were converted to log-odds and analyzed using two linear mixed models of the same factor design as the above RT ANOVAs, but with subject ID entered as a random effect. Error rates in the match condition did not significantly differ from error rates in the mismatch condition, $z = -0.09$, $p > .05$, $M_{diff} = 0.021$. Error rates in the irrelevant condition also did not significantly differ from error rates in the mismatch condition, $z = -0.39$, $p > .05$, $M_{diff} = 0.07862$.

Protected FLSD bars used in Figure 10 were computed including all combinations of cued region, target region, and cue-digit location matching as levels of one factor (Corresponding ANOVA: $F(3,87) = 3.47, p < .05, MSe = 20196.7$) for the interested reader to make comparisons not directly treated below (Figure 10).¹¹ Response times in the match condition were not significantly faster than RT in the mismatch condition, $t(29) = -0.2647, p > .05$. (Mdiff = 2.39ms, See Figure 10). Demonstrating the lack or even inversion of an Ishigami et al (2008)-like spatial ACS, RT in the irrelevant condition was not significantly faster, but in fact marginally slower (Mdiff = 11.41 ms) than RT in the mismatch condition, $t(29) = 2.0372, p = .051$.

Saccade Results

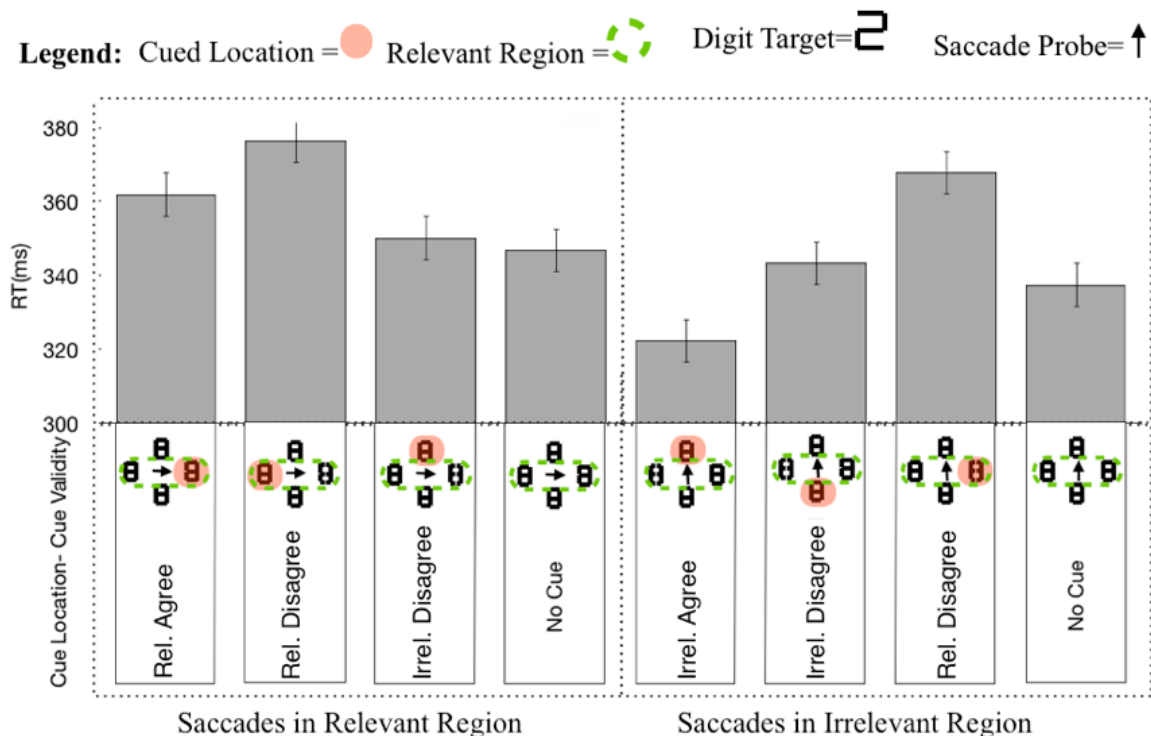


Figure 11. Saccade RT in E1B. revealing cue-arrow direction agreement effects.

¹¹ Saccade errors were also compared, see the footnote beneath Table 4.

Protected Fisher's Least Significant Difference bars used in Figure 11 were computed including all possible combinations of cued region, target region, and cue-arrow direction agreement (Agreement vs. Disagreement) as levels of one factor (Corresponding ANOVA: $F(7, 203) = 19.5, p < .001, MSe = 8886.4$) for the interested reader to make comparisons not directly treated below.

ANOVA 1, for which the cued region and the targeted region were the same, was used to assess the effect of the two IVs of cue-arrow direction agreement (agree v. disagree) and region of cue and response (relevant v. irrelevant) upon RT. A significant main effect of cue-arrow direction agreement ($F(1,29) = 24.6, p < .01, MSe = 5516.76$, see the two leftmost bars of each panel in Figure 11), revealed that cues exogenously captured the saccade system. Further, the region into which the saccade was directed had a strong effect on SRT ($F(1,29) = 46.62, p < .01, MSe = 5516.76$, for means and SDs see Table 4) such that saccades were much slower when directed into the relevant region than when directed into the irrelevant region. The interaction did not reach significance ($F(1,29) < 1$).

Response times as a function of both the cue and saccadic response's relationship to the relevant region were entered into a 2*2 repeated measures ANOVA. The main effect of the cued region was highly significant, ($F(1, 29) = 66.53, p < .05, MSe = 5334.28$) eye movements were slower following cues presented in the relevant region. The main effect of response location remained significant, eye movements were generally slower when directed into the relevant region than off ($M\ difference = 10.02ms, F(1, 29) = 4.59, p < .05, MSe = 5334.28$). The interaction between these effects was also highly

significant, (M difference = 26.95ms, ($F(1, 29) = 13.42, p > .05, MSe = 5334.28$). Specifically, following cues in the relevant region, there was no difference between responses commanded into or out of the relevant region. These data are shown in Figure 12, with means from the no cue condition data overlaid with 1/2 FLSD bars for comparison to the Irrelevant region data.

Effects of Intertrial Priming on Cue-Arrow

Direction Agreement & Cue Relevance

SRT was tested using a 2*2*2 repeated measures ANOVA. The three variables entered were cue-arrow direction agreement (agree v.

disagree), region of cue and saccade (Relevant v. irrelevant region) and previous trial type (manual v. saccade). Only those trials where cues and arrows were both directed into the same region were included in analyses.

A main effect of cue-arrow direction agreement revealed that eye movements were significantly (17.05ms) faster to be directed toward the cued location (agreement) than away from it (disagreement), ($F(1, 29) = 12.72, p < .05, MSe = 13520.55$). Saccades were also substantially (36.89ms) slower when the cue and the ensuing saccade fell in the relevant region than the irrelevant regions ($F(1, 29) = 53.71, p < .05, MSe = 13520.55$) and 24.96ms faster following a saccadic response trial than when following a digit

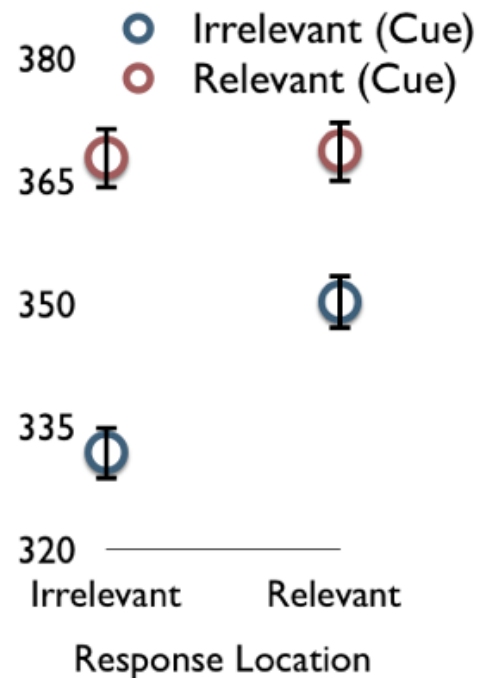


Figure 12. SRT by region relevance in E1B. Cues presented in the relevant region slowed response times substantially, even if upcoming responses were commanded outside of that region.

identification trial. There was also an interaction between previous trial type and the region of saccade deployment on the current trial ($F(1, 29) = 18.85, p < .05, MSe = 13520.55$): While having just previously performed a digit trial did delay SRT into the irrelevant regions by 13.87ms, it proved far more detrimental to SRT in the relevant region, slowing responding by 38.43ms. No other comparisons reached statistical significance ($F < 1$).

Another 2x2x2 repeated measures ANOVA was used to assess the effects between region of stimulus, region of response, and previous trial type in part to determine whether saccadic inhibition on the relevant region was owing to participants' endogenous preparatory sets or alternatively exogenous inter-trial effects. Only cue-arrow disagreement trials were included in analysis. All three main effects were statistically significant; participants executed their saccades on average 14.49ms more slowly into the relevant region than the irrelevant region, 30.89ms more slowly following the presentation of cues in the relevant region than cues in the irrelevant regions, and 21.91ms more slowly following digit trials than following saccade trials. Further, region of cue presentation interacted with task type on the previous trial such that saccades were much slower following cues in the relevant region given participants had just completed a manual response trial (39.7ms cost) than a saccade trial (22.1ms cost). No other interactions were statistically significant ($F < 1$).

2.5 Discussion

I would like to quickly orient the reader to the most crucial findings from both experiments before discussing their implications. In E1A where digit identifications were

frequent, we found strong evidence that exogenous cues shifted the covert beam of attention (evidence is found in a t-test on p.22) but no such evidence that they activated an oculomotor program (ANOVA 1, p.31). In E1B where saccade trials were more frequent the inverse pattern was revealed. We found very strong evidence that exogenous cues generated saccade programs (ANOVA 1; cue-arrow direction agreement vs. disagreement, p.42) and no such evidence for covert capture (t-test 1; cue-target match vs. mismatch, p.39). In neither of the experiments were the observed cueing effects mediated by sequential priming effects. Further, in both experiments participants were actually slower to saccade into the relevant region where digits could appear than the irrelevant region where they could not.

The findings of E1A extend those of Klein and Pontefract (1994) in two ways. Despite the fact that exogenous cues captured covert attention as measured by a cue-target matching effect in the primary task, there was no evidence of oculomotor activation at the cued location. Second, eye movements were initiated more slowly into the task-relevant region where participants should be endogenously preparing to detect a target. This effect, which we see in both of our experiments, nicely mirrors the endogenous cueing effect reported by Klein and Pontefract (1994) and Hunt and Kingstone (2003) and extends it to the ACS manipulation of Ishigami et al (2009).

In E1A, cues captured covert attention as indicated by faster digit identification responses at cue-target matching than at mismatching locations, but RT following cues presented in the irrelevant region did not differ from RT following mismatch cues in the relevant region which suggests that participants were not able to filter irrelevant cues

effectively. This result runs counter to the findings of Ishigami et al (2009) and indicates that participants were unable to fully implement a spatial attentional control setting in the present experiment, despite the fact that eye movements were slowed in the hypothetically attended region.

It is unclear why Ishigami et al's (2010) finding of reduced capture from cues in irrelevant regions was not seen here. It is possible that just as cues in the irrelevant regions expedited eye movements (non specifically), they contra-prepared digit task performance resulting in the statistical elimination of ACS effects. I consider this possibility consistent with the findings of Hunt and Kingstone (2003) that the likely saccade goal is subject to poor discrimination performance. It must be noted, however, that this cannot be clearly distinguished from a true absence of spatial ACS in the present experiment.

Though it was not directly tested using an ANOVA or t-test, post-hoc inspection of FLSD bars in the E1A digit identification task reveals generally superior performance when there was no peripheral cue as compared to when there was regardless whether the cue was match or mismatch. Further, participants were generally more accurate in their digit identification on trials where no cue was presented than when a cue was presented. It is unclear why there was a generally processing advantage on no cue trials and the following proposition is presently quite speculative, though it may be that the increased cognitive load associated with attenuating the distracting cue had a general cost to manual RT. Since the tone was presented on all trials, the cues were not as functionally

beneficial for temporal information, so there may have been no temporal cueing benefit to outweigh the cost of their interference.

Implications for the OMRH

Saccade facilitation was witnessed for central arrow probes when saccade locations spatially agreed with cued locations, but only when the relative probability of the saccade task was high (E1B). This strengthens my assertion that in E1A the total absence of a saccadic cueing effect is the result of task-induced saccadic inhibition. It is also important to note that in both E1A and E1B saccades were delayed when directed inside the task relevant region as compared to when they were directed outside of it, and SRT was further delayed when cues were presented in the relevant region. This indicates that the region-dependent saccadic inhibition observed in both experiments is likely to be endogenous in origin, and therefore distinguishable in origin from the exogenous cue agreement effects observed only in E1B. In this way two lines of conclusions can be drawn from the data. First, in E1A Klein and Pontefract's (1994) results have been reinforced by repeating the finding of delayed saccadic responding into a region that is being endogenously attended covertly. Second, the non-informative cues did activate exogenous shifts of covert attention but did not exogenously activate oculomotor programs. The cue-target matching effect we found in the digit task in E1A, in combination with the absence of such an effect with the saccadic probes, shows that the exogenous allocation of covert attention is not merely sub-threshold activation in reflexive saccade systems. The inverse finding in E2B disconfirms the converse statement; exogenous saccade activation is not/does not cause a covert shift of attention.

Does this mean that covert attention and overt attention are unrelated modes of attention? Of course not. In their second experiment, Hoffman and Subramaniam (1995) presented an arrow at center fixation that was 75% predictive of the location of an upcoming letter target, then 1500 to 3000ms later (500-200ms ISI) they presented a tone and 20ms thereafter the letter target display. Participants were told to saccade to a pre-set location (e.g., always saccade to the left box) when they heard the tone and when the array of four letters appeared in the placeholders to identify whether an “L” or a “T” was among them. The target display was only presented for long enough for participants to get approximately 80% of identifications correct. In this way a participant should prepare to saccade in one of four directions in anticipation of the tone and should simultaneously covertly attend the region cued by the arrow to identify the letter. They found that participants’ letter identification performance was not degraded by the arrow cue but instead was improved when the target letter appeared at the saccade location. This is strong evidence that eye movements *when actually executed* are preceded by shifts in covert attention (see also Posner, 1980; Shephard, Findlay & Hockey, 1986).

In E1A preparation to identify the digit in one region resulted in saccade inhibition in that region, and exogenous cues facilitated digit identification yet failed to generate oculomotor facilitation. Therefore, while the spatial placement of the covert beam is not accomplished by activation of the oculomotor system (quite the contrary), all executed eye movements are preceded by covert shifts of attention (see Klein, 1980, p. 273, for a similar proposal).

Future Considerations

Since most trials required digit identification responses while only a minority of trials required saccadic responses and cueing effects were only observed in the digit task, it was important to discover whether this pattern was owing to attention to task rather than a simple effect of inter-trial priming. Since cue-target matching effects did not significantly differ as a function of the previous trial type, it can be inferred that this cueing pattern was not explained by priming effects but was instead a function of the response strategy adopted by participants to perform in the dual-task.

A question remains as to why in E1 participants' digit identification performance did not appear to reflect a spatial ACS. Closely resembling the task that Ishigami, Christie, and Klein (2009) used, it was expected that responses to targets following mismatch cues presented in the irrelevant region would be faster than such responses following mismatch relevant cues; this would reflect reduced attentional capture from the cue. One possible explanation is centered on task requirements, and the other pertains to the OMRH.

Ishigami et al (2009) intermixed a second task among their manual tasks as was done in the current study, but their task (line motion judgments) did not require a *speeded response*, meaning that participants could (should!) have prepared *only* for their digit task. This could mean that the ACS effect which they were measuring would be more “immune” to the interfering effects of the dual task when compared to the saccade task used in the current study which did require speeded responses (See Hunt & Kingstone, 2003). Alternatively, it may not have been the speed, but the type of demand of the second task. Since eye movements were necessarily made into the irrelevant regions, it

may be that while attending a region of space may be accomplished without oculomotor activation (and maybe even some suppression) the possibility of eye movements into a region of space may interfere with the filtering out of irrelevant signals emanating from this region. Finally, as already noted, an ACS effect may have been present in the digit task but obscured by task demands. Specifically, if cues presented in the relevant region slowed SRT at the level of task it is conceivable cues in the irrelevant region slowed Manual RT in the digit identification task. One way to test this possibility, would be the replication of E1A while implementing VEP techniques in order to infer whether cues presented in irrelevant regions elicit smaller VEPs (as in Ishigami et al., 2012). The VEP is a more direct measurement of visual attention, and should not be affected by the participant's state of response preparedness. .

2.5.1 Conclusions

In experiment one it was shown that the effects of exogenous covert capture could occur in the absence of saccade preparation. These results extend the findings of Klein and Pontefract's (1994) second experiment from the endogenous to the exogenous mode of attention. This contrasts nicely with recent experiments that demonstrate the ability to plan an eye movement is necessary for an exogenous *shift* in attention (See Smith, Rorden, & Jackson, 2004 or Smith, Schenk, & Rorden, 2012). In a followup experiment (E1B) it was also confirmed that when saccade trials were more frequent than digit trials, cues could exogenously capture the eye movement system resulting in faster saccades toward the cued location without improving discrimination task performance (digit task) in that location. This experiment can also be taken as an important lesson regarding

exogenous effects because even reflexive capture can be dependent upon what systems are “online” and scanning the environment. These two experiments offer a double dissociation, exogenous cues can capture covert attention without oculomotor activation or generate oculomotor activation without capturing covert attention.

It has previously been shown that when a participant’s eyes are nearly-maximally abducted, peripheral cues no longer generate covert cueing effects (Smith, Schenk & Rorden, 2012). When E1 is taken together with this finding in the literature, it is tentatively proposed that shifts in exogenous covert attention and the eyes likely must occur together (shifting) but thereafter those systems can be maintained (inhibition or excitation) independently at the location of the shift relatively soon thereafter. However, as has been previously mentioned there is some need to determine why Smith et al’s (2012) “unfoveable” cues were capable of exogenously capturing attention when they did not match the target location. If these two systems truly do “engage” cues together, future experiments should further explore the conditions of persistence of capture in exogenous cueing paradigms. After all, though one’s best strategy is to filter the irrelevant cue on all of the mind’s “receiving channels” it is clear that exogenous signals can better penetrate attentional channels that participants are endogenously preparing to use.

Chapter 3 Attentional Control, Task Preparation, & Two Forms of IOR

3.1 Inhibition of Return

At longer cue target SOAs, after observers have disengaged from an exogenously cued location, they show impaired target detection at that location relative to uncued locations as though some process was actively suppressing it (Posner & Cohen, 1984). Thought to be a novelty-seeking mechanism useful for optimizing foraging and visual search behaviour, this cost to responding at a previously attended location is now known as Inhibition of Return (IOR; Posner, Cohen, Rafal, Choate, & Vaughan, 1985; for a recent review see Lupiáñez, Klein & Bartolomeo, 2006). Since IOR is often observed at a place that was also the object of attention, and since attention is believed by some to be the product of sub-threshold saccade activation, it is no surprise that many believe IOR to be caused by saccade activation as well. What is currently known about the linkages between eye movements and IOR motivated the experiments in chapter three, and this evidence reviewed shortly, but what immediately follows is a broader description of IOR.

Numerous factors determine the measurable presence and time course of IOR. While the shift in the biphasic cuing effect typically occurs within 300ms, facilitation tends to succumb to inhibition more quickly when the participants are required to perform saccadic responses to their subsequent targets than when they respond with manual key presses (Klein, 2000). Additionally, facilitation succumbs to the effects of inhibition sooner in detection tasks than in discrimination tasks such as the digit identification task used in the present experiments (Lupiáñez et al, 1997).

It is debatable whether attentional capture always precedes IOR. In some instances, cues that do capture attention do not seem to cause IOR (Gibson & Amelio, 2000; Pratt & McAuliffe, 2002), and when unnoticed arrow cues are presented at fixation they are capable of generating facilitation at the indicated location but not IOR (Gabay, Avni, & Henik, 2012). However, recent studies by Hilchey and Klein (2012) and Wang and Klein (2012), have provided limited evidence that spatial attentional allocation strategies may affect the expression of IOR. This serves as an impetus for further direct exploration into the matter.

Considerable evidence has also accumulated to suggest that IOR is not a unitary process, but instead that semi-independent inhibitory effects operating at different levels of information processing can produce two distinct forms of IOR. Taylor and Klein (2000) have previously demonstrated that even when a cue that is known to produce IOR is paired with a target known to be susceptible to it, IOR may or may not occur depending on the exact combination of the stimuli and the responses required to them. This pattern is not the product of either cue-target similarity or task similarity alone; when manual responses are made to central arrow probes, subsequent manual responses to central arrow targets do not exhibit IOR, yet saccades executed in the direction of the arrow cue *do* show IOR irrespective of whether those saccades are directed by peripheral onsets or central arrow targets (Taylor & Klein, 2000).

3.2 IOR Comes in Two Forms

In their exhaustive examination of its causes and effects, Taylor and Klein (2000) demonstrated that spatially non-predictive central arrow targets can be used not only to

generate, but also to probe the effects of IOR. By intermixing central arrows and peripheral onsets as both cues and targets within blocks, Taylor and Klein forced participants to adopt a single hybrid search strategy that would prevent differences in spatial attentional allocation before stimulus presentation. Then, by asking participants to adopt one stimulus response strategy for the pair of stimuli (e.g., no response to stimulus one, manual response to stimulus two; “S1” and “S2” respectively), the independent effects of the stimuli could be inferred within that response set. Their methodology can separate delayed perceptual processing within a region from delayed responding toward that region, because delayed perceptual processing should only affect stimuli in the cued periphery, only peripheral probes should be susceptible to it. In contrast, delayed responding should manifest in behavior regardless whether central arrow probes or peripheral onset probes are commanding the participant’s response.

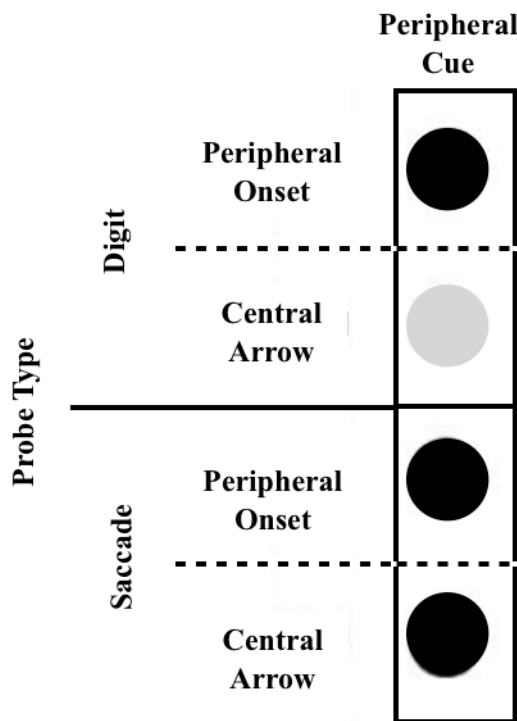


Figure 13. A sub-section of Taylor & Klein’s (2000) findings. It was observed that when participants were required to move their eyes to either S1 or S2 IOR could be measured using central arrow probes as well as peripheral onsets. Black dots indicate conditions where IOR was observed.

In one experiment, Taylor and Klein (2000) found that when participants were told not to respond to S1 and to respond to S2 with a keypress, IOR was only found when peripheral targets appeared at the cued location. This is characteristic of an attentional or perceptual delay (more accurately, probably a delay at the perceptual-motor interface). In another experiment, when participants instead responded to S2 with a saccade, responses were slowed regardless whether they were directed by peripheral onsets or central arrows (Two key samples from two experiments and their corresponding cueing effects (Cue match-mismatch RT) are indicated in Figure 13, Above). This is characteristic of a bias against responding to the cued location rather than a perceptual delay.

Taylor and Klein (2000) spoke of their dissociated findings as reflecting both a perceptual and a motoric form of IOR. When one of these forms of IOR is in effect the other is not. This view is evidenced by Taylor and Klein (2000) because in their experiment when the eyes were free to move and the cues spatially overlap the peripheral targets (thus both forms of IOR might be measured) IOR scores were not significantly greater than when only one of those two conditions were met (see also, Hilchey et al., 2012). Chica, Taylor, Lupiáñez and Klein (2010)¹² found further evidence for this view by demonstrating that when the oculomotor system was in a quiescent state, IOR could be measured in non-spatial discrimination tasks. However, when the eyes were forced to move to the cue, a speed-accuracy tradeoff emerged in the same task, reflecting that responding rather than perception was inhibited. Once again, the two forms of IOR were not additive but instead only one form of inhibition was apparent.

¹² Chica et al(2010) interpreted their results not using the term forms but components, however their intended meaning was more consistent with the “forms” account as defined here.

These systems can be behaviourally dissociated in numerous ways. In a multiple successive cueing paradigm, participants instructed to overtly orient to cue stimuli still showed IOR at least three cues back (Holec et al, 2010). Meanwhile, when participants are instructed to hold their eyes at fixation IOR dissipated after only two cues back, suggesting that oculomotor IOR may persist for a longer duration than attentional IOR, or that it may accommodate more inhibitory tags. Though the same experiment must be performed with the use of eyetracking equipment, the only difference between the two conditions was the instruction regarding whether or not participants should saccade to each onset.

3.3 Can IOR be modulated by a Spatial ACS?

Recent evidence suggests that spatial manipulations can modulate the expression or absence of IOR. Wang and Klein (2012) have shown that when task-relevant objects are presented at center fixation shortly preceding the presentation of a cue, IOR is not produced by cues presented in the periphery; if IOR manifests as a consequence of having shifted attention to the cue (which is one traditional view of IOR, Klein, 2000) then an inability to shift to the cue should disable IOR. In Wang and Klein's (2012) design, participants were told to ignore S1 stimuli (either central or peripheral) and then execute a manual button press in response to S2 targets. Additionally, numbers were presented either peripherally or centrally immediately after the presentation of the peripheral cue (For the design, see Figure 14). When all numbers were presented centrally and participants had to process those numbers, peripheral cues did not generate IOR; while when participants could ignore the numbers IOR was observed. When the

numbers were instead presented in the periphery (the region of cue presentation) IOR was observed whether or not these cues had to be processed.

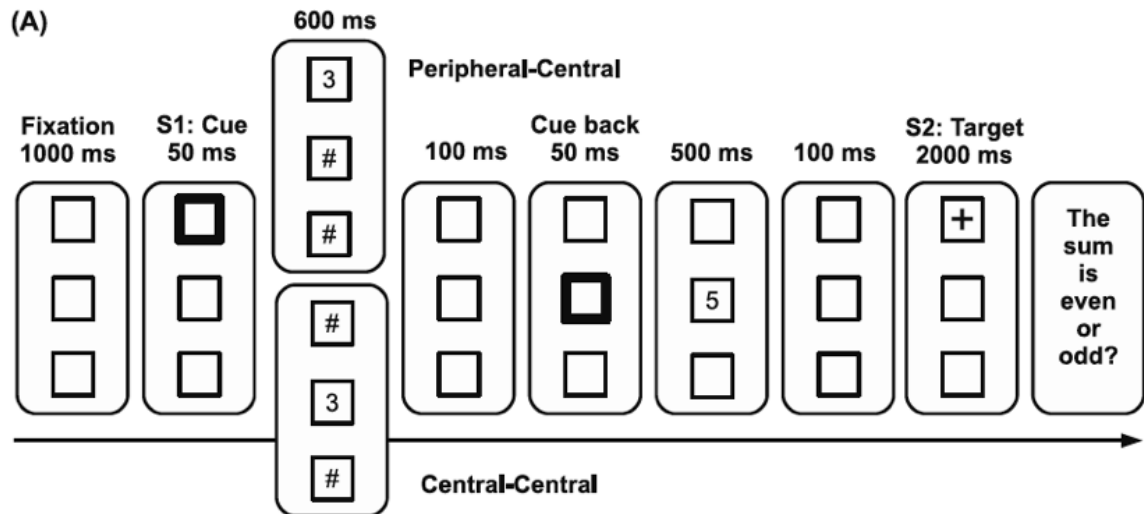


Figure 14. The design of Wang & Klein's 2012 experiments. Borrowed from their paper.

It could be argued that a spatial ACS is time-sensitive, such that the effect reported by Wang and Klein (2012) could occur only when the IOR-generating cue occurs in close spatiotemporal proximity to task-relevant information (or when it is itself used in a temporally predictive way as it likely is in conventional paradigms). This tight temporal pairing, however, is not necessarily required if there is not an important mental task to be performed at the time of S1. Hilchey, Ivanoff & Klein (2012) have shown that when targets only appear at center fixation, saccadic IOR is not observed following peripheral onset cues but is observed following central onset cues. When participants are searching for both centrally and peripherally presented targets, IOR is once again generated by peripheral cues.

3.4 Experiment 2A

In experiment 2, the procedure of Experiment 1 was applied using a longer CTOA manipulation to observe the effects of an ACS and task-set upon IOR. The saccadic component of this dual-task was critical for probing the effects of task-based response preparation on both the oculomotor and the attentional/perceptual forms of IOR, and the effects of a spatial ACS on the oculomotor form of IOR. Since this dual-task design strongly discouraged reflexive eye movements and since activation of the system generating such eye movements is believed to generate oculomotor IOR and suppress perceptual IOR, it was expected that the motor form of IOR would be absent while the attentional/perceptual form would express itself.

Spatially uninformative peripherally presented cues are effective in producing IOR both for saccadic responses to centrally presented arrows and manual (localization) responses to peripheral targets (Taylor & Klein, 2000). Thus, arrow targets can be presented within the ACS (at fixation) while still being used to measure the effects of IOR produced by cues outside of the ACS. However, despite an ACS being inferred to have affected the magnitude of IOR in attentional paradigms (in Wang & Klein, 2012, and in Hilchey & Klein, 2012), the effects of a spatial ACS on the presence and/or magnitude of oculomotor IOR have not yet been directly investigated.

As illustrated in Figure 3, at the start of each trial four figure-8s were presented above, below, and to the left and right of a central fixation stimulus. Peripheral cues were equiprobable at all locations across all trials. In 80% of trials, participants were required to identify a peripheral target (an 8 will turn into either a 2 or a 5). In 20% of trials,

subjects were required to respond to centrally presented arrows by making a saccadic response in the pointed direction of the arrow. These two tasks were randomly inter-mixed. Arrow targets commanded eye movements both inside and outside of the area of the peripheral offset targets, and as such provided a saccadic measure of cueing effects both within and outside of the hypothetical ACS.

3.4.1 Methods

Participants

Thirty (12 male, 18 female) undergraduate students volunteered to participate in the present study in exchange for course credit. Ages ranged from 18 to 30, with a mean age of 20. One participant reported himself to be left-handed, the remaining 29 reported as being right-handed. All participants reported normal or corrected-to-normal vision, and were informed not to wear eyeliner in order to improve calibration quality.

Stimulus & Apparatus / Procedure

All methods in the present experiment were the same as those from E1A with two exceptions. The CTOA was increased from 200ms to 800ms, and 100ms after the presentation of the peripheral cue, a circular “cue back” to fixation with a diameter of half of a degree was presented for 100ms. This cue back was added in order to ensure that attention is summoned away from the peripherally cued location to avoid contaminating the measurement of IOR.

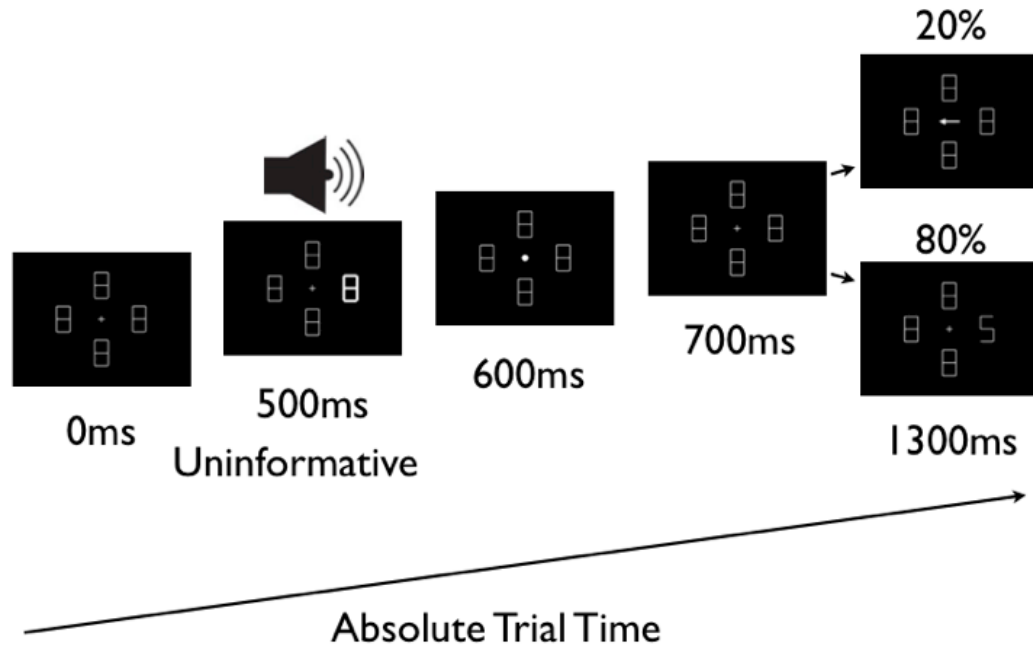


Figure 15. The time-course of stimulus presentation in E2A

3.4.2 Predictions & Data Analysis

Predictions- Digit Task

Of primary interest is the measurement of IOR in the relevant region as measured with the digit task. IOR has long been known to affect responding in discrimination tasks (Lupiáñez, Milan, Tornay, Madrid, & Tudela, 1997) thus IOR characterized by slower and/or less accurate digit identification responses should be present in the current task unless the participant's infrequent requirement to move their eyes results in the expression of the motor form of IOR, in which case IOR should manifest as a speed-accuracy tradeoff with participants setting a more conservative response criterion for targets presented at the cued location. Though Chica et al (2010) have shown that the requirement to execute saccades toward S1 stimuli before the onset of target stimuli results in an IOR effect characterized by a speed-accuracy tradeoff (output based), it has also been noted that when the S1 commands antisaccades the resultant IOR is marked by

a true performance deficit (Hilchey et al., submitted) rather than a tradeoff (input-based). Therefore, given that in the current experiment participants cannot make eye movements (reflexive or otherwise) to peripheral stimuli at either the time of cue or target presentation, it is expected that IOR will manifest as an input-based effect. This will be assessed with a paired samples t-test comparing participants' RT in match vs. mismatch-relevant trials and a linear mixed effects model comparing digit identification errors on the same levels of cueing. Unlike in E1A, here an ACS can only be assessed using the saccade task because IOR in the irrelevant regions may not affect RT to digit targets in the relevant region and any effect it did have would be confounded with any task effects resultant of cueing the irrelevant regions.

Predictions- Saccade Task

If IOR is not componential in nature and typically manifests *either* as a motoric *or* attentional form, the active or inactive state of eye movement systems should dictate which form is expressed. It is expected that the prohibition of eye movements on manual trials, the higher proportion of manual trials to saccade trials, and the fact that participants cannot predict which task will be performed until the onset of the target will be sufficient to produce tonic suppression of reflexive oculomotor systems. Eye movements, therefore, would be unaffected by IOR (Klein & Hilchey, 2011). However, if the insertion of infrequent eye movement trials is sufficient to generate a motor form -or- if IOR is componential, IOR might affect saccades in the relevant region while only affecting saccades in the irrelevant regions in the event of a failure of an ACS.

If IOR is absent both inside and outside of the ACS this will provide converging evidence for a reflexive oculomotor cause for the form of IOR which affects eye movements because eye movements had to be inhibited in the present task, but the contribution of spatial attentional control on cue-generated motoric IOR will remain ambiguous. However, if the motor form is still observed on the relevant axis it can be inferred whether an ACS can affect the motor flavor of IOR by differences in cueing effects on the irrelevant axis. To test for IOR and general ACS effects (The blue comparison in the Bottom Panel of Figure 5 should still be valid if the effect of the spatial ACS is endogenous in nature) two 2x2x2 repeated measures ANOVAs of the same structure as those used in E1A will be used in the present experiment.

3.4.3 Results

All trials that contained either an eye-movement or keypress error were removed from analysis. Further, digit identification responses faster than 200ms or slower than 1000ms, and saccadic responses faster than 300ms or slower than 660ms were removed from analyses as outliers¹³. A total of 129 (1%) digit trials and 299 (8.9%) saccade trials were removed via this procedure, and a further 720 (~23%) eye movement trials where the eye landed at a distance greater than 1.5 degrees visual angle from the placeholder indicated by the arrow were removed from RT analysis and coded as errors. This criterion

¹³ The lower bound for data inclusion was determined by identifying the first point where participant accuracy rose above chance (50%). The upper bound for the inclusion criteria was determined by binning digit identification error data across response times; in each condition peak responding was identified, and the first following dip in response accuracy was taken as the cutoff to prevent the inclusion of trials reflecting untoward participant response strategies. Both E1A & E2A were collapsed to determine cutoffs.

was set to avoid contaminating RT analyses with trials where participants were not foveating the target-placeholder. For all mean RT and error data for all experiments, see Table 5 presented below.

Table 5

Means from Experiment 2A. See saccade error comparison below¹⁴

Condition	Cuing	Mean RT (ms)	SD	Digit Error Rate (Log-odds)	Cued - Uncued RT
Manual	Match	541.4	60.7	-2.88	<u>13.5</u>
	Rel. Mismatch	527.9	62.1	-2.80	
	Irrel. Mismatch	534.1	64.8	-2.90	
	No Cue	535.1	63.1	-2.96	
Read as.....	“Cue:Target Agreement”			% > 1.5 Deg	
Saccade	Rel:Rel Agree	505.2	38.3	-1.46	3.2
	Rel:Rel Disagree	502.0	55.1	-1.36	
	Irrel:Rel Disagree	493.5	39.4	-1.30	
	No Cue:Rel	493.6	39.9	-1.33	
	No Cue:Irrel	485.9	48.3	-1.49	
	Rel:Irrel Disagree	480.1	42.6	-1.40	
	Irrel:Irrel Agree	480.7	45.8	-1.26	1.8
	Irrel:Irrel Disagree	478.9	47.4	-1.24	

¹⁴ The two linear models did not differ significantly ($\chi^2(7, N = 30) = 3.03, p > .05$).

Manual Results

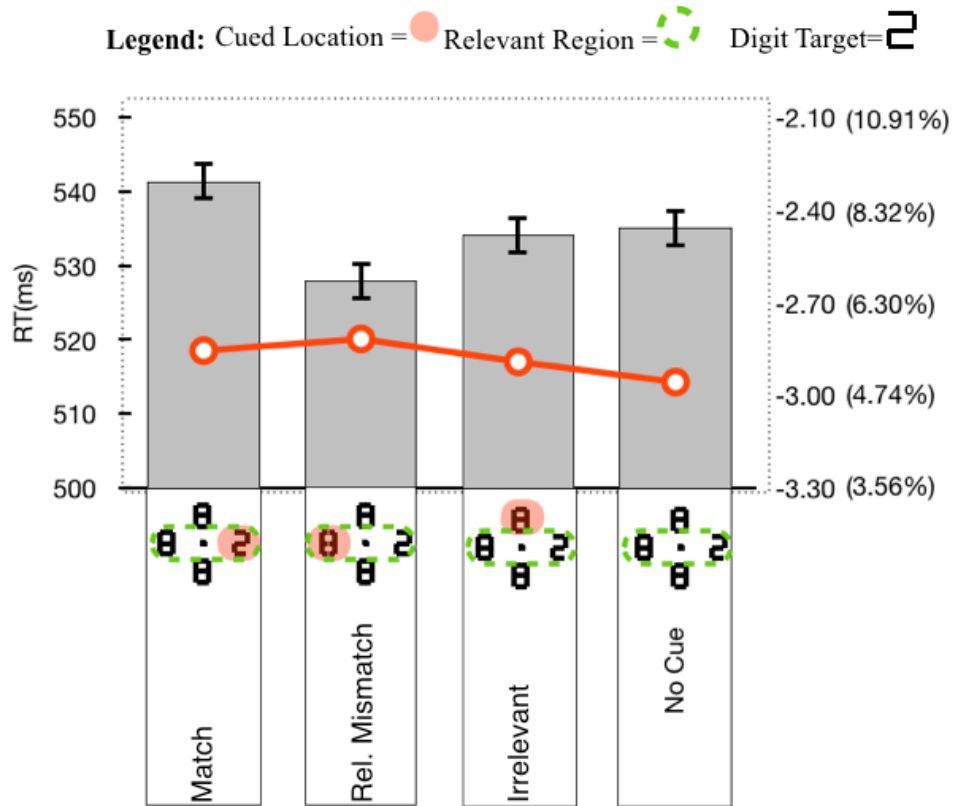


Figure 16. Discrimination RT in E2A. Manual RT (bars) and key-press errors (points), revealing IOR (match - mismatch RT). Error values are shown in log-odds scale with corresponding percentages for ease of interpretation.

Protected Fisher's Least Significant Difference bars used in Figure 16 were computed including all possible combinations of cued region, target region, and cueing (match vs. mismatch) as levels of one factor (Corresponding ANOVA: $F(3,87) = 8.78$, $p < .01$, $MSe = 15401.8$) for the interested reader to make comparisons not directly treated below. Manual response time data were submitted to a t-test of cue-target location matching (Match cue vs. mismatch cue). Reflecting the effects of IOR, identification responses following match cues were significantly slower than those following mismatch cues, $t(29) = 4.4013$, $p < 0.05$. ($Mdiff = 13.46$, See Figure 16).

Digit identification error rates were converted to log-odds and analyzed using two linear mixed models of the same factor design as the above RT ANOVAs, but with subject ID entered as a random effect. Error rates in the match condition did not differ from error rates in the mismatch condition, $z = -0.37$, $p > .05$, $M_{diff} = 0.03949$.

Saccade Results

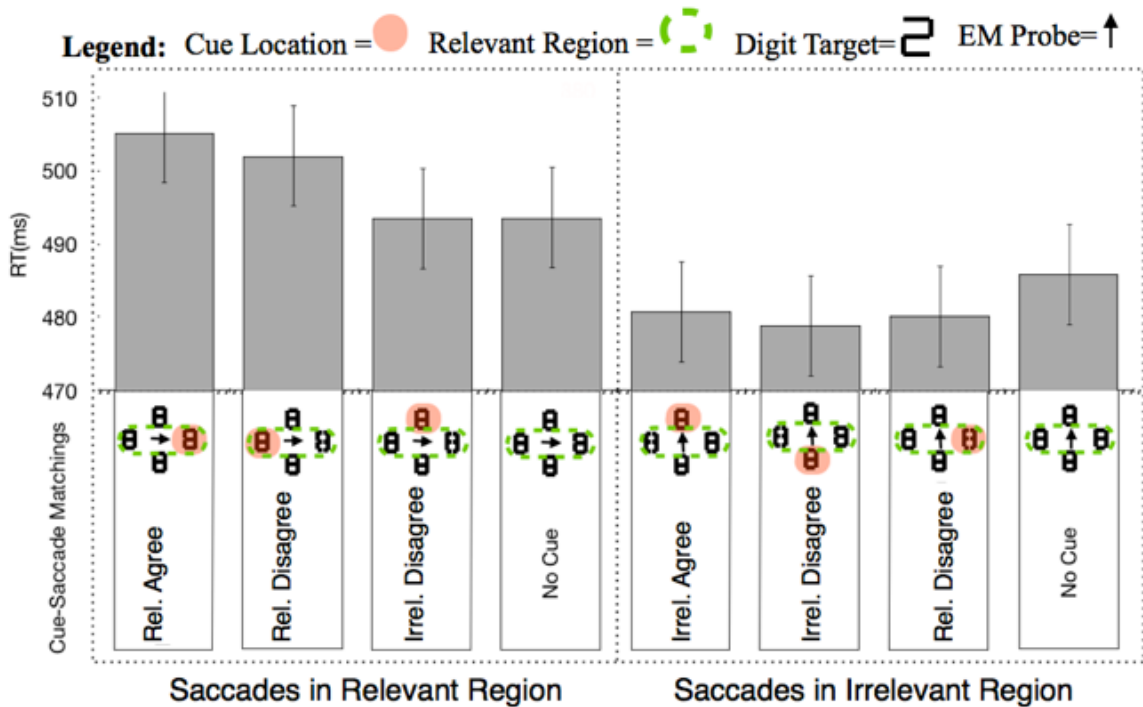


Figure 17. SRT in E2A. No cue-saccade agreement effects (agree v. disagree) were observed.

Protected Fisher's Least Significant Difference bars used in Figure 17 (above) were computed including all possible combinations of cued region, saccade region, and cue-arrow direction agreement (agree vs. disagree) as levels of one factor (Corresponding

ANOVA: $F(7,203) = 4.18, p < .01, MSe = 10911.8$) for the interested reader to make comparisons not directly treated below ¹⁵.

The above eight conditions were compared in two ANOVAs, one comparing cue-arrow direction agreement effects and the other region of response. This was done because while any two of these three factors can be analyzed together, all three together make the analysis non-orthogonal (e.g., if a placeholder in the relevant region is cued, a subsequent saccade into the non-relevant region is never directed toward the cued placeholder and will therefore never agree). ANOVA 1 was used to measure the effect of two IVs; cue-arrow direction agreement (agree v. disagree) and region of cue and response (relevant v. irrelevant). Only trials where both cue and response were directed onto the same type of region (relevant-relevant or irrelevant-irrelevant) were included to maintain the soundness of cue-arrow direction agreement comparisons. The main effect of cue-arrow direction agreement was not significant ($F(1,29) < 1$) suggesting that cues did not locally affect the saccade system. However, the region into which the saccade was directed had a strong effect on SRT ($F(1,29) = 14.6, p < .01, MSe = 5720.1$, for means and SDs see table 5) such that saccades were much slower when directed into the relevant region than when they were directed into the irrelevant one. This is not IOR but instead is proposed to be the same inhibitory phenomenon observed in Klein & Pontefract (1994), Hunt & Kingstone (2003), and the OMRH two papers of this study. The interaction between cued region and region of response did not reach significance ($F(1,29) < 1$).

¹⁵ Saccade errors were also compared, see the footnote beneath Table 4.

The data were separated by whether cues and responses occurred inside of or outside of the relevant region, and were submitted to a 2x2 Repeated Measures ANOVA¹⁶. Since SRT was statistically equivalent on cue-arrow direction agreement and disagreement trials, both trial types were included in this analysis to improve statistical power but they were collapsed into the remaining two factors (cued region and saccade region). The ANOVA revealed a significant main effect of response location ($F(1, 29) = 19.8, p < .05, MSe = 517.77$), meaning that responses directed into the relevant region were inhibited relative to responses directed into the irrelevant regions ($M_{relevant} - M_{irrelevant} = 15.65ms$). Neither the main effect of cue location ($F(1, 29) = 3.5, p = .07, MSe = 517.77$) nor the interaction ($F(1, 29) = 3.03, p = .092, MSe = 517.77$) were statistically significant at the .05 level.

Though the main effect of cue location and its interaction with target location were only marginally significant (.07 and .09, respectively), the separation of the data by cue and target revealed that when responses were made into the irrelevant regions, cueing did not affect response times. However, when responses were made in the relevant region, cues presented in the relevant region further delayed response times ($M_{difference} = 9.9945ms$,

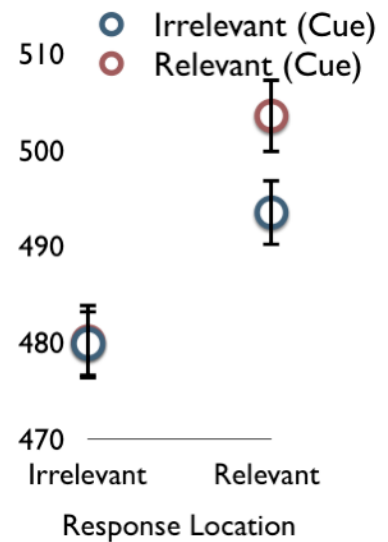


Figure 18. SRT by region relevance in E2A. Saccades were executed more slowly in the relevant region.

¹⁶ Since SRT was equivalent on cue-arrow direction agreement and disagreement trials, both match and mismatch trials were included in this analysis to improve statistical power but as in E1A they were collapsed into the remaining two factors (cued region and saccade region).

Figure 18). A follow-up simple effects t-test supported the assertion that cues presented in the relevant region delayed responses in the relevant region but not the irrelevant regions ($t(29) = -2.9, p < .05, 95\% \text{ CI } [-17.03, -2.96]$). This is not an effect of primary interest in this study, but due to the marginal significance of both a main effect and interaction, this result is offered to the reader for their own consideration.

Effects of Intertrial Priming on Cue-Target Location Matching & Regional Effects

The effects of intertrial priming will only be tested for the primary response task as dividing the secondary task (which contains less observed values) would reduce statistical power to an untenable level. Digit identification RT data were submitted to a 2*2 repeated measures ANOVA with cue-target matching (Match-Relevant vs. Mismatch-Relevant) entered as one variable and the task from the previous trial (Saccade vs. Digit identification) as the other. As expected there was a main effect of cue-target matching revealed such that responses were significantly slower following match cues than mismatch cues in the relevant region, $M_{\text{diff}} = 13.46\text{ms}, F(1, 29) = 10.13, p < .05, MSe = 17385.66$. Also, a main effect of previous trial type revealed that participants responded significantly (23.24ms) faster on digit trials which followed digit trials than digit trials following saccadic response trials, $F(1, 29) = 29.01, p < .05, MSe = 17385.66$). However, the two variables did not have an interactive effect on response time ($F < 1$). Thus, both cue-target matching and inter-trial task priming affected responses on a given trial, but cue-target matching effects were not dependent upon intertrial task priming as indicated by the absence of any interaction between the two variables.

Digit identification error rate data were submitted to a generalized linear model with the same 2x2 factor design as the RT data, but digit identification errors were entered as a binomial dependent variable. The output z-scores were evaluated to determine the effect of each variable on participant error rates; the estimate of the intercept was -2.88, SE = 0.17. Participant response accuracy did not vary as a function of cue-target matching ($z = -0.594$, $p > .05$), or previous trial type ($z = -1.524$, $p > .05$), and there was no interaction observed between the two variables ($z = -1.351$, $p > .05$).

Table 6

Digit Task Performance by cue-target matching and previous trial type

Previous Trial	Cue-Target Matching	Mean RT(ms)	SD	Errors (Log-Odds)
Manual	Match	536.3	60.0	-2.82
	Mismatch	523.0	57.1	-2.72
Saccade	Match	560.7	67.8	-2.85
	Mismatch	547.0	86.2	-3.12

Further, a second 2x2 ANOVA was conducted to assess whether inter-trial task priming affected responses to mismatch relevant and mismatch irrelevant cues differently; the two independent variables were cue type (mismatch relevant v. mismatch irrelevant) and previous trial type (identification or EM). However, an exogenous cue's ability to capture attention and/or generate response preparation is short-lived and it is not clear whether the presence of IOR at a non-target placeholder would affect RT. Only if one believes that IOR reduces competition at the perceptual or motoric level from a stationary placeholder location and that this reduction would improve performance at other placeholders should an effect be observed. Specifically, if IOR is operating on a

cued placeholder, RT on mismatch trials should be faster than on no cue trials because IOR serves to bias participants away from that placeholder. A main effect of previous trial type reflected that participants were faster overall when they had previously performed in a digit identification trial than a saccade trial ($F(1,29) = 3.06, p < .05, MSe = 18164.6$). There was no significant main effect of region of mismatch cue presentation and no interaction between the two variables was observed.

A linear mixed effects model with the same factor structure was used to compare error rates. The estimate of the intercept was -2.96869 , the SE 0.16039 . Once again there was a significant effect of previous trial type on response times overall ($z = -3.664, p < .05, SE = 0.06661$) reflecting that participants were more error prone following a digit trial than following a saccadic response trial. There was no significant effect of cued region ($z = -1.038, p > .05, SE = 0.06655$), and an interaction was not observed ($z = -0.696, p > .05, SE = 0.06654$).

Table 7

Digit Task Performance by cued region and previous trial type

Previous Trial	Cue Region	Mean RT(ms)	SD	Errors (Log-Odds)
Manual	Relevant	523.0	57.1	-2.70
	Irrelevant	529.2	86.2	-2.75
Saccade	Relevant	547.0	63.9	-3.10
	Irrelevant	553.9	69.3	-3.33

3.5 Experiment 2B

3.5.1 Methods

Participants. Thirty (12 male, 18 female) undergraduate students volunteered to participate in the present study in exchange for course credit. Ages ranged from 18 to 26, with a mean age of 19.9. Three participants reported themselves to be left-handed, the remaining 27 reported as being right-handed.

3.5.2 Predictions & Data Analysis

All data analysis methods used in E2B were identical to its twin experiment E2A except that inter-trial effects analyses were performed on SRT with an additional factor added to each one to account for saccade directed both inside and outside of the digit task relevant region. The purpose of this experiment was similar to the purpose of E1B, to determine whether the observed IOR pattern would reverse as a consequence of inverting task probabilities. Specifically, if the requirement to frequently perform saccadic responses results in re-engagement of the oculomotor machinery IOR should manifest in the digit task as a speed-accuracy tradeoff and in the saccade task as slower SRT when the saccade destination matches the cued location than when it does not. However, if only preparation to generate *reflexive* eye movements is sufficient to witness the motor form and if participants continue to inhibit their tendency to reflexively shift their eyes in order to perform the digit task the form of IOR witnessed should remain attentional in nature and manifest as a cost to digit discrimination at the cued location without affecting SRT.

3.5.3 Results

All trials that contained either an eye-movement or digit identification error were removed from RT analysis. Manual responses faster than 400ms or slower than 1050ms,

and saccadic responses faster than 100ms or slower than 800ms were removed from analyses as outliers. A total of 252 (8%) manual response trials and 312 (2%) saccade trials were removed in this way. Further, 3078 (~28%) inaccurate ($>1.5^\circ$) eye movements were removed from RT analysis as errors. For all mean RT and error data see Table 8.

Table 8

Means from Experiment 2B. See saccade error comparison below¹⁷

Condition	Cuing	Mean RT (ms)	SD	Digit Identification Error Rate (Log-odds)	Match - Mismatch RT
Manual	Match	657.8	91.0	-2.98	7.34
	Rel. Mismatch	650.4	75.6	-2.98	
	Irrel. Mismatch	654.8	72.6	-2.87	
	No Cue	649.2	81.3	-2.70	
Read as.....	“Cue:Target Agreement”			% > 1.5 Deg	SRT (Agree - Disagree)
Saccade	Rel:Rel Agree	364.9	38.8	-1.40	1.81
	Rel:Rel Disagree	363.1	39.9	-1.47	
	Irrel:Rel Disagree	362.4	39.4	-1.40	
	No Cue:Rel	366.4	40.4	-1.44	
	No Cue:Irrel	352.4	47.6	-1.48	
	Rel:Irrel Disagree	348.0	46.9	-1.47	
	Irrel:Irrel Agree	351.6	44.3	-1.52	-0.46
	Irrel:Irrel Disagree	352.1	47.0	-1.51	

¹⁷ The two linear models did not differ significantly ($\chi^2(7, N = 30) = 3.81, p > .05$).

Manual Results

Unprotected Fisher's Least Significant Difference bars used in Figure 19 were computed including all possible combinations of cued region, target region, and cueing (match vs. mismatch) as levels of one factor (Corresponding ANOVA: $F(3,87) = 0.61$, $p > .05$, $MSe = 23558.71$) for the interested reader to make comparisons not directly treated below.

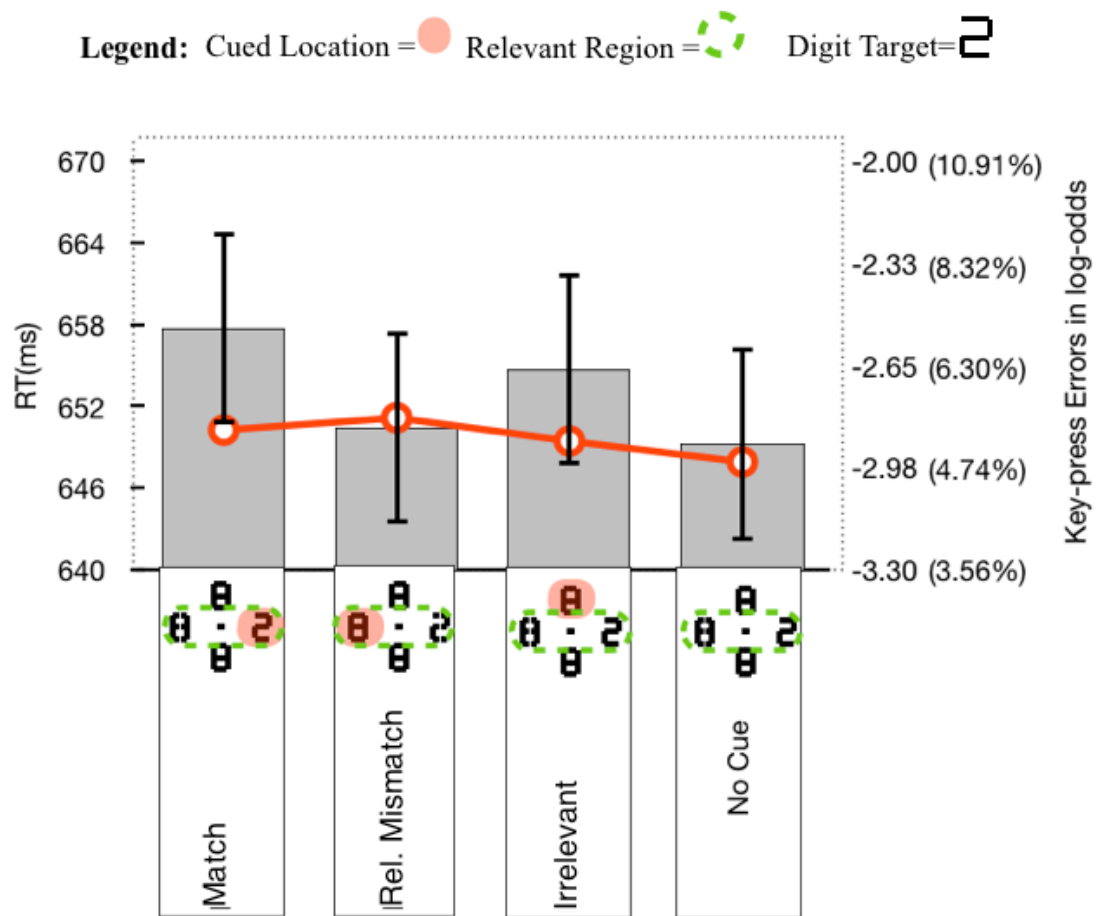


Figure 19. Discrimination RT in E2B. No RT differences reached significance.

The same paired t-test used in E2A was conducted in E2B. Participant RT in the match condition was not significantly faster than RT in the mismatch condition, $t(29) =$

-0.92, $p > 0.05$. ($M_{diff} = 7.34ms$, See Figure 19). Digit identification error rates were converted to log-odds and analyzed using to a linear mixed models of the same factor design as the above RT t-test, but with subject ID entered as a random effect. Error rates in the match condition did not significantly differ from error rates in the mismatch condition, $z = -0.15$, $p > 0.05$, $M_{diff} = 0.037$.

Saccade Results

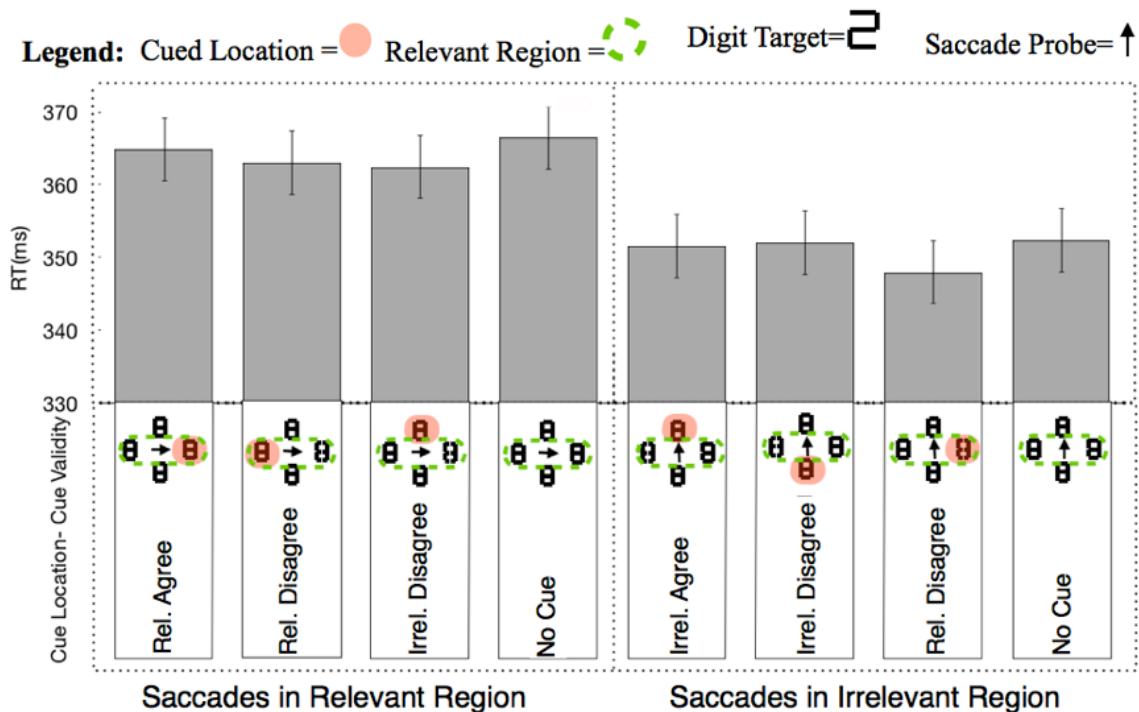


Figure 20. SRT by region relevance in E2B. Post hoc inspection revealed no cue-arrow agreement effects and another apparent main effect of region-of-response (explored below). All error bars are 1/2 FLSD.

Protected Fisher's Least Significant Difference bars used in Figure 20 were computed including all possible combinations of cued region, target region, and cueing (match vs. mismatch) as levels of one factor (Corresponding ANOVA: $F(7, 203) = 5.24$, p

< .05, MSe = 12793.44) for the interested reader to make comparisons not directly treated below.¹⁸

ANOVA 1 was used to assess the impact of two IVs were cue-arrow agreement (agree v. disagree) and region of cue and response (relevant v. irrelevant) upon RT. Only trials where both cue and response were directed onto the same type of region (relevant-relevant or irrelevant-irrelevant) were included to maintain the soundness of cue-arrow agreement comparisons. Again SRT was much slower when saccades were directed into the relevant region ($F(1,29) = 7.35, p < .01, MSe = 6385.96$, for means and SDs see Table 8). Neither the main effect of cue-arrow agreement nor the interaction between the two variables reached significance ($F(1,29) < 1$).

The data were once again separated by whether cues and responses were inside or outside of the relevant region, and were submitted to a 2*2 repeated measures ANOVA. The ANOVA revealed a significant main effect of response location ($F(1, 29) = 11.34, p < .0022, MSe = 9691.93$), meaning that responses directed into the irrelevant regions were significantly faster than responses directed into the relevant region (See Figure 21, Right). Neither the main effect of cue location ($F(1, 29) = 0.27, p = .61, MSe = 9691.93$) nor the interaction ($F(1, 29) = 1.80, p = .19, MSe = 9691.93$) were statistically

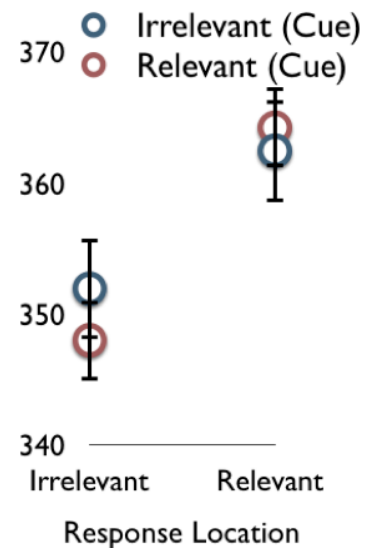


Figure 21. SRT as a function of cues and responses into v. out of the relevant region. Errors bars are 1/2 FLSD.

¹⁸ Saccade errors were also compared, see the footnote beneath Table 8.

significant at the .05 level.

Effects of Intertrial Priming on Cue-Arrow Direction Agreement & Regional Effects

SRT data were submitted to a 2*2*2 repeated measures ANOVA with the first variable being cue-arrow direction agreement (Agree vs. Disagree) the second being response type required on the previous trial (Saccade vs. Digit identification), and the third being the region of required response (Relevant vs. Irrelevant regions). Only trials where both the cue and probe response both occurred in the same region type were included in this analyses to retain comparability between the agree and disagree conditions. There was no main effect of cue-arrow direction agreement ($F(1, 29) = 0.2196617, p > .64, MSe = 14165.43$) and no interactions were observed between cue-arrow direction agreement and any other main effects of interest ($p > .05$). However, a main effect of previous trial type revealed that participants responded significantly (33.86 ms) faster on saccade trials which followed saccade trials than saccade trials following digit trials, $F(1, 29) = 43.73, p < .05, MSe = 14165.43$. As noted in previous analyses participants were significantly faster to respond when arrow probes commanded saccades into the irrelevant regions than when they commanded saccades into the relevant region ($Mdiff = 12.29$ ms, $F(1, 29) = 9.32, p < .05, MSe = 14165.43$). A significant interaction between the effects

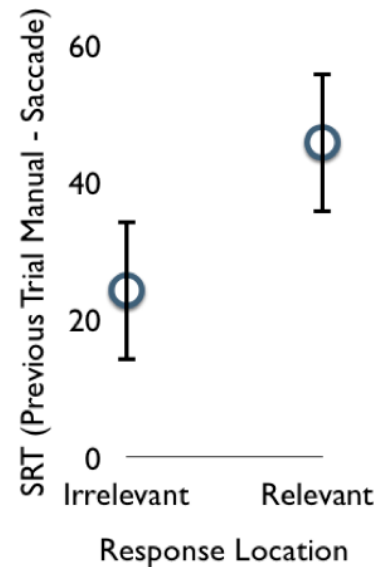


Figure 22. SRT for saccades directed into the relevant vs. the irrelevant region. Error bars are 1/2 FLSD.

of previous trial type and region of response also revealed that saccadic response inhibition associated with having previously performed in a digit identification trial was greater if participants were required to saccade into the relevant region in the present trial. Immediately after a digit trial, participants were 24ms slower to saccade into the irrelevant regions but were 45ms slower to saccade into the relevant region (Shown in Figure 22). There were no other significant interactions observed between any of the three variables ($p > .05$).

Another 2*2*2 ANOVA was conducted to compare the effects of cues and responses as a function of their region of presentation, and this comparison differed from the one above by removing the matching cue-target comparison in order to include those trials where cues and responses occurred on different axes. Trials where the saccade target placeholder was cued were not excluded from this analysis because cue-arrow direction agreement did not affect SRT, and thus by the inclusion of both agreement and disagreement trials a greater quantity of data could soundly be brought to bare. Again a main effect of region of saccade indicated that eye movements were more rapidly executed into the irrelevant regions than the relevant region ($MDiff = 11.58$, $F(1, 29) = 20.49$, $p < .05$, $MSe = 6493.45$). Further, a main effect of trial type revealed that participants executed their saccades much faster ($MDiff = 32ms$, $F(1, 29) = 64.99$, $p < .05$, $MSe = 6493.45$) following saccade trials than following digit trials. An interaction between saccade region and previous trial type was also revealed which indicated that while eye movements were still inhibited in the relevant region following a saccade trial ($Relevant - Irrelevant = 9.32ms$) that inhibition was more substantial immediately

following a digit identification trial (Relevant - Irrelevant = 23.36). No other main effects or interactions attained significance ($F < 1$).

3.6 Discussion

Implications: Two Forms? Components?

Let's consider the most crucial findings from both experiments before discussing their implications. In E2A where digit identifications were frequent, we found strong evidence of IOR (this evidence comes our t-test on p.51) but no evidence that the cues activated an oculomotor program (ANOVA 1, p.53). In E1B where saccade trials were more frequent a different pattern was revealed. We did not find evidence that exogenous cues generated either the perceptual form (t-test 1, p.58) or the oculomotor form of IOR (ANOVA 1, p.60). Further, in both experiments participants were actually slower to saccade into the relevant region where digits could appear than the irrelevant region where they could not.

The pivotal finding of E2A was the simultaneous presence of IOR on digit identification trials and the absence of IOR on saccade trials. This is taken as converging evidence in support of a form of IOR that inhibits target processing rather than motor production which is (at least in the time that the effect is observed) independent of oculomotor activation. Rafal, Calabresi, Brennan, and Sciolto (1989; see also Li & Lin, 2002 and Godijn & Theeuwes, 2002) theorized that saccade preparation is a crucial component in the behavioural manifestation of IOR. The present results demonstrate that this is not the case for perceptual IOR; in fact, the requirement to withhold eye

movements can entirely ablate the normal effects of oculomotor IOR while a non-oculomotor form of IOR is still exhibited in a non-spatial discrimination task.

There are two cue-target combinations used in the present experiments, a peripheral cue followed by a peripheral target calling for a response and a peripheral cue followed by a central arrow calling for an endogenously driven saccade. Both of these combinations have previously been shown to produce the behavioral effects of IOR¹⁹ (Taylor & Klein, 2000), but never in a dual-response task such as that used here. The results from both E2A and its mirror E2B are presented as converging evidence for an input form of IOR. In E2A it was demonstrated that the attentional (input) form of IOR can still be expressed even in a region of space that is uniformly affected by oculomotor inhibition. In E2B, it was shown that a high probability of executing a saccade on a given trial is not in itself sufficient to manifest a motoric form of IOR regardless whether it is measured by eye movements or digit identification responses. This is an important elaboration upon the findings of Chica et al (2010) because it illustrates that preparation to perform in a saccade task is not sufficient to manifest a non-attentional form of IOR. Of key importance in this paradigm, although participants should be prepared for the saccade task they must withhold reflexive eye movements (to all cues and all digit targets) and execute saccades endogenously only after the onset of the arrow target.

Data from E2A support a two forms account of IOR, in which only the motor form *or* the attentional/perceptual form are operating at any one time. This is evidenced

¹⁹ It is important to note that Taylor and Klein's (2000) participants performed a location discrimination task in their key press task rather than a feature discrimination such as the digit identification performed by participants in the present study.

by the fact that participants, when performing an attentionally demanding task in which eye movements were strongly discouraged, still exhibited IOR when making digit identification responses to peripheral stimuli while not exhibiting IOR for saccadic responses. Importantly, participants were expected to withhold eye movements on the majority of trials, presumably inhibiting the oculomotor machinery to a sufficient degree to block the expression of oculomotor IOR, as would likely have been predicted by Taylor and Klein (2000). At the conclusion of experiment E2A, because saccade preparation before the appearance of the target is unlikely and maladaptive in E2A and oculomotor IOR was not observed, the hypothesis of Taylor and Klein (2000) and also Klein and Hilchey (2012) that the eyes must be free to move to witness oculomotor IOR is supported. Further, in E2B eye movement targets were frequent but there was no incentive to permit reflexive deployment of eye movements because participants could never saccade to peripherally presented objects; again oculomotor IOR was not observed (Though see the “Issues and Future Directions” section for a discussion of why the perceptual form of IOR was not observed).

Implications: The Effects of a Spatial ACS on IOR

It remains unclear whether the motor form of IOR can be affected by a spatial ACS. Since oculomotor IOR was not observed in either the relevant or irrelevant regions, it cannot be inferred from the present results whether a spatial ACS can modulate oculomotor IOR. An alternative method for testing specifically whether one form of IOR or the other can be affected by a spatial ACS is suggested in the section below.

3.6.1 Conclusions

It has previously been shown in numerous paradigms that IOR slows the execution of eye movements toward a cued location even if the saccade “go” stimulus is presented away from the cued location, suggesting that the inhibition operates at a motoric level. Others have shown that IOR slows performance in discrimination tasks without an opposing effect in accuracy (without a speed-accuracy tradeoff), suggesting that it operates at the perceptual or stimulus integration level. Further, it has been reported that the requirement to execute eye movements in advance of a target display can result in saccadic IOR, but the same method causes a SAT in the discrimination task rather than a true perceptual effect (Chica et al, 2009). Finally, in E2A of the present study it has been shown that when eye movements are inhibited IOR operates at an attentional perceptual level but not a motoric level. When in E2B digit identification trials were rare and endogenously executed eye movements were made frequent neither form of IOR was observed, which is taken as support that a motoric form of IOR is contingent upon whether one is free to reflexively deploy saccades to peripheral stimuli. The crucial factor appears not to be that the reflexive oculomotor machinery has been engaged, but that it has not been *actively disengaged* by task demands.

Chapter 4 General Discussion

The experiments presented here showcase a remarkably high degree of independence between overt and covert orienting effects. In E1A and E1B it was shown that the maintenance of covert spatial attention and saccade preparation need not accompany one-another following the presentation of exogenous cues; a finding at odds with an OMRH of exogenous attention. Further, eye movements were inhibited to enter regions where participants were performing a digit identification task, a finding similar to that of Klein and Pontefract (1994) and Hunt and Kingstone (2003) which runs counter to an OMRH of endogenous attention. However, after presenting their evidence which ran counter to the OMRH, Klein and Pontefract (1994) proposed that a restricted form of their theory might be salvaged if it were found that spatial eye movement preparation and endogenous shifts of the covert beam occur together non-optionally, but could then uncouple based on task demands. For example, to endogenously attend left an eye movement must be programmed to the left, but once the covert beam had shifted to that region the motor program could be inhibited. Findings on this shifting account regarding the endogenous mode are mixed, but strong evidence suggests that the OMRH may be true of shifts in the exogenous mode (Belopolsky & Theeuwes, 2009; Smith, Rorden, & Jackson, 2004; Smith, Schenk, & Rorden, 2012). Taken with our data it is suggested that exogenous capture is strongly linked to the eye movement system, but that the two modes of attention uncouple independently following exogenous capture. Future experiments should explore the conditions under which disengagement of either system is delayed,

with modulations of task expectancy and task region apparently being two contributing factors.

One form of IOR in the clear absence of another is apparent in E2A; IOR did not emerge in saccade trials presumably because the reflexive oculomotor system was in an inactive state but the attentional/perceptual form of IOR was still affecting target discrimination performance. Further, in E2B it was revealed that when eye movement trials were made highly probable and digit trials rarer, the attentional form of IOR was reduced (to non-significance). Taken with the findings of Chica et al (2010) that requiring participants to make eye movements prior to the onset of the target abolished the attentional form of IOR in location discrimination tasks, this provides converging evidence that task-driven increases in the preparatory state of the saccade system can modulate the attentional form of IOR. Further, the participants' continued inability to engage their reflexive eye movement system (lest they execute saccades towards peripheral targets) was itself apparently sufficient to result in the absence of oculomotor IOR. Not only was the attentional form absent, but oculomotor IOR was not observed as indicated by absence of IOR on eye movement trials and the absence of a speed-accuracy tradeoff in the discrimination task. While further investigation is necessary, this should be considered as tentative evidence that the motor form of IOR can be blocked by the need to withhold reflexive saccades. The design of a similar dual-task that can bring forth the motor form while abolishing the attentional form should be a high priority to strengthen this evidence. This experiment might be made feasible by employing unique stimuli for the discrimination trials which have been shown to bypass those systems governing

reflexive saccade activation, the presentation of which would not require active suppression of reflexive eye movements (Sumner, Nachev, Vora, Husain, & Kennard (2004).

When all experiments are taken together it becomes apparent that the cues' ability to affect saccade programming is dictated partially by the SOA (cues more reliably affected SRT at a short SOA) and partially by the degree of incentive to inhibit eye movements (cues also more reliably affected SRT when eye movement trials were frequent). See the data as presented in a "saccade findings roundup" in Appendix B to better visualize these effects. The contribution of SOA upon regional cueing effects is not necessarily surprising, but two causes may equally well explain the result. It may be that the time-course of the cue's effect is relatively short and though strong at 200ms in all experiments is much weaker when responses are made at the 800ms SOA. Alternatively, target expectancy should be ramping up at the time of the cue in a 200ms CTOA experiment and may cause greater capture from the peripheral cue. Conversely this may limit the degree to which the cue can generate capture at the 800ms SOA. The first explanation is a matter of effect and the second of cause, and the two could be dissociated by re-running experiment with the two SOAs mixed. This manipulation is doubly recommended since the absence of oculomotor IOR in E2B is theoretically important, and it is possible that IOR was absent due to the relative ineffectiveness of the cues in that experiment.

Issues & Future Directions

While previous studies have reported that the effects of inter-trial priming can masquerade as a true ACS (Belopolsky, Schreij & Theeuwes, 2010), this did not seem to be the case in the present study. The comparison of inter-trial sequence effects revealed that the identity of the previous trial (digit identification vs. saccade) only affected overall response times in a current trial, but did not affect the magnitude of cue-digit location matching effects in E1 or cue-arrow direction agreement effects in E2. This was of particular importance since it was expected that modulations of oculomotor preparation would result in the expression or inhibition of the forms of IOR, and while general task switching costs are observed, they did not affect the variable of interest.

One limit in the interpretability of this data and that of similar studies is the inherent statistical inequality of the primary and secondary tasks in each experiment. It was hypothesized that when digit identification was the primary task, cue location match effects would emerge in only the digit task in the absence of eye movement preparation. This is what was found, but insufficient data was available to tease apart differences in the secondary task (a necessary product of a dual-task paradigm in which infrequent probes are used to assess mental states).

It is possible that in E2B's digit identification task IOR was simply reduced in magnitude and more power was required to reveal it. It is also possible that all cues failed to exogenously capture covert attention due to the high probability of task-relevant stimuli being presented at center fixation. Another experiment either mixing the two SOAs or using peripheral saccade signals may be necessary to reinforce or potentially to correct the findings of E2B.

Future experiments focussing on the relationship between spatial attentional control and IOR might benefit from asking a single response type of their participants rather than both eye movements and keypresses for to-be-identified digits. Replacing the manual response component and the digit task with a simpler peripheral localization saccade task would likely serve to separate the contributions of a spatial ACS and oculomotor suppression on IOR. A similar test could be performed for the attentional form of IOR: another experiment using 90% peripheral digit targets in one region and only 10% peripheral digit targets in the orthogonal regions. Without the potentially occluding effects of oculomotor preparedness and with a certain (very low) percent of digit targets presented in the irrelevant region, we can better observe the effects of an ACS on the attentional form of IOR.

Additionally, a strong hypothesis in the field of IOR is that a motoric form of inhibition is specifically linked to the reflexive *oculomotor* system. The experiments presented in the present study are further evidence in support of that hypothesis because the form operating in my experiments where reflexive eye movements must be withheld is, unlike IOR in other studies when the eyes are “free to move”, plainly non-motoric in its effects. However, in order to determine whether the eyes truly are unique in their ability to generate the motor flavor, future experiments should attempt to permit participants to use natural movements of other appendages to make their responses. A task to establish a motor form might consist of *pointing* to onset targets on a majority of trials, with a minority of trials instead consisting of a digit discrimination (i.e., if a you see a “2” point at the word “two” at the bottom of the screen). If the output form of IOR

(which was not observed in any of our experiments) can be instantiated in multiple response systems then speed-accuracy tradeoffs may manifest in the secondary task.

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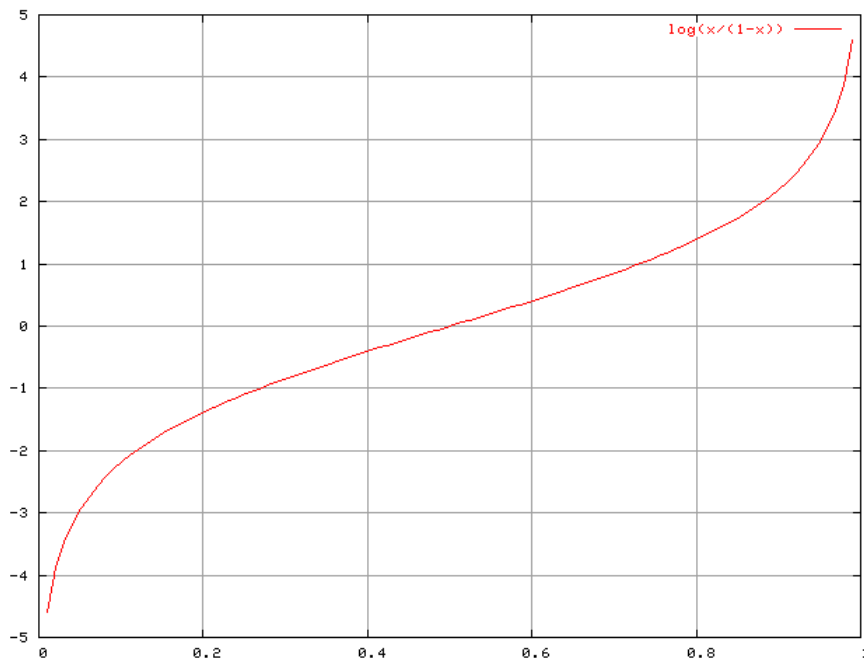
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Appendix A: Graphical Representation of a Log-Odds Transform

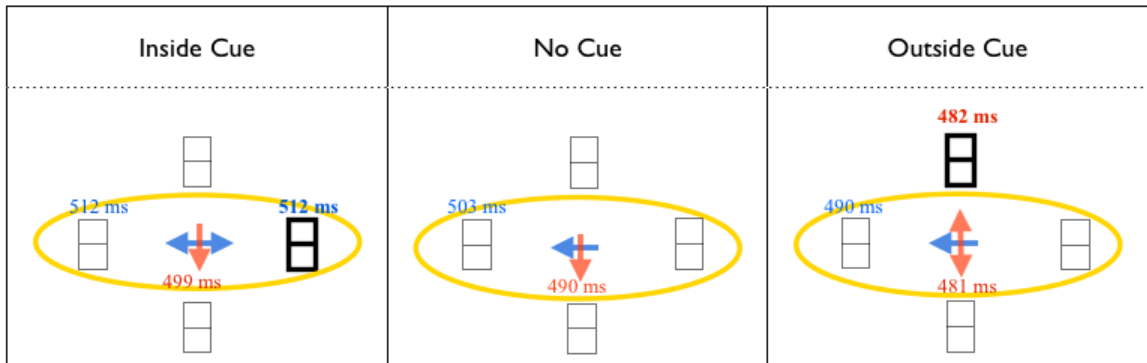


*Log-odds transformation: On the X axis is some proportion from 0 to 1 (i.e., some mean drawn from a binomial variable coded as 0 and 1), on the Y axis is the log scale equivalent of each value (Logit, 2013). A log-odds transform was chosen for the following reason: According to Signal-Detection Theory (Swets, 1964), a person's probability of correctly discriminating one signal from another is well illustrated by two partially overlapping normal distributions. An increase in the participant's response criterion will increase accuracy *dramatically* if their current criterion is liberal, but an equal increase in their response criterion will do *very little* if their criterion is already set very conservatively. This manifests as an exponential recovery function which overestimates the true differences between participants with high error rates and underestimates the true differences between those with low error rates, a log-odds transformation which is an exponential *gain* function resolves this issue (Dixon, 2008).*

Appendix B- Graphical Summary of Saccade Results.

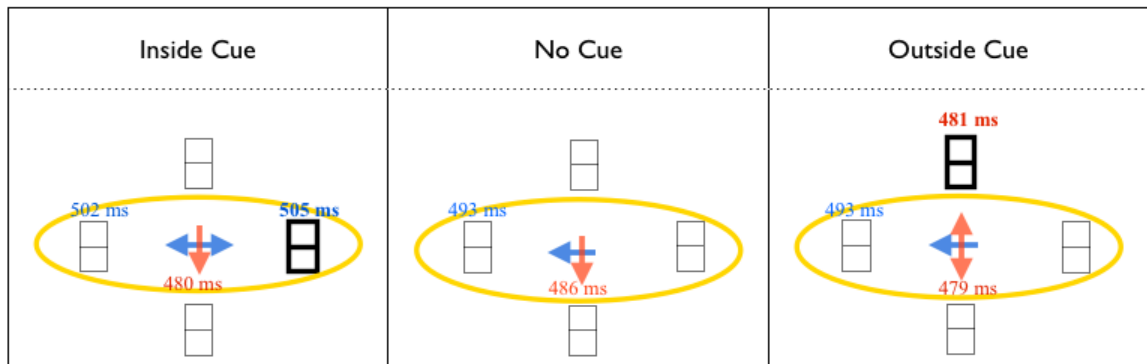
Everything

E1A - Short Cue Target Onset Asynchrony, high probability of digit identification



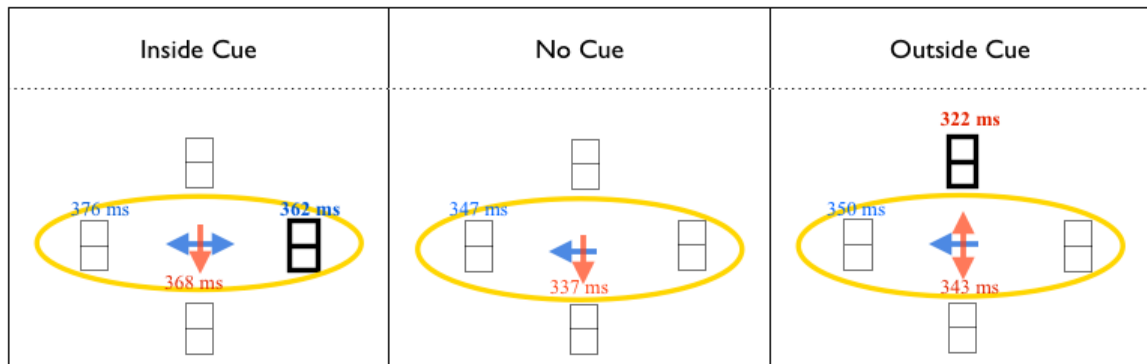
Effects of Interest: Saccadic inhibition is found in the relevant region (red vs. blue) and cues in the relevant regions slow responding while cues in the irrelevant regions speed responding (left vs. right panel).

E2A- Long Cue Target Onset Asynchrony, high probability of digit identification



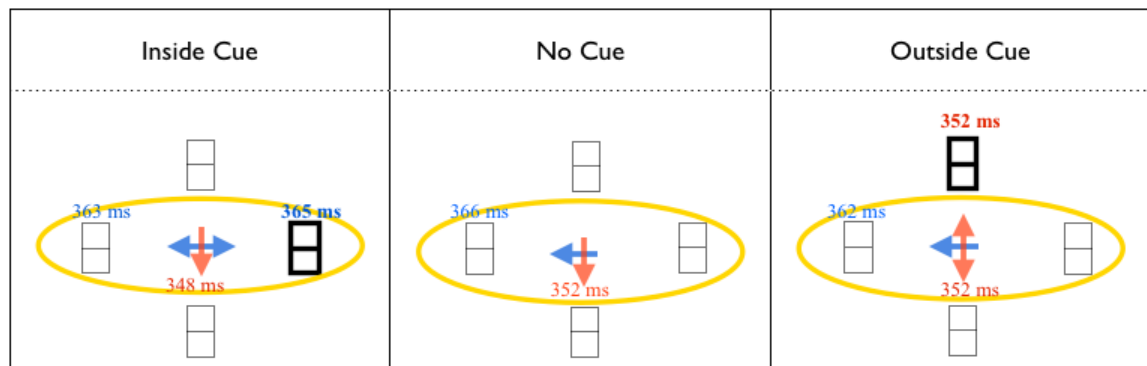
Effects of Interest: Saccadic inhibition is found in the relevant region (red vs. blue) and a marginally significant interaction indicates that only SRT in the relevant region is affected by cues (e.g., compare unbolded blue values) whereas SRT in the irrelevant regions was not (e.g., compare unbolded red values).

E1B - Short Cue Target Onset Asynchrony, high probability of saccade target



Effects of Interest: Cues exogenously capture the saccade system resulting in faster and more accurate saccade execution (bold vs. unbolded), cues presented in the relevant region globally slow responding (left vs. right panel) and saccades are slower into the relevant region than the irrelevant region (Red vs. Blue).

E2B- Long Cue Target Onset Asynchrony, high probability of saccade target



Effect of Interest: Saccadic inhibition is found in the relevant region (red vs. blue).