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Scene Search Guidance under
Salience-driven and Memory-driven Demands

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ABSTRACT

Visual search involves selecting relevant information while ignoring irrelevant information. Most search models predict what relevant features attract gaze; yet few consider search guidance from previous knowledge of scenes. This dissertation used eye movements to examine the guidance of attention when an immediate or delayed distractor appeared during novel and repeated searches.

The experiments showed efficient search for repeated scenes, a classic result of contextual cueing. During repeated searches, an immediate attentional bias was found for distractors close to the target location. Automatic and controlled selective attention processes, measured using the antisaccade, were found within search behavior. The final experiment showed an automatic mechanism explained implicit – rather than the explicit – associative learning for a consistent target location within a repeated scene. Additionally, there was a controlled mechanism related to successful identification of the search target.

Taken together, the findings support an immediate implicit guidance of attention that biases initial scene searches. After enough time passes, explicit guidance can directly guide the eyes to a known target location. The early effect of implicit bias from conceptual short-term memory, which is an abstraction of object-scene relationships, suggests task demands prioritize objects relevant for efficient search when familiar.

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LIST OF ABBREVIATIONS

CV	Coefficient of Variation
EEG	Electroencephalogram
PPA	Parahippocampal Place Area
RSC	Retrosplenial Cortex
SPR	Scan Path Ratio

CHAPTER 1

INTRODUCTION

To successfully make decisions, we need to be able to attend to relevant information while ignoring irrelevant information. Search is a daily and essential process of attention control when we select or suppress visual information depending on task instructions (Buswell, 1935; Yarbus, 1967). Selection may occur in an automatic or bottom-up way based on a unique event or visual features, like color or brightness. Suppression requires more controlled or top-down processes based on a particular goal, like finding a target, or withholding a response so another can be made. If there is an awareness of a particular goal or suppression of an automatic response then the process can be considered *explicit*. If an action occurs without awareness or specific instruction, then the process underlying the response is *implicit*. The goal of this dissertation aims to distinguish implicit and explicit processes using eye movements to better understand how we prioritize our attention during scene search.

Eye movements provide a moment-to-moment overt indication of where we focus attention. The eyes move from one location to another (saccade) or pause at a location to further encode detailed visual information (fixation). The time spent looking at a location has been related to consolidation of selected information while an eye movement signifies a shift of attention to a new location.

Intuitively, we cannot visually explore our environment without shifting attention prior to a saccade (Kowler, Anderson, Dosher, & Blaser, 1995; Parkhurst, Law, & Niebur, 2002). Numerous studies have connected oculomotor control with mechanisms of attention (Corbetta et al., 1998; Kustov & Robinson, 1996; Hoffman & Subramaniam, 1995; Wright & Ward, 2008). To some, eye movements require the same underlying mechanisms as shifts in attention (Rizzolati. Riggio, Dascola, & Umiltá, 1987).

Models of oculomotor control that explain visual search behavior include attention as the driving factor for an eye movement. Selection of features occur in parallel across multiple perceptual dimensions until an explicit process restricts attention using scene knowledge; yet few models consider whether scene schema directs attention implicitly.

ARRAY SEARCH

Within the visual search literature using arrays, feature integration theory explains the selection process across two stages: an automatic pre-attentive stage and a controlled attentive stage (Treisman & Gelade, 1980). The pre-attentive stage processes information in parallel to create multiple feature saliency maps (i.e., colors or shape). Then, the second stage adds top-down influences to determine the likelihood of an object (i.e. red circle) by combining the feature saliency maps into a *priority map*. The selection process is a winner-take-all prioritization across multiple saliency map locations (e.g. red or circle items) until the location of a target object (e.g. red circle) matches what is available in visual short-term memory. Feature-based search, as described in this example, is a type of *salience-driven* guidance within arrays.

Other than maintaining the target object features (e.g. red circle) within visual short-term memory, search within arrays has been regarded as memoryless (Wolfe & Horowitz, 1998). However, consistent arrangement of the spatial layout from repeated arrays can guide search behavior from memory implicitly. *Memory-driven* search guidance within arrays is known as *contextual cueing* (Chun & Jiang, 1998; Chun, 2000). The task involves searching for a letter ‘T’ among many ‘L’s in an array that is either repeated or novel. The salience-driven search is detection of the ‘T’ within the ‘L’s. Memory-driven guidance comes from the repetition of the spatial layout. Memory for the repeated array is implicit – meaning that participants do not recognize the repeated layouts but search is still faster to the target. Memory guidance is also local – meaning that spatial arrangement of items close to the target guide attention to the area. Contextual cueing results show repeated spatial layouts with a consistent target location have faster search times compared to novel layouts without a consistent target location.

SCENE SEARCH

Unlike arrays, scenes provide a richer spatial structure that can be recognized as well as consistent associations between objects and scene context. Across multiple eye movements, objects within scenes are maintained with long-lasting and detailed episodic short-term and long-term memory (Hollingworth, 2006; Hollingworth, Richards, & Luck, 2008). *Salience-driven* search occurs within scenes from selecting visual features in parallel, like feature-based search in arrays, but consistent associations of objects within scenes, also known as *scene schema* or *gist* (Biederman, Mezzanotte, & Rabinowitz, 1982; Greene & Oliva, 2009), also influence search (Neider & Zelinsky, 2006; Võ & Henderson, 2009). When viewing a scene, participants focus their gaze on objects that are unique to the scene schema (Võ & Henderson, 2009). Shorter fixation durations are found when viewing predictable (i.e. sink in kitchen) compared to unpredictable objects (i.e. sink in living room) within a schema (Biederman et al, 1982; Greene & Oliva, 2009; Oliva & Torralba, 2006). So, objects are selected based on features but also their relationship to the context during scene search.

Saliency-based models (Itti & Koch, 2000; Tatler, Land, & Hayhoe, 2011) work fairly well to predict eye movement behavior for the first few seconds of viewing a scene, but fail for more complex processing like search (Castelhano, Mack, & Henderson, 2009; Henderson et al., 2007). The *target acquisition model* begins to address search behavior within scenes (Zelinsky, 2008); yet, the model does not include any effects found from memory, such as efficient search when a scene is familiar or knowledge of scene schema.

Torralba and colleagues (2006) developed one of the first computational models of scene search, called the *contextual guidance model*, to include a memory-based component. The contextual guidance model has two pathways that participate in search guidance: one local and another global. The local pathway interprets multiple locations for object identities independently to prioritize relevant locations (Itti & Koch, 2000), like *salience-driven* guidance. The global pathway participates in rapid scene categorization (Greene & Oliva, 2009; Oliva & Torralba, 2001) to restrict unlikely target locations within the search context. Global schema provides an attentional template for search guidance.

Wolfe and colleagues (2011) developed a similar conceptual model using selective and non-selective pathways as a proxy for local and global pathways, respectively. The main difference from the contextual guidance model being that the non-selective pathway can be separated further into semantic and episodic processes. Semantic guidance prioritizes probable targets while episodic guidance requires the selection pathway to prioritize locations from previous knowledge of the scene schema. Whether each process requires suppression or enhancement of perception is still unknown.

According to current theories of contextual cueing within scenes (Brockmole & Henderson, 2006ab; Brockmole, Castelhano, & Henderson, 2006), search guidance is explicit and based on global schema. This view differs from theories of contextual cueing within arrays that search behavior is implicitly guided by local information near the target. Because scenes are explicitly recognized (Brockmole & Henderson, 2006ab) and guidance is drawn from the global schema (Brockmole et al., 2006), search guidance to the target location within repeated scenes is faster compared to arrays (Brockmole & Henderson, 2006b).

RATIONALE

Knowing how eye movements prioritize information through salience-driven and memory-driven search guidance is necessary for a full understanding of scene search. With the addition of a distractor, prioritization of attention from each type of scene guidance can be examined using oculomotor capture. Oculomotor capture is when an object or event draws the eyes to the location despite task goals (Theeuwes, 2010). Oculomotor capture has been investigated within change detection tasks but there has not been any examination within repeated scene searches. Within scenes, a distractor may disrupt search unless explicit control can reorient an eye movement or suppress the response, as the scene contextual cueing literature suggests. If eye movements are successfully directed away from a distractor, then such a finding would support an explicit search guidance from contextual cueing in scenes.

The antisaccade task can be an additional measure of explicit control. The antisaccade paradigm shows that eye movements can be directed based on explicit instructions (i.e. look away from stimulus) rather than always responding reflexively to a stimulus (Hallet, 1978). Common measures, such as latency and error rates, have consistently shown longer latencies and more errors for antisaccades compared to prosaccades. The pattern of results suggests that antisaccade generation is more effortful (i.e. more errors) and requires reorienting from an automatic response (e.g. prosaccade) through inhibition (i.e. longer latencies). Debate still remains as to whether the automatic and controlled processes are interactive (Kristjánsson, 2007; Kristjánsson, Chen, & Nakayama, 2001; Mokler & Fisher, 1999) or independent (Massen, 2004; see Amador, Schlag-Rey, & Schlag, 1998) but there is a consensus that the mechanism to generate an antisaccade involves inhibition. Measures of inhibitory control from the antisaccade task can be used to support the claims within the contextual cueing literature regarding explicit or implicit guidance.

The following chapters examine immediate or delayed interference from a distractor presented during an eye movement in salience-driven and memory-driven scene search. Chapter 2 examines immediate or delayed oculomotor capture by a distractor during scene search, more specifically a contextual cueing task. Assuming an explicit knowledge of the target location from a repeated scene is available to guide attention, as posited from scene contextual cueing theories, a distractor in repeated scenes (memory-driven search) should interfere less often compared to distractors in novel scenes (salience-driven search). Chapter 3 examines whether common measures from the antisaccade task explain an interactive mechanism of attention control or independent automatic and controlled processes. Although heavily supported in the literature as a task that measures separate automatic (prosaccade) and controlled (antisaccade) processes, a strong correlation between two measures supports shared and interactive mechanisms. Chapter 4 examines whether salience-driven or memory-driven search behavior could be explained by an automatic or controlled mechanism using antisaccade task measures. Again assuming that contextual cueing in repeated searches is an explicit process, repeated search behavior should involve more controlled mechanisms that direct saccades to the target location than novel search behavior.

This dissertation aims to understand whether explicit knowledge of a repeated scene with a consistent target location from long-term memory explains efficient search behavior using a measure of overt attention, namely eye movements. Discussing the findings in Chapter 5, I argue that contextual cueing in scenes involves implicit guidance to relevant locations that initially biases perception within the first eye movement. The results contradict a commonly held belief that the explicit search guidance drives efficient scene search. Within visual search, implicit processes enhance information for faster search times until explicit processes reorient the eyes to likely target locations.

CHAPTER 2

EFFICIENT SEARCH FROM CONTEXTUAL CUEING DESPITE OCULOMOTOR CAPTURE

Visual search requires a combination of salience-driven and memory-driven processes to complete a goal: for example, finding a lost phone. Visual features of a scene can attract the eyes automatically to objects or locations (salience-driven). Alternatively, previous experiences may influence where the eyes will move in a more controlled way (memory-driven). Depending on the task, you may prioritize salience-driven or memory-driven processes. Salience-driven behavior relies on more bottom-up processing, which is usually automatic and perceptual. Memory-driven behavior relies on more cognitive processes drawn from prior knowledge or scene schema. For example, you will predominantly use a salience-driven search when distinctive features help detect the item, like a personalized phone case. If you are familiar with the environment, you will likely engage in a memory-driven search that prioritizes locations you last used your phone or id.

Salience-driven prioritization discussed in this study used looks towards a distractor, an event that changes the visual features within a scene, to capture attention away from the overall task goal of finding a letter target. Prioritizing eye movements towards the changed information results in longer search times, known as attentional capture (Theeuwes, 2010). Attentional capture is an event-based salience-driven prioritization that is rapid and involuntary. According to Theeuwes (2010), the attentional capture effect is not long lasting and not modulated by top-down processes, such as memory. However, features maintained in working memory are known to capture attention automatically (Folk & Remington, 2006; Mannan et al., 2010).

Oculomotor capture is the same concept as attentional capture but using eye movement measurements. Using letter search arrays, the eyes move immediately to a distractor onset before the target (Du, Qi, Li, & Zhang, 2013; Theeuwes, Kramer, Hahn, & Irwin, 1998). Recent research has used this idea to examine prioritization of new objects added to scenes (Brockmole & Henderson, 2005; 2008; Matsukura et al., 2009). In these studies, the search task was to detect a change within a scene. Unbeknownst to participants, the addition of a new object would either occur during a saccade (saccade target) or while the eyes remained at a location for at least 100 ms (gaze target). The results showed immediate looks to the new object when it appeared as a *gaze target*; yet, looks to the *saccade target* were delayed until the second eye movement after the new object appeared. Brockmole and Henderson (2005) suggested a *dual-process theory of oculomotor capture* from these results. The immediate response to the target is salience-driven prioritization similar to oculomotor capture. The delayed response to the target is a memory-guided prioritization of new information because a perceptual change attracts attention to an area that was not consolidated into long-term memory.

Memory-driven processes within this study describe the encoding of visual information into memory during search. Within scenes, memory-driven effects are more robust due to the inherent conceptual layout of where items are located (Võ & Wolfe, 2015; Wolfe, Võ, Evans, & Greene, 2011). Specifically, people will find objects within scenes faster than objects within arrays (Wolfe et al., 2011) because more information can be inferred from previous experience (i.e. sinks are found in kitchens but not living rooms). When a target location is consistent within a scene, then search time is faster or more efficient (Võ & Wolfe, 2012).

Compared to novel searches, repeated searches demonstrate *efficient search behavior*: better ability to find the target, faster search times to the target, and more directed search to the target with fewer fixations; this effect is known as contextual cueing (Chun, 2000; Chun & Jiang, 1998). Contextual cueing usually involves search for an embedded letter target at a consistent location within a given scene (Brockmole et al., 2006; Brockmole & Henderson, 2006ab; Olejarczyk et al., 2014). Participants search for the target letter in scenes across multiple blocks that contain a mix of novel scenes and scenes that repeat across blocks.

Few studies have explored the effects of oculomotor capture on repeated search behavior, or contextual cueing. Using letter arrays, Peterson and Kramer (2001ab) examined oculomotor capture from distractor onsets during repeated searches. The task was to search for a target letter ‘T’ among an array of ‘L’s despite the sudden appearance of a distractor. Some letter arrays repeated the spatial layout while some layouts were new. When a distractor appeared, search times increased despite established contextual cueing benefits. These effects were found for letter arrays but explicit memory-based guidance from contextual cueing using scenes has not been done. The mechanism behind contextual cuing in scenes has been debated as either implicit statistical learning (Goujon, Didierjean, & Thorpe, 2015; Chun & Jiang, 1998) or explicit association (Brockmole & Henderson, 2006a) of the target location within a scene's global context, known as gist (Biederman et al, 1982; Greene & Oliva, 2009). Contextual cueing from scene searches may diminish interference from a distractor if associations between the target location and scene involve an explicit association.

Given that scenes provide a stronger and faster contextual cueing search benefit than arrays, explicit memory-driven guidance from repeated searches should reduce the interference of an irrelevant distractor. The dual-process theory of oculomotor capture was tested during salience-driven (novel) and memory-driven (repeated) scene searches. Previous studies of oculomotor capture in scenes used change detection as the task goal. This study used search for a letter target while a distractor appears during a fixation (gaze distractor) or during a saccade (saccade distractor) to test the generalizability of the dual-process theory within search. If a gaze distractor captures gaze less often for repeated compared to novel scenes, then the results would suggest explicit memory of the scene modulates the salience-driven component. The dual-process theory would need to be revised into an interactive theory. If the saccade distractor attracts gaze more often for repeated compared to novel scenes, then prioritizing the change from a distractor within repeated scenes from a long-term memory representation would support the memory-based prioritization component of the theory. Validation of a memory-based component would further the understanding of long-term memory representations of a specific scene on search behavior.

Method

Participants. Seventy-seven undergraduate volunteers, (age: 18-36; 18 males; 14 left-handed) were recruited using the SONA systems participant pool from the University of South Carolina. All participants gave informed consent prior to the IRB-approved experiment and had normal or corrected to normal vision to participate for extra credit.

Apparatus. Eye movements were recorded via an SR Research Eyelink 1000 eye tracker (spatial resolution 0.01°) sampling at 1000 Hz. Participants were seated 90 cm away from a 45 cm Viewsonic G225f CRT monitor with a refresh rate of 85 Hz display raised 22.5 cm above the table. Head movements were minimized with chin/forehead rests. Eye movements were recorded from the right eye although viewing was binocular. The experiment was programmed with SR Research Experiment Builder software. Before blocks, a nine-point calibration routine was used to map eye position to screen coordinates. Eye tracker calibration was not accepted until the average error was less than .49° and the maximum error was less than .99°. Participants were recalibrated as needed during testing.

Scenes. Full-color photographs of real-world scenes were selected from Google Images. Scenes were 800 x 600 pixels (22.28°x16.55°). All 122 scenes were pseudo-randomly assigned to 20 sets of 6 scenes with 2 added scenes for practice. Two sets were combined to form 12 repeated search scenes used for each participant. The remaining 18 sets provided 108 novel search scenes. Sets were chosen to have similar proportions of indoor and outdoor scenes as well as similar clutter statistics across sets (Rosenholtz, Li, & Nakano , 2007). A one-way ANOVA for clutter measures showed no difference in feature congestion, *F*(1,18) = 0.009, η_p^2 = .001 *p* = .926, or subband entropy, *F*(1,18) = 0.611, η_p^2 = .033 *p* = .444.

Targets*.* Search letter targets were either a gray T or L in Arial 9 pt font (0.62° x 0.31°). For each scene, a target letter was pseudo-randomly assigned to one of 6 positions approximately 8° from central fixation and spaced radially equidistant from one another surrounded by an invisible detection boundary (1.5° x 1.5°; dashed squares in Figure 2.1). Each repeated search scene had two versions: one with a T as the letter target and another with an L. The location was the same in both versions (marked as a white dot in Figure 2.1). Each novel scene had either a T or an L target letter in a fixed position. Across all scenes, the target letters were uniformly distributed among all 6 positions. Targets were placed so that the letter did not overlap any edges in the scene.

Distractors*.* Distractors only appeared within the last two blocks of trials, either as a gaze or saccade distractor (distractor onset). Distractors were (1° x 1°) red squares positioned 4° to the left or right of scene center surrounded by an invisible detection boundary (1.5° x 1.5°). Distractors were presented either during a fixation or a saccade. The gaze distractor was presented 100ms after the search scene appeared while the eyes focused at the center. The eyes had to remain within the 2° central circle boundary (Figure 2.1) for at least 100 ms in order for the distractor to appear. The saccade distractor block had the distractor appear during an eye movement beyond the 2° central circle boundary. Once the eyes landed outside the trigger boundary, the distractor would already be in the scene. Repeated search scenes had two versions for the distractor position (see Figure 2.1): one with the distractor on the same side (close) and one on the opposite side (far) relative to the target location. Novel scenes had one version with the distractor position either far or close relative to the target location (distractor position).

Design and Procedure. After being comfortably situated into the tower mount chin/forehead rest, participants began the experiment by reading a set of instructions with example search scenes and 2 practice trials. The calibration procedure mapped the eye position of the participant onto the display screen. Calibration was done before practice trials or any time the participant removed their head from the chin rest. Each trial began with a drift check: black and gray bull’s eye presented at the screen center on a gray background. Participants then searched through a scene and pressed a left or right button after identifying the target letters “L” or “T” respectively. The trial ended after 7 s if the target was not found. Participants were asked to search as quickly as possible and use their dominant hand for all responses.

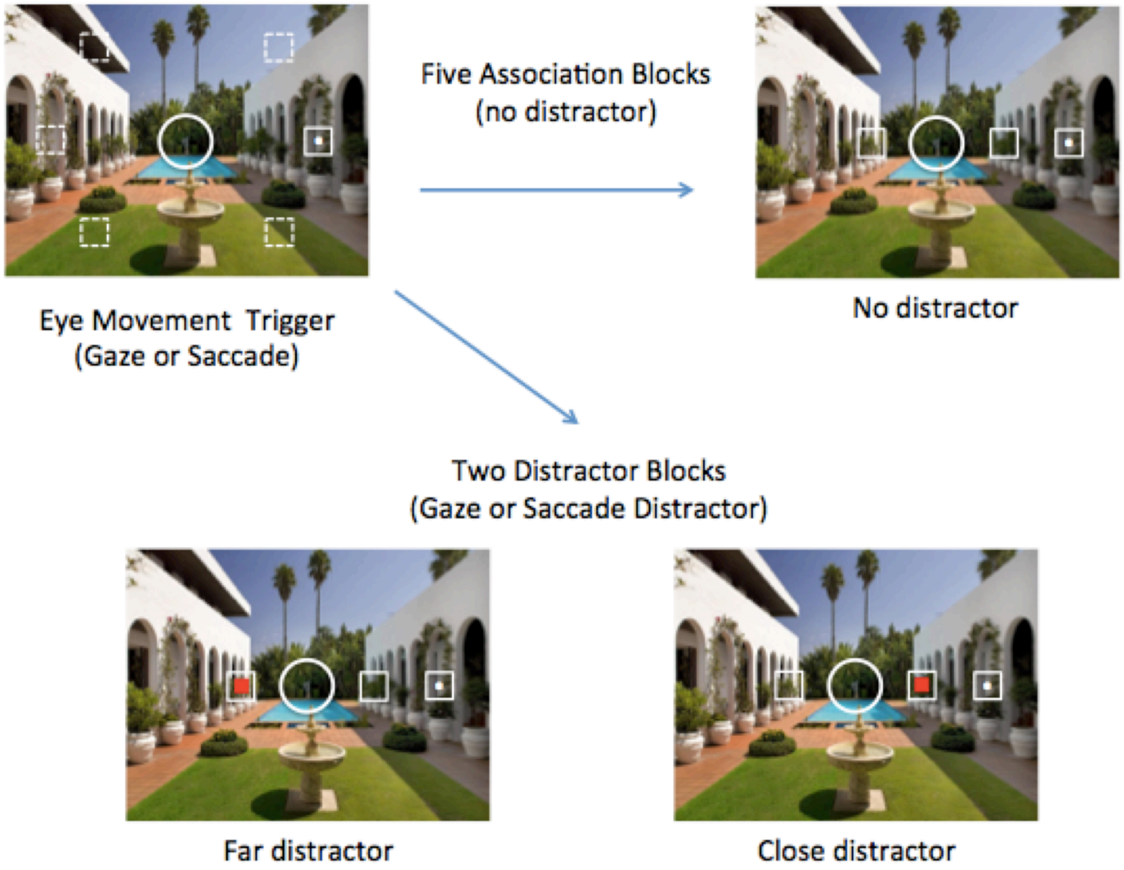


Figure 2.1. Example of repeated search trials within association and distractor blocks. The top-left scene depicts a 2° eye movement trigger boundary (center circle), the six target locations (dashed squares and solid square outline), and target letter marked as a white dot. White outlines are interest areas monitored for eye tracking and invisible to participants. Once the search scene (repeated or novel) appeared, an eye movement (fixation within or saccade to area outside the center circle) triggered a display change to the same scene during association trials or added a distractor (red square) during distractor trials. Both distractor positions are shown in this example of a repeated scene, however novel search scenes only had one version for a specific scene. The far and close distractor positions are relative to the side of the target location (distractor position).

The design included five association blocks to search for a target. Each block contained a mix of novel and repeated scenes (scene context) followed by two distractor blocks (distractor type: gaze or saccade) in which the distractor was presented either far from or close to (distractor position) the target location.

Association blocks contained a total of twelve novel scenes per block. Distractor blocks contained twenty-four novel scenes each block.

Each association block consisted of 24 trials and each distractor block had 48 trials each. The order of the distractor blocks always presented the gaze distractor block first and saccade distractor block last. The scene context (repeated or novel), target location, target letter, and distractor position (close or far relative to the target) conditions were counterbalanced across the entire block as well as within the first and second halves of each distractor block. The order of trials was pseudo-randomized to control for condition repetition and stayed fixed in that order throughout the study. The entire study was a total of 218 trials including practice and was completed in 6.39 min (*SD* = 0.91) of testing.

Results

Trials were eliminated if the center boundary was not properly triggered due to loss of tracking (1%). Fixations were eliminated if the durations were less than 80 ms or greater than 1500 ms (4%).

Efficient search behavior from association blocks. Efficient search behavior was examined using three measures: ability to find the target letter, search time to target letter, and scan path ratio (Figure 2.2). When comparing repeated searches to novel searches, I replicated previous contextual cueing effects that the target is easier to find, faster search times, and scan path ratios (SPR) are smaller over time (Brockmole & Henderson, 2006a; Chun, 2000; Chun & Jiang, 1998). The SPR estimates how directly the eyes move to a target by using the cumulative distance the eyes traveled (sum of saccade amplitudes) as a ratio of the direct path from initial search position (center) to the target (8^o). In the analysis of association blocks, every two association blocks were combined

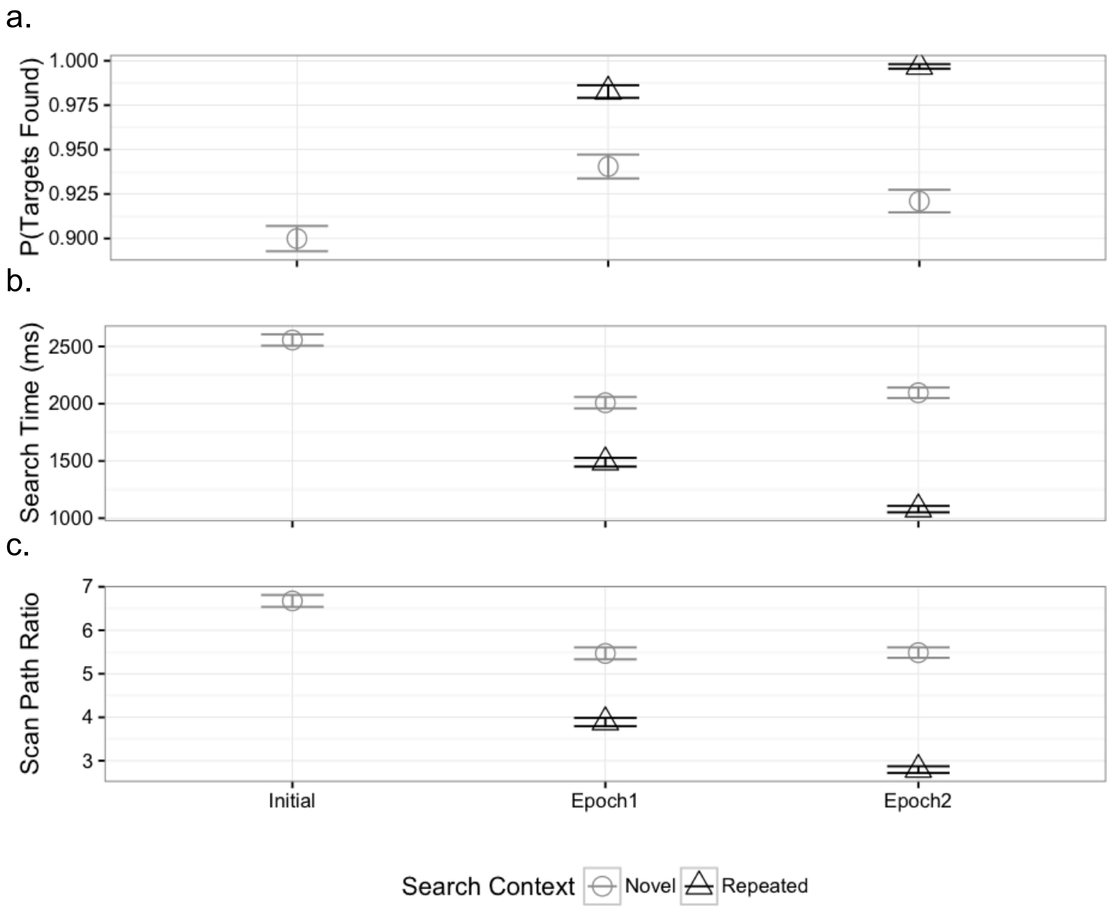


Figure 2.2. Proportion of targets found (a), search time (b), and scan path ratio (c) for repeated and novel scenes across epochs. The Initial time point represents the first instance of search (24 scenes). Epoch 1 and 2 combine two association blocks for a total of 24 repeated and 24 novel scenes per epoch. Repeated scenes showed more targets found, faster search times, and smaller scan path ratios compared to novel scenes.

to form one epoch of 48 trials. The initial search block was excluded from ANOVAs as all scenes were novel to participants. The ANOVAs were based on a 2 (scene context) x 2 (epoch) repeated-measures design to examine search efficiency measures.

Ability to Find Target. Here I examined proportion of targets found as the ability to find the target. Participants were able to find the target more often within repeated scenes than novel scenes, $F(1,76) = 159.1$, $\eta_p^2 = .676$, $p < .001$, and there was no main effect of epoch, $F(1,76) = 0.467$, $p = .496$. However there was an interaction of epoch and scene context, $F(1,76) = 16.49$, $\eta_p^2 = .178$, $p <.001$; Participants found the targets more often for repeated scenes, $t(76) = 3.84$, $p < .001$, across epochs. Additionally, novel scene targets were found less often, $t(76) = 2.70$, $p = .008$, across epochs (Table 2.1). In summary, targets were found more often within repeated scenes and less often in novel scenes over time.

Table 2.1. Mean Accuracy (*SD, CV*) for Search Epoch and Scenes

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
First Epoch	.98 (.03)	.03	.94 (.06)	.06
Second Epoch	.99 (.01)	.01	.92 (.06)	.07

Search Time to Target. Here I examined search time as the amount of time until the target was found or the trial timed out (7000 ms) across scenes and epochs. Results showed significant main effects of the scene, $F(1,76) = 387.3$, $\eta_p^2 = .836$, $p < .001$, since targets were found faster in repeated than novel scenes. There was a significant main effect of epoch, $F(1,76) = 32.88$, $\eta_p^2 = .301$, $p < .001$, search was faster from the first to the last epoch. Also, a significant interaction, $F(1,76) = 133.3$, $\eta_p^2 = .599$, $p < .001$, showed a decrease in search times, $t(76) = 13.13$, $p < .001$, for repeated scenes while search times increased, $t(76) = 2.11$, $p = .038$, for novel scenes across epochs (Table 2.2).

Table 2.2. Mean Search Time (ms, *SD, CV*) for Search Epoch and Scenes

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
First Epoch	1489 (336)	.23	2009 (434)	.22
Second Epoch	1079 (244)	.23	2096 (405)	.19

Scan Path Ratio. Here I examined how directly the eyes moved to the target across scenes and epochs. Results showed a significant main effect of the scene, *F*(1,76) = 358.3, η_p^2 = .825, *p* < .001, since scan paths in repeated scenes were more directed to the target compared to novel scenes. There was a significant main effect of epoch, *F*(1,76) = 46.96, η_p^2 = .382, *p* < .001, with more directed searches across epochs. A significant interaction was found, *F*(1,76) = 80.45, η_p^2 = .514, *p* < .001, since repeated searches were more directed to the target, *t*(76) = 13.25, *p* < .001, while novel searches did not differ across epochs, *t*(76) = 0.16, *p* = .876 (Table 2.3).

Table 2.3. Mean Scan Path Ratio (*SD, CV*) for Search Epoch and Scenes

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
First Epoch	3.89 (0.85)	.22	5.47 (1.20)	.22
Second Epoch	2.80 (0.68)	.24	5.49 (1.04)	.19

Discussion. The results from the search portion of the experiment showed that participants successfully associated the target location with the repeated scene. Efficient search behavior within repeated searches was demonstrated by a better ability to find a target, faster search times, and more directed movements towards the target compared to novel searches. The interactions demonstrate how efficient search within repeated scenes decreases search time and scan path ratio while increasing ability to find the target over time. In contrast, the novel searches did not show efficient search over time but decreased ability to find the target, increased search time, and no difference in scan path ratios.

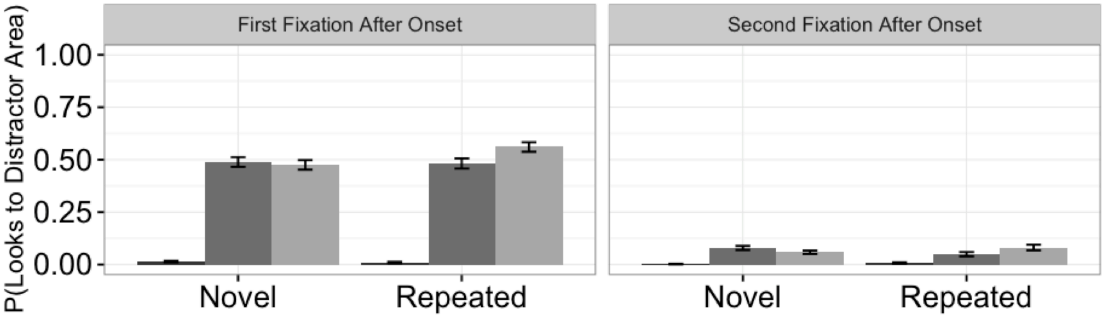
Looks to Distractor across Ordinal Fixation. Proportion of looks to the distractor (gaze or saccade) was examined across two ordinal fixations. Ordinal fixations were the first and second fixation after the distractor appeared. For the gaze distractor block, the first and second fixations were labeled first and second ordinal fixation, respectively. For the saccade distractor block, second and third fixations were labeled first and second ordinal fixation, respectively.

Gaze and saccade distractor blocks examined the salience-driven and memory-driven effects from the dual-process theory, respectively (Brockmole & Henderson, 2005; Du et al., 2013). The first ordinal fixation tested the salience-driven effect, such as immediate and involuntary looks to the distractor. The second ordinal fixation tested the memory-driven effect (a.k.a. memory prioritization), such as delayed and voluntary looks to distractor (Brockmole & Henderson, 2008; Matsukura et al., 2009).

Fixations were eliminated from analyses if lost from tracking (0.65%). T-test comparisons examined whether proportion of looks to the distractor area was significantly different than the previous epoch without a distractor. Each ordinal fixation within each distractor onset block was a separate ANOVA of 2 (scene: repeated or novel) x 2 (distractor position: close or far).

Gaze Distractor. The salience-driven effects from the dual-process theory would expect equal amount of looks to the distractor area for novel and repeated searches because of the involuntary capture of attention. Additionally, the theory would claim more looks to the distractor for the first than the second ordinal fixation to support the immediate capture of attention (Brockmole &

a. Gaze Distractor



b. Sacade Distractor

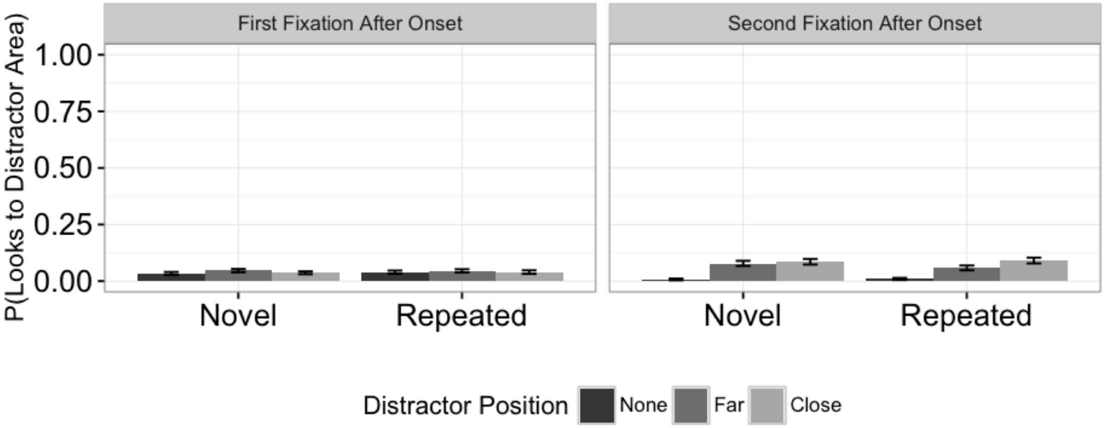


Figure 2.3. Proportion of looks to the distractor area as a gaze distractor (a) and saccade distractor (b) for repeated and novel scenes across ordinal fixation.

Henderson, 2005, 2008; Matsukura et al., 2009). The immediate salience-driven effect was found with more looks in the first rather than second ordinal fixation; however the involuntary salience-driven effect was modulated for repeated scenes only with more looks to distractor close to rather than far from the target (Figure 2.3a).

For the first ordinal fixation after the appearance of a gaze distractor, there were significantly more looks to the distractor across both scenes (*p*s < .001) compared to searches without the distractor. The ANOVA for the first ordinal fixation showed a significant main effect of the scene, *F*(1,76) = 5.89, η_p^2 = .072, *p* = .018, a significant main effect of distractor position, *F*(1,76) = 5.46, η_p^2 = .067, *p* = .022, and an interaction, *F*(1,76) = 9.67, η_p^2 = .112, *p* = .002. Close distractors were viewed more often than far distractors within repeated scenes, *t*(76) = 3.98, *p* < .001. There were no differences for distractor positions within novel scenes.

Table 2.4. Mean Gaze Distractor Looks (*SD, CV*) for Distractor Position and Scenes at First Ordinal Fixation

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	.56 (.20)	.36	.48 (.20)	.42
Far	.48 (.21)	.44	.49 (.20)	.42

For the second fixation after the gaze distractor, there were more looks to the far distractor within the novel scenes, *t*(76) = 3.36, *p* = .001, and the close distractor within the repeated scenes, *t*(76) = 2.90, *p* = .005, compared to initial searches without a distractor. The ANOVA only showed a significant interaction, *F*(1,76) = 11.65, η_p^2 = .133, *p* = .001. There was no difference in distractor position for the novel scenes, *p* = .077, but there was a significant difference in distractor position for the repeated scenes, *t*(76) = 2.19, *p* = .032. There was more looks to the close rather than far distractor for repeated scenes.

Table 2.5. Mean Gaze Distractor Looks (*SD, CV*) for Distractor Position and Scenes at Second Ordinal Fixation

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	.08 (.12)	1.43	.06 (.07)	1.26
Far	.05 (.09)	1.86	.08 (.08)	1.06

Discussion. I replicated results from previous studies that the distractor had more looks for the first ordinal fixation and fewer looks by the second ordinal fixation regardless of the scene context. Similar to previous literature the results suggest immediate and involuntary capture of attention for gaze distractors.

The new finding from the study showed more looks to close distractors in repeated scenes within the first fixation that extended into the second fixation after distractor appearance. The increase in attentional capture to the close distractor may suggest an attentional bias to the target within the first 100 ms before the distractor appears. Because the increase occurred for the repeated scenes in which a learned association was made to the target location, there is likely an influence of implicit memory-driven effects on attentional capture to the distractor. If explicit control were involved, there would have been less looks to the distractors within repeated scenes. These results suggest an attentional bias prior to the gaze distractor's appearance. The distractor interferes with selective attention to the target location but only on the same side as the distractor.

Saccade Distractor. If the memory-guided prioritization from the dual-process theory explains delayed and voluntary capture of attention, there should be more looks to the distractor for the second than the first ordinal fixation (Brockmole & Henderson, 2008; Matsukura et al., 2009). More looks to the distractor for repeated compared to novel scenes would support the claim that the process is memory-driven. Such findings would suggest that new information from a distractor interferes with previous memory representations of the repeated scenes. Our results replicate previous findings across ordinal fixations but fail to support memory-driven prioritization as a mechanism for oculomotor capture (Figure 2.3b).

For the first ordinal fixation, there were no significant differences between search with a distractor and previous searches without the distractor. The ANOVA did not reach significance for scene context nor distractor position. So, the eyes were not drawn to the distractor area more than searches without a distractor present. These results replicated previous findings of fewer looks to the distractor within the first compared to second ordinal fixation.

Table 2.6. Mean Saccade Distractor Looks (*SD, CV*) for Distractor Position and Scenes at First Ordinal Fixation

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	.04 (.07)	1.69	.04 (.05)	1.46
Far	.04 (.06)	1.38	.05 (.06)	1.36

For the second ordinal fixation after the distractor onset, significant differences were observed for both distractor positions in novel scene searches, *t*s > 2.85, *p*s < .006, compared to previous distractor-absent searches. The repeated searches only showed a significant difference for the close distractor compared to distractor-absent searches, *t*(76) = 3.42, *p* < .001. The ANOVA for scene context and distractor position during the saccade onset distractor epoch showed no significant results.

Table 2.7. Mean Saccade Distractor Looks (*SD, CV*) for Distractor Position and Scenes at Second Ordinal Fixation

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	.09 (.11)	1.23	.09 (.11)	1.27
Far	.06 (.09)	1.59	.08 (.10)	1.27

Discussion. Similar to previous research, the distractor did not attract attention to the area until the second fixation. Delayed looks to a saccade distractor have been described in previous research as memory-prioritization (Brockmole & Henderson, 2005, 2008; Matsukura et al., 2009). However, no differences were found between novel and repeated searches in our study suggesting that long-term memory for a repeated scene did not prioritize the distractor more so than novel scenes without long-term memory.

There may be a difference in task demands so a memory-driven prioritization was not found. Previous literature had change detection for a task while this study used search. Long-term memory representations within a single continuous view may be more sensitive to local changes compared to multiple repetitions of the same scene using global information to search over time. Perhaps a short-term memory representation of selected objects may be enough to show delayed capture despite the visual complexity of scenes and previous long-term representations.

In summary, the results suggested explicit long-term memory for a repeated scene did not prioritize looks to the distractor more than novel scenes with only a short-term representation. This means memory does not play a role in delayed oculomotor capture during search. The memory prioritization effects found in previous tasks did not generalize to scene search with a distractor. Additionally, delayed looks to the distractor may be a delayed salience-driven prioritization since novel and repeated searches did not differ in behavior despite differences in memory, short-term and long-term respectively.

Search behavior with Gaze Distractors. Similar to the association epochs, search efficiency was operationalized as ability to find the target, search time, and scan path ratios. T-test comparisons examined differences in search behavior with a distractor (distractor position: close, far) and the last association epoch without the distractor (distractor position: none). When analyzing search efficiency within the distractor epochs, ANOVAs were based on 2 (scene context) x 2 (distractor position) design.

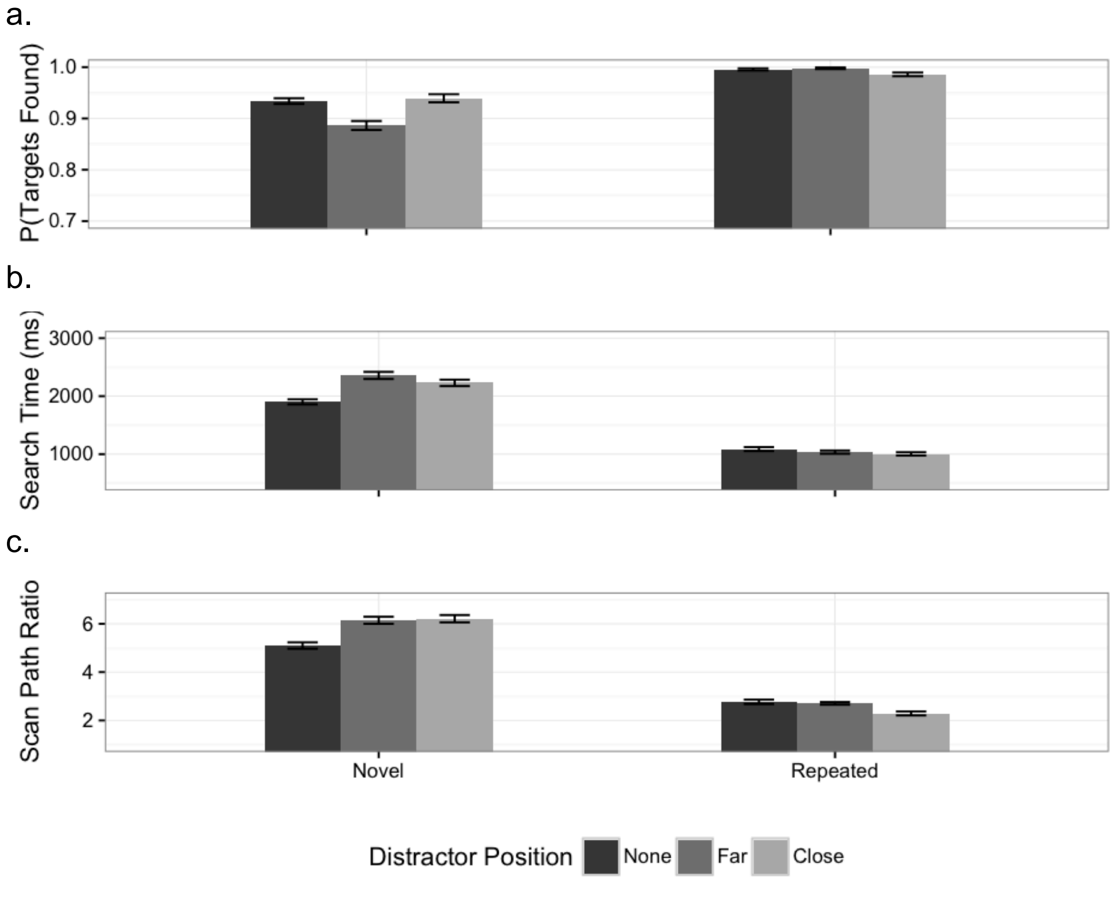


Figure 2.4. Proportion of targets found (a), search time (b), and scan path ratio (c) for repeated and novel scenes in the presence of a gaze distractor.

Efficient search behavior – better ability to find the targets, faster search times, and shorter scan path ratios – was found for repeated searches compared to novel searches. The presence of a gaze distractor showed interference effects: poor ability to find the letter target for close distractors in repeated scene but far distractors in novel scenes (Figure 2.4a), no differences in search time for repeated scenes but increased search time for novel scenes (Figure 2.4b), and finally larger scan path ratios for repeated scenes but no difference for novel scenes (Figure 2.4c).

Ability to Find Target. There was a significant decrease in ability to find the target with the far distractor in novel scenes, *t*(76) = 5.67, *p* < .001, and with the close distractor in repeated scenes, *t*(76) = 3.23, *p* = .001, compared to no distractor.

The ANOVA for the gaze distractor epoch showed participants' ability to find the target had a significant main effect for the scene, *F*(1,76) = 147, η_p^2 = .66, *p* < .001, since the repeated search targets were found more often than the novel targets. There was a main effect of distractor position, *F*(1,76) = 19.46, η_p^2 = .20, *p* < .001, since the far distractor interfered with search more than the close distractor. The interaction was also significant, *F*(1,76) = 36.54, η_p^2 = .32, *p* <.001, since far distractors interfered more for novel searches, *t*(76) = 5.67, *p* < .001, and close distractors interfered more in repeated searches, *t*(76) = 3.23, *p* =.002.

Table 2.8. Mean Accuracy (*SD,CV*) for Distractor Position and Scenes during Gaze Distractor Epoch

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	.99 (.03)	.03	.94 (.07)	.07
Far	1.00 (.01)	.01	.88 (.08)	.86

Search Time. There were no differences in search time with a distractor or without a distractor for repeated scenes. Search times, however, increased when distractors were added to novel scenes, *t*s > 3.51, *p*s < .001, compared to no distractor. The ANOVA for the gaze distractor epoch showed a significant main effect of scene, *F*(1,76) = 701.1, η_p^2 = .90, *p* < .001, since repeated searches were faster than novel searches. Additionally, there was a main effect of distractor position, *F*(1,76) = 4.22, η_p^2 = .05, *p* = .043, since longer search times were found for far compared to close distractors. The interaction was not significant (*p*s > .05).

Table 2.9. Mean Search Time (ms, *SD,CV*) for Distractor Position and Scenes during Gaze Distractor Epoch

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	1004 (246)	.24	2229 (482)	.21
Far	1035 (236)	.23	2357 (529)	.22

Scan Path Ratio. Compared to search without a distractor, larger scan path ratios were found for both distractor positions in novel scenes, *t*s > 3.42, *p*s < .001, while there was only a significant decrease in scan path ratio for the close distractor in repeated scenes, *t*(76) = 5.67, *p* < .001. The ANOVA for the gaze distractor epoch had a significant main effect of the scene, *F*(1,76) = 845.7, η_p^2 = .92, *p* < .001, since smaller scan path ratios were found for the repeated compared to novel searches. There was a significant main effect of distractor position, *F*(1,76) = 4.74, η_p^2 = .06, *p* = .032, because searches with the far distractor were longer compared to the close distractor. There was also a significant interaction, *F*(1,76) = 5.89, η_p^2 = .07, *p* = .018, due to longer scan paths for far compared to close distractors within repeated scenes, *t*(76) = 5.97, *p* < .001, but no difference novel scenes (*p* = .701).

Table 2.10. Mean Scan Path Ratio (*SD,CV*) for Distractor Position and Scenes during Gaze Distractor Epoch

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	2.29 (0.73)	.32	6.21 (1.33)	.23
Far	2.71 (0.48)	.17	6.14 (1.29)	.21

Discussion. The presence of a distractor disrupted search behavior in novel scenes. Search behavior within novel scenes had decreased ability to find the target in the presence of the far distractor, longer search times, and larger scan path ratios. The interference probably directed more attention to the area and prolonged disengagement from the distractor so search could continue.

Repeated searches maintained efficient search times and small scan path ratios from contextual cueing benefits; however, the close distractor interfered with ability to find the target in repeated scenes. Perhaps due to the explicit expectation of the target location, close gaze distractors demand more attention and interfere arises from the competition of resources within the same visual field. Overall, efficient search remained for repeated scenes despite the salience-driven effects from the gaze distractor.

This is the first time scene search measurements tested the claims of the dual-process theory. For novel scenes, there is an interference effect on search behavior supporting the dual-process theory's claim of an involuntary salience-driven capture of attention. These interference effects seem to ripple into cumulative measures of search. For repeated scenes with a long-term memory representation, the results showed interference in finding the target but also benefits of search being more directed to the target in the presence of a close gaze distractors.

Overall, the results suggest an involuntary interference of a gaze distractor when searching for a target. The involuntary interference effect is most notable for novel searches. Repeated searches showed contextual cueing benefits

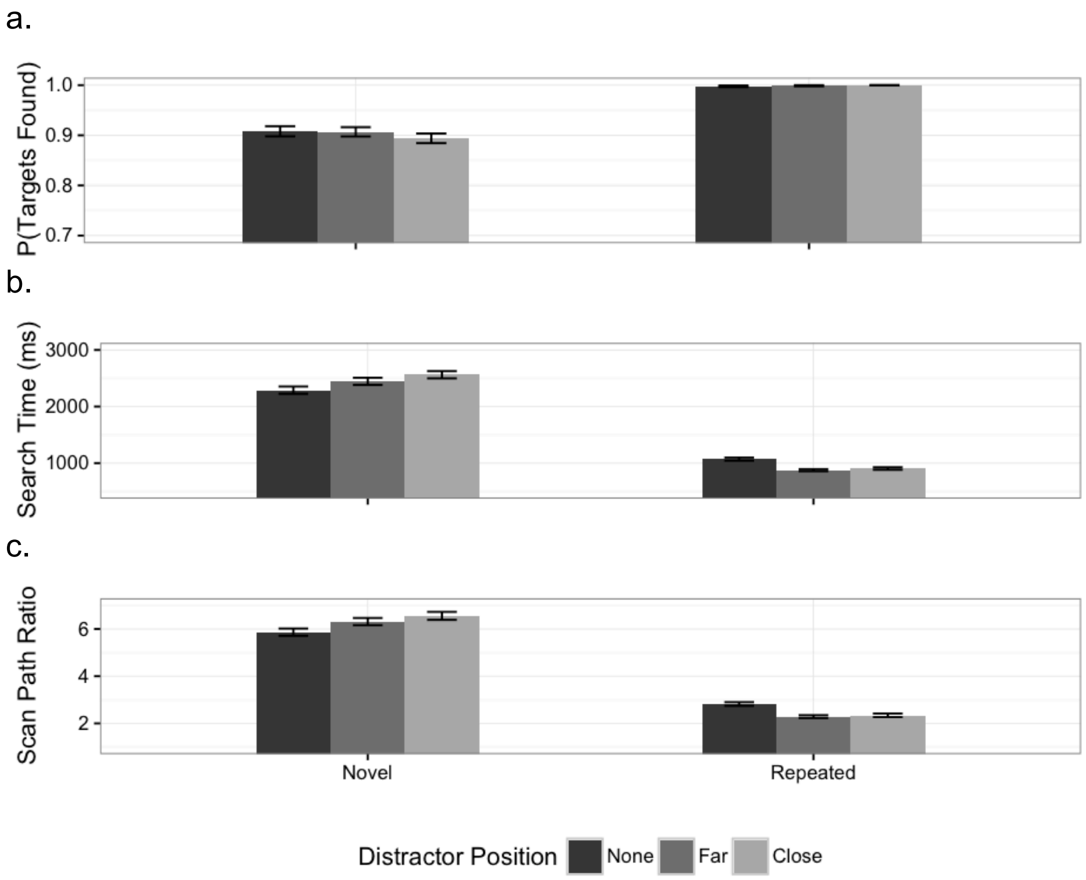


Figure 2.5. Proportion of targets found (a), search time (b), and scan path ratio (c) for repeated and novel scenes when the distractor appeared as a saccade onset.

remained for scan path ratios and search times suggesting a long-term memory representation may reduce the involuntary interference effects of the gaze distractor.

Search Behavior with Saccade Distractors. Analyses were similar to the gaze distractor. Better ability to find the target, faster search times, and smaller scan path ratio were expected for repeated compared to novel searches. Any decreased ability to find the target, such as slower search times or larger scan path ratios, would suggest interference from the distractor.

Efficient search behavior – better ability to find the targets, faster search times, and shorter scan path ratios – was maintained for repeated searches compared to novel searches. The presence of a saccade distractor did not interference with repeated searches; however novel searches had interference effects: poor ability to find the letter target (Figure 2.5a), increased search time (Figure 2.5b), and larger scan path ratios (Figure 2.5c).

Ability to Find Target. Compared to searches without the distractor, ability to find the target decreased when a distractor appeared in novel searches, *t*s > 2.62, *p*s ≤ .01, and no difference for repeated scenes. The ANOVA for the saccade distractor epoch only showed a main effect of the scene, *F*(1,76) = 163.6, η_p^2 = .68, *p* < .001, since targets were found more often within repeated than novel scenes.

Table 2.11. Mean Accuracy (*SD,CV*) for Distractor Position and Scenes during Saccade Distractor Epoch

	Repeated (*SD*)	*CV*	Novel (*SD*)	CV
Close	1.00 (.00)	.00	.89 (.08)	.09
Far	.99 (.01)	.01	.90 (.08)	.09

Search Time. Compared to searches without a distractor, a significant increase in search time was found for novel searches, *t*s > 7.92, *p*s < .001, that suggested interference from the distractor. A significant decrease was found for repeated searches, *t*s > 5.87, *p*s < .001, so search time to the target was faster despite the added distractor. The ANOVA for the saccade distractor epoch showed a significant main effect of the scene, *F*(1,76) = 874.7, η_p^2 =.92, *p* < .001, because novel searches took longer than repeated searches. There was also a main effect of distractor position, *F*(1,76) = 4.50, η_p^2 = .06, *p* = .037, since the close distractor had longer search times than the far distractor. There was no interaction effect.

Table 2.12. Mean Search Time (ms, *SD,CV*) or Distractor Position and Scenes during Saccade Distractor Epoch

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	906 (194)	.21	2562 (560)	.22
Far	876 (161)	.18	2446 (560)	.23

Scan Path Ratio. There was a significant increase in scan path ratio for novel searches, *t*s > 5.50, *p*s < .001, and a significant decrease for repeated scenes, *t*s > 5.46, *p*s < .001, compared to searches without the distractor. The t-test comparisons showed the distractor interfered with search again in novel scenes but maintained efficient search behavior in repeated scenes. The ANOVA only showed a significant effect of the scene, *F*(1,76) = 926.2, η_p^2 = .92, *p* < .001, since repeated searches had smaller scan path ratios than novel searches.

Table 2.13. Mean Scan Path Ratio (*SD,CV*) or Distractor Position and Scenes during Saccade Distractor Epoch

	Repeated (*SD*)	*CV*	Novel (*SD*)	*CV*
Close	2.34 (0.66)	.28	6.56 (1.48)	.23
Far	2.29 (0.53)	.23	6.32 (1.34)	.21

Discussion. Despite the presence of a saccade distractor, repeated searches maintained their contextual cueing benefits with some added benefits: decreased search times and smaller scan path ratios. Novel searches, without a long-term memory representation, showed interference for all search measures: lower ability to find the target, longer search times, and larger scan path ratios.

With regards to the dual-process theory, the memory-driven prioritization was only observed for novel searches. Again, the results suggest that memory-driven oculomotor capture component from the dual-process theory may be a delayed salience-driven process. The only interference effect for repeated searches was longer search times as a main effect of the close distractor compared to far distractor. The results suggest that the close distractor requires extra processing time (Table 2.12: 30 ms for repeated, 116 ms for novel) but contextual cueing benefits remain. The results suggest increases in search time for the close compared to far distractor occur when attention is biased towards the target but the distractor requires additional attentional processing.

CHAPTER 3

SUPPORT FOR INTERACTIVE AND INDEPENDENT SYSTEMS FROM COMMON MEASURES IN THE ANTISACCADE TASK

A well-known measure of top-down explicit control is the antisaccade task. An antisaccade involves suppressing an automatic response to a peripheral stimulus (prosaccade) and moving the eyes in the opposite direction from the stimulus location (Hallet, 1978; Munoz & Everling, 2004). The mechanism has been described as a goal redefinition process (Hallet & Adams, 1980), but current literature labels it inhibitory control over a reflexive response (Munoz & Everling, 2004). Additionally, connections have been found between antisaccade performance and working memory (Kane et al, 2001; Roberts et al., 1994). Individuals with low-span working memory capacity had more errors and longer latencies compared to high-span participants (Kane et al, 2001; Unsworth, Schrock, & Engle, 2004). Diamond (2013) suggests that inhibitory control is necessary for working memory in order to filter out irrelevant information but also working memory is important for inhibitory control for maintaining the task goals of what counts as irrelevant.

Ability to perform the antisaccade task (error rate) and the time to respond after onset of the target (latency) are the most common measures reported in the literature. In particular, antisaccade latencies are longer and error rates typically occur more often (~20%; Hallet, 1978; Evdokimidis et al., 2002) than prosaccade latencies and errors (~1%). The antisaccade cost, which is the difference between antisaccade and prosaccade latencies, averages 100 ms. More cost has been associated with less target predictability (Chiau et al., 2011; Lui et al., 2010) and increased task demand (Godijn & Kramer, 2008a; Jóhannesson et al., 2013). The cost can also be thought of as the time necessary for an antisaccade motor plan to overcome the prosaccade motor plan. Despite the consistent differences between antisaccade and prosaccades, there remains a debate of whether automatic and controlled processes are distinct from one another or interact across a common attention network.

An interactive viewpoint, known as the *interactive competition account*, assumes that delayed inhibitory processes (antisaccade) and immediate automatic processes are shared within the oculomotor system so competition arises between saccade plans (Kristjannson, 2007; Roberts & Pennington, 1996). Kristjansson and colleagues (2001) tested their idea of competitive interaction using a dual-task paradigm. Participants were asked to make a prosaccade or antisaccade to a peripheral stimulus while attending to a discrimination task above and below the horizontal saccades. The discrimination task involved either a shift in peripheral motion or change in spatial frequencies. When engaged in both the oculomotor planning and the discrimination task, planning a saccade was faster for antisaccades but slower for prosaccades compared to perceptual changes occurring above and below without the attending to the discrimination task. The authors suggested that prolonged prosaccade latencies may be from an oculomotor suppression mechanism.

When attention resources are used in a dual-task, selection of the peripheral stimulus is more difficult. The same mechanism also facilitated the antisaccade response since these results were not found when attention was not engaged in the discrimination task.

Those in support of independent processes suggest separate automatic and controlled attention affect the oculomotor system (Massen, 2004, Amador et al., 1998). Rather than focusing solely on latency measures, error rates were included as a judgment of task demands. Massen (2004) showed in a series of studies that increased error rates occur when there was only an increase in antisaccade latencies not prosaccade latencies. However, when both antisaccade and prosaccade latencies increased, error rates remained the same. The results suggest a slower inhibition process cannot effectively inhibit an automatic process unless the automatic process is slowed as well. Despite hints of interaction between antisaccade and prosaccade latencies (ie both increased latencies), the inhibition process is isolated within the cost measure. Specifically, the time to inhibit a prosaccade and move away from the stimulus will always be delayed to account for each stage of controlled processing. Additionally, research has shown frontal lobe patients have difficulty with the antisaccade task but show similar results with the prosaccade (Pierrot-Deseilligny et al., 2002). The results support independent automatic and contolled processes.

The above literature reviewed ample evidence that antisaccade performance is related to inhibitory control. However, the interactive competition account suggests similar results can be found if restricted to the oculomotor orienting system. The purpose of this experiment is to replicate previous findings in the antisaccade literature and examine how common measures from the task explain competitive or independent controlled and automatic processes. Once results are replicated from previous literature, then a simple correlation analysis can determine whether task measures suggest shared or separable processes. Antisaccade and prosaccade latencies are likely to share oculomotor processes because both require an eye movement for response; however, antisaccade cost, an isolated measure of inhibition time, is less likely to be related to prosaccade latency, a measure of automatic stimulus response.

In addition to discovering interactive or independent systems from common antisaccade measures, the gap effect for the antisaccade cost was examined. The gap effect explains decreased antisaccade latencies for longer gap durations as disengagement of fixation neurons from central gaze. Prior to stimulus onset, there is a gap of time, between 100ms and 200ms, without any visual information (ie blank screen). The expected pattern of results shows reduced antisaccade latencies but also reduced error rates with longer gaps. When there is less visual information, then prioritization of peripheral locations can be completed faster. Faster selection of peripheral locations would mean faster prosaccades as well. The current literature has not examined the gap effect for antisaccade cost despite the known effects of attentional competition. A gap effect would be found for the antisaccade cost if there are shared competitive processes of foveal disengagement and saccade planning.

Method

Participants. Eighty undergraduate volunteers, (age: 18-36; 18 males; 14 left-handed) were the recruited in the same manner from Chapter 2. Three participants were in a previous version of the search task not included in this dissertation.

Stimuli. A 1° diameter black circle appeared in the middle of a grey screen to check any drift in eye position from center fixation (drift check) every 10 trials. A black ‘X’ (1° x 1.5°) in the center of a grey screen was the fixation cross with flanking black square markers (0.5° x 0.5°) oriented horizontally 8° to the left and right to designate the upcoming target location. The target was a black box (1° x 1°) to the left or right 8° from center.

Apparatus. Same as Visual Search Methods from Chapter 2.

Procedure. After calibration, instructions were given prior to each prosaccade block to ‘*look at the center X. As soon as a target appears to the left or right, look at it as fast as you can*’. Once the instructions were understood, there were 10 practice prosaccade trials before the first prosaccade block. A screen indicated when the practice ended and the first prosaccade block of 60 trials began. Prior to each antisaccade block, instructions were given to ‘*look at the center X. As soon as the target appears, look in the opposite direction as fast as you can*’. Once instructions were understood, three practice trials were completed before the first antisaccade block of 40 trials, as recommended by Antoniades et al. (2013).

Each block began with a drift check where participants looked at a black and gray bull's eye in the center after every set of 10 trials within a block. After the drift check, a fixation screen appeared with an 'X' in the center surrounded by flanking markers to begin each trial. The fixation screen was presented for a random variable amount of time with an average of 1.5 s fixation screen, a blank gray screen appeared an average of 150 ms with a range from 100 ms to 200 ms as a gap. After the gap duration, the target appeared to the left or right of fixation for 1 s. The fixation screen immediately continued to the next trial until the drift

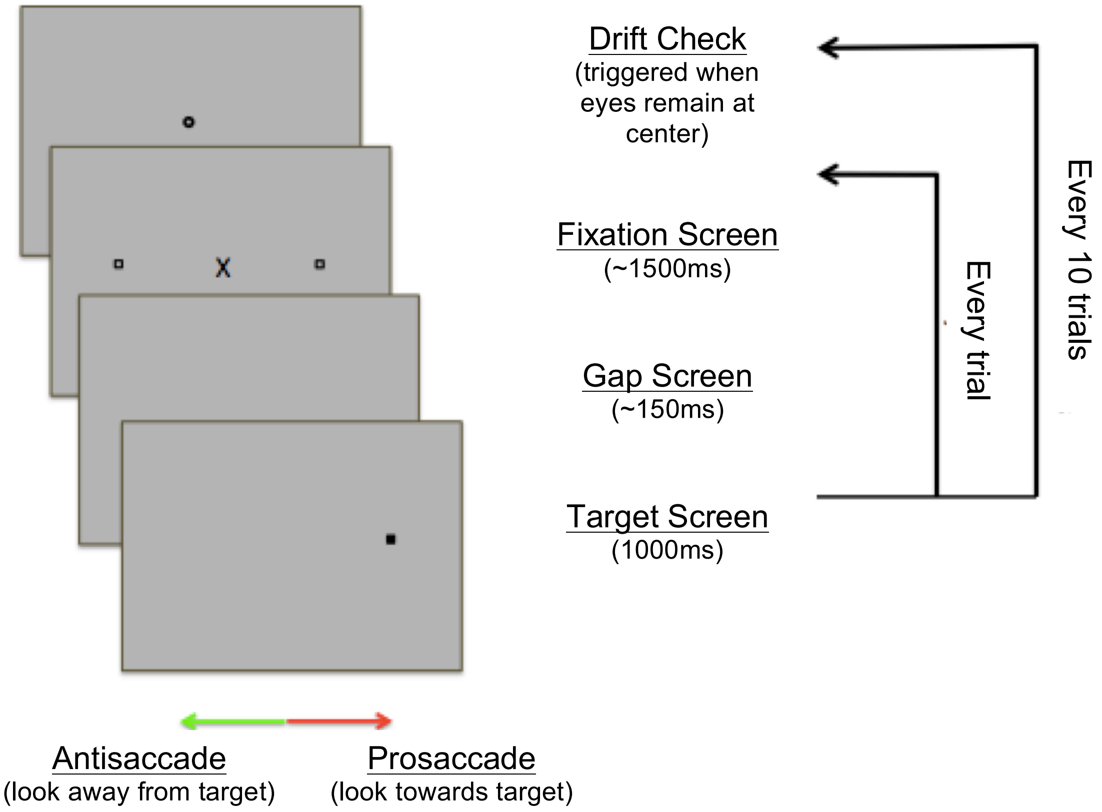


Figure 3.1. Example trial for prosaccade (eye movement towards target) or antisaccade (eye movement away from target). The eyes began at the center of the drift check screen. Otherwise, eyes remain at center during the fixation and gap screens until the target (black square) appeared to the left (or right).

check every tenth trial (Figure 3.1). Within each block, target location was counterbalanced to be equally on the left or right. There were 1 min breaks in between each block. The order of blocks began with a set of 10 prosaccade practice trials, the first test block of 60 prosaccade trials, a set of three antisaccade practice trials, three test blocks of 40 antisaccade trials, and a final test block of 60 prosaccade trials. The task was completed within a range of 18 min to 30 min with breaks.

Data Analysis. Eyelink's built-in saccade detection algorithm was used for categorization of saccades. The eye-movement data was analyzed using the R system for statistical computing (version 3.1.0; R Core Team, 2014). Descriptive statistics were computed using the *psych* package (Revelle, 2014). Figures were created using the *ggplot2* package (Wickham, 2009).

Results

Trials were eliminated if the eyes were not positioned within 2° of center (2.3%) at the start of the trial, a blink occurred before or after the eye movement (1.5%), or saccade latencies were less than 50ms or greater than 600ms (1.74%). Statistical analyses included repeated-measures ANOVAs to test whether there were any biases for target location (left or right), differences in gap duration (two bins of 50 ms ranging from 100 ms to 200 ms), and task instructions (prosaccade or antisaccade) across common measures for the task: error rates, saccade latencies, and cost. Latencies were analyzed only using correct trials.

Repeated-measures 2 (task: antisaccade or prosaccade) x 2 (target direction: left or right) x 2 (gap duration: short or long) ANOVA was carried out to examine any differences in antisaccade from prosaccade performance based on the spatial position of the target or timing of gap prior to the target.

Direction errors. There was a significant main effect of task, *F*(1,79) = 144.4, η_p^2 = .65, *p* < .001, such that more errors occurred during antisaccade (*M* = .21, *SD* = .15) than prosaccade trials (*M* = .01, *SD* = .02). There was no main effect of direction or interaction suggesting that the side the target appeared did not affect performance. There was a main effect of gap duration, *F*(1,79) = 5.12, η_p^2 = .06, *p* = .026, that showed more errors for shorter gap durations (*M* = .12, *SD* = .09) compared to longer gap durations (*M* = .10, *SD* = .08). An interaction between task and gap duration, *F*(1,79) = 5.12, η_p^2 = .11, *p* = .002, showed more antisaccade errors, *t*(79) = 3.18, *p* = .002, for shorter than longer gaps while prosaccade errors did not differ (*p* =.218) across gap durations (Table 3.1).

Table 3.1. Mean Error Rates (*SD, CV*) for Antisaccades and Prosaccades across Gap Duration

	Gap Duration ≤ 150		Gap Duration > 150	
	M (*SD*)	*CV*	*M* (*SD*)	*CV*
Prosaccade	.01 (.02)	1.80	.01 (.03)	1.56
Antisaccade	.22 (.16)	.73	.19 (.15)	.81

Saccade latencies. Longer latencies are expected for antisaccades due to additional timing for sufficient inhibition of the prosaccade response. There was a significant main effect of task, *F*(1,79) = 655.4, η_p^2 = .89, *p* < .001, in which antisaccades (*M* = 229, *SD* = 41) had longer latencies than prosaccades (*M* = 152, *SD* = 25). However, there was no main effect of direction or interaction suggesting that the target location did not affect latency. There was a significant main effect of gap duration, *F*(1,79) = 125.1, η_p^2 = .61, *p* < .001, that showed shorter latencies for longer gaps. There was an interaction between task and gap duration, *F*(1,79) = 4.03, η_p^2 = .05, *p* = .048. Latencies were longer during trials with shorter gap durations for both antisaccades, *t*(79) = 7.62, *p* < 001, and prosaccades, *t*(79) = 7.13, *p* < .001, compared to shorter latencies from longer gap durations (Table 3.2).

Table 3.2. Mean Saccade Latency (ms, *SD, CV*) for Antisaccades and Prosaccades across Gap Duration

	Gap Duration ≤ 150		Gap Duration > 150	
	M (*SD*)	*CV*	*M* (*SD*)	*CV*
Prosaccade	156 (25)	.16	149 (25)	.17
Antisaccade	248 (37)	.15	237 (39)	.16

Antisaccade Cost. The effect of cost has never been explored with regards to the gap effect, which was found for both error rates and latencies. If the cost explains disengagement from the fixation, then a positive trend would be expected: longer costs with longer gap durations. Instead, I found shorter costs for long gaps (*M* = 87.81, *SD* = 32.66) but the t-test comparison was not significantly different from shorter gaps (*M* = 91.72, *SD* = 32.44; *p* = .448).

Interactive or Independent Systems. To examine whether the different measures for each task share a common mechanism, Pearson correlations were calculated for prosaccade and antisaccade latencies along with antisaccade cost and error rate measures. Antisaccade errors correlated negatively with prosaccade latency, such that shorter latencies resulted in more errors. Antisaccade latency correlated positively with prosaccade latency such that individuals with longer antisaccade latencies also had longer prosaccade latencies. There was no relationship between antisaccade cost and prosaccade latencies.

Table 3.3. Correlations (*p*-value) of Prosaccade Latency and Common Antisaccade Measures

	Error Rate	Latency	Cost
Prosaccade	-.47 (.001)	.56 (.001)	-.11 (.591)

Discussion. Here we examined whether common task measures support separate automatic (prosaccade) and controlled (antisaccade) processes or possibly interactive shared resources. The gap effect has been related to foveal disengagement in which fixation neurons reduce activity at central fixation that subsequently facilitates prosaccade generation. Evidence of this mechanism was found for antisaccade latencies and error rates; however not for cost. Overall, the results supported interactive systems for antisaccade error rates and latencies with prosaccade latencies as well as separable processes between prosaccade latencies and antisaccade cost.

First, two correlations supported an interactive competition between measures. The antisaccade error rate showed a strong negative correlation with prosaccade latency. This relationship has been found many times in the literature and labeled speed-accuracy tradeoff – faster responses produce more errors. The foveal disengagement could also explain this relationship. When prosaccade generation is easier (ie weak fixation neurons, active saccade neurons), then more inhibitory control is necessary to stop an automatic response. For trade offs to occur, an interactive system is more likely. Additional support for a shared and interactive system was a positive relationship found for prosaccade and antisaccade latencies. The results suggest that the time to plan a movement away from or towards a peripheral stimulus have shared mechanisms. The shared system is likely the fact that both responses involve processes specific to eye movements. Previous studies have shown a systematic relationship between the distance the eyes travel and the time to make a response, known as the main sequence (Bahill et al., 1975). Thus, the motor response system could be a potential source for a shared mechanism in this case.

Second, independent automatic and controlled processes were supported from the antisaccade cost. The cost, which measures the time to inhibit an automatic response, did not correlate with prosaccade latency and did not show a gap effect. The cost likely measures a controlled process after stimulus selection since the gap effect explains competition between central fixation and a peripheral stimulus prior to stimulus onset. The results suggest a controlled process after selection of the peripheral stimulus occurs, such as inhibition.

Taken together, the above correlations support a shared motor mechanism and a well-known speed-accuracy tradeoff effect for antisaccade errors and prosaccade response time. Evidence of a shared system at a motor level contradicts previous literature connecting antisaccade to frontal lobe damage (Pierrot-Deseilligny et al., 2002). However, the antisaccade cost likely measures an independent inhibitory control mechanism, like reorienting attention, because there were no correlations with other measures.

These findings were important to find separable automatic and controlled processes from the antisaccade task. Evidence for an interactive and shared system was found for oculomotor responses; however common measures from the antisaccade task do show separable processes. The antisaccade cost was the only measure to isolate the inhibitory process as independet from prosaccade latencies and even the gap effect.

CHAPTER 4

AUTOMATIC AND CONTROLLED SCENE SEARCH BEHAVIOR

This chapter examined the relationship between automatic and controlled processes from antisaccade measures to determine what aspects of scene search behavior are explicitly controlled. Previous findings of oculomotor capture during novel and repeated searches in this dissertation conflicted with claims of the dual-process theory. Authors of the dual-process theory propose that salience-driven and memory-driven mechanisms prioritize oculomotor capture separately (Brockmole & Henderson, 2005). However, search within repeated scenes showed an attentional bias to the salience-driven gaze distractor when it was close to a known target location. The results suggest that the involuntary salience-driven capture of attention is influenced from long-term memory representations. The early bias suggests that the association of a target location within repeated scenes may be implicit. If an explicit process were used, then suppression of the distractors would be more noticeable for repeated compared to novel searches. Additionally, the memory-driven component of the dual-process theory should have prioritized the saccade distractor within repeated compared to novel searches; yet no difference was found. Results from oculomotor capture of the saccade distractor suggest that memory does not influence behavior but capture may still be salience-driven.

The purpose of this study is to use antisaccade measures to determine the mechanisms behind oculomotor capture results not supported by claims in the dual-process theory. If search behavior is salience-driven, then correlations with prosaccade latencies would support automatic processing. If search behavior is memory-driven, then correlations with antisaccade errors or cost would support controlled processing. The claim that explicit guidance occurs for repeated searches was also examined. Using antisaccade measures to determine whether contextual cueing benefits are automatic (implicit) or controlled (explicit) would add new evidence towards understanding search guidance in scenes.

Method

Participants. Same as Chapter 2.

Data Analysis. Pearson correlations were used between measures of prosaccade latency, antisaccade cost, and antisaccade error rate and search performance measures.

Results

Automatic effects supported by correlations with prosaccade latency. Prosaccade latency was positively correlated, *r* (75) = .288, *p* = .011, with search time in the first epoch during repeated searches (Figure 4.1 – left). Other measures of search efficiency across epochs did not show a relationship. However, there was a negative trend, *r* (75) = -.224, *p* = .050, with scan path ratio during repeated searches when a gaze distractor appeared.

Prosaccade latency did not correlate with looks to the gaze distractor in repeated or novel scenes. However, a strong correlation was found for the difference in proportion of looks to the far distractor between novel and repeated searches at the first ordinal position, *r (*75) = .410, *p* < .001 (Figure 4.1 – right). The far-side distractor was viewed more often for novel searches when prosaccade latency was short (<153ms) and viewed more often for repeated searches when latency was long.

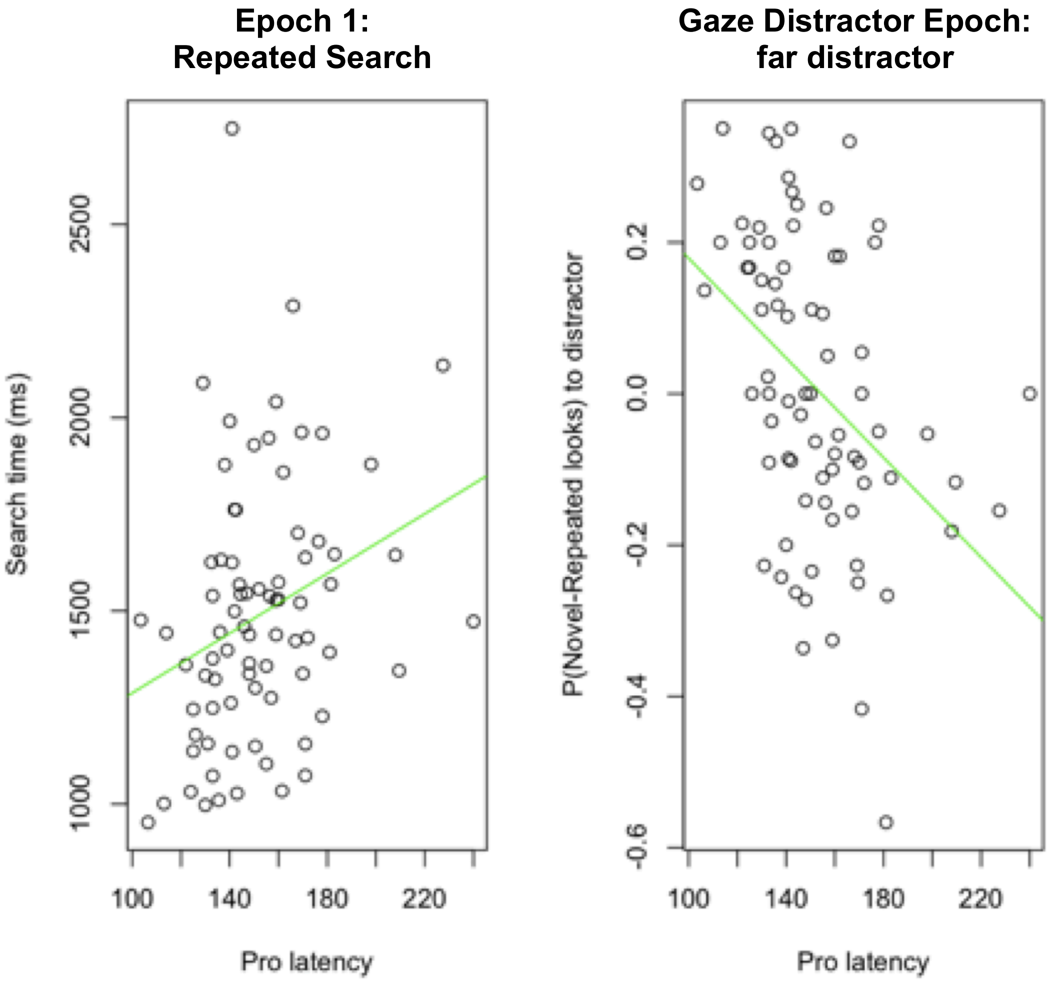


Figure 4.1. Scatterplots for prosaccade latency with search time (ms) in repeated scenes (left) and difference in proportion of looks to the gaze distractor that is far from the target location in scene search (right).

Controlled effects supported by correlations with antisaccade error rate and cost. There was one correlation between antisaccade error rate and search behavior: ability to find the target in novel searches, *r* (75) = -.289, *p* = .011 (Figure 4.2 – left). As mentioned in Chapter 3, the antisaccade error rate correlated with prosaccade latency measures. So, error residuals from a linear regression were used, which eliminated the effect of prosaccade latency in error rates, to confirm a stronger correlation, *r* (75) = -.312, *p* = .006, with the same measure: ability to find the target in the second epoch of novel searches.

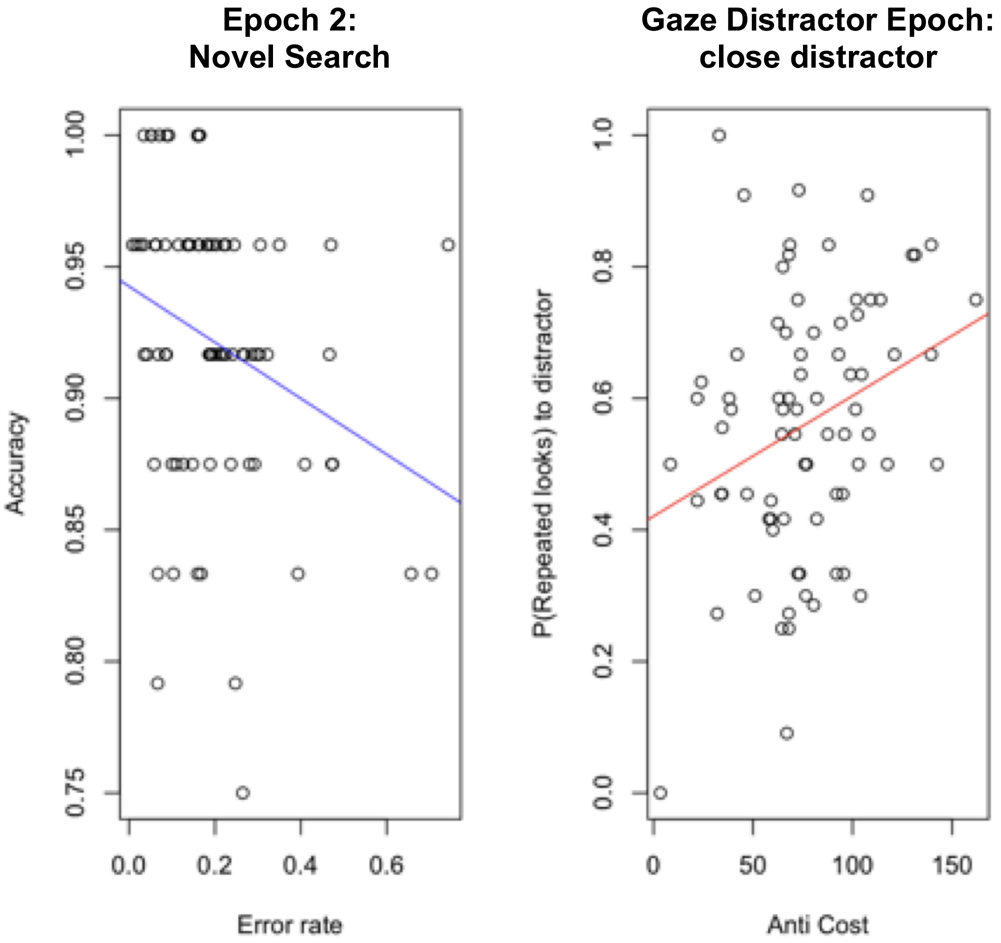


Figure 4.2. Scatterplots for antisaccade error rate with search ability (a.k.a accuracy) to find the target in novel searches (left panel) and antisaccade cost with looks to close gaze distractor in repeated searches (right panel).

Antisaccade cost was positively correlated with the proportion of looks to the gaze distractor close to the target location during repeated searches, *r* (75) = .295, *p* = .009 (Figure 4.2 – right) within the first ordinal fixation during the gaze distractor epoch. There were no correlations between cost and search efficiency measures for repeated or novel searches.

Discussion

The dual-process theory proposed separate salience-driven and memory-driven systems of oculomotor capture. Salience-driven processes are immediate and automatically capture attention. Memory-driven oculomotor capture is delayed and attracts attention based on changes to a stored memory representation. The addition of distractors within novel searches resulted in eye movement data that supported the dual-process theory while the data from repeated searches did not. Antisaccade measures were used to distinguish aspects of search behavior that are automatic or controlled. An implicit and automatic guidance for repeated searches was supported.

Prosaccade latency was used as an indicator of automatic orienting to a selected location. Search measures were expected to correlate with prosaccade latencies to the extent that they reflected salience-driven effects. There were two correlations with prosaccade latency suggested an automatic salience-driven process in search behavior. First, search time for repeated scenes during the first epoch correlated with prosaccade latency. These results were likely attributed to biases in the attention system at an early perceptual level to orient attention to the target location faster. Similar mechanisms have been proposed in contextual cueing literature (Brady & Chun, 2007). Search times were longer when prosaccade latency was longer suggesting delayed orientation of attention prolonged the search task. This may be the first piece of evidence to demonstrate a connection between cumulative search times across multiple eye movements that relates to an automatic process from a single, horizontal movement.

The second correlation with prosaccade latency showed differences in looks to the far distractor across novel and repeated searches within the gaze distractor epoch. The correlation with looks to gaze distractor supports previous evidence of automatic and immediate capture of attention (Theewues, 2010). When prosaccade latencies are short, the distractor captures attention more often during novel searches. When prosaccade latencies are long, the distractor captures attention more often during repeated searches. Despite having memory for a target location in repeated scenes, longer time to orient attention to the target location resulted in automatic capture by the gaze distractor. The correlation of prosaccade latency with looks to the far gaze distractor does support a salience-driven component of oculomotor capture. Because the attentional bias was found for the gaze distractor and search times within repeated scenes correlated with prosaccade latencies, both pieces of evidence support an early automatic guidance of attention within repeated scenes. In contrast to the current view of explicit search guidance from contextual cueing with scenes (Brockmole & Henderson, 2006a), automatic bias of attention may be facilitated by an implicit knowledge of the scene to promote faster searches compared to contextual cueing in arrays. One potential mechanism could use conceptual short-term memory to promote search guidance implicitly. An implicit guidance mechanism would also support previous findings using contextual cueing of scenes that are later mirror-reversed (Brockmole & Henderson, 2006a). Search behavior was directed to the target location within repeated scenes in a single saccade from contextual cueing benefits. However, search behavior within mirror-reversed images of repeated scenes did not show immediate allocation to the target location within the changed spatiotopic context. Instead the results found search continued in the direction of the original target location suggesting that the concept of the scene was guiding attention rather than a specific arrangement of objects. If conceptual short-term memory (Potter, 2012) can explain initial perceptual processing of scene search, this would be a new link for developing models.

Antisaccade error rate and cost were expected to relate to controlled processes during visual search. Search measures were expected to correlate with controlled measures from the antisaccade task, like error rate and cost, to support memory-driven effects. When a stored long-term memory representation is available, the dual-process theory predicted a memory prioritization mechanism would guide attention. Rather than correlations with the repeated search measure, error rate correlated with ability to find a target within the second search epoch for novel scenes. The result suggests a controlled process is necessary to locate targets within unfamiliar scenes. The relationship may not have occurred within the first epoch because there was not sufficient familiarity with the task. With practice, inhibitory control of irrelevant information during search may be optimized. With regards to the competition integration theory, these results support the idea that error rate may indicate an ability to manage irrelevant information during search.

Antisaccade cost measured the time to inhibit an automatic saccade to a peripheral location and was used as a measure of a controlled process. Antisaccade cost correlated with proportion of looks to the close gaze distractor during repeated searches. The pattern of results suggested a controlled process was necessary when a gaze distractor appeared close to the target location in repeated searches. These results support the idea that the attentional bias found for the gaze distractor in repeated scenes required a controlled process to inhibit the salience-driven response. This evidence argues against the salience-driven component of the dual-process theory not being affected by top-down modulation. The results showed that there were less looks to the distractor when less time was required to inhibit oculomotor capture. More looks to the distractor occurred when more time was needed to inhibit the response.

Salience-driven search behavior was found for the gaze distractor; however the saccade distractor did not show any memory-driven correlations with antisaccade measures or salience-driven correlations with prosaccade latencies. Either salience-driven effects are too weak for this type of distractor or implicit memory-guided prioritization is not a component of the dual-process theory that can be measured by a saccade distractor within search.

Overall, automatic and controlled search behaviors were supported by respective proaccade and antisaccade measures. Automatic search behavior related to immediate oculomotor capture. The automatic process found for search time in repeated scenes suggests implicit learning of the target location from perceptual (salience-driven) information. This finding is novel compared to previous literature suggesting an explicit guidance of contextual cueing in scenes. In contrast to the dual-process theory that oculomotor capture to a gaze distractor is involuntary, there was a controlled process that could inhibit oculomotor capture. If inhibition time was fast enough, there were less looks to the gaze distractor. Finally, novel searches require more inhibitory control than repeated searches. The finding is intuitive but has not been explicitly tested using antisaccade saccade measures until this study. The finding supports more inhibitory control is necessary within the complexity of scenes that was not previously found for search arrays (Kane et al., 2006).

CHAPTER 5

GENERAL DISCUSSION

This dissertation explored the role of selective attention within salience-driven and memory-driven processes of eye movement behavior during scene search. Oculomotor capture is the allocation of gaze onto irrelevant information added to a scene. The dual-process theory of oculomotor capture (Brockmole & Henderson, 2005) emphasizes two processes important for directing the eyes to an object. According to this model there is a salience-driven process that involves an immediate response to a location due to dramatic changes in visual features (i.e. color, edges, brightness) and a memory-driven process that involves a delayed implicit prioritization of locations based on previous experiences. In the current project these processes were examined in a single visual search task by combining paradigms from the contextual cuing and oculomotor capture literature. Participants searched through repeated and novel scenes for a letter target. Eventually, the previous experience of finding the target within repeated scenes leads to faster search times, known as contextual cueing. Oculomotor capture was examined with the addition of distractors during the last two epochs: either during the first 100 ms of fixation (gaze distractor) or an eye movement (saccade distractor). The gaze distractor trials examine effects of a salience-driven prioritization. The saccade distractor trials examine effects of a memory-driven prioritization. Additionally, this design allowed the examination of both processes in the absence of (novel searches) as well as the presence of previous knowledge for a scene (repeated searches).

Antisaccade task data was also collected from each participant to further examine search behavior by correlating antisaccade task measures with measures obtained from visual search. Given that a prosaccade or movement towards a peripheral flash in the antisaccade task reflects an automatic orienting of attention, then search measures correlated with prosaccade measures should support automatic salience-driven processes. Given that an antisaccade or an eye movement away from a peripheral flash reflects controlled inhibition, then search measures correlated with antisaccade measures should support controlled processes that require inhibition. Related neural mechanisms are discussed that support the current pattern of results.

What do we know about oculomotor capture during scene search?

Based on the dual-process theory, immediate capture of attention to a location or object is facilitated by salience-driven mechanisms while delayed capture uses implicit memory-driven mechanisms. The gaze distractor condition changed visual features of the scene after the first 100 ms of fixation, which reduced the time available to select a location for a subsequent eye movement. More looks to the gaze distractor by the first fixation supports the salience-driven process because the capture of attention is immediate and involuntary. The saccade distractor condition presented the distractor during an eye movement, so initial encoding of the scene was complete and a location selected. More looks to the saccade distractor by the second fixation supports the memory-driven process because a change is detected from a stored memory representation so the change becomes more noticeable. The results below replicate previous oculomotor capture effects as well as new interpretations of the dual-process theory with regards to distractors during repeated and novel searches.

First, there were more looks towards the gaze distractor compared to the saccade distractor within the first ordinal fixation. These results demonstrate that noticeable perceptual changes strongly capture attention through salience-driven prioritization. Changes in visual information are masked during saccades (Matin, 1974). Since less perceptual information is available during a saccade, there is less attention engagement to visual changes. These findings remained despite differences in task design across studies suggesting that salience-driven prioritization from oculomotor capture was task-invariant.

Second, the saccade distractor was viewed more often in the second rather than first fixation. As described by the dual-process theory, the saccade distractor was viewed more often by the second fixation because the change in visual information required a change to the internal memory representation of the responder. The mismatch between the external and internal scene representations prioritizes the new information by looking to the changed area.

Lastly, the immediate allocation of attention to the gaze distractor supports the salience-driven component of the dual-process theory. Specifically, results showed more views to the gaze distractor in the first rather than the second fixation. The salience-driven prioritization has been labeled involuntary given that looks occur to the distractor despite being irrelevant to finding the target.

These findings are all consistent with previous results of the dual-process theory from Brockmole and Henderson (2005). Both salience-driven and memory-driven processes of the dual-process theory were found while engaged in a visual search task. Although the pattern of results were similar to previous literature, specific claims of salience-driven and memory-driven components do not hold when results from the memory-driven repeated searches are considered in more detail.

Given the known contextual cueing effects from memory-driven guidance for repeated searches, results were expected to show more looks to the saccade distractor within repeated compared to novel searches. Specifically, changes to a scene should be more readily detected from long-term memory of a repeated scene than short-term memory from a novel scene. However, there was no difference in looks to the distractor across search contexts. The results conflict with the claims of a memory-driven prioritization within the dual-process theory because a change in a familiar scene should be noticed faster. Results from this study, however, may vary from the original because the saccade distractor epoch was always after the gaze distractor epoch. This set order of conditions could have led to an expectation of change. Further testing is necessary to examine whether expectation played a role in suppressing the eyes from moving to the distractor location regardless of scene context. If the saccade distractor epoch was presented prior to the gaze distractor epoch then there should be less influence of expectation for the saccade distractor. If the same results persist when epoch conditions are reversed, then such a finding may suggest a process unrelated to memory.

Given the involuntary capture of attention elicited by a gaze distractor is involuntary and salience-driven, there should be no differences in looks to the gaze distractor across repeated and novel searches. Unexpectedly, there was a bias to look at the close gaze distractor within the first fixation of repeated searches. This new finding of an early bias towards the distractor closer to the target suggests an early facilitation of attention to the target location. The early salience-driven bias for repeated searches suggests memory-driven guidance can interact with salience-driven processes prior to the first fixation. This study is the first to explore an attentional bias with repeated scene search for further consideration in the literature.

Results from the current study replicated previous patterns of results from oculomotor capture in scenes. However, evidence emerged from this study that conflicted with the claims of the dual-process theory. The memory-driven prioritization did not show differences in looks to the saccade distractor across scene context even though memory-driven guidance was involved for repeated searches. Strikingly, there was an influence of memory-driven modulation affecting salience-driven prioritization despite claims that salience-driven behavior is involuntary. Given that both salience-driven prioritization and memory-driven guidance occur within the first 100 ms of scene encoding, these processes may interact within brain regions that have multiple feed-forward and feedback connections, like the superior colliculus or visual cortex.

Why does repeated search become more efficient over time?

Previous research on contextual cuing in scenes has demonstrated that repeated searches had more efficient search behavior with better detection ability, faster search times, and more directed movements to find the target letter (Brockmole & Henderson, 2006ab). Theories of contextual cueing in scenes claim that efficient search behavior was facilitated by an explicit (controlled) memory for the scene and target location (Brockmole & Henderson, 2006b). However, previous research using letter arrays described an implicit (automatic) memory mechanism that biased attention towards the target within repeated contexts (Chun, 2000). The possibility that contextual cueing benefits within scenes involve implicit guidance has not been fully tested (c.f. Goujon et al., 2013; 2015).

Results from repeated searches revealed that there was an immediate bias towards the gaze distractor close to the target location within the first eye movement. For repeated searches, the eyes were directed to the gaze distractor more often when it was close to rather than far from the target location. Such a finding provides evidence that repeated contextual information immediately modulates selective attention, at least within the first 100 ms of exposure. However, rapid deployment of attention can benefit search with as little as 50 ms of previewing the scene (Võ & Henderson, 2010). These results suggest an implicit memory or automatic mechanism may facilitate immediate biasing towards the target. If an explicit mechanism were used within the first 100 ms then the results should show less looks to gaze distractors rather than more. Although explicit memory can aid recognition after search, an automatic implicit memory guides attention in the moments prior to the first eye movement. Evidence of preview benefits within scene search may use these implicit memory-driven mechanisms in guiding search behavior.

Neurophysiological evidence of contextual cueing in scenes supports the role of early biasing within repeated searches (Summerfeld et al., 2011). In particular, shorter reaction times for repeated searches were related to more alpha desyncronization on the side contralateral to the target location. Alpha desyncronization has been related to enhancement of visual areas, which suggests facilitation of task-relevant locations on a perceptual level.

Converging pieces of evidence from this behavioral study as well as neurophysiological studies support an automatic implicit process that biases perception to relevant locations. Explicit processes can control behavior given more time but the alpha desyncronization from Summerfield and colleagues (2011) suggests active suppression is not involved for repeated searches. Additionally, the idea that attentional bias towards the target occurs within the first 100 ms suggests early influences of scene processing areas, like PPA or RSC. Contextual cueing in scenes has been labeled as an explicit search process but this research suggests search guidance is automatic and implicit.

What aspects of search behavior are supported by automatic orienting processes? Conflicting results from the dual-process theory of oculomotor capture were examined using prosaccade latency as an individual differences measure of automatic orienting of attention. For example, previous oculomotor capture results from repeated searches showed a bias to the gaze distractor close to the target location. If the bias is driven from implicit processes, then behavior during repeated searches should relate to automatic mechanisms. Two findings supported automatic processes within search behavior.

Evidence supporting an automatic orienting mechanism was found for search times in repeated scenes. Shorter prosaccade latencies correlated with faster search times within repeated scenes. This relationship was only found in the first epoch of search rather than the second. One reason is that a certain level of neural activation is necessary to reach a response threshold. If some participants have a lower threshold, then they should show faster prosaccade latencies. Brady and Chun (2007) found the response selection threshold was lower for repeated search contexts. Lower response thresholds suggest a perceptual advantage for encoding information. So, the results from my study support faster perceptual learning for participants with faster search times, at least within the initial repeated searches. The second epoch did not reveal any automatic mechanisms within repeated searches. By the second search epoch, memory-driven guidance may prioritize a more direct path to the target. For example, the second epoch had shorter scan path ratios compared to the first. Shorter scan paths suggest a controlled process inhibits automatic responses that were relevant from the first epoch. Fatigue from searching, which adds noise in the response system, would also be higher in the second compared to the first epoch. So, repeated searches may use implicit guidance initially but switch to more explicit and controlled processes over time.

Oculomotor capture from the gaze distractor is an automatic process; one that is dependent on timing and search context. Evidence of immediate responses was found for proportion of looks to the gaze distractor since more looks were found in the first fixation compared to the second. Surprisingly, looks to the far, rather than the close, gaze distractor correlated with prosaccade latency. Participants with short latencies looked at the distractor more often during novel rather than repeated searches. The opposite was observed for participants with longer latencies (>153ms). If we assume more time is necessary to process perceptual information, then irrelevant information more likely interferes with visual processing to capture attention. If the selection process is too slow to bias attention to relevant locations, then signal changes from the visual cortex or superior colliculus may involuntarily force a saccade (Eimer, 2015). These results suggest that when selection of relevant information is fast then there is more interference from a distractor in novel rather than repeated scenes. When selection of relevant information for search is slow, a distractor interferes more often in repeated scenes despite knowing the target location. These results explain how timing of a response (e.g. prosaccade latency) is affected by involuntary capture of irrelevant information. Because differences in capture occur across search contexts depending on response time, faster responders may have more efficient perceptual selection.

Surprisingly, there was no relationship between looks to the close gaze distractor and prosaccade latency despite the evidence of a spatiotopic bias in repeated scenes. Because the distractor was not task-relevant for search, then maybe these automatic processes are only related to selection of relevant information for the task. The capture of attention from irrelevant information may instead be a competition of attention resources explained by more controlled processes, like competition resolution (Godijn & Kramer, 2008ab).

In conclusion, automatic processes within search were related to rapid selection of relevant locations. Theories have suggested expectation of the target location can bias attention (Bundesen, Habekost, & Kyllingsbæk, 2005; Desimone & Duncan, 1995). These findings provide new information about scene search as well as new ways to distinguish automatic mechanisms in search. Future studies could investigate the rapid deployment of attention to relevant locations in scenes in relation to conceptual short-term memory (Potter, 2012). For example, a mix of repeated and novel kitchen scenes may show slower contextual cueing benefits if multiple concepts of a particular schema interfere with search guidance.

What aspects of search behavior are supported by controlled inhibitory processes? The aspects of search behavior related to inhibitory control were expected to correlate with antisaccade cost or error rate, which commonly reflect controlled mechanisms. Antisaccade cost is the difference in timing between longer antisaccade latencies and shorter prosaccade latencies. More cost has been associated with less target predictability (Chiau et al., 2011; Lui et al., 2010) and increased task demand (Godijn & Kramer, 2008ab; Jóhannesson et al., 2013). Error rates refer to prosaccades towards the peripheral stimulus rather than away from it. Lower antisaccade error rates have been associated with higher working memory capacity (Kane et al., 2004) and greater intelligence (Klein, Rauh, & Biscaldi, 2010). Miyake and Friedman (2012) have recently shown error rates reflect an integral component of executive functioning, which is important for flexible decision-making. For this dissertation, two findings supported inhibitory control processes within search.

First, results from this study showed antisaccade cost correlated with proportion of looks to the close gaze distractor within repeated scenes. Originally the close gaze distractor findings were related to salience-driven prioritization and spatiotopic bias (memory-driven modulation). However, in this instance, the cost is explaining the likelihood of being captured by the gaze distractor based on a person's inhibition time. Specifically, the cost describes the amount of time needed to inhibit the involuntary selection of an irrelevant distractor so another response could be made to a relevant or goal location. Based on the competitive integration theory, Godijn and Kramer (2008a) support such a finding as the competition resolution between an automatically selected location and a goal location. If a gaze distractor demands more cognitive resources, then the cost time must be longer to compensate for the increase in attention demand.

Second, ability to find a target involves practiced or sustained inhibitory control. Antisaccade error rate correlated with ability to find a target during the second epoch of novel searches. To the best of my knowledge, this is the first instance in which antisaccade error rate has correlated with a search measure, target detection ability. Every eye movement first requires selecting peripheral information covertly before moving to another location (Hoffman & Subramaniam, 1995; Rizzolati et al.,1987). Because there is no prior knowledge of the target location, novel searches require multiple instances of selecting then inhibiting peripheral information until the target is found. The decrease in search time to the target in novel scenes suggests that certain strategies, like selecting and reorienting after inhibition, become more efficient to maximize the chances of finding the target. This idea is similar to Friedman and Miyake's (2004) resistance to proactive interference, which is the ability to resist (or inhibit) interference from previously relevant information held in memory that become irrelevant for the task. There appears to be a shared inhibitory control mechanism at play between antisaccade error rate and target detection during search.

Previous research has not been able to find a relationship between search and inhibitory processes using the antisaccade task (Kane, Poole, Tuholski, & Engle, 2006). However, this dissertation used scenes, which have robust effects from contextual cueing and oculomotor capture, to examine whether inhibitory control processes may exist within search. Additionally, search within arrays may have smaller effect sizes and less variability than search within scenes. For example, contextual cueing benefits within scenes require less repetitions than letter arrays (Brockmole & Henderson, 2006b).

To conclude, controlled processes were found in search that related to inhibition of selected visual information. Antisaccade cost explained competition between a close gaze distractor and a relevant location, such as the target, within repeated searches. If the cost time was short, there was less capture from the distractor due to faster inhibitory control. The error rate explained sustained effort of using inhibitory control on irrelevant information until the task goal was completed, such as detection of the letter target.

Are there separable automatic and controlled selective attention processes found in the antisaccade task? Although consensus within the antisaccade literature supports separable automatic and controlled mechanisms, recent research debates whether the processes are independent (Kristjánson, 2007). Whether inhibitory control during antisaccade generation involves interactive (Kristjánsson, 2007) or separate (Massen, 2004) systems from prosaccade generation was examined using correlation analyses for shared variance. These results are considered in the context of what is known about the neural correlates of oculomotor and attention systems.

Two correlations emerged from the current study that supported a shared mechanism. First, there was a positive relationship between antisaccade and prosaccade latencies. Given that the distance the eyes must move for a prosaccade or antisaccade are always the same, the timing to execute such an eye movement should also be very similar. Although antisaccade latencies are longer on average, these results were not affected by the latency differences and suggest that the time to plan a movement away from or towards a peripheral stimulus have shared mechanisms. Previous studies have shown a systematic relationship between the distance the eyes travel and the time to make a response, known as the main sequence (Bahill et al., 1975). Thus, the motor response system could be a potential source for a shared mechanism in this case. Second, a relationship was found that higher antisaccade errors correlated with shorter prosaccade latencies. This relationship has been found many times in the literature and labeled speed-accuracy tradeoff – faster responses produce more errors. Previous research explained increases in error rates as a function of a preparatory motor response towards the stimulus (Koval, Hutchison, Lomber, & Everling, 2004). The results suggest that faster responses may have already executed a motor plan that is too fast to control, so errors are made.

Taken together, the above correlations support a shared motor mechanism and a well-known interaction between errors and response time. Evidence of a shared system at a motor level contradicts previous literature connecting antisaccade to frontal lobe damage (Pierrot-Deseilligny et al., 2002). However, one finding from this study supported separate processes across tasks. The absence of a correlation between antisaccade cost and prosaccade latency suggests these two measures may explain separable controlled and automatic processes. For the current study, the finding suggests that time to inhibit an eye movement after selection is a separate process from the time to select and move to the location. Although a correlation analysis across tasks was not found in the literature, larger increases in prosaccade latency compared to antisaccade cost were found when task trials were interleaved rather than blocked (Jóhannesson et al., 2013). The results can be interpreted as less changes to the cost when task instructions vary from trial to trial whereas more changes to prosaccade latency may explain more difficulty in selection. Given Jóhannesson and colleagues (2013) results, inhibition time may be more resistant to changes in expectancy while selection time is more heavily dependent on expectancy from a blocked design. This explanation may support a role for parietal lobe within selection and expectancy while frontal structures are necessary for inhibition and control.

Although not thoroughly tested in this dissertation, these results suggest that antisaccade and prosaccade processes interact at the motor level yet automatic and control mechanisms are separable at the level of attention. The neural correlates of antisaccade generation require participation from multiple networks (i.e. fronto-parietal attention, oculomotor orienting). Within current anatomical models, competition will occur across different areas that integrate information (i.e. frontal lobe, parietal lobe, visual cortex, superior colliculus). The fronto-parietal attention network manages selective attention either through expectation or inhibition (Aron, Robbins, & Poldrak, 2014; Corbetta & Shuman, 2002) while oculomotor responses interact across layers of the superior colliculus (Trappenburg et al., 2001; see White & Munoz, 2011). Neurophysiologically, antisaccades require both fronto-parietal and orienting networks for responses (Jamadar, Fielding, & Egan, 2013) so an interactive system is more likely to exist with prosaccades, which predominately uses the orienting network. Results from the current study found common shared systems between antisaccades and prosaccade at a motor level, yet evidence was found for separable automatic and controlled mechanisms between antisaccade cost and prosaccade latency at an attention level.

Conclusion. The results presented in this dissertation have highlighted a variety of new findings towards understanding how we prioritize information during scene search. Oculomotor capture was used as an indication of salience-driven (gaze distractor) and memory-driven prioritization (saccade distractor) during search. Automatic and controlled selective attention processes from the antisaccade task were used to support or refute claims of controlled processes used for efficient search from repeated scenes. This dissertation concludes efficient search within repeated scenes was guided by an implicit memory mechanism that enhanced perception to relevant locations.

REFERENCES

Amador, N., Schlag-Rey, M., & Schlag, J. (1998). Primate Antisaccades. I. Behavioral Characteristics. *Journal of Neurophysiology*, *80*(4), 1775–1786.

Antoniades, C., Ettinger, U., Gaymard, B., Gilchrist, I., Kristjánsson, A., Kennard, C., et al. (2013). An internationally standardised antisaccade protocol. *Vision Research*, *84*, 1–5. doi:10.1016/j.visres.2013.02.007

Aron, A. R., Robbins, T. W., & Poldrack, R. A. (2014). Inhibition and the right inferior frontal cortex: one decade on. *Trends in Cognitive Sciences*, *18*(4), 177–185. http://doi.org/10.1016/j.tics.2013.12.003

Biederman, I., Mezzanotte, R. J., & Rabinowitz, J. C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology, 14(2*), 143-177.

Brady, T. F., & Chun, M. M. (2007). Spatial constraints on learning in visual search: Modeling contextual cuing. *Journal of Experimental Psychology: Human Perception and Performance*, *33*(4), 798–815. http://doi.org/10.1037/0096-1523.33.4.798

Brockmole, J. R., & Henderson, J. M. (2005). Prioritization of New Objects in Real-World Scenes: Evidence From Eye Movements. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(5), 857–868. http://doi.org/10.1037/0096-1523.31.5.857

Brockmole, J. R., & Henderson, J. M. (2006a). Recognition and attention guidance during contextual cueing in real-world scenes: Evidence from eye movements. *The Quarterly Journal of Experimental Psychology*, *59*(7), 1177–1187. http://doi.org/10.1080/17470210600665996

Brockmole, J. R., & Henderson, J. M. (2006b). Using real-world scenes as contextual cues for search. *Visual Cognition*, *13*(1), 99–108. http://doi.org/10.1080/13506280500165188

Brockmole, J. R., & Henderson, J. M. (2008). Prioritizing new objects for eye fixation in real-world scenes: Effects of object–scene consistency. *Visual Cognition*, *16*(2-3), 375–390. http://doi.org/10.1080/13506280701453623

Brockmole, J. R., Castelhano, M. S., & Henderson, J. M. (2006). Contextual cueing in naturalistic scenes: Global and local contexts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(4), 699–706. http://doi.org/10.1037/0278-7393.32.4.699

Bundesen, C., Habekost, T., & Kyllingsbæk, S. (2005). A Neural Theory of Visual Attention: Bridging Cognition and Neurophysiology. *Psychological Review*, *112*(2), 291–328. http://doi.org/10.1037/0033-295X.112.2.291

Buswell, G. T. (1935). How People Look at Pictures (pp. 1–33). The University of Chicago Press.

Castelhano, M.S., Mack, M., & Henderson, J.M. (2009) Viewing task influences eye movement control during active scene perception. *Journal of Vision, 9(3),* 1–15. doi: 10.1167/9.3.6.

Chiau, H. Y., Tseng, P., Su, J. H., Tzeng, O. J. L., Hung, D. L., Muggleton, N. G., & Juan, C. H. (2011). Trial type probability modulates the cost of antisaccades. *Journal of Neurophysiology*, *106*(2), 515–526. http://doi.org/10.1152/jn.00399.2010

Chun, M.M. (2000). Contextual cueing of visual attention. *Trends in Cognitive Science, 4*,170–78

Chun, M. M., & Jiang, Y. (1998). Contextual Cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology, 36*, 28-71.

Corbetta, M., Akbudak, E., Conturo, T. E., Snyder, A. Z., Ollinger, J. M., Drury, H. A., et al. (1998). A Common Network of Functional Areas for Attention and Eye Movements. *Neuron*, *21*, 761–773.

Corbetta, M., & Shulman, G. L. (2002). Control of Goal-directed and Stimulus-driven Attention in the Brain. *Nature Reviews Neuroscience*, *3*(3), 215–229. http://doi.org/10.1038/nrn755

Desimone R, & Duncan J. (1995). Neural mechanisms of selective visual attention. *Annual Reviews Neuroscience, 18*, 193–222.

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, *64*, 135–168. http://doi.org/10.1146/annurev-psych-113011-143750

Du, F., Qi, Y., Li, X., & Zhang, K. (2013). Dual Processes of Oculomotor Capture by Abrupt Onset: Rapid Involuntary Capture and Sluggish Voluntary Prioritization. *PloS One*, *8*(11), e80678. http://doi.org/10.1371/journal.pone.0080678.t005

Eimer, M. (2014). The neural basis of attentional control in visual search. *Trends in Cognitive Sciences*, *18*(10), 526–535. http://doi.org/10.1016/j.tics.2014.05.005

Evdokimidis, I, et al. (2002). The antisaccade task in a sample of 2,006 young men. *Experimental Brain Research*, *147*(1), 45–52. http://doi.org/10.1007/s00221-002-1208-4

Folk, C. L., & Remington, R. (2006). Top-down modulation of preattentive processing: Testing the recovery account of contingent capture. *Visual Cognition*, *14*(4-8), 445–465. http://doi.org/10.1080/13506280500193545

Friedman, N. P., & Miyake, A. (2004). The Relations Among Inhibition and Interference Control Functions: A Latent-Variable Analysis. *Journal of Experimental Psychology: General*, *133*(1), 101–135. http://doi.org/10.1037/0096-3445.133.1.101

Greene, M. R., & Oliva, A. (2009). Recognition of natural scenes from global properties: Seeing the forest without representing the trees. *Cognitive Psychology, 58*, 137–179.

Godijn, R., & Kramer, A. F. (2008a). The effect of attentional demands on the antisaccade cost. *Perception & Psychophysics*, *70*(5), 795–806. http://doi.org/10.3758/PP.70.5.795

Godijn, R., & Kramer, A. F. (2008b). Oculomotor capture by surprising onsets. *Visual Cognition*, *16*(2-3), 279–289. http://doi.org/10.1080/13506280701437295

Goujon, A., Didierjean, A., & Poulet, S. (2013). The emergence of explicit knowledge from implicit learning. *Memory & Cognition*, *42*(2), 225–236. http://doi.org/10.3758/s13421-013-0355-0

Goujon, A., Didierjean, A., & Thorpe, S. (2015). Investigating implicit statistical learning mechanisms through contextual cueing. *Trends in Cognitive Sciences*, *19*(9), 524–533. http://doi.org/10.1016/j.tics.2015.07.009

Hallet, P. E. (1978). Primary and Secondary Saccades to Goals Defined By Instructions. *Vision Research*, *18*, 1279–1296.

Henderson, J. M., Brockmole, J. R., Castelhano, M. S., & Mack, M. (2007). Visual Saliency Does Not Account for Eye Movements during Visual Search in Real-World Scenes. *Eye Movement Research: Insights Into Mind and Brain*, 1–41.

Hoffman, J.E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception Psychophysics*, 57, 787–95

Hollingworth, A. (2006). Visual memory for natural scenes: Evidence from change detection and visual search. *Visual Cognition*, *14*(4-8), 781–807. http://doi.org/10.1080/13506280500193818

Hollingworth, A., Richard, A. M., & Luck, S. J. (2008). Understanding the function of visual short-term memory: Transsaccadic memory, object correspondence, and gaze correction. *Journal of Experimental Psychology: General*, *137*(1), 163–181. http://doi.org/10.1037/0096-3445.137.1.163

Horowitz, T. S., & Wolfe, J. M. (1998). Visual search has no memory. *Nature, 394*, 575–577.

Itti., L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research, 40*, 1489-1506.

Jamadar, S. D., Fielding, J., & Egan, G. F. (2013). Quantitative meta-analysis of fMRI and PET studies reveals consistent activation in fronto-striatal-parietal regions and cerebellum during antisaccades and prosaccades. *Frontiers in Psychology*, *4*, 1–15. doi:10.3389/fpsyg.2013.00749/abstract

Jóhannesson, Ó. I., Ásgeirsson, Á. G., & Kristjánsson, A. (2012). Saccade performance in the nasal and temporal hemifields. *Experimental Brain Research*, *219*(1), 107–120. doi:10.1007/s00221-012-3071-2

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A Controlled-Attention View of Working-Memory Capacity. *Journal of Experimental Psychology: General*, *130*(2), 169–183. http://doi.org/10.1037/0096-3445.130.2.169

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The Generality of Working Memory Capacity: A Latent-Variable Approach to Verbal and Visuospatial Memory Span and Reasoning. *Journal of Experimental Psychology: General*, *133*(2), 189–217. http://doi.org/10.1037/0096-3445.133.2.189

Kane, M. J., Poole, B. J., Tuholski, S. W., & Engle, R. W. (2006). Working memory capacity and the top-down control of visual search: Exploring the boundaries of "executive attention". *Journal of Experimental Psychology:*

Learning, Memory, and Cognition, *32*(4), 749–777. http://doi.org/10.1037/0278-7393.32.4.749

Klein, C., Rauh, R., & Biscaldi, M. (2010). Cognitive correlates of anti-saccade task performance. *Experimental Brain Research*, *203*(4), 759–764. http://doi.org/10.1007/s00221-010-2276-5

Koval, M. J., Hutchison, R. M., Lomber, S. G., & Everling, S. (2014). Effects of unilateral deactivations of dorsolateral prefrontal cortex and anterior cingulate cortex on saccadic eye movements. *Journal of Neurophysiology*, *111*(4), 787–803. http://doi.org/10.1152/jn.00626.2013

Kowler, E., Anderson, E., Dosher, B., Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research*, *35*, 1897–916

Kristjánsson, A. (2007). Saccade landing point selection and the competition account of pro- and antisaccade generation: The involvement of visual attention? A review. *Scandinavian Journal of Psychology*, *48*(2), 97–113. doi:10.1111/j.1467-9450.2007.00537.x

Kristjánsson, A., Chen, Y., & Nakayama, K. (2001). Less attention is more in the preparation of antisaccades, but not prosaccades. *Nature Neuroscience*, *4*(10), 1037–1042. doi:10.1038/nn723

Kustov, A.A., & Robinson, D.L. (1996). Shared neural control of attentional shifts and eye movements. *Nature, 384*, 74–77.

Mannan, S. K., Kennard, C., Potter, D., Pan, Y., & Soto, D. (2010). Early oculomotor capture by new onsets driven by the contents of working memory. *Vision Research*, *50*(16), 1590–1597. http://doi.org/10.1016/j.visres.2010.05.015

Massen, C. (2004) Parallel programming of exogenous and endogenous components in the antisaccade task. *Quarterly Journal of Experimental Psychology A, 57,* 475–498.

Matin, E. (1974). Saccadic Supression: A Review and an Analysis. *Psychological Bulletin*, *81*(12), 899–917.

Matsukura, M., Brockmole, J. R., & Henderson, J. M. (2009). Overt attentional prioritization of new objects and feature changes during real-world scene viewing. *Visual Cognition*, *17*(6-7), 835–855. http://doi.org/10.1080/13506280902868660

Miyake, A., & Friedman, N. P. (2012). The Nature and Organization of Individual Differences in Executive Functions: Four General Conclusions. *Current Directions in Psychological Science*, *21*(1), 8–14. http://doi.org/10.1177/0963721411429458

Mokler, A. & Fischer, B. (1999) The recognition and correction of involuntary prosaccades in an antisaccade task. *Experimental Brain Research, 125*, 511– 516.

Munoz, D. P., & Everling, S. (2004). Look away: the anti-saccade task and the voluntary control of eye movement. *Nature Reviews Neuroscience*, *5*(3), 218–228. doi:10.1038/nrn1345

Neider, M. B., & Zelinsky, G. J. (2006). Scene context guides eye movements during visual search. *Vision Research, 46*, 614–621.

Olejarczyk, J. H., Luke, S. G., & Henderson, J. M. (2014). Incidental memory for parts of scenes from eye movements. *Visual Cognition*, *22*(7), 975–995. http://doi.org/10.1080/13506285.2014.941433

Oliva, A., & Torralba, A. (2001). Modeling the shape of the scene: A holistic representation of the spatial envelope. *International Journal of Computer Vision, 42,* 145–175.

Oliva, A., & Torralba, A. (2006). Building the gist of a scene: The role of global image features in recognition. *Progress in Brain Research, 155,* 23–36.

Parkhurst, D., Law, K., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual attention. *Vision Research, 42*, 107-123.

Pierrot-Deseilligny, C. H., Ploner, C. J., Müri, R. M., Gaymard, B., & Rivaud-Péchoux, S. (2002). Effects of Cortical Lesions on Saccadic Eye Movements in Humans. *Annals of the New York Academy of Sciences*, *956*, 216–229.

Peterson, M. S., & Kramer, A. F. (2001a). Attentional guidance of the eyes by contextual information and abrupt onsets. *Perception & Psychophysics*, *63*(7), 1239–1249.

Peterson, M. S., & Kramer, A. F. (2001b). Contextual cueing reduces interference from task-irrelevant onset distractors. *Visual Cognition*, *8*(6), 843–859. http://doi.org/10.1080/13506280042000180

Potter, M. C. (2012). Conceptual Short Term Memory in Perception and Thought. *Frontiers in Psychology*, *3*. http://doi.org/10.3389/fpsyg.2012.00113

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltá, C. (1987). Reorienting Attention across the Horizontal and Vertical Meridians: Evidence in Favor of a Premotor Theory of Attention. *Neuropsychologia*, *25*(1A), 31–40.

Roberts, R. J., Hager, L. D., & Heron, C. (1994). Prefrontal Cognitive Processes: Working Memory and Inhibition in the Antisaccade Task. *Journal of Experimental Psychology: General*, *123*(4), 374–393.

Roberts, R. J., & Pennington, B. F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology*, *12*(1), 105–126.

Rosenholtz, R., Li, Y., & Nakano, L. (2007). Measuring visual clutter. *Journal of Vision*, *7*(2), 1–22. doi:10.1167/7.2.17

Summerfield, J. J., Rao, A., Garside, N., & Nobre, A. C. (2011). Biasing Perception by Spatial Long-Term Memory. *Journal of Neuroscience*, *31*(42), 14952–14960. http://doi.org/10.1523/JNEUROSCI.5541-10.2011

Tatler, B. W., Hayhoe, M. M., & Land, M. F. (2011). Eye guidance in natural vision: Reinterpreting salience. *Journal of Vision*, *11*(5), 1–23. http://doi.org/10.1167/11.5.5

Theeuwes, J., Kramer, A.F., Hahn, S. & Irwin, D.E. (1998). Our eyes do not always go where we want them to go: capture of the eyes by new objects. *Psychological Science, 9*(5), 379-385.

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, *135*(2), 77–99. http://doi.org/10.1016/j.actpsy.2010.02.006

Torralba, A., Oliva, A., Castelhano, M.S., & Henderson, J.M. (2006) Contextual guidance of eye movements and attention in real-world scenes: The role of global features in object search. *Psychological Review, 113*, 766–786. doi: 10.1037/0033-295X.113.4.766.

Trappenberg, T. P., Dorris, M. C., Munoz, D. P., & Klein, R. M. (2001). A Model of Saccade Initiation Based on the Competitive Integration of Exogenous and Endogenous Signals in the Superior Colliculus. *Journal of Cognitive Neuroscience*, *13*(2), 256–271.

Treisman, A. & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working Memory Capacity and the Antisaccade Task: Individual Differences in Voluntary Saccade Control. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(6), 1302–1321. doi:10.1037/0278-7393.30.6.1302

Võ, M. L.-H., & Henderson, J. M. (2009). Does gravity matter? Effects of semantic and syntactic inconsistencies on the allocation of attention during scene perception. *Journal of Vision*, *9*(3), 1–15. http://doi.org/10.1167/9.3.24

Võ, M. L.-H., & Henderson, J. M. (2010). The time course of initial scene processing for eye movement guidance in natural scene search. *Journal of Vision, 10*(3):14, 1–13, http://journalofvision.org/10/3/14/, doi:10.1167/10.3.14.

Võ, M. L.-H., & Wolfe, J. M. (2012). When does repeated search in scenes involve memory? Looking at versus looking for objects in scenes. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(1), 23–41. http://doi.org/10.1037/a0024147

Võ, M. L.-H., & Wolfe, J. M. (2015). The role of memory for visual search in scenes. *Annals of the New York Academy of Sciences*, *1339*(1), 72–81. http://doi.org/10.1111/nyas.12667

White, B. J., & Munoz, D. P. (2011). The superior colliculus. In S. P. Liversedge, I. D. Gilchrist, & S. Everling, *Oxford Handbook of eye movements* (pp. 195–214). New York: Oxford University Press Inc.

Wolfe, J. M., Võ, M. L. H., Evans, K. K., & Greene, M. R. (2011). Visual search in scenes involvesselective and nonselective pathways. *Trends in Cognitive Sciences*, *15*(2), 77–84. http://doi.org/10.1016/j.tics.2010.12.001

Wright, R. D., & Ward, L. M. (2008). Eye Movements and Attention Shifts. In *Orienting of Attention* (1st ed., pp. 121–152). Oxford University Press.

Yarbus, A. (1967). *Eye movements and* V*ision*. New York: Plenum.

Zelinsky, G.J. (2008). A theory of eye movements during target acquisition. *Psychology. Review*, *115*, 787–835.