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Investigating priming, inhibition, and individual differences in visual attention

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INVESTIGATING PRIMING, INHIBITION, AND INDIVIDUAL DIFFERENCES IN VISUAL ATTENTION

BY

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Bachelor of Science, Fairfield University, 2007

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DISSERTATION

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy

in

Psychology

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Dedication

I can do all things through Him who strengthens me (Philippians, 4:13)

Without the love of my family and friends I would have abandoned this dream years ago.

To my parents, for teaching me their strength, for their confidence that I could succeed, for their emotional and financial support, and for their guidance and patience all these years. They have shaped me into a person who sets and achieves goals, and finishing this Dissertation is one of my greatest.

To my brother, Kevin, and my sister, Sarah, for teaching me to persevere in countless ways. I will always be thankful for both of them and for their encouragement.

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To my closest friends, Chase and Arielle, who answered the phone late at night to buoy my spirits and keep me thinking positive, for their steadfast friendship and belief that I could actually do this.

To the process, for teaching me it is all right to not know all of the answers.

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I would like to thank Colin Ware for being a member of my Dissertation Committee, and for taking time out during his Sabbatical year to help guide my dissertation. He provided thought provoking comments to help me develop a deeper understanding of how the visual system performs.

I could never have survived graduate school had it not been for the friendship, guidance and support of Erika Wells. She was the first to welcome me into the lab in 2009, answering question after question as I explored the visual system and attentional control. Her favorite phrase "google-it" I can still hear repeating in my head as I struggled to understand new concepts and the secrets to using Matlab (I never did figure those out!). My conference partner in crime, she always saw things from an angle that I did not even know existed, and this final year without her in lab solidified my hope to always have her friendship in my life.

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ABSTRACT

INVESTIGATING PRIMING, INHIBITION, AND INDIVIDUAL DIFFERENCES IN VISUAL ATTENTION

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While much has been explored within the attentional control literature, questions still exist as to how attentional processing is modulated, and how different types of visual search paradigms can elucidate the underlying mechanisms involved in successful visual search. Throughout this dissertation, I will focus on the multifaceted aspects that come with the study of visual attention. After discussing visual attention I explore priming of pop out along two different dimensions. Specifically, using a rapid serial visual presentation design, I demonstrate that temporal and spatial priming interact along a similar mechanism. This result adds to the priming literature by demonstrating simultaneous multidimensional priming in our ability to efficiently process our visual environment. Next, I explore attentional distraction and psychophysical thresholds to examine whether an individual's sensitivity to a visual feature can predict the individual's magnitude of distraction by that feature. Results reveal that psychophysical thresholds are not sensitive enough to reflect a definite relationship between an individual's baseline stimulus-driven sensitivity to visual features and the magnitude of distraction by those features. Finally, I explore the role of inhibition (using a stop signal paradigm) in individual differences in abilities to avoid distraction, and examine how working memory capacity influences target selection. Results failed to elucidate this relationship and further research is needed to uncover whether individual differences in avoiding distraction are subserved by either inhibitory processing, or working memory capacity. In conclusion, this dissertation uses various visual search paradigms to explore the interactions of stimulus-driven and goal-driven effects, to illuminate how individual differences inform models of attentional distraction, and to investigate how inhibiting a distractor modulates attentional processing.

CHAPTER 1

PROCESSING THE VISUAL ENVIRONMENT

If I asked you to describe a specific item in your current visual environment, you could easily do so, directing your attentional focus directly to the item in question. This would not be a difficult task, merely one that required you to attend to a subset of the limitless expanse of possible information available to you at any given moment. Despite the request's seeming simplicity, exactly how you are able to direct your attention around your visual environment has been the topic of study for over one hundred years, pioneered by William James in 1890, who claimed, "Everyone knows what attention is. It is the taking possession of the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought" (pp. 403-404). Many of the studies conducted after James' time within the realm of attention focused on audition, requiring participants to attend to one set of incoming auditory stimuli while ignoring another, commonly referred to as dichotic listening (Cherry, 1953; Broadbent, 1958).

At the start of the 1970s, many studies of attention shifted into studying attention in the visual modality due to the fact that researchers could control the timing of stimuli better to study selective attention than in the auditory studies of the past (Beck & Ambler, 1973). In order to conduct visual attention experiments, researchers needed to understand the underlying sequence of visual processing. Visual processing has been studied extensively to elucidate how information travels from the retina through the cortex to provide the overarching sensation of vision. One major question asked is how does our visual system integrate the millions of details in our environment into cohesive objects? Our minds might be organized into distinct visual processing pathways to provide the main functions of the visual system: what are the objects in my visual environment, where are they, and how can I use them? By creating a separately organized system for each of these functions, more efficient processing would be possible, allowing for faster recognition of objects, and faster localization of those objects in our visual environment. As humans evolved, we depended on correct visual inputs to alert us to whether the shape in the distance was a tiger or a rock, so that we could act accordingly and survive.

Two main visual pathways

As curiosity developed to understand how visual information is processed, Livingstone and Hubel began examining the primate visual system and determined there were two main cell systems, parvocellular and magnocellular pathways (made up of M & P cells) within the lateral geniculate nucleus (1988). The parvocellular pathway has displayed activation patterns that make it responsible for form and color processing, and it is composed of small cells along the ventral side of occipital cortex projecting through the temporal cortex. The primary input for the parvocellular pathway comes from the cones on the retina, and parvo- cells have been shown to analyze spatial information at a much finer level of detail than magno- cells. The second stream of processing is the magnocellular pathway, which is implicated in motion processing and is composed of larger cells projecting along the dorsal side of the brain through the parietal cortex. Its primary input is from the rods, and like the parvocellular pathway, its output projects to early visual areas in occipital cortex (Livingstone & Hubel, 1988). These cellular pathways with seemingly dissociated functions, spurred many researchers to examine why they existed and what exactly they were used for within visual processing.

In 1982, Mishkin and Underleider argued that vision is used for two critical functions: object perception "what" and spatial perception "where." They based their concept on primate visual pathways from Livingstone and Hubel (1988). The ventral pathway from primary visual areas to inferior temporal cortex is responsible for object perception, designated "what," and the dorsal pathway from primary visual areas to posterior parietal cortex is specialized for spatial perception designated "where." The research conducted in monkeys showed that when the inferior temporal lobes were removed, the animals had problems in using object information, while still being able to utilize spatial information (Mishkin & Underleider, 1982). Alternatively, monkeys whose parietal lobes were removed had difficulty using spatial information, but could utilize object information. This evidence created a clear double dissociation, supporting the idea that the ventral "what" and the dorsal "where" processing streams were separate and relatively independent.

Building on what the magno- and parvo- cellular pathways could be accomplishing within visual attention, Goodale and Milner compiled electrophysiological, neuropsychological and behavioral evidence and proposed an alternative to the "what-where" model, terming the two streams of visual processing "what" and "how" (1992).

They named their theory the perception-action model and emphasized the division between vision primarily used for perception and vision used for action in our environment. The "what" pathway was concerned with identifying objects and was located as a ventral pathway with projections from early visual areas to temporal cortex. The "how" pathway was concerned with visually guided actions with the objects in the visual environment, showing dorsal projections from early visual cortex to parietal cortex (Goodale & Milner, 1992). Milner and Goodale in 1998, claimed that the dorsal system "is designed to guide actions purely in the here and now, and its products are consequently useless for later reference...it is only through knowledge gained via the ventral stream that we can exercise insight, hindsight and foresight about the visual world" (pp. 12). Understanding where the current literature on visual processing stands, researchers were able to elucidate how visual attention is directed in our environment to help us selectively process behaviorally relevant information.

Theories of visual attention

Many theories of visual attention proliferated into the 1970s, and in 1972, Erikson and Hoffman developed what is now known as the flanker paradigm in order to demonstrate that visual attention might behave like a spotlight, zooming in to obtain much detail on a specific object or area of the visual scene, or zooming out to view more of the visual field with less detail. In the flanker paradigm, participants are asked to identify a target item, usually a letter, as it appears at fixation, pressing one button for one target letter and another button if they see a different target letter. Task irrelevant stimuli appear peripherally to the target items on some trials, and reaction times (RTs) to find the target are influenced by the identity of these flanking stimuli. The greatest effect of the flankers occurs when they appear within 1° visual angle of the target, suggesting that attention has a specified size of focus.

Posner supported the spotlight model of attention proposed by Erikson and Hoffman (1972) by showing that attention is close to independence from eye movements, and we can orient our attention to a location before we detect the object in that location with an eye movement, by using active endogenous processing (1980), see Figure 1.1.

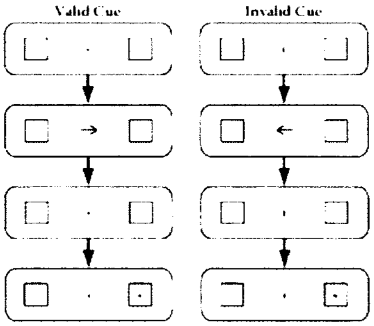


Figure 1.1: Sample trials from a Posner cuing task. A brief interval (top panel) shows the two potential target locations, followed by an arrow cue, pointing to one of the two boxes where the target could appear. Following this cue presentation, another brief blank interval is presented followed by the target. On valid cue trials, the target appears in the cued location (left column) and on invalid cue trials, the target appears in an uncued location (right column) from Posner 1980.

Concurrently, Treisman and Gelade were working on a theory of visual attention in 1980 that addressed answering the binding problem, i.e., how does the visual system integrate different features in our visual environment to create objects in space? Their theory of feature integration suggests that the purpose of attention in our visual environment is to bind features to objects and that attention must be directed from one object to the next in a display when more than one object is present (1980). The concept of directing attention from one item to the next in a display is known as serial processing, and the more items that are present in a display, the longer it takes participants to find the target. Conversely, parallel processing of a display occurs when participants are able to find the target quickly regardless of the number of distracting items in the display, see Figure 1.2.

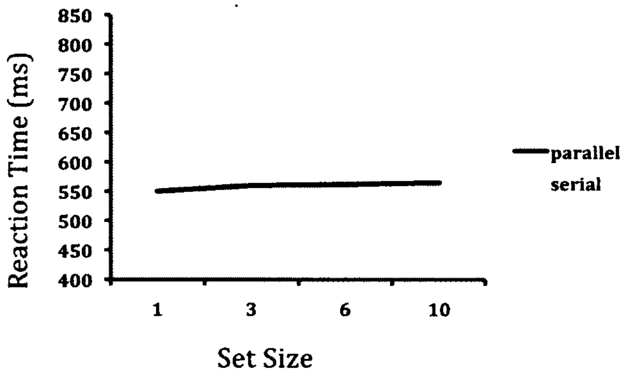


Figure 1.2: Example of plausible data during a visual search task. A parallel search shows no difference in RTs as the number of items in the set size increases, whereas in serial search, as the number of items in the display increases, so does the RT to identify the target item.

These two types of search modes are important when researchers seek to design studies with either serial or parallel processing as the tenet of attentional control. Treisman & Gelade concluded that objects are recognized by their features through either focal attention or (if focal attention is overloaded or diverted) through the current goals and expectations of the observer (1980).

Duncan and Humphreys broke away from feature integration theory and proposed a theory of visual selection where parallel search processing models match internal schemas to input stimuli for current behaviors, entering relevant information into visual short-term memory (1989). Researchers have developed various procedures to measure the orienting and successful processing of our environment using visual search paradigms, usually exemplified using parallel search modes. To make visual search better able to explain complex phenomena, researchers split attentional processing into two main systems of thought: stimulus-driven and goal-driven processing, which will be discussed in the next chapter.

CHAPTER 2

CAPTURE: GOAL-DRIVEN & STIMULUS-DRIVEN ATTENTIONAL PROCESSING

In 1997, while describing how they believed attention was controlled, Egeth & Yantis noted two major attentional systems within vision: goal-driven or top-down attentional control and stimulus-driven or bottom-up attentional control. These two systems came under much scrutiny for determining how separate and independent they might be, how they might possibly interact, and which of them might be responsible for visual processing at any given moment. Deferring back to William James, his belief was that attention had these two modes of processing such that attention was considered active when it was controlled in a top-down way by an individual's goals or expectations, and considered to be passive when controlled in a bottom-up way by external stimuli in the environment (1890).

To immerse you further into this debate, imagine you are going on a job interview in a building you have never been in before. Once you locate the correct building in its business complex, your current behavioral goal is to find the room in which your interview is taking place so that you won't be late. While you are searching the building for the correct room, the fire alarm goes off demanding you evacuate the building immediately. You momentarily forget about searching for your interview room and shift your search to move towards the nearest exit. In this example, the fire alarm captured your attention, even though you had different behavioral goals in mind; however, as soon as the fire department arrives, determines it is safe to go back into the building, and the salient irrelevant fire alarm cue is gone, you will resume your attentional focus on searching for your interview room.

How does visual attentional control guide us toward prioritizing the fire alarm in this example? Do we automatically orient to such salient stimuli? Or, is our attention shifted toward the salient cue, while still maintaining our initial goals? Researchers have long debated whether attentional control is dominated by goal-driven processing, where we orient toward a known feature or quality (e.g., searching for the interview room), or if attentional control is dominated by stimulus-driven processing, where we orient to the most salient, or noticeable item in the display (e.g. the fire alarm). Visual salience can be thought of as distinct perceptual qualities that make some stimuli stand out from other stimuli in our environment, orienting our attention towards them.

To address the debate outlined above, researchers have developed various procedures to measure the processing of our environment using attentional control. Frequently employing a paradigm measuring the response latencies for locating a target in a visual display with and without a distracting stimulus present, researchers can directly measure visual attention (see Figure 2.1). When a distracting stimulus is present in a visual search task it takes participants significantly longer to identify the target than if the distractor were absent, a phenomenon known as attention capture (Theeuwes, 1992).

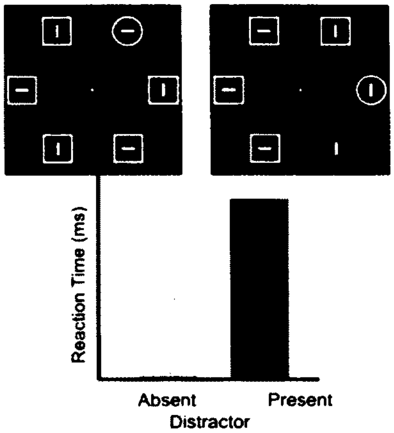


Figure 2.1: Example of the Theeuwes paradigm where participants search for the circle and identify whether the bar inside is vertical or horizontal. The top stimuli presentation shows the target circle among non-target squares on the left with no distractor present, while the top right presentation shows an oddball color singleton distractor item. In the bottom stimuli presentation, a graph of plausible data shows that when the distracting item is present, there is an increase in participant's RTs to find the target item.

Attention capture paradigms allow researchers to discover potential interactions of both stimulus-driven and goal-driven components of attentional processing. Attention capture has been extensively studied due to its abundance and its fundamentality in our every day lives. The literature exploring attention capture holds many inconsistencies about how attentional processing enables the avoidance of visual distraction. Some researchers advocate that stimulus-driven attentional processing determines priority of stimuli, such that on every trial in a visual search task, participants' attention will be immediately drawn to the most salient item in the display (e.g., Theeuwes, 1992).

Specifically, such researchers found that even when participants knew the features of the target on the upcoming trials, they were still unable to avoid becoming distracted by the irrelevant distracting stimulus in the display.

Many stimulus feature dimensions, such as color and form, have been employed to examine whether conditions exist in which goal-driven control allows participants to avoid distraction by salient stimulus features. Yantis & Jonides (1990) showed that participants could avoid distraction by a very salient distractor singleton when attention was highly focused on specific locations in the visual display. Replicating this finding, Theeuwes asked whether salience in a visual display could be avoided when participants were given knowledge of the target on the upcoming trials and extensive practice (1991). Theeuwes explored this question using two salient features in his visual displays, one serving as the target and the other as the distractor, and found even knowing that the distracting stimulus feature would never be the target, participants were unable to avoid both salient items in the display, and thus were incapable of using goal-driven attentional search strategies to avoid distraction (Theeuwes, 1991).

In subsequent studies, Theeuwes has continued to advocate for stimulus-driven processing as the dominant mode of attentional control with salient irrelevant items being unavoidable in visual search (Theeuwes, 1992, 1994a, 1994b). Using feature singletons (a unique feature that causes the item to stand out in a visual display), Theeuwes argued that attention will be captured in a stimulus-driven way only, such that the distractor singleton "pops-out" from the surrounding non-target and target features and subsequently captures our attention regardless of our current behavioral goals (Theeuwes, 2004).

Contrary to the research discussed above, other researchers have found that participants are able to exert goal-driven (i.e. top-down) control strategies to avoid distraction by a salient irrelevant singleton in the display. When directing participants' attention to specific locations, they appear to avoid becoming distracted as Yantis & Jonides (1990) demonstrated, but what about when attention is directed toward known features of the target item rather than a spatial location? Bacon and Egeth demonstrated that attention can be oriented toward items possessing known features (i.e. color and shape) and a salient irrelevant distractor can be avoided (Bacon & Egeth, 1994; see also Leber & Egeth, 2006).

In addition, Folk, Remington & Johnston used a paradigm where participants were cued on upcoming trials: sometimes the cue was in the same stimulus dimension (i.e., color) and sometimes it was in a different dimension, i.e., abrupt onset, (Folk et al., 1992). These researchers found that when the cue shared the same stimulus dimension as the upcoming target, participants took longer to identify the target, suggesting they were more distracted by the cue when it matched the known feature of the target, than when it employed a different stimulus dimension. They also demonstrated that participants are able to avoid distraction by an irrelevant distracting cue if that cue shares no common features with the target. For example, if participants were searching for a red circle in a display of green squares, a distracting item contingent on the participants' goals would present as a red square, capturing attention and causing longer RTs for the participant to correctly locate the target red circle. A distracting item that would not cause contingent attention capture in this particular example would be a circle or square of a different color than what participants were searching for, such as a blue or yellow item. New hypotheses based on contingent capture effects developed; stating the degree to which a salient stimulus involuntarily captures attention depends on the degree to which that item matches the participants' current goals and its similarity with the target (Folk et al., 1992).

CHAPTER 3

ATTENTIONAL CONTROL & PRIMING: TEMPORAL AND SPATIAL DIMENSIONS INTERACT DURING SEARCH

In studying attentional processing using visual search paradigms, variability in the data often stems from the differences in performance across individuals, with some individuals performing faster, with shorter RTs during distractor present conditions than other individuals. Another source of variability in attentional control data stems from within individuals' performances across sessions of trials. While overall RT on a given trial should be reflective of the individual's state of attentional control (with greater RTs indicating greater distraction by an irrelevant singleton), incidental aspects of the stimulus display also necessarily influence RT (Kumada & Humphreys, 2002). Specifically, aspects about the visual display can facilitate or hinder RTs depending on the previous visual display in a sequence of trials.

Priming-of-popout interacts along simultaneous spatial and temporal dimensions

Introduction

Processing current information from our visual environment efficiently requires reliance on stimuli from previous moments to guide attentional processing and facilitate a behavioral response. Information that repeats, or is familiar to our visual system, will be more rapidly processed than novel stimuli. In 1994, Maljkovic & Nakayama examined how attention to subsets of a visual scene affects RT to find a target. What subjects attended to during one trial, affected how they processed future trials, a phenomenon named priming of popout (PoP) that has been replicated in many experiments (i.e. Becker, 2008; Fecteau, 2007; Lamy, Antebi, Avani & Carmel, 2008).

This PoP effect has been observed beyond simple feature repetitions in our environment and has been demonstrated in more complex paradigms with repetitions in spatial position of the target across trials producing faster RTs (Maljkovic & Nakayama, 1996; Kristjansson, Vuilleumier, Malhotra, Husain, & Driver, 2005). Our visual system is able to develop a complex representation for our current environment and retrieve it during subsequent visual presentations, reflecting the operation of a low-level short-term memory system (Brascamp, Pels, & Kristjansson, 2011). The more information that repeats from trial to trial (i.e. color and spatial location), the better the visual system's ability to process and execute the correct behavioral response (Huang, Holcombe, & Pashler, 2004). One question that remains unanswered in the literature on PoP is exactly how different repeating dimensions (i.e. spatial location or color) in our visual environment combine to facilitate responses.

There are two potential explanations as to the effect of repeating multiple dimensions across trials. The first possible way two dimensions could combine could be an additive type of processing of different dimensions, suggesting two distinct mechanisms underlying each form of dimensional priming. The other possible explanation for how two dimensions could combine during visual search could be interactive, suggesting each dimension uses similar processing along same underlying mechanism. Research has explored both of these possibilities and delivered conflicting views. Kristjansson examined the two dimensions of color and spatial repetitions and concluded that these combine in an additive way during repetitions along these dimensions, such that both color and spatial repetitions during trials facilitates a faster RT and are subserved by two distinct mechanisms (2006; see also Maljkovic & Nakayama, 2000). Perhaps the degree of saliency of the items in the current display is given a weighted average, accounting for both the current items, and the previous visual display's weighting of target and distractors, where the highest weighted item receives attentional priority during a trial (Yashar & Lamy 2010a). Kristjansson argues that each dimension has its own mechanism involved in visual priming, suggesting that each dimension varies the weighting of the target item differently, specifically that color may have a weighted saliency that is different from spatial position during visual search, and the appearance on the previous trial matching the current trial would receive the highest saliency weighting, directing participants fastest to the target location based on the addition of the distinct mechanisms for color and spatial information.

Contrary to this finding, Yashar & Lamy examined temporal and spatial repetitions and concluded a similar underlying mechanism exists for priming, suggesting an interactive nature of these priming dimensions (2010b). Here, the weighting of items' salience in the display would interact, such that the weighting for temporal position information of the target would have similar weighting as the spatial position information. Temporal priming was examined using a rapid serial visual presentation (RSVP) stream where items are presented in the same spatial location in succession, one after the other during a trial. These researchers weaved the two trial types of a spatial display with no temporal information, and a temporal display with no spatial information to come to their conclusion that they interact along a similar priming mechanism (Yashar & Lamy, 2010b). They suggest that PoP will occur any time there is a need for attentional selection in a display, specifically that differences in saliency are prevalent and bias the speed at which the participant can identify the target. Due to the methodology of the two above experiments, the different dimensions being examined were done first in a simultaneous way (for color and space in Kristjansson's experiment) and then in a separately displayed way interleaving the two dimensions in different trial types (Yashar & Lamy in 2010b), and the question still remains unanswered as to how different dimensions in a visual display combine.

If we combine spatial and temporal information in a simultaneous visual search paradigm will we see these two dimensional features combine in an additive or an interactive way? In the present study, I hypothesize that when target information repeats on a trial-to-trial basis in both spatial location and temporal position, there will be an interactive facilitation effect, speeding responses more strongly than repetition of only one or neither dimension.

Methods and Materials

Participants. Twenty-nine healthy participants (mean age = 19.5, 17 women), with normal or corrected-to-normal visual acuity and normal color vision, participated in exchange for partial class credit. Informed consent was obtained from each participant all of whom were students enrolled at The University of New Hampshire. Participation included a brief (<5 min) practice session followed by ~45 min of experimental trials. The Institutional Review Board of the University of New Hampshire approved all procedures.

Stimulus Presentation. Stimuli were generated via a Windows 7 Bootcamp setup on an Apple Macbook computer using EPrime software and presented on a 19 inch CRT display (ViewSonic G90fb) at a viewing distance of ~50 cm. Responses were collected using the computer keyboard.

Design and Procedure. Participants completed 20 practice trials, followed by 720 experimental trials divided into twelve blocks of 60 trials each. Each trial began with a fixation display consisting of a cross (0.2° by 0.2°) in the center of a black background, and participants were instructed to maintain fixation during the experiment. This display was presented for 500 ms and was followed by 4 RSVP streams presented in 4 corners of an imaginary square with an eccentricity of 2.5°, (see Figure 3.1). Each RSVP stream consisted of 12 successively presented color digits (font size = 30) randomly selected with replacement from 1 to 9, with the restriction that no two consecutive digits were the same. One singleton color digit, the target, appeared in one of the 4 streams on 70% of trials, while the other 11 or 12 digits (depending on the stream, the distractors) were the same non-target color. On each trial, the target and distractor colors were randomly selected from four possible colors, red, blue, green and yellow. More than two possible colors were used so the color of the distractors on a trial could not predict the upcoming colors in the next trial (see Yashar & Lamy, 2010b). Target absent trials were included to counter anticipation effects of successive digits having a greater chance of being the target as the stream progressed to the 12th digit.

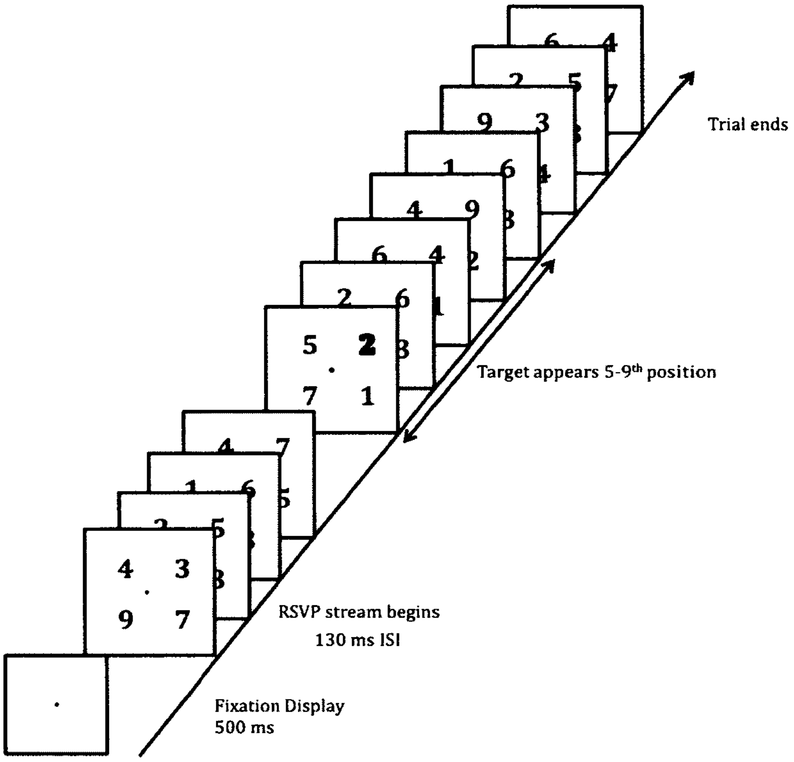


Figure 3.1: Representation of trial stimuli where the oddball color is the target in the RSVP stream. Actual backgrounds were black with colored numbers.

The target's spatial and temporal position was randomly selected, with the target equally likely to appear in any of the four spatial positions, but temporally restricted to the fifth through ninth positions in the RSVP sequence. The presentation duration of each digit and the inter-stimulus interval (ISI) were 130 ms per item. Participants were instructed to report whether the target was an odd or an even number by pressing a designated key ("2" with the right hand for an even number or "x" with the left hand for an odd number) as accurately and quickly as possible. On trials where no target appeared, participants were instructed to press nothing. On each trial, a blank screen followed the RSVP stream for 5 s or until response. Incorrect responses were signaled by an auditory tone, indicating to the participant they responded incorrectly. After the participants' response a blank screen was presented for 500 ms before the next trial began.

Results & Discussion:

Several participants (*n* = 4) were excluded from the analysis due to their mean RT (1 subject) or error rate (3 subjects) exceeding the group mean's by more than 2.5 standard deviations. In addition, trials with incorrect responses (3.5% of all trials) or outlying RTs (less than 2% of all trials) were removed from all RT analyses.

Reaction Time Measures. A 2x2 analysis of variance (ANOVA) was run for spatial and temporal position. The two levels of spatial position reflect when the spatial position of the target repeats across consecutive trials, and when the spatial position of the target appears in a different location than the previous trial's target. The two levels of temporal position reflect when the temporal position of the target repeated across two trials, and when the temporal position of the target is in a different temporal position in the RSVP stream than the previous trial's target.

Reaction time data were examined for a main effect of spatial priming and results show participants were significantly faster to respond when the spatial position of the target repeated across consecutive trials than when it appeared in a different location, $F(1, 22) = 36.11, p < 0.05$, see Figure 3.2.

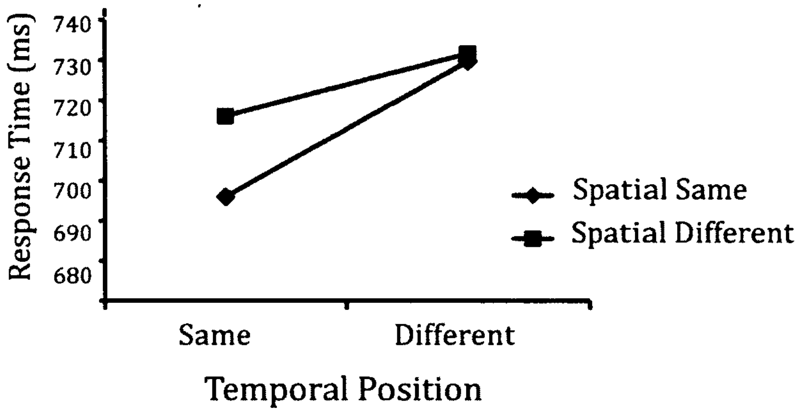


Figure 3.2: Results of Spatial x Temporal PoP. Participants are faster to find the target when both spatial and temporal position repeat, than when either dimension alone repeats.

This result suggests that when the target repeats in spatial position across trials as opposed to appearing in a new spatial position, participants are faster to process the visual environment and find the target. Reaction time data were examined for a main effect of temporal priming and results show participants were significantly faster to respond to the target when it repeated temporal position compared to when the target appeared in a different temporal position in the RSVP stream, $F(1, 22) = 63.28, p < 0.05$. This suggests that when the target repeats its position in time, the faster participants respond, as opposed to when the target appears in a different temporal position. This could potentially be because the implicit memory representation from the previous trial matches most with identical temporal positioning.

Finally, we tested for an interaction of spatial x temporal position, which revealed a significant interaction of spatial x temporal position, F (1, 22) = 34.96, $p < 0.05$. This result suggests that individuals are faster to respond when the target repeats both spatial and temporal position across consecutive trials than when the target appears in a different position. In addition, planned comparisons reveal participants were significantly faster when temporal position information repeated and spatial position was the same (M = 695.91) than when spatial position was different (M = 716.17), t (22) = 6.32, $p < 0.05$. Also, when temporal position was different and spatial position was the same (M = 729.65) there was no significant difference than when spatial position was different (M = 731.61), t (22) = 0.39, $p > 0.05$. This demonstrates that the significant spatial priming effect is contingent upon the temporal position information during the display, further illustrating the interactive effect of these two dimensional variables during visual priming. These results suggest the visual system uses all potentially repeating information to facilitate responding in our complex visual environment.

Accuracy Measures. A 2x2 ANOVA was run on the accuracy data for spatial position and temporal position for the levels described above. Error rates reflect evidence of spatial position PoP where the task was significantly harder when the target appeared in a new spatial position than when it repeated positions, F (1, 22) = 4.514, $p < 0.05$. There were no significant effects of temporal position on accuracy or spatial x temporal position on the accuracy data, all Fs < 1.

General Discussion

When something is familiar to us, we process the information rapidly, matching it to a memory of previous experience. The current study demonstrates as more information from our visual environment repeats across trials, the faster we are at efficiently processing our surroundings. Simultaneous multidimensional priming demonstrated here with the interaction of spatial and temporal priming suggests PoP occurs every time attentional selection needs to be employed during visual search. It also reveals that PoP might operate along a similar mechanism regardless of the dimension of repeating information, providing support for Yashar & Lamy's proposition that spatial and temporal PoP operate according to the same underlying process (2010b).

A possible explanation for the interactive nature of PoP demonstrated here, could be that during both temporal and spatial pop-out search, the degree of saliency of each target and distractor in the visual scene is allocated some weighted average (positive or negative) of a value assigned to its current and previous trial feature in accordance with the goals of the participant, with PoP affecting feature prioritization for the allocation of attention (Yashar & Lamy, 2010a). In the current experiment, with both spatial and temporal information available to participants, the weighted average for the target feature is more salient than the weighted average would be for spatial or temporal information alone, speeding the engagement of attention to the target when both spatial and temporal information repeat. Yashar & Lamy (2010b) urged researchers to examine whether task demands could modulate the relative weights of PoP. Here, we demonstrate clear evidence that when the visual scene is more complex, including information about spatial and temporal position simultaneously, the demands modulate the magnitude of the PoP effect. Specifically, when both the temporal position and the spatial position of the target repeat, our visual system is able to retrieve the implicit memory representation from the previous trial, guiding our attention toward behaviorally relevant stimuli to speed any response we might be required to make.

Previous research suggests these speeded response times are occurring in two distinct ways, namely an early perceptual stage and a later response related stage of processing (Lamy, Yashar & Ruderman, 2010). Krummenacher, Grubert & Muller suggested these two sources of PoP (pre-attentional and post-selectional) are composed of separable memory mechanisms (2010). Understanding how these potential memory mechanisms interact, researchers sought to investigate their respective roles within PoP and demonstrate that the pre-attentive source guides attentional engagement to the target feature, while the post-selective response based component is a result of retrieving an episodic memory representation of the previous trial (Lamy, Zivony, & Yashar, 2011). This memory speeds the response decision after the target has been selected and aids efficient processing of the visual scene in order to execute a motor response. The results of temporal priming in this study replicate and extend previous RSVP tasks where participants are faster to respond to the target when consecutive trials contain a target similar in temporal position than when the targets on consecutive trials are more distant in time (Yashar & Lamy, 2010b).

In sum, the current study was the first to demonstrate simultaneous multidimensional interactive priming by spatial and temporal position information. Future research will investigate how all available information in our visual environment, including other features such as color, in our visual environment combines to guide and enhance future visual processing.

CHAPTER 4

ATTENTIONAL CONTROL & FEATURES: CAN MAGNITUDE OF DISTRACTION BE PREDICTED BY VISUAL SENSITIVITY?

Understanding how individual differences play a large role in the variability seen in attention capture paradigms is important as we seek to elucidate how attentional control is implemented. Lechak & Leber in 2012 explored how the features of the visual environment might modulate attentional processing, such that greater sensitivity to a specific stimulus feature might predict one's ability to avoid distraction by that feature. We examined the effects of visual motion sensitivity and distraction to motion on an individual subjects level. Visual motion sensitivity was measured using a hemifield localizer task in the fMRI scanner to localize motion sensitive area MT (V5) in each hemisphere per participant. Sensitivity was measured as the neural fMRI signal in MT (V5) during the presentation of passively viewed motion during the hemifield localizer. Distraction to motion was measured behaviorally using a visual search task where participants attempted to ignore a salient irrelevant moving distractor. We proposed that an individual's inherent sensitivity to visual motion could be used to predict how susceptible those individuals are to distraction by motion. Results showed that individuals with greater evoked fMRI activity in motion sensitive area MT (V5) during the passive viewing of moving stimuli exhibited greater behavioral distraction in a separate task when a motion distractor was to be ignored. Therefore, an individual's baseline sensitivity to a passively viewed stimulus feature (e.g., motion) predicted how distracting that stimulus feature was when the individual is instructed to ignore it, suggesting that greater sensitivity to visual motion makes one less able to resist processing it.

Experiment 2: Linking Motion Sensitivity to Capture by Motion

Lechak & Leber illuminated that individual differences play a role along the stimulus-driven component of visual attention, by showing that individuals differ in their ability to process a salient feature in their environment (2012). Building upon this work, we believe that perhaps passive viewing is not the best measure of motion sensitivity, as we previously had argued, because it could be conceived that some individuals may have attended the moving stimuli more than others during the passive viewing task. Individuals were instructed to maintain fixation on a dot at center while dots moved radially toward and away from fixation. Were it the case that some individuals attended the motion more than others, these individuals would have shown larger evoked fMRI activity in MT (V5) as a reflection of attentional processing of motion, rather than a measure of inherent sensitivity.

If we advocate that individuals' sensitivity to motion predicts capture by motion, we must develop a precise measure of sensitivity. Lechak, Wells & Leber employed a more accurate measure of motion sensitivity by assessing individuals' psychophysical motion thresholds (VSS abstract, 2011). Previous research has suggested that psychophysical motion thresholds could be a more precise measure of an individual's sensitivity to motion (Newsome & Pare, 1988). With this new sensitivity to motion approach and the original attention capture paradigm with the to-be-ignored motion distractor we investigated whether greater sensitivity to visual motion makes one less able to resist processing it.

To obtain motion thresholds, observers completed a two-interval forced choice task in which coherent motion was to be discriminated from random dot motion. Dots in the coherent interval were varied in coherence from 4% to 50%, and an accuracy threshold of 75% was estimated for each observer (see Figure 4.1).

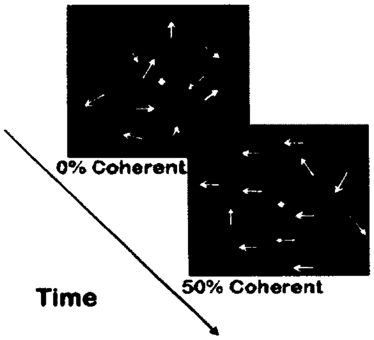


Figure 4.1: Participants were shown two separate intervals of moving dots, one of which had a larger percent of dots moving in the same direction. Participants were instructed to indicate which interval contained the coherent dot motion.

To obtain a measure of behavioral distraction, participants performed a visual search task where the distracting irrelevant item was a moving distractor singleton. Initial stimulus presentation involved a placeholder display presented for 100 ms, which consisted of an outline circle superimposed with an outline square at each of 10 locations (see Figure 4.2).

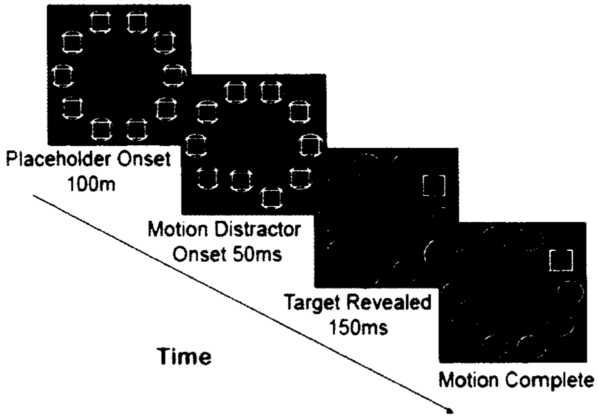


Figure 4.2: Participants searched for the square and reported whether it had a gap in the top or bottom. Half of the trials contained an irrelevant motion singleton distractor that could never be the target, which began oscillating during the placeholder presentation 50 ms before the search stimuli appeared.

On distractor-present trials (50%) a random, non-target placeholder began oscillating at 39° /s for 200 ms, first moving 1.95° toward fixation, then away from fixation until it was 1.95° more eccentric than its starting position, and finally back to the starting position. 50 ms after the motion began, the search objects were revealed (nine non-target circles and one target square), and the search objects remained for 200 ms, at which point all stimuli except for fixation were removed. Each of these search objects contained a small gap in the top or bottom. Participants were instructed to report the location of the target gap using the index and middle finger of their right hand (for top and bottom gaps, respectively). The 10 objects were green and were arranged symmetrically about the vertical and horizontal axes, with half of the items appearing to the left of fixation and half appearing to the right of fixation. Circles and squares were centered 5.85° from fixation and were drawn with a stroke of 0.20°. Squares were 2.34° per side and the circle's diameter was 2.69°. Gaps were 0.49° in length.

RT on distractor-present trials was compared to RT on distractor-absent trials to yield a measure of behavioral distraction to motion. Results showed a positive correlation between coherence thresholds and distraction, $r = 0.52$, $p = 0.023$, (see Figure 4.3). That is, observers who were less sensitive to visual motion were less able to ignore salient distracting motion.

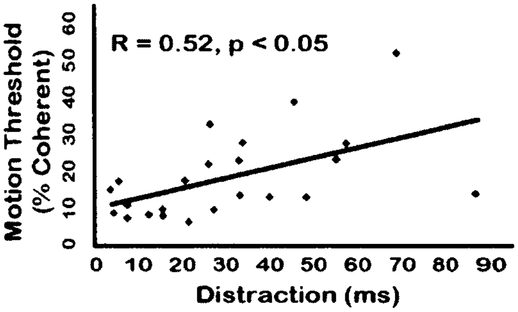


Figure 4.3: A positive correlation between behavioral distraction and motion thresholds, namely that the more distracted an individual is by an irrelevant motion distractor the less sensitive you are to detecting coherent motion.

These results are inconsistent with the proposal that greater sensitivity to motion makes one less able to resist it. Instead, an individual's ability to enhance processing of task-relevant stimuli and suppress processing of irrelevant stimuli could be subserved by a common mechanism. This unexpected positive correlation could be because a greater sensitivity to motion means greater resistance to distraction by motion, such that if you notice motion in your visual environment more swiftly than others you are better able to ignore it. It is also possible that the results might be affected by participant's individual abilities or motivational factors.

Due to the existence of this second plausible explanation, we decided to regress out two different measures of ability/motivation in our subject data, including the overall accuracy and the overall reaction time during the visual search task. After attempting to remove the contribution of these variables on performance, which are thought to reflect motivation to perform well during a task (Engelmann, Damaraju, Padmala & Pessoa, 2009) we re-plotted our correlation between the residual motion thresholds and the residual distraction and now find no significant relationships between these two variables (see Figure 4.4).

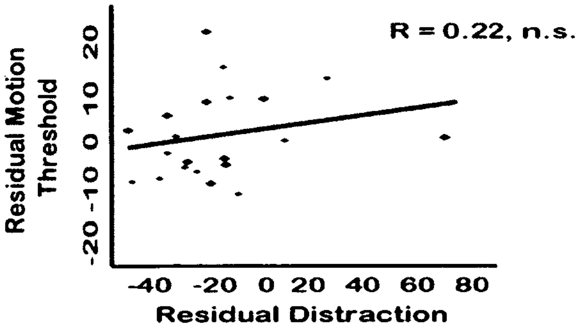


Figure 4.4: Residuals of motion thresholds and distraction plotted after regressing out overall RT and accuracy scores during the visual search task. The different coloring of the points on the graph indicates two different rooms that participants completed the study in.

With the post-regression results suggesting no relationship between individual's inherent sensitivity to visual motion and an individual's distraction by motion, we decided to reassess our experimental procedures and found several areas in need of more precise control.

Experiment 3: Increasing Experimental Control

In our previous experiment, participants were run in two separate testing rooms with dissimilar experimental setups, with most of our data stemming from the end of semester tide of last minute research participants. Deciding to rerun the study with different methodological concerns, such as using one testing room set up for all subjects, and avoiding end of the semester subjects (by running all of our subjects before the last 3 weeks of the semester), we sought to uncover the link between sensitivity to motion and capture by motion. We used the same experimental materials for both assessing psychophysical motion thresholds and behavioral capture to motion.

Results showed a negative correlation between coherence thresholds and distraction of marginal significance, $r = -0.35$, $p = 0.056$, (see Figure 4.5). That is, observers who were less sensitive to visual motion were better able to ignore salient distracting motion.

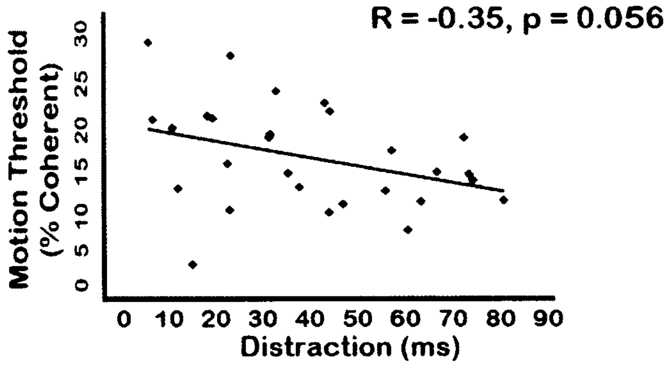


Figure 4.5: Capture by motion and motion threshold revealing a negative correlation, suggesting that individuals who are more sensitive to coherent motion in a visual display are more susceptible to becoming distracted by irrelevant motion.

These results were consistent with our initial prediction that an individual's inherent sensitivity to visual motion could be used to predict how susceptible those individuals are to distraction by motion, and subsequently the more sensitive an individual is to coherent motion, the less able they are to resist distraction. In light of our contradictory findings from one semester to another, we again regressed out ability/motivational factors of overall RT and accuracy during the behavioral capture task and we find the residuals trending further towards significance, (see Figure 4.6).

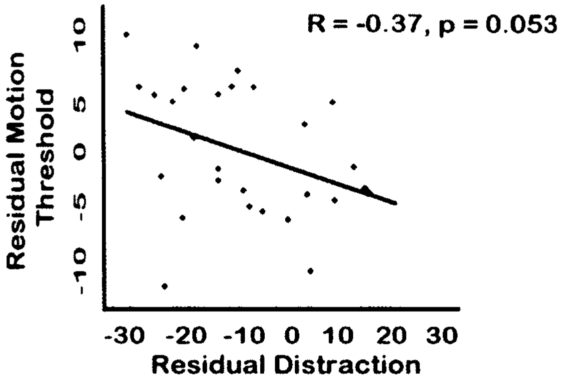


Figure 4.6: Residuals of distraction by motion and motion thresholds plotted after regressing out overall RT and accuracy on the attention capture task.

Combining the results from both of these experiments, we have contradictory findings that beg for reconciling. From these results we conclude that it is possible that more sensitivity to motion in our visual environment predicts greater susceptibility to distraction and there are influences of motivational factors, which might obscure results.

Experiment 4: Attempting to Dissociate Motion Capture from other Forms of Capture

The current study seeks to nail down the answer to the question of whether or not an individual's ability to perceive coherent motion predicts how susceptible to distraction that individual will be to irrelevant motion in their visual environment. Previous research has attempted to obtain a direct motivational measure of the task at hand, such as the

Intrinsic Motivation Inventory (IMI), designed to assess participant's investment in an experiment (Ryan, Koestner & Deci, 1991). If motivation is playing a large role in affecting the results of the study, regressing out an overall rating of intrinsic motivation during the task should reveal a clearer picture of the relationship between sensitivity to a feature and distraction by that feature.

In addition, I added another feature of sensitivity to aid the discussion of how different features in our visual environment are processed, as the question arises of whether being good at one task predicts good performance on another task. We can imagine, that perhaps some people are better across the board at following instructions, and that individuals who have less distraction to one visual feature in their environment, could also have less distraction to other features simply because they are better overall at multiple types of tasks. By adding a new component of orientation capture and orientation thresholds, I wanted to determine whether motion sensitivity is exclusively influencing one's ability to avoid distraction by motion (and not distraction to other visual features). In addition, I attempted to dissociate motion and orientation sensitivity, such that it could be possible that some individuals are more sensitive to a specific feature in their visual environment, e.g. motion more than orientation, rather than more sensitive to all visual features. This dissociation would also suggest that individuals have different sensitivities to different features in their visual environments, contributing to the literature on the stimulus-driven component of attentional control and processing, while stressing the importance of examining individual differences within large data sets.

Methods and Materials

Subjects. Participants were recruited from the University of New Hampshire's Psychology Subject Participation Pool, also known as SONA. Participants had normal or corrected-to-normal visual acuity and normal color vision, were right handed, and participated in exchange for course credit. The Institutional Review Board of the University of New Hampshire approved procedures.

Stimuli. Stimuli were generated via an Apple MacBook computer using MATLAB software (Mathworks, Natick, MA) with Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997) and presented on a 19in. CRT display (ViewSonic G90fb) at a viewing distance of approximately 50cm.

Design & procedure

Visual Search Task: Motion Capture. Participants completed 6, 8-minute blocks of 96 trials per block of the visual search task. A fixation dot was present for the duration of the run, and participants were instructed to maintain gaze on it. Initial stimulus presentation involved a placeholder display for 100ms, consisting of an outline square and an outline circle superimposed at each of 10 locations (see Figure 4.2). On distractor present trials (50%) a random, non-target placeholder oscillated at 39°/second for 200ms toward and away from fixation then back to its starting position. 50ms after the motion begins, the search objects were revealed (ten circles with a lighter green target circle), and the search objects remained on display for 200ms, and then disappeared to leave only the fixation dot.

All of the search objects had a gap in their outline either at the top or the bottom, and participants were instructed to report where the gap in the light green circle appears, pressing their index finger for a gap on the top and their middle finger on a different key for a gap on the bottom. The items were green and arranged symmetrically about the horizontal and vertical axes, with half of the items appearing to the left of fixation and half appearing to the right of fixation. Circles were centered 5.85° from fixation and were drawn with a stroke of 0.20°. The circle's diameter was 2.69°. All gaps were 0.49° in length.

Motion Threshold. To obtain motion thresholds, observers completed a two-interval forced choice task in which coherent motion was discriminated from random dot motion. Trials started with a 500ms display with only the fixation dot present, which remained present during the entire duration of the experiment. Participants performed six practice trials followed by 6 blocks of 72 trials per block, for approximately 30mins. After each trial, participants were asked, "Which interval contained some dots moving in the same direction?" and they indicated the first or second interval with the press of a button (either "1" or "2" key, respectively). Dots in the coherent interval were varied in coherence from 4% to 50%, and an accuracy threshold of 75% was estimated for each observer, (see Figure 4.1).

Visual Search Task: Orientation Capture. Participants completed 6 blocks of 96 trials per block for a total of 8 mins per block. A fixation dot was present for the duration of the run, and participants were instructed to maintain gaze on it. Initial stimulus presentation involved a placeholder display for 100ms, consisting of a horizontal and vertical bar superimposed at each of 10 locations, (see Figure 4.7).

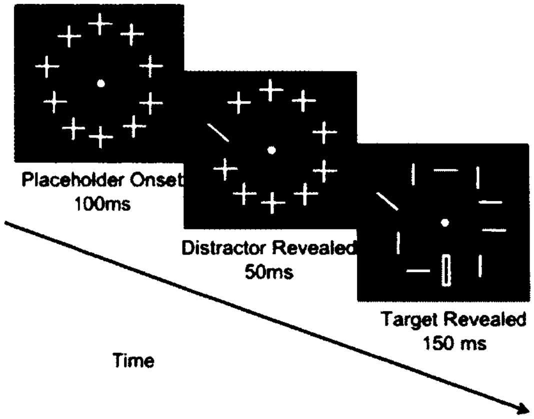


Figure 4.7: Representation of a trial where participants searched for the oddball color target and reported whether it is horizontal or vertical. Half of the trials contained an irrelevant orientation singleton distractor that could never be the target, which appeared during the placeholder presentation 50 ms before the search stimuli was presented.

On distractor present trials (50%) a random, non-target placeholder revealed a tilted bar while the other non-target & non-distractor items were either vertical or horizontal. The target was a horizontal or vertical bar on every trial and was a light green. Participants were asked to search for the light green target and report whether it was horizontal (the ">" key) or vertical (the "<" key) in orientation. 50 ms before the search objects were revealed, the distracting bar was revealed to maximize the capture effect. The search objects were revealed for 200ms, and then they disappeared to leave only the fixation dot.

<u>Orientation Threshold.</u> To obtain orientation thresholds, observers completed a two-interval forced choice task in which one interval contained homogeneously oriented bars and the other contained heterogeneously oriented bars. Participants were asked to report in which interval the heterogeneous display was presented. In the homogeneous interval, all bars were tilted either 45° clockwise or counterclockwise from vertical. In the heterogeneous interval, half of the bars were presented at the standard 45° rotation from vertical (either all clockwise or all counterclockwise, and never the same orientation as in the homogeneous interval); the remaining half of the bars in this condition deviated from the standard orientation (half clockwise and half counterclockwise). The deviation of all non-standard bars, which determined task difficulty, was selected on each trial from among 10 values, ranging from 0.5° to 6°, (see Figure 4.8).

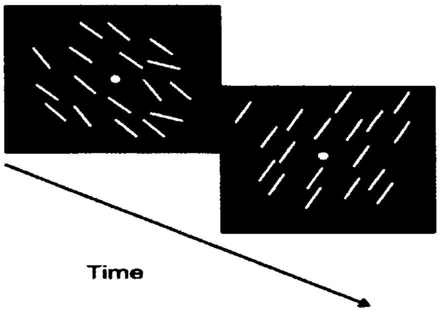


Figure 4.8: Participants were shown two separate intervals of tilted parallel bars, one of which had a display of tilted bars that were not perfectly parallel. Participants were instructed to indicate which interval contained bars that were not parallel to one another (above answer would be "1").

Participants completed 10 practice trials, followed by 6 blocks of 72 trials. A fixation dot was present for the duration of the run, and participants were instructed to maintain gaze on it. After each trial, participants were asked, "Which interval contained bars that were not perfectly parallel?" and they indicated the first or second interval with the press of a button (either "1" or "2" key, respectively). Finally, an accuracy threshold of 75% was established for each participant.

Intrinsic Motivation Inventory. All participants filled out a modified version of the Intrinsic Motivation Inventory (IMI) at the completion of the above four behavioral sections (see Appendix B). Responses were given on a likert scale and were individually coded (using the original criteria outlined by Ryan, Mims & Koestner, 1983) to obtain an overall motivation measure on the experiment. In addition, the data were divided into three subcategories of effort, usefulness and interest. These measures were then correlated with performance on the four tasks to assess the degree to which motivation affects performance, to reveal a clearer picture of how the variables are related.

Results & Discussion:

In this experiment, I sought to determine whether an individual's baseline sensitivity to a passively viewed stimulus feature could predict how distracting that stimulus feature was when the individual was instructed to ignore it. I predicted I could replicate results from Experiment 3 to find that the more sensitive an individual is to coherent motion, the less able they are to resist distraction by motion.

Behavioral Distraction. Behavioral data on the motion capture task was analyzed for an effect of distractor presence on RT, and results revealed an average of 21.8 ms of capture, and distractor absence RT (M = 607.1 ms) compared to presence (M = 628.9) was significant, $t(29) = 11.24, p < 0.05$. When examining the orientation capture data, results revealed an average of 15.2 ms, and distractor absence RT (M = 442.1 ms) compared to presence (M = 457.3 ms) was significant, $t(29) = 7.64, p < 0.05$. These results support that it took participants longer to respond to the target when an irrelevant distractor was present compared to when it was absent during visual search.

Feature Sensitivity. For both motion thresholding and orientation thresholding an accuracy threshold of 75% was estimated for each observer using pfit and psignafit programs created using MATLAB software (Mathworks, Natick, MA). Psignafit performs a constrained maximum likelihood estimate on the data to specified threshold cuts (75%). Pfit then fits a psychometric function to the data and performs 1999 bootstrapping simulations in order to estimate the variability of the fitted parameters and estimated thresholds. Finally, a sensitivity analysis is run to gauge how sensitive the variability estimates would be to inaccuracy of the initial fit, see Figure 4.9.

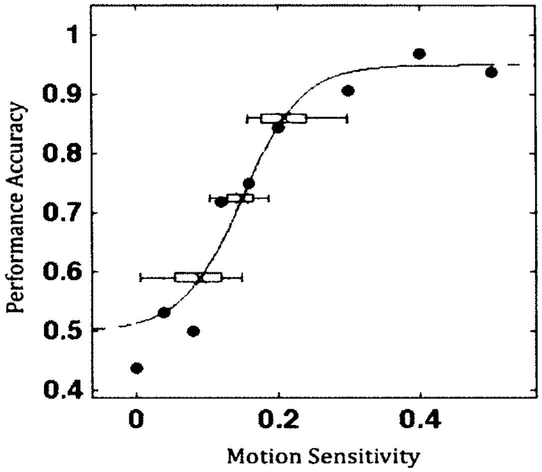


Figure 4.9: Example of a psychometric function fitting performance accuracy to motion sensitivity for the motion thresholding task.

Participants had an average of 0.132 motion coherence threshold (SD = 0.045), and an average of 2.797 degrees deviation threshold (SD = 0.544). These results suggest that psignafit and pfit were adequately able to calculate sensitivity thresholds for both the motion threshold and the orientation threshold tasks.

<u>Correlating Sensitivity and Capture.</u> Results from thirty subjects revealed no significant correlations between any of the variables identified in the Methods section of this chapter. Behavioral capture by motion was not significantly correlated with sensitivity to motion,

r (28) = 0.09, $p > 0.05$. In addition, I predicted I could find link between orientation capture and orientation threshold, such that people who are better able to detect a deviation in the angle of a tilted bar will be more distracted by tilted bars during a capture task. Orientation capture and sensitivity to orientation were not significantly correlated, *r* (28) = -0.19, $p > 0.05$. I had also hoped to determine a double dissociation between these two features (motion and orientation) by finding that motion threshold and motion capture correlate (as in Experiment 3) and that orientation threshold and orientation capture correlate, but that motion threshold and orientation capture do not significantly correlate, nor do orientation threshold and motion capture. I found no significant results for these features predicting either capture or sensitivity to another feature: motion capture and sensitivity to orientation, *r* (28) = 0.29, $p > 0.05$; orientation capture and sensitivity to motion, *r* (28) = 0.12, $p > 0.05$.

Examining the relationship between both forms of sensitivity to features in our visual environment, motion thresholds and orientation thresholds did not significantly correlate, *r* (28) = 0.14, $p > 0.05$.

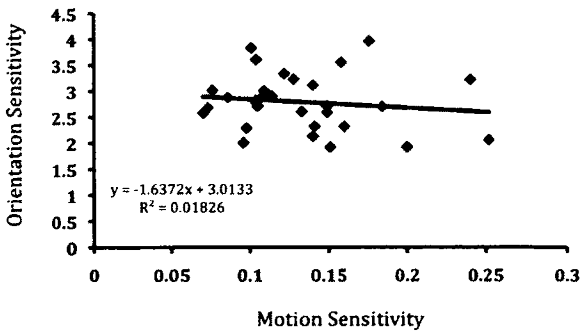


Figure 4.10: No correlation between two measures of sensitivity.

This suggests that individuals have different sensitivities to different features in their visual environments; contributing to the literature on the stimulus-driven component of attentional control and processing, see Figure 4.10. Examining whether capture by one feature predicted the magnitude of capture by the other feature, I correlated motion capture and orientation capture and found no significant result, *r* (28) = 0.02, $p > 0.05$.

Internal Motivation Inventory Scores. Using the likert scale from 1-7, participants rated 13 items containing statements about the tasks they had just completed, with 1 = not at all true, to 7 = very true. The items were coded such that the higher the value of the reported number, the more effort invested, or interest in the task reported, or usefulness of the task to the participant. Overall IMI responses (M = 4.54, SD = 1.02) indicated that subjects were above average (3.5) in their effort, interest and imagined usefulness of the task. Breaking down the variables further into effort (M = 5.78, SD = 0.78), interest (M = 3.35, SD = 1.35) and usefulness (M = 4.05, SD = 1.51), it is possible to examine whether these variables are related to each other under the overarching motivation measure. A repeated-measures analysis of variance (ANOVA) was run on these three measures, *F* (2,58) = 73.13, $p < 0.05$, indicating that these three variables were significantly different from one another. Specifically, a participant's report of putting in more effort on the task is not related to how useful they thought the task was, or the amount they were interested in the task. This suggests that even if individuals believe the task is not very interesting (the mean was below average of 3.5) they still invest a large amount of effort.

I initially predicted that motivation and ability variables could be obscuring the relationship between baseline sensitivity to a feature and capture by that feature. I sought to determine how much of a role motivation could be playing in the results. Looking at motivational measures in the data, specifically overall accuracy and overall RT, I examined the partial correlations when controlling for overall accuracy and overall RT and found no significant correlation between motion capture and motion sensitivity, r (28) = 0.10, $p > 0.05$, or between orientation capture and orientation sensitivity, r (28) = -0.21, $p > 0.05$. The IMI data were also examined in another analysis of partial correlations, controlling for the three measures from the IMI of interest, usefulness and effort, and again no significant correlations were found between motion capture and motion threshold, r (28) = 0.14, $p > 0.05$, or orientation capture and orientation threshold, r (28) = -0.24, $p > 0.05$.

Due to the lack of significant findings from this experiment, I imagined it was possible that not enough subjects were run to achieve significant relationships between the variables. To further explore this possibility, power analyses were run to discover how many subjects' data would need to be collected for the current correlation value (r) to be significant. Using the r-value (0.09) for the correlation between motion capture and motion sensitivity, which had already been found to significantly correlate in past semesters, the number of subjects that would be needed based on this current data is 520 subjects. This large amount of participants needed, based on the experiment's results, suggest no definite relationship between sensitivity to a feature and capture by that feature, and I acknowledge the following limitations, with suggested future directions.

First of all, a null result from Experiment 4 does not confirm that there is no relationship between an individual's baseline sensitivity to a feature in our visual environment and the degree of capture by that visual feature. Neither can I confirm that there is a relationship based on not only the current semester of data, but also the combination of three semesters of data. In Experiment 2, we found a negative correlation, which suggested that the more sensitive an individual was to motion in their environment the less distracted they would be by moving stimuli. In Experiment 3, the opposite pattern was found where the more sensitive an individual was to a feature in their visual environment, the more distracted they were by that feature during a visual search task. These differing semesters of data were thought to diverge due to motivational or overall ability variables during the task, and Experiment 4 examined not only overall accuracy and RT, but also an internal motivation survey, that revealed no significant relationships in the data.

Limitations of the current study are apparent in the threshold tasks for both motion threshold and orientation threshold. A more precise measure of sensitivity to visual features could have yielded a clearer result with more variability between subjects' abilities to detect the feature of interest. The methods currently used were not sensitive enough to detect the relationship that was so clearly suggested from the fMRI data from 2012 (Lechak & Leber). Specifically, I predicted that the more sensitive an individual was to a visual feature the more distracted they would be by that feature. Unfortunately it is possible that using a two alternative forced choice for the detection of coherent motion is not akin to having participants passively view motion, as they had in the neuroimaging study.

Future directions with this research avenue to identify whether or not an individual's baseline sensitivity to a visual feature in the environment can predict how distracted that individual will be by that feature, should seek out a more direct measure of motion sensitivity. Perhaps changing the task from the two alternative forced choice for coherent motion, to a task where the subject presses a button when there is perceived or detected motion in the display would yield clearer results. For example, have the subject fixate on a dot at the center of the screen, and if there were ten items in the display when the trial begins, one of them could begin to oscillate toward and away from fixation at varying SOAs from the trial starting. I would predict that the time it takes subjects to identify the motion in the display will vary across subjects and that it could be related to the magnitude of attention capture by motion during a separate visual search task. Previous research has shown that motion detection mechanisms have not been fully illuminated and are more complex than they seem, adding another layer of difficulty to finding an accurate and precise way to behaviorally measure sensitivities to motion in our visual environment (Krekelberg, 2008).

It is possible that behavioral measures are not sensitive enough and that neural measures of visual feature sensitivities are needed to uncover more information about whether there is a link between an individual's baseline sensitivity to a feature in the visual environment and distraction by that feature. Understanding how individual differences can play a large role in the variability seen in different attention capture paradigms is important as we seek to elucidate how attentional control is implemented.

CHAPTER 5

ATTENTIONAL & INHIBITORY CONTROL: CAN WORKING MEMORY & ABILITY TO DISENGAGE PREDICT CAPTURE?

Watson & Humphreys in 1997 proposed previous search items can be inhibited during search to facilitate the current search for the target. They defined the process as an intentional resource-limited mechanism that seeks to link the to-be-ignored distractor features so that attention may be directed elsewhere. This link of distracting information was described as *visual marking*, an idea that has carried through decades and is still discussed as the process by which our attentional system can avoid further processing of distracting or marked information (Horowitz & Wolfe, 2003). Understanding how distractor features are processed and consequently how they affect current target processing is important because much of our visual environment at any given moment does not match our behavioral goals for the scene. For example, we might be reading a book, attending only the information in our immediate sensory environment, while everything else around us, in other sensory modalities, could be considered distracting information. Individuals differ in their abilities to ignore distracting information, and researchers have started to propose possibilities as to how some individuals are less susceptible to distraction than others.

Experiment 5: Linking working memory, inhibition, & capture

When searching for a target in a diverse visual environment, how do individuals differ in their abilities to ignore distracting information? In terms of goal-driven information processing, both attention and working memory systems increase accessibility of relevant information (Awh, Vogel & Oh, 2006). Researchers have uncovered that variability exists in individuals' abilities to avoid distracting information (Kane, Bleckley, Conway & Engle, 2001; Kanai, Dong, Bahrami, & Rees, 2011; Kawahara & Kihara, 2011). In 2011, Chun advocated that working memory capacity was the interface for selective attention of relevant items in the visual environment and avoidance of distracting items. In addition, neuroimaging studies of brain waves using electroencephalography (EEG) revealed that subjects with higher working memory capacity only represent relevant items in memory, suggesting the efficiency of subjects to represent their visual environment is more important than the actual capacity of the system (Vogel, McCollough, & Machizawa, 2005).

Upon further investigation of this suggestion, McNab and Klingberg (2007) used functional magnetic resonance imaging (fMRI) to examine brain activity during a working memory task and found the basal ganglia and right prefrontal cortex were activated as subjects attempted to ignore distracting information by selectively processing relevant information compared to processing the entire display. In 2008, McNab and colleagues went a step further to suggest that working memory capacity and the ability to ignore distracting information was linked to inhibitory processing, and that working memory capacity and inhibition have common neural components that might reside in the basal ganglia and right prefrontal cortex (McNab, Leroux, Strand, Thorell, Bergman & Klingberg 2008).

Examining inhibitory processing for its role in individual's abilities to ignore distracting information can be done in several ways, due to the several types of inhibition that have been identified, namely motor inhibition (where the subject needs to inhibit a specific response) and cognitive inhibition (where the subject must cognitively shift their attentional focus and inhibit a distracting item). In 1984, Logan and Cowan suggested that during either motor or cognitive inhibition subjects are required to do something actively, rather than passively to achieve their inhibitory goals. More recent research has suggested that in order for a subject to inhibit a motor response, they must first cognitively disengage from the target of the response, or the item (Blakely. Wright, Dehili, Boot, & Brockmole, 2012). This suggests there is a link between cognitive inhibitory processes and motor inhibitory processes.

Motor inhibition has frequently been studied using a stop-signal response paradigm, where subjects are required to inhibit a preplanned motor response to the appearance of a stop-signal (usually a tone). In a stop-signal task, participants are instructed to respond in separate ways to two different stimuli, for example press "X" when you see a circle, and press "Y" when you see a square. On some trials, a stop-signal will appear at varying staircased intervals following the presentation of the stimuli to indicate for the participant to inhibit their motor response of pressing a button. Stop-signal reaction times (SSRTs) are a covert measure of the time it takes subjects to inhibit their response to the stimuli after the presentation of the stop signal. In 2003, Aron and colleagues examined patients with damage to their right frontal cortex and found that the greater the region of damage in cortex, the longer it took subjects to inhibit their preplanned motor responses, evidenced by longer SSRTs (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003). Additionally, Aron examined a specific region in right frontal cortex, the inferior frontal cortex (R IFC) and found that activity in the R IFC responded to both a cognitive inhibition task of controlling interference while switching items, and motor inhibition during the stop-signal paradigm (Aron, Robbins & Poldrack, 2004). This finding suggests that both cognitive and motor inhibitory processes could be carried out by the same underlying substrate in cortex, namely the R IFC.

Upon further investigations of this region, R IFC, Clark and colleagues examined to the relationship between SSRTs and spatial working memory capacity (Clark, Blackwell, Aron, Turner, Dowson, Robbins & Sahakian 2007). They found that when successful inhibition of a motor response occurs, both R IFC and a region called the subthalamic nucleus (STN) are activated, and subjects with higher spatial working memory were better able to inhibit their motor response, exhibiting faster SSRTs. They suggest that the stop-signal is executed via a fronto-subthalamic circuitry, specifically that STN activation inputs to a basal ganglia-thalamocortical pathway leading to neural inhibition of the primary motor response. This fronto-subthalamic circuitry has characteristics for an inhibitory circuit with downstream primary motor areas, supporting previous researchers' proposal of a direct route for motor inhibition: R IFC excites STN which then excites globus pallidus to suppress basal ganglia thalamocortical output to suppress the motor response (Aron & Poldrack, 2006; Aron, 2010).

Neurochemical research has advocated that motor inhibition is supported by an ascending monoamine system, such that increased levels of norepinephrine (stimulated by administration of a norepinephrine reuptake inhibitor known as atomoxetine) improved response inhibition during a stop-signal task (Chamberlain, Muller, Blackwell, Clark, Robbins, & Sahakian, 2006; Bari, Eagle, Mar, Robinson, & Robbins, 2009). Finally, a newer neuroimaging technique known as diffusion-weighted imaging (DWI) was used to illuminate white matter tracts in cortex that directly connect R IFC, pre-sensory motor cortex, and STN (Coxon, van Impe, Wenderoth, & Swinnen, 2012). These researchers also had subjects perform the stop-signal task and found that the integrity of the white matter connections between these three regions in cortex predicted performance on the stop-signal task, with faster SSRTs predicted by larger white matter connections.

Shifting back to the initial question of this experiment, perhaps what modulates the variability between individuals in their ability to avoid distraction is an inhibitory process, potentially measurable using SSRTs, and not a function of working memory capacity as was previously suggested. This role for inhibitory processes in avoiding distracting information was hinted at when Fukuda & Vogel used an attention capture paradigm and measured the time it takes participants to recover after they have been distracted (2011). By first intentionally distracting participants, they could then measure the amount of time it takes individuals to recover from distraction, namely how long until the participant correctly identifies and responds to the target. Fukuda & Vogel in 2009 varied the temporal gap between the distractor appearance and the target appearance to force participants to initially engage the distracting item. Once the distracting item had been engaged, or attended, they could measure the time it took participants to disengage from the distracting item and engage the target item to make a correct response. The time it takes participants to disengage their attention from a distracting item varies by individual, and in 2011, Fukuda & Vogel found that these individual differences in ability to recover from attentional capture was linked to the individual's working memory capacity. Specifically, individuals with high working memory capacity were able to disengage from distracting items more rapidly than those with low capacity, suggesting greater abilities of high-capacity individuals to execute goal-driven control. This research proposes that working memory capacity modulates the speed at which you recover from distraction, and there are two possibilities for why this could be the case.

First, it could be possible that higher working memory capacity drives the ability to disengage from distracting stimuli by the overall enhancement in processing the visual environment. Individuals with higher capacity could have more available attentional resources and success on one task would predicts success on other attentional tasks due to general overall abilities. Second, it also could be possible that the inhibitory processes that are involved in disengagement fuel an individual's ability to avoid distracting information, and working memory capacity takes a lesser role in this relationship.

In the current experiment, I sought to illuminate how inhibition, working memory capacity, and disengagement are related to an individual's ability to ignore distracting information. Maybe the R IFC plays a common inhibitory role across cognitive disengagement and motor inhibition stop-signal tasks? A correlation between an individual's SSRT and their time to disengage from distraction would suggest that the tasks are potentially linked to the same underlying substrate in cortex. Also, can SSRT predict working memory capacity, such that the ability to inhibit a response predicts the ability to hold items in working memory, and subsequently the ability to inhibit or disengage from distracting information in the visual environment? This experiment uses three tasks: working memory capacity, a stop-signal paradigm, and the Fukuda & Vogel time to disengage paradigm to examine the variability in individuals' abilities to avoid distracting information.

Materials and Methods

Subjects. Participants were recruited from the University of New Hampshire's Psychology Subject Participation Pool, also known as SONA. Participants had normal or corrected-to-normal visual acuity and normal color vision, were right handed, and participated in exchange for course credit. The Institutional Review Board of the University of New Hampshire approved procedures.

Stimuli. Stimuli were generated with an Apple G4 desktop or Apple Mac Mini computer using Matlab (Mathworks, Natick, MA) with PsychToolbox extensions (Brainard, 1997; Pelli, 1997) and presented on a 19in. CRT display (ViewSonic G90fb) at a viewing distance of 50 cm. The 4'x8' windowless rooms are controlled for sound and a spotlight in the back left corner of the room gave minimal illumination.

Design & Procedure

Stop It Task. All participants performed the STOP-IT task, which is a stop-signal paradigm used for the investigation of response inhibition. (Verbruggen, Logan & Stevens, 2008; Verbruggen & Logan, 2008). Participants fixated at a dot at center, and prepared to identify either a circle or a square, to press with the index finger of their right hand the "?" for a circle and with the index finger of their left hand the "Z" for a square. On one third of trials, an auditory tone was presented at varying onsets before the shape was presented and alerted participants to inhibit or stop their response, and not press the response button. This auditory tone alerted participants that they are to try and withhold their response to the current symbol on the screen. The tone occurred occasionally, was unpredictable, and occurred at various latencies after the appearance of the letter. The auditory tone was timed to adjust with each participant's speed of response, to obtain a near 50% accuracy of inhibiting the response. A measure of stop signal reaction time (SSRT) for each participant was recorded. The SSRT is an estimation of the time an individual needs to stop their usual behavior (i.e. pressing a key every time they see the symbol) in response to the stop signal, and is calculated by subtracting the mean stop signal duration (SSD) from the untrimmed mean reaction time to the primary task (Logan, Schachar, & Tannock, 1997). This measure of SSRT was subsequently correlated with the other tasks in this experiment, attempting to link inhibitory measures to recovery from capture, and working memory.

Time to Disengage Paradigm. This task was a replication of Fukuda & Vogel's 2011 Experiment 1 task of measuring recovery time from attentional capture in each participant. There were two sections of this task. The first calibrated the target duration in milliseconds for each participant using a staircase procedure. Since I was examining individual differences in how long individuals are distracted by irrelevant information, I needed to know how long it takes the individual to find the target when there is no distracting information present. Participants viewed a display of 4 empty boxes for 200ms, after which 4 "C" shapes appeared in different colors (red, green, blue, & purple) in different orientations (left, right, up or down). Participants were asked to identify the location of the gap or opening of the "C" shape based on target color (either red or green) as quickly and accurately as possible. When participants responded incorrectly, the target duration increased by 30ms for the following trial and when they answered correctly the target duration decreased by 10ms for the following trial. Participants performed 3 blocks of 60 trials each, after which the target duration was specified when participants were 75% correct on trials.

After the calibration blocks were over, the second section of this task began (see Figure 5.1). Participants performed the same task as before, identifying the gap in the "C" shape in their target color, however, in the main trials there is a 2/3 chance that a flanking colored box appeared near one of the target locations before the target was revealed. Flanker stimulus-onset-asynchrony (SOA) was varied at either 50ms before the target, 150ms, 350ms, 500ms, or 700ms. Flankers were either relevant (the same color as the target color) or irrelevant (a different color from the target). Participants performed 6 blocks of 160 trials per block and capture costs in accuracy were assessed.

Upon completion of these trials, an accuracy measure of capture costs of each trial type (no flanker, irrelevant flanker, and relevant flanker) was obtained at each of the flanker SOAs for two different conditions: stimulus driven attentional capture (irrelevant flanker minus no flanker trials) and contingent capture (relevant flanker minus no flanker trials). In addition, a measure of the time (ms) it takes subjects to recover from attentional distraction was obtained. Fukuda & Vogel used a linear derivation to model the capture cost for both stimulus driven and contingent capture when the cost reduced to 5%, suggesting that there was little affect of the flanker on the accuracy of participants response to the target (2011).

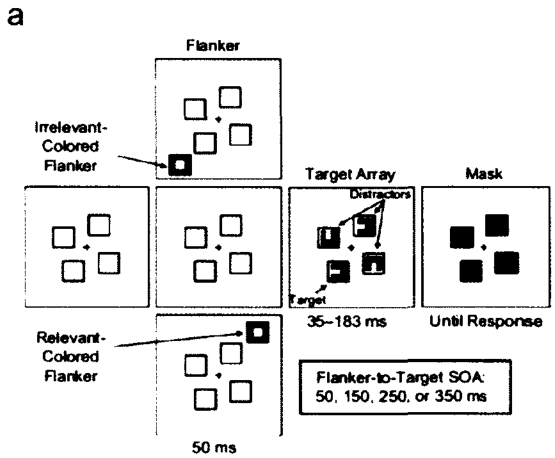


Figure 5.1: Taken from Fukuda & Vogel, 2011. On one third of the trials, a relevant or irrelevant flanker, in either the target color (relevant) or a different color (irrelevant), was presented at varied stimulus onset asynchrony (SOA) across trials before the search array was presented. The duration of the search array was titrated for each subject. Participants reported the orientation of the "C" shape presented in the target color.

Fukuda & Vogel found that individuals with higher working memory capacity were faster to disengage from the distracting item and respond to the target (2011). We used individuals' time to disengage by correlating it with not only working memory, hoping to replicate their above finding, but also with inhibition measures of SSRT.

Working Memory. Participants viewed two intervals of displays of either 4 or 8 colored squares in each trial. Squares were randomly arranged on the screen around fixation and could be 8 different colors (green, red, blue, yellow, cyan, magenta, black or white). After the first array was presented for 100 ms a delay of 1 second occurred, and then the second array was presented for 100 ms and participants had 3 s to make a response as to whether the squares stayed the same color across the interval or whether one of the squares changed color (see Figure 5.2). Participants indicated their response with a button press, and performed a 16 trial practice block, followed by five test blocks of 60 trials each.

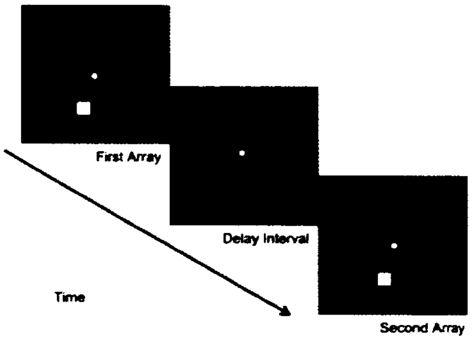


Figure 5.2: Stimuli for the working memory task. Participants viewed a first array of colored squares followed by a delay interval and then made a judgment on the second interval of squares as to whether they stayed the same color or if one of the squares changed color.

A measure of working memory capacity was obtained by calculating Cowan's K (Cowan, 2000). Cowan postulated that participants can hold K out of N items in a display of N items, and based on signal detection theory a formula for calculating K. K would equal the hit rate plus the correct rejection rate minus one, multiplied by set size N. This formula takes into account the probability that sometimes participants are guessing on their responses, and provides a sensitive measure of working memory capacity. I examined the relationship between individuals working memory capacity, their SSRT from the stop-signal task, and the time during which they recover from distraction during the disengagement task in the hope of creating a better understanding of how these different aspects of attentional cognitive control interact.

Results & Discussion:

In this experiment, I sought to find answers as to how some individuals are better able than others at ignoring distracting information. I predicted I could replicate results from Fukuda and Vogel's 2011 Experiment 1 linking higher working memory capacity to faster ability of individuals to disengage from distracting information. In addition, I sought to link inhibitory processes to both the ability to disengage, and working memory capacity.

A total of fifty-four subjects were run in the procedure as described above. Five subjects were excluded from the following analyses for having working memory capacities (*M* = 0.95) that were more than 2.5 SDs away from the remaining group mean (*M* = 3.34). In addition, one subject was excluded for having an accuracy average of 28% on the time to disengage task, which was 2.5SDs lower than the remaining group mean of (69%). Finally, sixteen subjects were cut for having inhibited significantly more or less than 50% of the time during the STOP-IT task, the subtraction method used in the ANALYZE-IT program to calculate SSRT cannot use subjects who inhibit more or less than 50% (Verbruggen, et al., 2008). The remaining thirty-two subjects are included in all of the following analyses.

<u>Working Memory Capacity Task.</u> The mean working memory capacity estimate was 3.34 (SD = 0.59). The range of estimates was from 1.92 to 4.3, which is comparable to findings of previous experiments using this paradigm (Vogel, et al., 2005; Fukuda & Vogel, 2011).

<u>Visual Search Task: Staircase Procedure:</u> The baseline search array durations (M = 50.19, SD = 14.17) ranged from 28 ms to 80 ms. There was a significant correlation between this estimate and the working memory capacity estimate ($r = -0.49, p < 0.05$). This result suggests that individuals with higher working memory capacity were able to correctly identify the target at the 75% accuracy threshold faster than individuals with

lower working memory capacity. Fukuda and Vogel had not found a significant relationship between these variables in 2011.

Visual Search Task: Flanker Capture: Starting with the no flanker condition overall accuracy was 72.9% (SD = 0.137); the relevant flanker-same color as the target color-condition had a mean accuracy of 64.3% (SD = 0.144); and the irrelevant flanker-different color than the target-condition had a mean accuracy of 68.6% (SD = 0.143). A repeated measures analysis of variance (ANOVA) was carried out to examine the effect of the relevant and irrelevant flankers on accuracy. First, there was a main effect of flanker type (none, relevant and irrelevant), $F(2,62) = 40.47, p < 0.05$, with the no flanker condition having significantly higher accuracy than both relevant and irrelevant flanker conditions, with mean differences from the no flanker condition of 0.085, and 0.043, respectively. In addition, irrelevant flanker accuracy was significantly higher than relevant flanker accuracy with a mean difference of 0.042. Second, there was a significant interaction of flanker type and SOA, $F(4,124) = 8.304, p < 0.05$. Irrelevant flankers induced no significant capture costs across SOA, however, relevant flankers induced significant capture costs at both the 50 ms ($p < 0.05$) and the 150 ms ($p < 0.05$) see Figure 5.3.

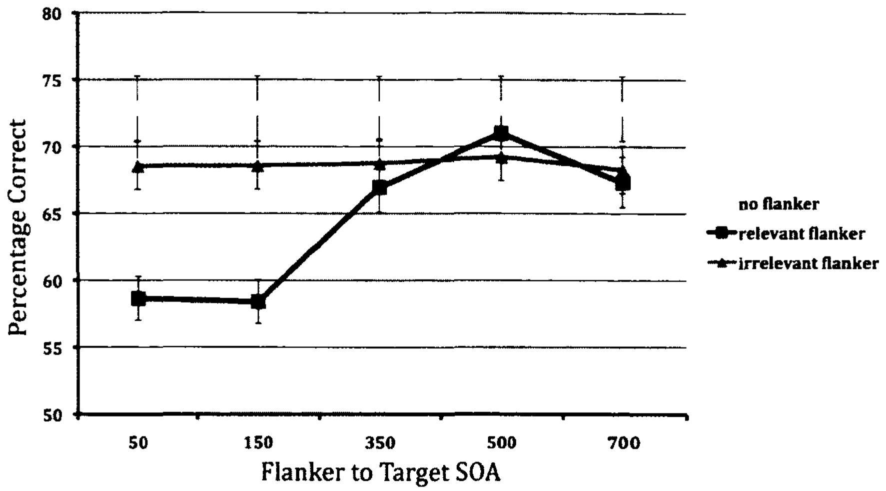


Figure 5.3: Percent correct as a function of trial type and SOA. Chance performance is 25%. Error bars represent the standard errors of the mean.

These results add to the conclusions of Fukuda & Vogel, because in their experiment, the time course of attentional disengagement (SOA) ended at 350 ms, therefore they concluded that contingent attentional capture might endure for longer than 350 ms (2011). In the current experiment, I extended the time course to 700 ms to get a better measure of the recovery time from attentional capture. Here, results demonstrate that by 350 ms, the capture cost is no longer significant for contingent capture, suggesting 350 ms might be cut off for the lasting effects of contingent capture, which is consistent with Fukuda and Vogel's suggestion (2011). These results are inconsistent in that there are no significant capture costs for stimulus driven capture, whereas Fukuda and Vogel found a significant difference at 50 ms, suggesting stimulus driven capture was shorter lived than contingent capture (2011). With my current data set, I cannot comment on whether or not stimulus driven capture is shorter lived, as I found no significance of stimulus driven capture at any SOA.

Individual Differences in Attentional Capture: A median split was performed on the working memory capacity estimates to divide individuals into high capacity (M = 3.82, SD = 0.26) and low capacity (M = 2.89, SD = 0.40). Figure 5.4 shows the capture costs for each group as a function of SOA.

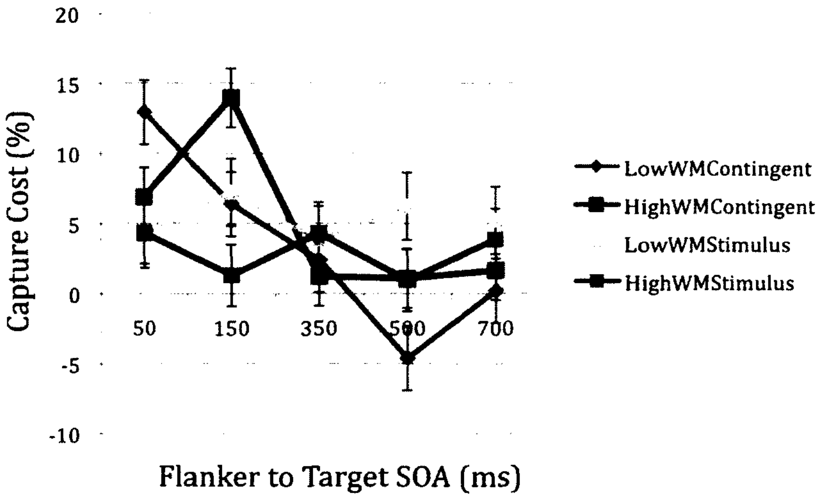


Figure 5.4: Capture cost as a function of the flanker to target SOA, in addition to low and high working memory capacity, as well as stimulus and contingent capture.

Unlike Fukuda and Vogel, who found significant differences at the different SOAs between working memory capacity groups for contingent capture, I found no significant differences across SOAs for either stimulus driven or contingent capture by working memory capacity (2011).

Recovery Time: To estimate recovery time from attentional capture for each subject, I used the same method as Fukuda & Vogel, using a linear derivation to model the flanker to target SOA at which the capture cost decreased to 5% for both stimulus driven and contingent capture. This analysis revealed that recovery time from stimulus driven capture (M = 314.34) was not significantly different than recovery time from contingent capture (M = 321.06), $p > 0.05$.

Examining recovery time as a function of working memory capacity, I was able to replicate Fukuda & Vogel's finding that working memory capacity does not predict individuals' abilities to recover from stimulus driven capture ($r = -0.21$. $p > 0.05$); however, I found no correlation between contingent recovery times and working memory capacity ($r = 0.025$, $p > 0.05$). My inability to replicate this piece of the previous literature, that higher working memory capacity predicts faster recovery from contingent capture, was disappointing, and could be due to slight differences in overall time to disengage paradigm, such as a longer time course for the flanker to target SOAs, and changing the color of the irrelevant flanker to be of a true counterbalancing design; rather than the possibility of 3 different colors, I only had 1.

Stop-signal Reaction Time Task: The mean SSRT for this task was 244.51 (SD = 44.9) with a range from 148.4 ms to 322 ms. Examining the relationship between the ability to inhibit a motor response with working memory capacity estimates I find a significant positive relationship, $r = 0.36$, $p < 0.05$, suggesting that the higher an individual's working memory capacity the higher the SSRT (or poorer ability to inhibit a motor response, see Figure 5.5).

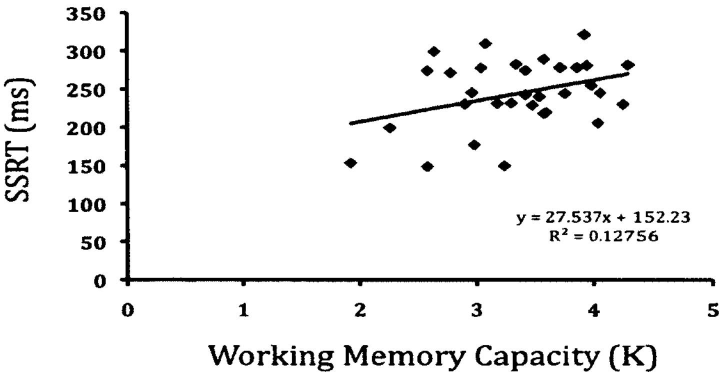


Figure 5.5: Correlation between stop signal reaction time (SSRT) and working memory capacity.

This result was puzzling, as I had predicted that individuals who were better at inhibiting a motor response would have higher working memory capacity. I can only speculate as to why the opposite correlation was found. Perhaps individuals with higher working memory capacity are better able to hold onto the correct response during the stop-signal task, specifically they see the target (circle or square) and are unable to inhibit their response to this target quickly, resulting in higher SSRTs.

Another prediction I had had with SSRT was that it was a comparable measure of cognitive inhibition akin to the processes involved in disengaging from distracting information. Examining the relationship between SSRT and recovery time for stimulus driven capture, I found no significant correlation, and SSRT and contingent capture also had no significant relationship. Next, I examined the relationship between SSRT and capture cost at each SOA. SSRT is significantly correlated to contingent capture at 150 ms, $r = 0.44$, $p < 0.05$, see Figure 5.6a.

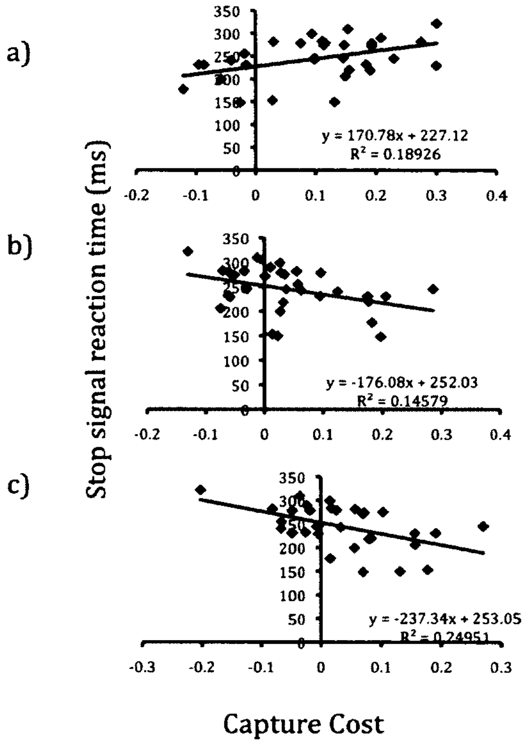


Figure 5.6: a) Correlation between SSRT and contingent capture cost at 150 ms SOA. b) Correlation between SSRT and stimulus driven capture cost at 150 ms SOA. c) Correlation between SSRT and stimulus driven capture cost at 500 ms SOA.

This result suggests that individuals who are better able to inhibit a motor response on a given trial are less distracted during an attention capture trial after 150 ms, evident with lower SSRTs and lower capture costs for contingent capture at this specific

SOA. Perhaps, individuals who are better able to inhibit a motor response are better at executing goal driven control at 150 ms after a flanker that is the same color as the target has been presented. Contingent capture at other SOAs and SSRT were not significant. Examining SSRT and stimulus driven capture at each SOA, both 150 ms ($r = -0.38, p < 0.05$) and at 500 ms ($r = -0.50, p < 0.05$) were significant, see Figure 5.6b and 5.6c.

These results suggest that for stimulus driven capture, that is, when a different colored flanker than the target appears at 150 ms or 500 ms before the target, individuals are more distracted when they have a better ability to inhibit a motor response than individuals who are worse at inhibitory control. Observing that the correlation flips between stimulus driven (positive) and contingent capture (negative) to SSRT, is supportive of different processes involved in each of these types of attentional distraction. Fukuda & Vogel supported that stimulus driven and contingent capture may not reflect the operation of a single mechanism (2011). Contingent capture relies upon the goals of the observer, where the color of the distracting flanker and the upcoming target match, and in order to avoid capture more goal driven control is needed. In stimulus driven capture, there are more bottom-up attentional control mechanisms at work, and the relationship between ability to inhibit a response and ability to avoid capture shifts.

This study sought to uncover how some individuals avoid attentional distraction better than others by proposing that inhibitory processing played an underlying role in how quickly one recovers from distraction. Unfortunately, I found no significant relationships between the time to disengage recovery time paradigm and either working memory capacity or SSRT. Failing to replicate Fukuda & Vogel's work, and not supporting my predictions, leads me to the following limitations of this experiment. It is possible that measuring the time course of attentional recovery from distraction is not best done using the paradigm outlined here. The time to disengage task examines attentional capture as a function of accuracy, and the differences in accuracy across conditions. Measuring SSRT is done using reaction times, and perhaps it would be better to examine attentional capture using reaction times as well, by employing a different paradigm to examine the attentional recovery time course. Future experiments to examine whether or not a relationship exists between inhibition and recovery time from attention capture could alter the paradigms used.

In 2006, Li, Huang, Constable, and Sinha used fMRI techniques to examine the differences in cortex during a stop-signal reaction task to examine regions in cortex that were active in successful and failed attempts to inhibit responses. They found multiple regions that were involved in successful stopping, including the right inferior frontal cortex (discussed more in-depth in the Introduction), therefore, perhaps a neuroimaging experiment to examine SSRT responses in addition to disengagement times from attentional capture would be a better way to examine what brain regions are involved in successful inhibitory processing, both cognitive inhibition (the visual search task measuring recovery times from capture) and motor inhibition using the stop-signal reaction time task.

Blakely and colleagues in 2012 suggested that before successful inhibition of a motor response can occur, the individual must first cognitively disengage from the distracting information. Perhaps using neuroimaging techniques to observe brain activity during these two tasks could better link these forms of inhibition, as the current behavioral experiment failed to do. Integrating and synthesizing the literature on attentional control by seeking to understand the individual differences that exist in the ability to avoid distracting information in a visual environment is an important area for researchers to continue to pursue.

CHAPTER 6: SUMMARY AND CONCLUSIONS

Every moment, our visual environment is filled with endless possible items to attend to. Individuals differ in their abilities to prioritize this environment to focus on relevant items that match their current behavioral goals. For example, if I am searching a large crowd for a friend whom I know is wearing blue; I want to prioritize blue items while avoiding other colors, even similar colors such as green or teal. Being able to avoid distraction by other salient irrelevant colors is an important task in this particular example, and my ability to do so depends strongly on attentional processing during my search. Attentional processing has two major components. One is top-down or goal-driven processing, where the goals and expectations that an observer brings into the search dominate where attention is focused. The second is bottom-up or stimulus-driven processing where the stimuli in the environment guide attentional focus at any given moment. Attentional control consists of the interaction between these two types of processes, guiding how well an individual can perform a search.

While much has been explored within the attentional control literature, questions still exist as to how attentional processing is modulated, and how different types of visual search tasks can elucidate the underlying mechanisms involved in successful visual search. The purpose of this dissertation was to explore different aspects of attentional control using various search paradigms. I discussed the theory behind visual attention delving back into the research done by William James in 1890. During the exploration of how visual attention works and is directed around our visual environment, researchers sought to understand how individual features of items were bound together to create one cohesive object. In 1980, Treisman and Gelade proposed feature integration theory, where visual attention serves to bind individual features of items into a whole object. They argued that one object at a time needs to be completed before the observer can move to another object. This idea of directing attention from one object to the next in a display is known as serial processing, and the more items that are present in a display, the longer it takes participants to find the target. Conversely, parallel processing of a display occurs when participants are able to find the target quickly regardless of the number of distracting items in the display, due to the target seemingly "popping-out" from the surrounding items.

Over the past 30 years, different paradigms were proposed to invade every aspect of attentional processing, with the goal of creating an integrated view of visual attention. During any of these paradigms, researchers noted that performance on a given trial was not isolated from previous trials. While overall RT on a given trial should be reflective of the individual's state of attentional control (with greater RTs indicating greater distraction by an irrelevant singleton), incidental aspects of the stimulus display also necessarily influence RT (Kumada & Humphreys, 2002). Specifically, aspects about the visual display can facilitate or hinder RTs depending on the previous visual display in a sequence of trials. In 1994, Maljkovic and Nakayama proposed visual priming, where the performance on the current trial is dependent on where the items appeared on the previous trial. Specifically, if the target appeared in the same spatial position two trials in a row, or if the target was the same color two trials in a row, participants would be faster to make their response to the target. In 2010, Yashar and Lamy used the RSVP paradigm to examine visual priming in the temporal domain, by varying the temporal position of the target from trial to trial. They also attempted to examine how temporal priming relates to spatial priming, and by interleaving spatial and temporal trials during an experiment, concluded that these two visual dimensions interact with one another, possibly using the same underlying mechanistic processing (2010b).

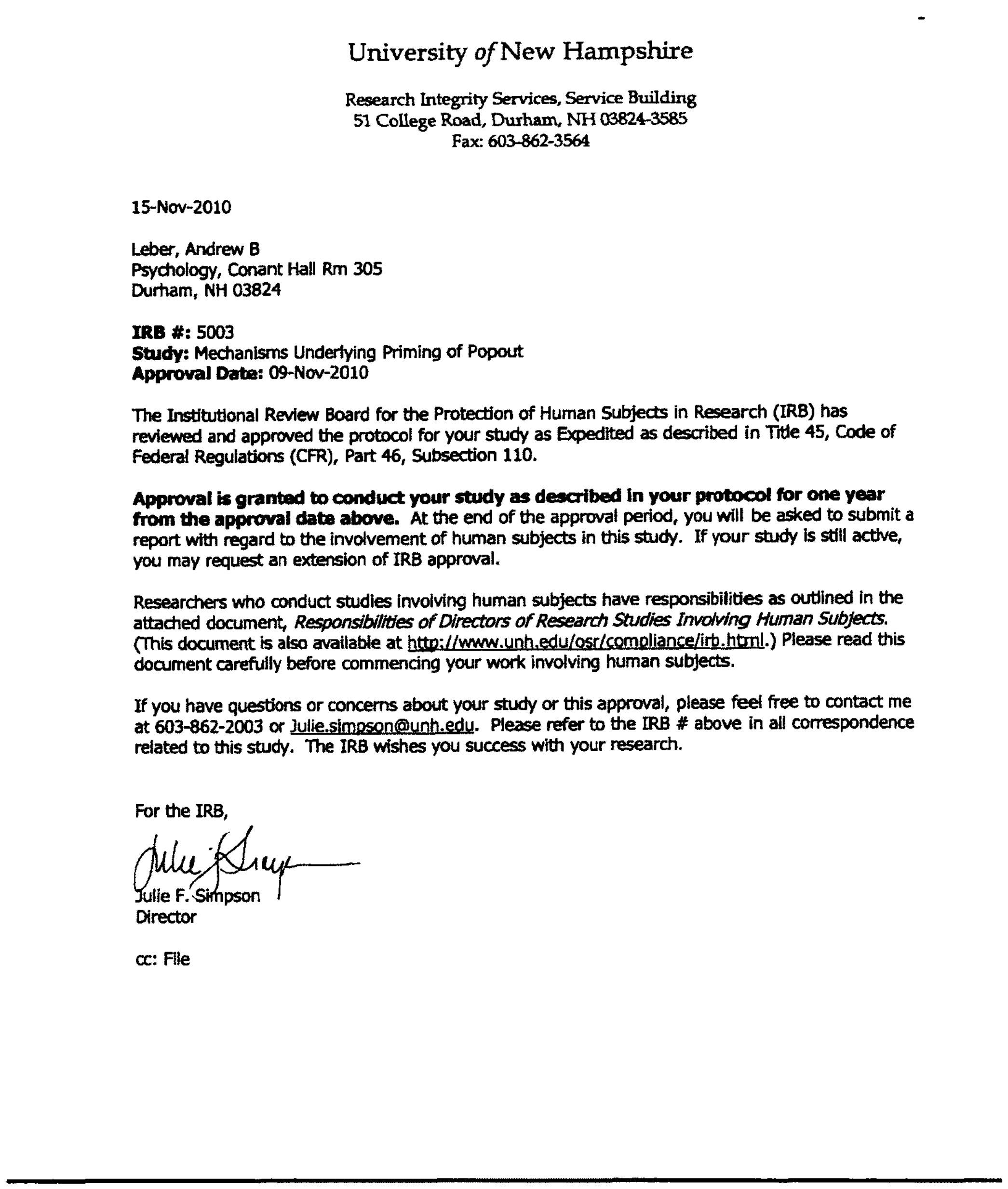
In Experiment 1 of this dissertation I expanded upon their suggestion of interactive dimensions of priming by combining spatial and temporal information into a single paradigm. Specifically, using 4 spatial locations of the RSVP design, I demonstrate that temporal and spatial priming interact along a similar mechanism, such that when both dimensions repeat, an individual is faster to find the target than when no target information repeats or when either spatial or temporal information alone repeat. This suggests that individuals use all available information in a visual scene to guide attentional processing on future trials. Demonstrating simultaneous multidimensional priming in our ability to efficiently process our visual environment is important as researchers continue to question how visual attentional control is implemented.

My next Experiments 2-4 employed a visual search paradigm initially design by Theeuwes in 1991, where individuals search for a target item in a spatial display of multiple items, while avoiding an irrelevant distractor. Based on neuroimaging results from Lechak and Leber (2012), where the magnitude of distraction to an irrelevant moving item was predicted by the amount of evoked fMRI activity in motion sensitive area MT in cortex, I sought to link visual sensitivity and attention capture. Specifically, I predicted that an individual's sensitivity to a visual feature could predict the magnitude of distraction by that feature. Unfortunately, results revealed no definite relationship between visual sensitivity and attention capture, and it is possible that psychophysical thresholds are not quite sensitive enough to reflect a concrete relationship between an individual's baseline stimulus-driven sensitivity to visual features and the magnitude of distraction by those features.

Finally, in Experiment 5 I sought to answer the question of how some individuals are better at avoiding irrelevant stimuli in the visual environment than others. I wanted to synthesize various aspects of attentional control by attempting to link working memory capacity, attention capture and inhibitory processing. Clark and colleagues in 2007 demonstrated a link between spatial working memory and inhibitory processing in ADHD individuals, such that higher spatial working memory predicted better ability to inhibit a pre-planned motor response (measured using SSRT). In addition, Fukuda and Vogel (2011) linked working memory capacity to the ability to recover from attentional capture, or the ability to cognitively disengage, which suggested a role for inhibitory processing. I sought to explore whether this cognitive inhibition (disengagement) could be linked to the ability to inhibit a motor response (SSRT). Results failed to elucidate this relationship, and further research is needed to uncover whether individual differences in avoiding distraction are subserved by inhibitory processing, or working memory capacity.

The research presented in this dissertation provides further evidence for the complexities of visual attentional control and how it is implemented in our visual environment. In conclusion, this dissertation used various visual search paradigms to explore the interactions of stimulus-driven and goal-driven attentional processing, to illuminate how individual differences inform models of attentional distraction, and to investigate how inhibiting an irrelevant distractor modulates attentional processing.

APPENDIX A IRB APPROVAL LETTERS



University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

15-Nov-2010

Leber, Andrew B
Psychology, Conant Hall Rm 305
Durham, NH 03824

IRB #: 5003
Study: Mechanisms Underlying Priming of Popout
Approval Date: 09-Nov-2010

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Expedited as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 110.

Approval is granted to conduct your study as described in your protocol for one year from the approval date above. At the end of the approval period, you will be asked to submit a report with regard to the involvement of human subjects in this study. If your study is still active, you may request an extension of IRB approval.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* (This document is also available at http://www.unh.edu/osr/compliance/irb.html.) Please read this document carefully before commencing your work involving human subjects.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie F. Simpson
Director

cc: File

University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

29-Nov-2011

Leber, Andrew B
Psychology Department
Conant Hall Rm 305
Durham, NH 03824

IRB #: 5003
Study: Mechanisms Underlying Priming of Popout
Review Level: Expedited
Approval Expiration Date: 09-Nov-2012

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved your request for time extension for this study. Approval for this study expires on the date indicated above. At the end of the approval period you will be asked to submit a report with regard to the involvement of human subjects. If your study is still active, you may apply for extension of IRB approval through this office.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the document, *Responsibilities of Directors of Research Studies Involving Human Subjects*. This document is available at http://unh.edu/research/irb-application-resources or from me.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie F. Simpson
Director

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Fax: 603-862-3564

02-Feb-2010

Leber, Andrew B
Psychology, Conant Hall
Durham, NH 03824

IRB #: 4755
Study: Attention and Cognitive Control in the Human Brain
Approval Date: 29-Jan-2010

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Expedited as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 110.

Approval is granted to conduct your study as described in your protocol for one year from the approval date above. At the end of the approval period, you will be asked to submit a report with regard to the involvement of human subjects in this study. If your study is still active, you may request an extension of IRB approval.

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For the IRB,

Julie Simpson

Julie F. Simpson
Manager

cc: File

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09-Feb-2011

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IRB #: 4755
Study: Attention and Cognitive Control in the Human Brain
Review Level: Expedited
Approval Expiration Date: 29-Jan-2012

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved your request for time extension for this study. Approval for this study expires on the date indicated above. At the end of the approval period you will be asked to submit a report with regard to the involvement of human subjects. If your study is still active, you may apply for extension of IRB approval through this office.

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For the IRB,

Julie Simpson

Julie F. Simpson
Director

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26-Jan-2012

Leber, Andrew B
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IRB #: 4755
Study: Attention and Cognitive Control in the Human Brain
Review Level: Expedited
Approval Expiration Date: 29-Jan-2013

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved your request for time extension for this study. Approval for this study expires on the date indicated above. At the end of the approval period you will be asked to submit a report with regard to the involvement of human subjects. If your study is still active, you may apply for extension of IRB approval through this office.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the document, *Responsibilities of Directors of Research Studies Involving Human Subjects.* This document is available at http://unh.edu/research/irb-application-resources or from me.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

For the IRB,

Julie Simpson

Julie F. Simpson
Director

cc: File

APPENDIX B: INTERNAL MOTIVATION INVENTORY

Subject Number:______________________________

For each of the following statements, please indicate how true it is for you, using the following scale:

1 2 3 4 5 6 7

(not at all true) (somewhat true) (very true)

1. It was important to me to do well at this task. 1 2 3 4 5 6 7
2. I believe doing this activity could be beneficial to me. 1 2 3 4 5 6 7
3. I tried very hard on this activity. 1 2 3 4 5 6 7
4. I think this is a useful activity. 1 2 3 4 5 6 7
5. I put a lot of effort into this. 1 2 3 4 5 6 7
6. I would be willing to do this again 1 2 3 4 5 6 7
7. I enjoyed doing this activity very much 1 2 3 4 5 6 7
8. I thought this was a boring activity. 1 2 3 4 5 6 7
9. I didn't try very hard to do well at this activity. 1 2 3 4 5 6 7
10. This activity did not hold my attention at all. 1 2 3 4 5 6 7
11. I would describe this activity as very interesting. 1 2 3 4 5 6 7
12. I think this is an important activity. 1 2 3 4 5 6 7
13. I didn't put much energy into this. 1 2 3 4 5 6 7

LIST OF REFERENCES

Aron, A. R., Fletcher, P.C., Bullmore, E.J., Sahakian, B. J., & Robbins, T. W. (2003). Stop signal inhibition disrupted by damage to right inferior frontal gyrus in humans, *Nature Neuroscience,* DOI: 1038/nn1003.

Aron, A. R., Robbins, T.W., & Poldrack, R. A. (2004). Inhibition and the right inferior frontal cortex, *Trends in Cognitive Sciences, 8 (4),* 170-177.

Aron, A. R., & Poldrack, R. A. (2006). Cortical and subcortical contributions to stop signal response inhibition: Role of the subthalamic nucleus, *The Journal of Neuroscience, 26 (9),* 2424-2433.

Aron, A. R. (2010). The neural basis of inhibition in cognitive control, *The Neuroscientist, 13 (3),* 214-228.

Awh, E., Vogel, E.K. & Oh, S.H. (2006). Interactions between attention and working memory, *Neuroscience, 139*, 201-208.

Bacon, W.F., & Egeth, H.E. (1994). Overriding stimulus-driven attentional capture, *Perception & Psychophysics, 55(5),* 485-496.

Bari, A., Eagle, D. M., Mar, A. C., Robinson, E. S., & Robbins, T. W. (2009). Dissociable effects of norepinephrine, dopamine, and serotonin reuptake blockade on stop task performance in rats, *Psychopharmacology, 205 (2),* 273-283.

Beck, J., & Ambler, H. (1973). The effects of concentrated and distributed attention on peripheral acuity, *Perception and Psychophysics, 14,* 225-230.

Becker, S. (2008). Can intertrial effects of features and dimensions be explained by a single theory? *JEP Hum Percept & Perform,* 34 (6), 1417-1440.

Blakely, D. P., Wright, T. J., Dehili, V.M., Boot, W. R., & Brockmole, J. R. (2012). Characterizing the time course and nature of attentional disengagement effects, *Vision Research, 56,* 38-48.

Brainard, D. H. (1997). The psychophysics toolbox. Spat. Vis. 10, 433–436.

Brascamp, J.W., Pels, E., & Kristjansson, A. (2011). Priming of pop-out on multiple time scales during visual search, *Vision Research,* 51, 1972-1978.

Broadbent, D.E. (1958). Perception and Communication. New York: Pergamon.

Chamberlain, S. R., Muller, U., Blackwell, A. D., Clark, L., Robbins, T. W., & Sahakian, B. J. (2006). Neurochemical modulation of response inhibition and probabilistic learning in humans, *Science, 311 (5762), 861-863.*

Cherry, E.C. (1953). Some experiments on the recognition of speech, with one and two ears, *Journal of the Acoustical Society of America, 25,* 975-979.

Chun, M. M. (2011). Visual working memory as visual attention sustained internally over time, *Neuropsychologica, 49,* 1407-1409.

Clark, L., Blackwell, A.D., Aron, A.R., Turner, D.C., Dowson, J., Robbins, T. W., & Sahakian, B.J. (2007). Association between response inhibition and working memory in adult ADHD: A link to right frontal pathology? *Biological Psychiatry, 61,* 1395-1401.

Coxon, J. P., van Impe, A., Wenderoth, N., & Swinnen, S. P. (2012). Aging and inhibitory control of action: Cortico-subthalamic connection strength predicts stopping performance, *The Journal of Neuroscience, 32 (24),* 8401-8412.

Duncan, J., Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychol Rev, 96(3)*: 433-458.

Egeth, H.E. & Yantis, S. (1997). Visual attention: Control, representation and time course, *Annual Review of Psychology, 48,* 269-297.

Englemann, J.B., Damaraju, E., Padmala, S., & Pessoa, L. (2009). Combined effects of attention and motivation on visual task performance: Transient and sustained motivational effects, *Frontiers in Human Neuroscience, 3:*4, 1-17.

Erikson, C.W., & Hoffman, J.E. (1972). The extent of processing of noise elements during selective encoding from visual displays. *Perception and Psychophysics, 14,* 15-160.

Fecteau, J.H. (2007). Priming of pop-out depends upon the current goals of observers, *Journal of Vision,* 7 (6):1, 1-11.

Folk, C.L., Remington, R.W., & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings, *J Exp Psychol Hum Percept Perform, 18(4),* 1030-1044.

Fukuda, K., & Vogel, E.K. (2009). Human variation in overriding attentional capture, *Journal of Neuroscience,* 29, 8726-8733.

Fukuda, K. & Vogel, E.K. (2011). Individual differences in recovery time from attention capture, *Psychological Science, 22(3),* 361 –368.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15, 20-25.

Horowitz, T.S., & Wolfe, J.M. (2003). Memory for rejected distractors in visual search, *Visual Cognition,* 10(3), 257-298.

Huang, L., Holcombe, A.O., & Pahsler, H. (2004). Repetition priming in visual search: Episodic retrieval, not feature priming, *Memory & Cognition,* 32(1), 12-20.

James, W. (1890). *Principles ofpsychology.* New York: Holt.

James, T.W., Humphrey, K., Gati, J.S., Menon, R.S., & Goodale, M.A. (1999). Repetition priming and the time course of object recognition: an fMRI study, *Brain Imaging,* 10, 1019-1023.

Kanai, R., Dong, M. Y., Bahrami, B., & Rees, G. (2011). Distractibility in daily life is reflected in the structure and function of human parietal cortex, *Journal of Neuroscience,* 31(18), 6620-6626.

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.

Kawahara, J. I. & Kihara, K. (2011). No commonality between attentional capture and attentional blink, *Quarterly Journal of Experimental Psychology, 64 (5),* 991-1008.

Krekelberg, B. (2008). 2.09-Motion detection mechanisms, *The Senses: A Comprehensive Reference, 2* (Vision II), 133-155.

Kristjansson, A., Vuilleumier, P., Malhotra, P., Husain, M., & Driver, J. (2005). Priming of color and position during visual search in unilateral spatial neglect, *Journal of Cognitive Neuroscience,* 17(6), 859-873.

Kristjansson, A. (2006). Simultaneous priming along multiple feature dimensions in a visual search task, *Vision Research,* 46, 2554-2570.

Kristjansson, A., Vuielleumier, P., Schwartz, S., Macaluso, E., & Driver, J. (2007). Neural basis for priming of pop-out during visual search revealed by fMRI, *Cerebral Cortex,* 17, 1612-1624.

Krummenacher, J., Grubert, A., & Muller, H.J. (2010). Intertrial and redundant-signal effects in visual search and discrimination tasks: Separable pre-attentive and post-selective effects, *Vision Research,* 50, 1382-1395.

Kumada, T., & Humphreys, G.W. (2002). Cross-dimensional interference and cross-trial inhibition, *Perception & Psychophysics, 64(3),* 493-503.

Lamy, D., Carmel, T., Egeth, H.E., & Leber, A.B. (2006). Effects of search mode and intertrial priming on singleton search, *Perception and Psychophysics,* 68(6), 919-932.

Lamy, D., Antebi, C., Aviani, N., & Carmel, T. (2008). Priming of pop-out provides reliable measures of target activation and distractor inhibition in selective attention, *Vision Research,* 48, 30-41.

Lamy, D., Yashar, A., & Ruderman, L. (2010). A dual-stage account of inter-trial priming effects, *Vision Research,* 50-1396-1401.

Leber, A.B., & Egeth, H.E. (2006). It's under control: Top-down search strategies can override attentional capture, *Psychonomic Bulletin & Review, 13(1),* 132-138.

Lechak, J.R., & Leber, A.B. (2012). Individual differences in distraction by motion predicted by neural activity in MT/V5, *Frontiers in Human Neuroscience,* 6(12), 1-10.

Lechak J.R., Wells, E., & Leber, A.B. (VSS Abstract, 2011). Greater sensitivity to visual motion predicts a greater capacity to ignore it.

Lechak, J.R., Yashar, A., Leber, A.B., & Lamy, D. (In prep). Priming-of-popout interacts along simultaneous spatial and temporal dimensions.

Li, C.R., Huang, C., Constable, R.T., & Sinha, R. (2006). Imaging response inhibition in a stop-signal task: Neural correlates independent of signal monitoring and post-response processing, *The Journal of Neuroscience, 26*(1), 186-192.

Livingstone, M.S. & Hubel, D.H. (1988). Segregation of form, color, movement, and depth: anatomy, physiology, and perception. *Science, 240*, 740-749.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control, *Psych Rev 91,* 295-327.

Logan, G.D., Schachar, R.J., & Tannock, R. (1997). Impulsivity and inhibitory control, *Psychological Science, 8,* 60-64.

Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features, *Memory and Cognition,* 22 (6), 657-672.

Maljkovic, V., & Nakayama, K. (1996). Priming of pop-out: II. The role of position, *Perception and Psychophysics,* 58(7), 977-991.

Maljkovic, V., & Nakayama, K. (2000). Priming of pop-out: III. A short-term implicit memory system for rapid target selection, *Visual Cognition,* 7 (5), 571-595.

McNab, F., & Klingberg, T. (2007). Prefrontal cortex and basal ganglia control access to working memory, *Nature Neuroscience,* DOI: 10.1038/nn2024.

McNab, F., Leroux, G., Strand, F., Thorell, L., Bergman, S., & Klingberg, T. (2008). Common and unique components of inhibition and working memory: An fMRI, within-subjects investigation, *Neuropsychologica, 46,* 2668-2682.

Milner, A.D., & Goodale, M.A. (1998). The visual brain in action. *Psyche, 4,* 1-14.

Mishkin, M., & Underleider, L.G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioral Brain Research, 6,* 57-77.

Newsome, W. & Pare, E. (1988). A selective impairment of motion perception following lesions of the middle temporal visual area (MT), *The Journal of Neuroscience, 8,* 2201-2211.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: transforming numbers into movies. Spat. Vis. 10, 437–442.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32, 3-25.*

Ryan, R.M., Mims, V., & Koestner, R. (1983). Relation of reward contingency and interpersonal context to intrinsic motivation: A review and test using cognitive evaluation theory, *Journal of Personality and Social Psychology, 45*: 4, 736-750.

Ryan, R. M., Koestner, R., & Deci, E. L. (1991). Varied forms of persistence: When free-choice behavior is not intrinsically motivated. *Motivation and Emotion, 15*, 185-205.

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception and Psychophysics, 50(2),* 184-193.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception and Psychophysics, 51(6),* 599-606.

Theeuwes, J. (1994a). Endogenous and exogenous control of visual selection, *Perception, 23(4),* 429-440.

Theeuwes, J. (1994b). Stimulus-driven capture and attentional set: Selective search for color and abrupt visual onsets, *J Exp Psychol Hum Percept Perform, 20(4),* 799-806.

Theeuwes, J. (2004). Top-down search strategies cannot override attentional capture, *Psychonomic Bulletin & Review, 11(1),* 65-70.

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

Verbruggen, F., & Logan, G.D. (2008). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop-signal paradigms, *Journal of Experimental Psychology: General, 137:*4, 649-672.

Verbruggen, F., Logan, G. D., & Stevens, M. A. (2008). STOP-IT: Windows executable software for the stop-signal paradigm. *Behavior Research Methods, 40*, 479-483

Vogel, E. K., McCollough, A. W., & Machizawa, M. G. (2005). Neural measures reveal individual differences in controlling access to working memory, *Nature, 438 (24),* 500-503.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review,* 104, 90-122.

Yantis, S. & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation, *J Exp Psychol Hum Percept Perform, 16,* 121-134.

Yashar, A., & Lamy, D. (2010a). Intertrial repetition affects perception: The role of focused attention, *Journal of Vision,* 3, 1-8.

Yashar A., & Lamy, D. (2010b). Intertrial repetition facilitates selection in time: Common mechanisms underlie spatial and temporal search, *Psych. Science,* DOI: 10.1177/0956797609357928.