Winter 12-16-2016

Does Attentional Slippage Conform to a Simple Gradient?

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DOES ATTENTIONAL SLIPPAGE CONFORM TO A SIMPLE GRADIENT?

A Thesis Submitted to the Graduate School in
Partial Fulfillment of the Requirement
for the Degree of Masters of Science

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December, 2016

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ACKNOWLEDGEMENTS

I would like to express extreme gratitude to Dr. Bruce Warner for his time, patience, and humor at every stage of this project. His encouragement and dedication undoubtedly aided in sustaining my determination. Seldom does a masters-level graduate student have the opportunity to oversee the development of a project from initial explorative research to refined research from previous data analysis over the course of three years. Additionally, I would like to thank my family and friends for their concern and curiosity into the progress of this thesis as well as their support and sacrifice over the past few years.

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An Abstract of the Thesis by
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The following graduate thesis describes research designed to examine flanker interference at varying spatial distances from a target stimulus. Traditionally, much evidence has accumulated that the distribution of visual attention conforms to a monotonically decreasing gradient in which distractors at the farthest separations produce the least interference (e.g., Erikson & St. James, 1986). Different from this traditional conceptualization, Müller, Mollenhauer, Rösler, and Kleinschmidt (2005) describe what they termed a Mexican hat distribution of visual attention within which flankers at an intermediate zone produce less interference. The current study is designed to investigate whether flanker interference declines monotonically with distance or follows a Mexican hat-like distribution reported by Müller et al. (2005) In order to do so, the current study's flanker paradigm is distinguished from the design used by Müller et al. (2005) in that cue-target SOA is manipulated, target location is not fixed, and perceptual load is defined by the number of distracting stimuli. The present study found behavioral evidence for both a monotonically decreasing gradient and a Mexican hat distribution under different conditions. A gradient pattern was observed under low load conditions and a cubic trend was observed in the low load condition with the 114 ms precue. Precueing also reduced the amount of flanker interference observed. It appears that the amount of perceptual load and large spatial separations, at least partially, account for the efficiency of visual selective attention and that precueing can effectively reduce interference from distracting stimuli.

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CHAPTER I

Introduction

Purpose of the Study

The following graduate thesis describes research designed to examine flanker interference at varying spatial distances from a target stimulus. Unlike the designs used by Müller et al. (2005) and Caparos and Linnell (2009), the current experimental design manipulates two cue-target SOAs and does not fix target location. Additionally, the current study will determine if spatially separating a distractor stimulus from a target stimulus by varying degrees will produce interference in an individual's ability to respond to that stimulus. In addition, perceptual load, as defined by the number of distracting stimuli, will also be manipulated to further evaluate flanker interference. The proposed project is aimed at making critical tests of the effects of perceptual load on the allocation and distribution of attention (Lavie & Tsal, 1994; Lavie & Cox, 1997) and the Mexican hat model of the allocation of visual attention (Müller et al., 2005). Specifically, the current study tests the predictions made by Müller et al. (2005) that the largest flanker interference should be seen at the most nearby locations while interference essentially disappears at middle distances where the "suppression zone" is located, while interference then increases again past this inhibition zone and eventually tapers off. This area of study is at the forefront of visual attention within cognitive psychology. Research

concerning allocation of attention in humans is an essential part of the science of psychology as the research findings are important for areas of psychology that deal with human cognition and behavior.

CHAPTER II

Review of the Literature

There exist many theories regarding the manner in which the brain allocates attention to relevant and irrelevant stimuli within our visual environment. Interest in attention began long ago within psychology with Hermann von Helmholtz in the middle 1800s and William James in the late 1800s. James postulated about the "focalization and concentration of consciousness," understanding that in order to process stimuli effectively one must withdraw from other things. He even theorized upon distraction describing it as confused, dazed, or scatterbrained (James, 1890/1983). Hemholtz observed that attention could be directed to spatial locations independently from the position of the eyes. Further, he also considered it possible for one to focus attention simply by consciousness and voluntary effort (Hemholtz, H. von, 1925).

While we may consider ourselves good at multitasking, the human brain is actually inefficient when it comes to multitasking the allocation of attention – especially when required to divide attention (Hahn et al., 2008; Lavie & Cox, 1997; Shinn-Cunningham & Ihlefeld, 2004). Our modern environments contain so many stimuli that it would be highly ineffective for our attentional systems not to shut out or exclude some information. Therefore, the brain uses selective attention for both effectiveness and

efficiency. The ultimate question is how the brain determines priority in selective attention for maximum effectiveness and efficiency.

Through numerous studies, researchers have identified multiple components affecting selective attention, which makes it difficult to develop a unified explanation of attention. Difficulty and familiarity of the task at hand affects how efficiently attentional selection occurs and how much attention is needed in order to make a selection. The more difficult a task is; the more attention is needed to complete the task. Likewise, the more practice an individual puts into a difficult task, the less attention will be required, making that task easier. The classic Stroop task is a perfect example of this. John Ridley Stroop performed an experiment in which participants were required to read words that spelled out a certain color but that were printed in a contradicting color of ink. The participants were required to vocalize the color of ink that each word was printed in – not read aloud the words themselves. As imagined, error rates and response times were high at first. After 8 days of practicing, the participants decreased response times and decreased error rates showing that a difficult task demanding much attention can become almost automatic and require little attention after practice (Stroop, 1935).

A more recently studied phenomenon that affects selective attention is attentional capture. Attentional capture implies that certain stimuli mandate an involuntary and automatic shift in attention (Pashler, Johnston, & Ruthruff, 2001). This is considered a totally involuntary, bottom-up process driven by captivating features instead of goals or objectives (Yantis, 2000; Yantis & Egeth, 1999). This has been discovered in multiple studies of selective attention.

Even though selective attention, specifically visual selective attention, is difficult

to study and the tasks used to study it are demanding and taxing, multiple theories have been developed and tested. A historically prominent theory is Broadbent's (1958) early selection filter theory. Filter theory posits a limit on how much stimulation one can attend to at one time. In order to avoid overload, the information processing system filters out competing stimuli based upon fundamental perceptual characteristics, such as stimulus location. While the filter theory makes conceptual sense, many other researchers found contradictions for it. In a classic investigation by Moray (1959) of the attentional phenomenon termed the cocktail party effect, it was found that certain stimuli can grab one's attention and not be filtered out, even if they are not the focus of attention. Moray explained that only important stimuli – like someone's name – will disrupt the filter (1959). Treisman's attenuation theory proposes that at least some selection must be based on meaning or salience. Her theory states that unattended stimuli are processed instead of filtered out. However, the unattended stimuli are less processed or not as strongly represented as the attended stimuli. Only when the unattended stimuli reach a certain threshold of importance or salience do they get processed, which also contradicts filter theory (1960). In diametric opposition to filter theory, Deutsch and Deutsch (1963) and Norman (1968) proposed late selection theory. Late selection theory proposes that no stimuli are initially filtered out; rather, all stimuli are recognized but only limited numbers of them, those which are behaviorally relevant, are selected for awareness and conscious action. Over the years, each theory accrued a number of evidences in its favor.

Frequently in visual selective attention research, a flanker paradigm is used to measure attentional allocation and goal-oriented processing. In the flanker paradigm, originally developed by Eriksen and Hoffman (1972; 1973), participants are asked to

identify a target character or stimulus while ignoring an irrelevant stimulus meant to measure the dispersion of attention, also called a flanker. In a typical flanker task the participant identifies a letter (say, A versus B) at a given target position by pressing one of two buttons as quickly as possible. A second letter called the flanker is located at a given distance from the target. The flanker is either compatible with the target stimulus, meaning that it has the same identity, or is incompatible with the target, meaning that it has the opposite identity, or is neutral with respect to the target, meaning that it is a third letter, say, C. Flanker interference, which is believed to reflect the amount of processing that the flanker receives, is measured by average response time (RT) differences (incompatible – neutral, or incompatible – compatible). This difference RT is what is referred to as flanker compatibility or the flanker effect. RTs have been suggested by Eriksen and St. James (1986) to be a sensitive measure of the degree of concentration of attentional resources. Using this flanker paradigm and measuring RTs, many researchers have debated how we allocate attention to relevant and irrelevant stimuli in our visual field.

Cognitive psychology often uses different metaphors when discussing attention and the allocation of visual attention. One of the most influential metaphors used to conceptualize attentional allocation is the spotlight of attention. Some compare attention to a spotlight that highlights information chosen for further processing (Johnson & Dark, 1986). The spotlight's focal point can be moved from one area to another, meaning that attention can be focused and refocused to various information in the environment. It is further analogized that attention, like a spotlight, has indefinite or "fuzzy" boundaries meaning it often highlights more than one area or object at a time depending on the size

or capacity of the spotlight. However, the spotlight of attention has its shortcomings. It does not provide answers as to why the spotlight illuminates certain areas or that the spotlight is always directed at a specific area (Cave & Bichot, 1999). From the spotlight of attention came many other ideas and theories on the allocation of attention.

Of some of the most prominent theories explaining allocation of visual attention is Eriksen and St. James's zoom lens model (1986). The zoom lens model maintains that we are able to manipulate the size of focus in our visual field. When the zoom lens is low powered, or zoomed out, a wide area within our visual field is perceived with little discrimination of detail. In contrast, when the zoom lens is high powered, or zoomed in, a narrow area within our visual field is perceived, allowing more attention to be devoted to discriminating detail. Eriksen and St. James were able to show that the size of attentional focus can be manipulated by precuing certain areas within the visual field, allowing for the narrowing of the zoom lens. In addition, they also found attention conforms to a montonically decreasing gradient as the location of a flanking stimulus increases in distance from the cued area (1986).

When measuring the allocation of attentional resources over spatial separations, a cue-target paradigm is usually employed (Posner, 1980). Often, a cue precedes the target informing the observer about the potential location of the upcoming target. It is widely understood that there are two different types of covert attention that facilitate the selection and processing of information: endogenous and exogenous attention. Endogenous attention (sustained attention) is a voluntary system that facilitates willful selection of attention. Exogenous attention (transient attention) is an involuntary system that automatically orients attention to sudden stimulation. Posner (1980) differentiated

two types of cues: the peripheral cue and the central cue. A peripheral cue is an abrupt-onset stimulus that captures attention exogenously to a peripheral location. Conversely, a central cue occurs at a fixation, and orients attention to a potential target location endogenously. Exogenous and endogenous cueing processes differ in multiple ways including the time course of the cueing effect (Jonides, 1981; Müller & Rabbitt, 1989), the sensitivity to additional memory load, and the sensitivity to cue validity (Jonides, 1981). Studies regarding the time course of cueing effects generally show that exogenous attention has a faster time course than endogenous attention, with exogenous attention peaking roughly at 100-120 ms after a peripheral cue and endogenous attention peaking around 250 ms following a central cue. Also, unlike the transient effects of exogenous attention, endogenous attention is sustained as long as needed in order to make a decision about the information observed (Carrasco, 2011). According to Lu and Dosher (1998, 2000) memory load also has an effect on endogenous and exogenous attention. Endogenous attention affects performance only under high-noise conditions, but not under low-noise conditions whereas exogenous attention can operate under both low- and high-noise conditions (Lu & Dosher, 1998, 2000). Finally, Giordano, McElree, and Carrasco (2009) examined the effects of cue validity on endogenous versus exogenous attention with a speed-accuracy tradeoff procedure, which showed that with peripheral cues, the attentional benefits of endogenous attention increased with cue validity while costs remained relatively constant. Interestingly, with peripheral cues they found that the benefits and the costs of exogenous attention in discriminability were not more prominent with higher cue validity (2009).

Another theory to explain the allocation of attention that has received much support is perceptual load theory (Lavie & Tsal, 1994; Lavie & Cox, 1997). Perceptual load theory proposes that the efficacy of our attentional selection is dependent upon the amount of items in our visual field and/or the difficulty of discriminating those items—what Lavie and Tsal call perceptual load. According to Lavie and Tsal's conception, perceptual processing is a limited resource, but it proceeds automatically until it runs out of capacity (1994). A high perceptual load can be created by introducing several, say five or more, additional items to the visual field. According to perceptual load theory, in a high load situation, our visual selection is more efficient, because any spare attentional resources we have left over from target selection will be insufficient to fully process any of the additional items that may distract selection. Opposite of this is low perceptual load. In a low load environment, selection is less efficient due to spare attentional resources "spilling over" to fully process remaining stimuli. Perceptual load theory predicts that spare capacity will spill over to items that are most similar to the target stimulus and that flanker interference is a result of this spill over (1994). According to perceptual load theory, early selection occurs under high load and late selection occurs under low load.

Multiple studies have looked into the role of working memory in selective attention. It is thought that working memory plays a role in maintaining processing priorities in the face of potential distraction. Baddeley (1996) argued that a main function of working memory is to facilitate selective attention to relevant stimuli among potential distractions. However, it was not until much later that researchers were able to find a direct link between the role of working memory and selective attention. De Fockert (2001) combined a working memory task with a selective attention task and found that

selective processing was inhibited when working memory was unavailable to maintain selective attention by placing a high load task on working memory. Lavie et al. (2004) suggest that high perceptual load in the processing of task-relevant stimuli reduces distractor interference, but high load on processes of cognitive control such as working memory and task coordination leads to increased distractor interference. Multiple studies since have demonstrated that the availability of working memory affects distractibility in selective attention (Pecchinenda & Heil, 2007; De Fockert et al., 2010).

While research has been able to show an overlap in working memory and selective attention, it remains somewhat muddy as to which mechanisms underlie this link or overlap. Between Lavie et al. (2004) and De Fockert et al. (2010), it has been shown that manipulations of cognitive processes lead to increases in distractibility. Many studies show that the notion that working memory load affects distribution of spatial attention (Poole & Kane, 2009; Heitz & Engle, 2007). Chen & Chan (2007) controlled attentional focus while manipulating working memory load. They found no evidence that the degree of distractor interference varied as a function of working memory load when the extent of attentional focus was controlled (Chen & Chan, 2007). The above-mentioned studies and many more studies on the role of working memory in selective attention show a close relationship between performance on working memory and selective attention.

An alternative explanation for flanker interference under conditions of high perceptual load proposes that the observed reduction in flanker interference with high perceptual load is a result of dilution (Tsal & Benoni, 2010). In other words, while trying to identify the target stimulus, "cross talk" between all other non-target stimuli is

diminishing the ability of the flanker to capture attention and to be processed because the presence of additional stimuli weakens, or dilutes, the perceptual representation of the flanker (Chen & Cave, 2014; Wilson et al., 2011). Gaspelin et al. (2014) suggest a different conceptualization of dilution. They describe dilution as an averaging of flanker-attended trials versus flanker-non-attended trials. Over trials, a flanker in proximity to the target is more likely to capture attention and undergo processing than a flanker further away from the target. If the nearby flanker captures attention on more trials than the distanced flanker, it is possible that a participant's responding could slow down (due to flanker interference) compared to his/her responding on trials with a distant flanker. In other words, responses will slow down (RTs will increase) simply because there will be more trials in which the flanker captures attention due to its close proximity to the target. It is possible that dilution may not be "dilution," but rather a simple averaging of flanker interference over trials.

To also challenge the predictions of perceptual load theory is the salience account (Biggs & Gibson, 2014). The salience of a stimulus refers to the unique or conspicuous qualities of that stimulus that could set it apart so much that it is perceived and/or processed involuntarily. According to Biggs and Gibson, if the flanker is salient enough, due to perhaps its location or color, then it will capture attention even if the perceptual representation is diluted by the presence of additional stimuli. To support this claim, Biggs and Gibson conducted a study that looked at the role of high and low salience on distractor processing while dilution and load were held constant. They discovered that the relative salience of the distractor influenced the magnitude of distractor interference under these conditions, which suggests that the effects of visual salience can coexist with

the effects of dilution and load (2014). In other words, they suggest that a salient distractor will still interfere with target processing despite being diluted on any other dimension. Even with much support for the salience account, there is an alternative explanation suggesting that capture by salient stimuli can be overridden by strong top-down attentional control settings called contingent attentional capture.

Contingent attentional capture posits that the ability of a stimulus to capture attention involuntarily, perhaps due to its strong salience, depends on top-down control settings. In other words, Folk et al. (1992) concluded that salient stimuli do not have unavoidable power to capture attention, because capture depends on the similarities between the stimulus and the observer's control settings. According to Lien, Ruthruff, Goodin, and Remington (2008), inevitability of capture is counterintuitive, because even though capture of attention is involuntary and triggered by the stimulus, it still depends on top-down task settings. Several studies, including Lien et al. (2008), support contingent attentional capture with data indicating that attentional capture is contingent on the control setting placed on the individual (e.g., Gibson & Amelio, 2000; Gibson & Kelsey, 1998; Pashler, 2001; Yantis & Egeth, 1999). Lien et al. state that it "remains possible that capture by certain salient stimuli is the default state, which can be overridden by strong top-down attentional control settings" (2008). However, despite multiple studies supporting contingent attentional capture, there is a larger pool of support for the salience account and involuntary capture. For example, Theeuwes has conducted multiple studies in order to determine the limitations of the top-down control system. In multiple experiments, he has collected data indicating that, despite the abilities of top-down control systems or control settings to direct attention, salient items still

involuntarily capture attention (Theeuwes, Reimann, & Mortier, 2006; Theeuwes & van der Burg, 2007; 2008; 2011).

Gaspelin et al. (2014) have suggested that neither perceptual load theory nor dilution adequately explain the effects of nontarget stimuli on flanker interference. Instead, they propose a "slippage" account of the earlier findings and provide new data to support the slippage hypothesis. Slippage is essentially an early selection account of flanker effects, which proposes that the flanker involuntarily captures attention due to the flanker's visual similarity to the target. This is the same conceptualization of the averaging of flanker interference due to proximity of the flanker to the target described previously by Gaspelin et al. (2014). Items further from the focus of attention are less likely to receive attentional focus unless they are highly salient.

In a test of the two-stage model of dilution by Wilson et al. (2011), Rennie, Warner, Drouhard, and Smith (2014) cued potential target locations in advance of their appearance and found that the spatial configuration of precues modulated flanker interference, with spatially separated precues resulting in the most flanker interference and a single, focal precue virtually eliminating flanker interference. Furthermore, the pattern of results did not fit the prediction of either perceptual load theory or dilution. Rather, the results were more in line with slippage theory, leading Rennie et al. (2014) to conclude "whether dilution effects emerge in an experimental setting is critically dependent upon perceptual grouping and attentional control."

One model of visual selection that claims to combine, or produce a "hybrid" of both perceptual load theory and dilution is Scalf, Torralbo, and Beck's concept of biased

competition (2013). Biased competition proposes that, instead of selective attention being a limited resource, visual selection utilizes a top-down bias to decide where to focus attention within a given visual field. Biased competition has two main components, the first being that items in a given display compete for representation and that this competition is resolved in favor of the target through a top-down bias. Accurate identification of the target requires a goal-oriented, top-down selection. Secondly, it is the application of this bias in favor of the target that diminishes the representation of the distractor (Scalf et al., 2013). In other words, it is a push-pull relationship where one stimulus is "pushed up" by attention and competing stimuli are necessarily "pulled down." There are now also numerous neuroimaging studies that find such a push-pull relationship between target and distractor (Somers et al., 1999; Pinsk et al., 2004; Gazzaley et al., 2005; Pestilli & Carrasco, 2005; Hopf et al., 2006), where the extent of this relationship is modulated by the load of the relevant task (Handy et al., 2001; Schwartz et al., 2005; Parks et al., 2011). According to Scalf et al., under low load, target representation is already clear and top-down bias is not needed, leaving the attentional filter open, allowing for greater distractor processing (2013). The opposite would remain true under conditions of high load. Additionally, Scalf et al. (2013) propose a mechanism for directing attention and filtering out task-irrelevant stimuli. Instead of simply running out of or having an abundance of a limited capacity, there exists a specific mechanism for biased competition.

Other studies provide results consistent with the role of the visual cortex in selective attention and a more top-down competitive approach in visual selection. For example, Torralbo and Beck (2008) produced results showing that spatially separating a

task-relevant item or placing the target and nontargets in different visual fields increased interference from distractors. This is consistent with the idea that the ability to ignore such distracting information results, in part, from the need to actively resolve competitive interactions in the visual cortex, and is not exactly the consequence of an exhausted capacity suggested by the perceptual load and dilution accounts.

Some studies have used visual search designs to determine how attentional selection occurs within or between hemifields and what that means for some theories of selective attention. In particular, Nishimura and Yoshizaki (2010) conducted research using a response competition paradigm to determine if a distractor can be ignored when it is projected to a highly-loaded hemisphere. A compatibility effect was found only when the distractor appeared in the low-loaded hemisphere suggesting that processing lowly loaded tasks leaves ample resources to spill over and process the distractor despite task relevance. To further support this claim, they also state that it is possible that the processing of the distractor in the low-loaded hemifield could also be due to the salience of the distractor within that hemifield, which would also support the salience account described by Biggs and Gibson (2014). Finally, to further support their claims, they report that their findings are consistent with Torralbo and Beck's (2008) findings of a reduction in competitive interactions within the visual cortex of the lowly loaded hemisphere (Nishimura & Yoshizaki, 2010). A different study looking at selective attention within/across hemifields was conducted by Wei, Kang, and Zhou (2013) using a traditional flanker paradigm. Importantly, this study differentiated conditions where the target and a peripheral flanker were presented in the same hemifield and also across hemifields. Interestingly, they found a flanker effect for the low load condition only when

the presentation was within hemifields, but did not find an effect in either condition when the presentation was across hemifields (Wei, et al., 2013). These findings support the finding of Nishimura & Yoshizaki (2010) mentioned previously, suggesting that the ability to ignore a distractor is affected by competition within a single hemisphere. Multiple other visual selective attention studies, both behavioral and neuroimaging (Alvarez & Cavanagh, 2005; Pollmann et al., 2003; Torralbo & Beck, 2008; Delvenne, 2005), have found that processing within a hemisphere can lead to the most efficient processing of visual stimuli. In order for these findings to fit within perceptual load theory, Nishimura and Yoshizaki (2010) assumes that each hemisphere having a separate pool of attention allows for a basis for explaining competition within each hemisphere.

In a recent study, Müller et al. (2005) assessed interference of flanker letters on target identification as a function of the distance between incompatible flankers and targets. In that study, Müller et al. described the attentional field as a "Mexican hat distribution." This Mexican hat distribution does not follow a simple gradient like the one seen in Eriksen and St. James's zoom lens (1986). Instead, this distribution hypothesizes an inhibition zone where attentional selection is suppressed at middle locations in relation to a target. These middle locations are on the borderline between the attentional field containing the target and another attentional field containing the largest distance in their display. The borderline location of these middle distances could be causing their suppression. Other studies have also reported perceptual regions of suppression surrounding the region of enhanced processing (Slotnick, Hopfinger, Klein, & Sutter, 2002; Pan & Eriksen, 1993). However, unlike many prior experiments, such as Eriksen and St. James (1986), the displays used by the studies reporting suppression zones had a

broader spatial extent with greater spatial separation between target and flanker. Torralbo and Beck (2008) also found that spatially separating the task-relevant items in a display or placing the target and nontargets in different visual fields increased interference from a distractor that was to be ignored.

Interestingly, in a study conducted by Caparos and Linnell (2009), it was found that increasing load focuses spatial attention, with the focus of attention following a monotonically decreasing gradient distribution under low load, but a Mexican hat-like distribution under high load. This same study discovered that simply increasing perceptual load does not improve overall selectivity, but improves selectivity at near separations – not at far separations. However, it is important to note that Caparos and Linnell used only neutral and incompatible flankers for their analysis, supposedly to avoid the “unreliable” compatible baseline. In addition, their flanker effect was rather small in all conditions (2009). Without the compatible condition, participants could potentially learn to use the incompatible flanker to ascertain the identity of the target, which may be the cause of the small flanker effect. It is also possible that it would have a greater effect for flankers close to the target and in the low load conditions.

Some studies have explored an interesting phenomenon called the negative compatibility effect, which contrasts with the concept of flanker interference. The negative compatibility effect is described by Bavelier, Deruelle, and Proksch (2000) as the result of compatible distracting stimuli producing slower and less accurate target identification performance compared to incompatible distracting stimuli. Based on all of the results of studies and explanations of flanker interference, a negative compatibility effect is puzzling with regard to why a compatible flanker should generate slower RTs

than an incompatible flanker. To account for this, Bavelier et al. proposed and found support for the negative compatibility effect being the result of early processes that guide selection, such as salience, task difficulty, and gestalt properties (specifically, similarity) of stimuli (2000). These processes may act to group distractors together based on salience or physically similar properties, making a separate group of distractors and a separate group of targets. Bavelier et al. (2000) stated the negative compatibility effect should be strongest when the target and distractors are separated into two different groups. Other studies have found support for the negative compatibility effect (Briand, 1994; Van Leeuwen & Bakker, 1995). However, a report from Yagi and Kikuchi (2002) found a negative compatibility effect, but they claim it occurs at the post-categorical level due to inhibitory processing of task-irrelevant stimulus representations. Relevant to the current study's findings, Tagi and Kikuchi's report states that the emergence of the negative compatibility effect depends upon whether the degree of separation (near, intermediate, or far) between the target and the task-irrelevant stimuli creates the necessary preconditions for the effect (2002). Whether the negative compatibility effect results from early processes or from post-categorical inhibitory processes, one study conducted by Wyatt and Machado (2013) found a positive relationship between the strength of distractor inhibition and the intensity of that distractor, or what they termed the reactive inhibition process, which is an aspect of a model created by Houghton and Tipper (1994;1996) that attempts to explain the roles of target amplification and distractor inhibition in selective attention. In order to gain support for the reactive inhibition process, Wyatt and Machado created two experiments manipulating the proximity of the distractor to the target and the luminance of the distractor. They discovered that whether

the distractor's intensity was increased by proximity or by luminance, a positive relationship between salient distractors and larger negative compatibility effects occurred (2013).

The present study attempts to discover if the distribution of attention conforms to a simple gradient like that found in Eriksen and St. James's (1986) zoom lens model, or if it will take more of a Mexican hat distribution as observed in Müller et al. (2005), Slotnick et al., (2002), and Pan and Eriksen, (1993). Previously, Warner, Drouhard, Murali, Litchtenauer, Floyd, and West (2015) produced results consistent with Gaspelin et al. (2014) in that that neither resource overflow in the low load condition nor dilution were obligatory, and were instead affected by both precue SOA and proximity to the target. In addition, Warner et al. (2015) also stated their results were not only consistent with slippage, but also consistent with attentional gradients (Eriksen & St. James, 1986), or perceptual-grouping-based resource spillover (Lavie & Torralbo, 2010), in that proximity of the flanker to the target location, grouping by color, and precuing the target location as well as the addition of a precue determined the magnitude of flanker effects. The present study uses a design similar to those of Müller et al. (2005) and Warner et al. (2015) to determine if slippage will conform to a monotonically decreasing gradient or a Mexican hat-like distribution. Different from the design used by Müller et al. (2005), the present study creates a full circular display to provide the opportunity for an attentional gradient to manifest in a dynamic, location-cued display instead of using one hemifield, or half of a circular display, with a fixed target location that does not allow for the shifting of attention. The present study places the flanker and the target in the same hemifield but at large spatial separations in order to avoid confounding distance effects

with hemifield effects. Müller et al. claim that their display, with its fixed target location, prevents the spitting or shifting of attention, because attention does not have to cover uncued locations that could have pop-out characteristics immediately capturing attention (2005). While this design may be effective at doing such, it is not typical of the natural environment to have a single location of interest repeatedly sampled. In contrast, the present experiment uses a 100% valid cue on all trials, making the search of uncued locations unnecessary.

Finally, the present experiment tests whether attention will conform to a simple gradient or to a Mexican hat gradient in a dynamically cued display with large spatial separations between target and flanker. It is expected that flanker effects will be stronger and decline less fully with flanker distance in the low load condition at 0 ms SOA than in the low load condition at 114 ms SOA. This is due to the lack of a precue in the 0 ms SOA condition. As predicted by perceptual load theory, the flanker effects are expected to be smaller in the high load condition. An important observation is whether flanker effects will recover at the farthest target-flanker distance as predicted by Müller et al. (2005). Müller et al. maintain that RT differences should be largest for nearby distractors, drop to zero in the inhibition zone, and the increase again and finally taper off (2005). According to Caparos and Linnell (2010), the distribution of attention should follow a gradient under low load and follow a Mexican hat-like distribution under high load. If, per Müller et al. (2005), the suppression zone is located near or around the focus of attention it could be possible that a negative compatibility effect could be observed in the high load condition as a result of inhibition of response-compatible flankers in the suppression zone.

Chapter III

Methods

Participants

Sixty-nine Pittsburg State University students, 24 males and 47 females with a mean age of 22 years, were convenience sampled from a pool of students enrolled in introductory psychology classes. Students received either course extra credit or $25 of monetary compensation in exchange for their participation. Each session required approximately 1 hour and 15 minutes to complete. Participants were treated in accordance with the American Psychological Association (APA) ethics guidelines for research and publication. Participants were informed of the purpose of the research, expected duration and procedures, their right to decline to participate and to withdraw, the foreseeable consequences of declining or withdrawing, reasonably foreseeable factors that may be expected to influence their willingness to participate, such as potential risks, discomfort or adverse effects, any prospective research benefits, limits of confidentiality, incentives for participation, and whom to contact for questions about the research and research participants' rights (Ethical Principles of Psychologists and Code of Conduct; APA, 2010).

The qualifying criteria were approved by the Pittsburg State University institutional review board (IRB). The main screening criteria were: At least 18 years of

age, no history of seizures in response to visual stimulation (by self-report), normal or corrected-to-normal visual acuity (as measured), normal color vision (by self-report), and no current or prior history of diagnosed ADHD (by self-report).

Procedures and Measures

In this experiment, a 2 x 2 x 2 x 4 design was used. Within-subjects factors included distance of flanker (1.8, 3.4, 4.9, or 6.2 degrees of visual angle), cue-target stimulus onset asynchrony (0 ms or 114 ms; SOA is the time interval in between the onset of the cue and the onset of the target), and flanker compatibility (compatible or incompatible). The single between-subjects factor was the load condition (high or low). Consistent with many studies involving a flanker task, response time (RT) to identify the target was recorded in a speeded, two-alternative, forced-choice task. Whether the participant responded correctly or incorrectly (error rate) in discriminating the rotation of the target stimulus was also measured. Seventy-two responses per cell of the design were collected in order to create stable cell means, resulting in a combined total of 1152 trials per participant plus 50 practice trials.

Stimulus presentation and response time measurement was controlled by the eXpTools Library (Warner, 1999) and viewing distance was stabilized 102 centimeters from the screen by a chin rest. The stimuli were presented on a 16 inch, ViewSonic G773 cathode ray tube (CRT) computer monitor. Sample stimuli and the event sequence for the high load condition are shown in the Figure 1. On each of the 1152 trials of the experiment, participants first viewed a circular array of white dots (placeholders) on a black background, with a single white dot in the center of the display (fixation). The diameter of the circle was approximately 4.2° of visual angle and each square dot

subtended approximately 0.1° of visual angle. Six positions appeared in each hemifield of the circular display. Taking the top of the circle as 0°, the nearest position in each hemifield is 30° away – all distances were measured center-to-center. The distance between each pair of dots was 24°, with another 30° distance from the last position to the very bottom of the circle, which would be 180°. In the 114 ms SOA condition, participants then viewed a bright-white, four-dot cue around the location where the target would appear, while in the 0 ms condition, the four-dot cue appeared simultaneously with the target. The target always appeared where it had been cued with 100% validity. Finally, the participant responded to the target/flanker display, which consists of a cued white target letter T (rotated 90° clockwise or counterclockwise), a white flanker T (rotated 90° clockwise or counterclockwise) located 1.8, 3.4, 4.9, or 6.2° away from the target within the same hemifield, and white place-marker dots (low-load condition) or white Ls (high load condition). Each letter T or L, when rotated 90° from its canonical vertical orientation, measured approximately 0.79° of visual angle wide and 0.63° high, and the four-dot spot cue was approximately 1.05° wide and 0.79° high, with each dot being 0.05° square. The top left and right hemifield positions and the bottom left and right hemifield positions were the only possible positions at which a target appeared. The flanker always appeared in the same hemifield as the target and never appeared at the opposite target location in that same hemifield. The target/flanker display remained on the screen for 100 ms, after which the display went black for 4000 ms until a selection was made. Sample displays are presented in Figure 1. A summary list of visual angle measurements of all stimuli are presented in Table 1.

Target/flanker rotation was related to response compatibility versus incompatibility. If the target T and the flanker T were both rotated in the same orientation, this constituted target-flanker compatibility; if they were rotated into opposite orientations, this constituted target-flanker incompatibility. The letter Ls were pseudo-randomly selected from a set of rotated (0°, 90°, 180°, and 270°) and mirrored Ls, with the constraint that all instances of rotation and mirroring were unique within a hemifield.

The participants responded to the target by pressing one of two keys on a response box. The index finger of the right hand was used to press the left key indicating a T rotated counterclockwise and the middle finger of the right hand was used to indicate a T rotated clockwise. If a participant provided an incorrect response, he or she heard a beep and a screen appeared for three seconds reading, “Incorrect Response” or “No Response.” After this screen, a countdown in seconds to the next trial appeared. An incorrect response or no response contributed to the error rate. Participants were instructed to keep their eyes fixated at the center of the display while trying to make the correct selection as quickly, but accurately, as possible.

Within each session, participants responded to 18 blocks of 64 trials. In addition, participants responded to 50 practice trials at the beginning of the session. Within each between-subjects load condition, the 0 ms and 114 ms SOA conditions were presented in alternating blocks and order of alternation was counterbalanced between-subjects. Participants were provided with the option to take a rest break between blocks. Directions on how to proceed were provided on screen if the participant chose not to take a rest break. The rest break at the half-way point of the session was mandatory and lasted for 9 minutes. Participants were allowed a restroom break at that time.

CHAPTER IV

Results

Before analysis, outliers in the correct RTs were removed by discarding RTs under 200 ms, and then applying a recursive procedure in which RTs less than or greater than three standard deviations from their own cell mean were removed until no further outliers existed. The outlier procedure removed 3.09% of the correct RTs. Additionally, the Greenhouse-Geisser procedure (Greenhouse & Geisser, 1958) has been applied, as appropriate, in order to correct the degrees of freedom of the *F*-distributions.

Raw RT Effects

The raw RT data were submitted to a 2 x 2 x 2 x 4 mixed analysis of variance (ANOVA). Within-subjects factors were distance of flanker (1.8, 3.4, 4.9, or 6.2 degrees of visual angle), cue-target stimulus onset asynchrony (0 ms or 114 ms; SOA is the time interval in between the onset of the cue and the onset of the target), and flanker compatibility (compatible or incompatible). The single between-subjects factor was the load condition (high or low).

In the raw RT data, a main effect was found for distance, $F(2.31, 201) = 11.88$, $p < .001$, $\eta_p^2 = .151$. For the distance main effect, the mean RT ($M = 523.2$, $SE = 8.9$) at distance 1 was significantly slower than the mean RTs at distances 2 ($M_D = 9.1$ ms, $SE =$

2.2, p = .001), distance 3 (M_D = 9.2 ms, SE = 2.1, p < .001), and distance 4 (M_D = 7.9 ms, SE = 1.9, p < .001). Displayed probabilities are Šídák corrected. Regarding flanker compatibility, a significant main effect was found, $F(1, 67) = 117.71$, $p < .001$, $\eta^2_p = .637$. For the flanker compatibility effect, the mean RT (M = 507.82, SE = 8.51) for the compatible flanker was faster than the mean RT (M = 525.66, SE = 8.83) for the incompatible flanker. A main effect was also found for SOA, $F(1, 67) = 443.199$, $p < .001$, $\eta^2_p = .869$. The mean RT (M = 573.34, SE = 9.96) for 0 ms SOA was significantly slower than the mean RT (M = 460.14, SE = 8.03) for 114 ms SOA. No main effect was found for load (p = .558).

Significant two-way interactions were found for distance x flanker compatibility, $F(2.56, 201) = 14.08$, $p < .001$, $\eta^2_p = .174$, flanker compatibility x load, $F(1, 67) = 75.84$, $p < .001$, $\eta^2_p = .531$, SOA x distance, $F(2.389, 201) = 14.23$, $p < .001$, $\eta^2_p = .175$, and SOA x load, $F(1, 67) = 17.80$, $p < .001$, $\eta^2_p = .210$. The SOA x flanker compatibility two-way interaction was non-significant (p = .408). Because the significant two-way interactions are subsumed within significant three-way interactions, descriptions of interaction data patterns will be made at the three-way level.

Significant three-way interactions were found for distance x flanker compatibility x load, $F(2.56, 201) = 10.34$, $p < .001$, $\eta^2_p = .134$, SOA x distance x flanker compatibility, $F(2.94, 201) = 3.31$, $p = .022$, $\eta^2_p = .047$, SOA x distance x load $F(2.39, 201) = 15.03$, $p < .001$, $\eta^2_p = .183$, and SOA x flanker compatibility x load $F(1, 67) = 4.16$, $p = .045$, $\eta^2_p = .059$. Referring to Figure 2, the distance x flanker compatibility x load interaction results from a contrast between the fan-shaped decline in flanker compatibility effects (incompatible – compatible) seen in the low load condition of the left-hand panel versus

the marginal-to-absent flanker compatibility effects found in the high load condition of the right-hand panel. Also, a visually apparent quadratic trend is present in the low load condition that is not seen in the high load condition.

The four-way interaction of SOA, distance, flanker compatibility, and load closely approached, but did not attain significance (p = .053).

Raw Error Rate Effects

The same factors described above for the raw RT effects were also entered as factors for the raw error rate effects.

For the raw error rate data, a significant main effect was found for flanker compatibility, $F(1, 67) = 19.51$, $p < .001$, $\eta_p^2 = .226$, load, $F(1, 67) = 6.87$, $p = .011$, $\eta_p^2 = .011$, and SOA: $F(1, 67) = 98.21$, $p < .001$, $\eta_p^2 = .594$. No significant main effect was found for distance (p = .909).

Significant two-way interactions among the raw error rate data were distance x flanker compatibility, $F(2.71, 201) = 23.48$, $p < .001$, $\eta_p^2 = .259$, distance x load, $F(2.94, 201) = 6.41$, $p < .001$, $\eta_p^2 = .087$, SOA x distance, $F(2.58, 201) = 1.49$, $p = .223$, $\eta_p^2 = .022$, and SOA x load, $F(1, 67) = 8.39$, $p = .005$, $\eta_p^2 = .111$. The following two-way interactions were non-significant: flanker compatibility x load (p = .423) and SOA x flanker compatibility (p = .513).

Only one three-way interaction was found to be significant, SOA x Distance x Flanker Compatibility, $F(2.85, 201) = 4.26$, $p = .007$, $\eta_p^2 = .06$. The remaining three-way interactions were non-significant: distance x flanker compatibility x load (p = .320), SOA x distance x load (p = .575), and SOA x flanker compatibility x load (p = .502). The three-way interaction of SOA x distance x flanker compatibility is presented in Figure 3.

The four-way interaction of SOA, distance, flanker compatibility, and load was non-significant (p = .759).

Flanker RT Effects

Given that the predictions concerning the Mexican hat model are made for the magnitude of flanker compatibility effects across target-flanker distance, the mean flanker compatibility effects for both correct RTs and percent error were submitted to 2 x 2 x 4 mixed ANOVAs. Within-subjects factors included distance of flanker (1.8, 3.4, 4.9, or 6.2 degrees of visual angle), cue-target stimulus onset asynchrony (0 ms or 114 ms), and flanker compatibility (compatible or incompatible). The single between-subjects factor was the load condition (high or low).

Analysis of the main effect of distance found that mean flanker effects decreased significantly with increasing target-flanker separation, $F(2.56, 201) = 14.08$, $p < .001$, $\eta_p^2 = 0.174$; $M_1 = 29.35$, $SE_1 = 3.32$; $M_2 = 17.27$, $SE_2 = 2.27$; $M_3 = 12.92$, $SE_3 = 2.10$; $M_4 = 11.82$, $SE_4 = 1.99$. Šídák corrected pairwise comparisons found significant differences between distance 1 and distance 2 (M = 12.08, SE = 3.16, p = .002), distance 1 and distance 3 (M = 16.42, SE = 3.45, p < .001), and distance 1 and distance 4 (M = 17.53, SE = 3.59, p < .001). The main effect of load was also significant, $F(1, 67) = 75.84$, $p = .001$, $\eta_p^2 = .531$. Flanker compatibility effects were significantly larger in the low load condition (M = 32.16, SE = 2.20) than in the high load condition (M = 3.52, SE = 2.44). The main effect of SOA was non-significant (p = .408). No main effect was found for SOA (p = .408). The main effects for load (p = .65) and SOA (p = .513) were not significant.

Because the Mexican hat model predicts a cubic trend in the simple effects of distance at each level of other factors, the highest order significant interactions were decomposed and trend analyses performed in order to test those predictions. The two-way interaction of distance x load $F(2.56, 201) = 10.34$, $p < .001$, $\eta_p^2 = .134$, was significant. Overall, participants encountered less flanker interference in the high load condition than in the low load condition (Figure 4), and the amount of interference in the low condition declined with target-flanker distance, which was not observed in the high load condition. This interaction also suggests the most flanker interference occurs when the target is closets to the flanker in the low load condition. To further investigate the distance x load interaction, it was decomposed into the simple main effects of distance at each level of load. The simple main effect of distance at low load was significant, $F(2.56, 201) = 26.22$, $p < .001$, $\eta_p^2 = .281$, and, therefore trend analyses were performed on this simple effect. Conversely, the simple main effect of distance at high load was not significant (p = .505) and no further analyses were performed on this simple effect. In the low load condition, the linear decline in flanker effects with distance was highly significant, $F(1, 67) = 50.82$, $p < .001$, $\eta_p^2 = .431$, as was the quadratic trend, $F(1, 67) = 8.10$, $p = .006$, $\eta_p^2 = .108$, and the cubic trend was also reliable, $F(1, 67) = 4.23$, $p = .044$, $\eta_p^2 = .059$. Šídák corrected pairwise comparisons found significant differences between distance 1 and distance 2 (*M* = 22.92, *SE* = 4.24, *p* < .001), distance 1 and distance 3 (*M* = 26.6, *SE* = 4.62, *p* < .001), distance 1 and distance 4 (*M* = 34.06, *SE* = 4.82, *p* < .001), and distance 2 and distance 4 (*M* = 11.15, *SE* = 3.28, *p* = .007).

The two-way interaction of distance x SOA $F(2.94, 201) = 3.32$, $p = .022$, $\eta_p^2 = .047$ was also significant (Figure 5). The distance x SOA interaction was decomposed

into the simple main effects of distance at each level of SOA. The simple main effect of distance at 0 ms SOA was significant, $F(2.87, 201) = 4.99$, $p = .002$, $\eta_p^2 = .069$. In the 0 ms SOA condition, the linear trend was significant, $F(1, 67) = 11.19$, $p < .001$, $\eta_p^2 = .143$, but the quadratic ($p = .476$) and cubic trends ($p = .236$) were non-significant. Šidák corrected post-hoc pairwise comparisons revealed that the flanker effect at distance 1 ($M = 27.1$, $SE = 3.44$) was significantly higher than the flanker effect at distances 3 ($M_D = 13.93$, $SE = 4.47$, $p =.016$) and 4 ($M_D = 13.65$, $SE = 4.96$, $p = .045$). No other pairwise comparisons were significant at 0 ms SOA. The simple main effect of distance at 114 ms SOA was also significant, $F(2.46, 201) = 16.25$, $p = .476$, $\eta_p^2 = .008$. In the 114 ms condition, the linear trend of distance was significant $F(1, 67) = 27.56$, $p < .001$, $\eta_p^2 = .291$, as was the quadratic trend, $F(1, 67) = 10.51$, $p = .002$, $\eta_p^2 = .136$, and the cubic trend, $F(1, 67) = 7.41$, $p = .008$, $\eta_p^2 = .009$. Figure 5, showing the distance x SOA interaction, shows that the most flanker interference was observed at distance 1, whether the participant received a 114 ms cue or a 0 ms cue, and that flanker interference declined with distance, but that it declined more rapidly for the 114 ms SOA condition, becoming asymptotic at distance 2. Šidák corrected post-hoc pairwise comparisons at SOA 0 ms yielded significant differences between distance 1 and distance 3 ($M_D = 13.93$, $SE = 4.47$, $p = .016$) and distance 1 and distance 4 ($M_D = 13.65$, $SE = 4.96$, $p = .045$). Šidák corrected post-hoc pairwise comparisons at SOA 114 ms also yielded significant differences between distance 1 and distances 2 ($M_D = 20.24$, $SE = 4.3$, $p < .001$), 3 ($M_D = 18.93$, $SE = 4.05$, $p < .001$), and 4 ($M_D = 21.41$, $SE = 3.81$, $p < .001$). In the SOA x load interaction, $F(1, 67) = 4.16$, $p = .045$, $\eta_p^2 = .059$, flanker interference was higher for both SOAs in the low load condition (Figure 6). However, Šidák corrected post-hoc pairwise

comparisons showed significant differences between low load and high load at 0 ms (M_D = 35.45, SE = 4.42, $p < .001$) and between low load and high load at 114 ms (M_D = 21.83, SE = 4.94, $p < .001$). Finally, Šidák corrected post-hoc pairwise comparisons showed significant differences in the low load condition between SOA 0 ms and SOA 114 ms (M_D = 9.59, SE = 4.47, p .036). These findings suggest the most flanker interference was in the low load condition regardless of SOA.

The three-way interaction of SOA x distance x load closely approached, but did not attain, significance, $F(2.94, 201) = 2.62$, $p = .053$, $\eta^2_p = .038$. This interaction was not further analyzed. See Figure 7.

Flanker Error Effects

The same factors described above for the raw RT flanker effects were also entered as factors for these flanker error rate effects.

Analysis of the main effect of distance was significant, $F(2.71, 201) = 23.48$, $p < .001$, $\eta^2_p = .259$; $M_1 = 3.88$, $SE_1 = .47$; $M_2 = 1.46$, $SE_2 = .48$; $M_3 = .34$, $SE_3 = .39$; $M_4 = .49$, $SE_4 = .48$. Šídák corrected pairwise comparisons found significant differences between distance 1 and distance 2 (M = 2.42, SE = .53, $p < .001$), distance 1 and distance 3 (M = 3.55, SE = .50, $p < .001$), distance 1 and distance 4 (M = 3.40, SE = .52, $p < .001$) and distance 2 and distance 3 (M = 1.13, SE = .39, $p = .032$). See Figure 8.

Two-way interactions among the flanker error effects produced only one significant interaction. The significant two-way interaction of SOA x distance, $F(2.852, 201) = 4.258$, $p = .007$, $\eta^2_p = .06$. The two-way interactions of distance x load ($p = .319$)

and SOA x load (p = .502) were non-significant. The SOA x distance interaction was decomposed into simple main effects at each level of SOA. The simple main effects of distance at SOA 0 ms and distance at SOA 114 ms were both significant: SOA = 0 ms, $F(2, 201) = 14.67$, $p < .001$, $\eta_p^2 = .180$ and SOA = 114 ms, $F(3. 201) = 9.85$, $p < .001$, $\eta_p^2 = .128$. Both simple main effects were submitted to trend analyses. In the SOA 0 ms condition, the linear trend of distance was significant $F(1, 67) = 25.66$, $p < .001$, $\eta_p^2 = .277$, the quadratic trend was significant $F(1, 67) = 12.68$, $p = .001$, $\eta_p^2 = .159$, but the cubic trend was nonsignificant (p = .909). Šídák corrected pairwise comparisons found significant differences between distance 1 and distance 2 (M = 3.81, SE = .94, p = .001), distance 1 and distance 3 (M = 5.20, SE = .89, p < .001), and distance 1 and distance 4 (M = 4.41, SE = .90, p < .001). For the SOA 114 ms condition, the linear trend of distance was significant $F(1, 67) = 25.88$, $p = .001$, $\eta_p^2 = .279$, but the quadratic trend was nonsignificant (p = .459) and the cubic trend was nonsignificant (p = .863). Šídák corrected pairwise comparisons, for the 114 ms condition, found significant differences between distance 1 and distance 3 (M = 1.90, SE = .53, p = .004), distance 1 and distance 4 (M = 2.39, SE = .52, p < .001), and distance 2 and distance 4 (M = 1.36, SE = .43, p = .014). In examining the simple effects of SOA at each level of distance, Šídák corrected pairwise comparisons found a significant difference between SOA 0 ms and SOA 114 ms at distance 1 (M = 2.37, SE = .803, p = .004), as illustrated in Figure 9.

The three-way interaction of SOA x distance x load (p = .759) was non-significant.

CHAPTER V

Discussion

Müller et al., (2005) found that the distribution of attention followed what they termed a "Mexican hat distribution." This Mexican hat distribution predicts little or no flanker interference when an incompatible flanker is at the second and fourth distances from the target, the most flanker interference when it is at the first distance, and a small amount of interference when it is at the third distance (Müller et al., 2005). With some imagination, one could conceptualize a distribution taking the shape of a sombrero as distances increase in length.

This study examines behavioral evidence for both a monotonically decreasing gradient and a Mexican hat distribution under different conditions. In the present study's data, a Mexican hat distribution would be predicted under high load, as revealed by a cubic trend in the high-load flanker data, with the most distractor interference appearing at a cued location (distance 1), declining in the suppression zone (distance 2), recovering in the distant location (distance 3), and then tapering off again (distance 4). Regarding low load condition in the present study, a gradient pattern should be revealed by a linear trend in the low load flanker data, with the most flanker interference at occurring at distance 1 (Figure 4) and declining through distances 2-4. The low load condition showed a highly significant linear trend, although the quadratic and cubic trends also attained

significance at 114 ms SOA (see Figure 5). Flanker interference decreased as spatial separations increased supporting a gradient model. According to Gaspelin et al. (2014) the declining pattern of flanker interference could be a result of attentional slippage to flanker locations within or across trials, or it could indicate that if attention is fully engaged on the target, due to the cue, there is a declining pattern in density of resource allocation with distance. Gaspelin et al. (2014) state that slippage is more likely in a low load condition perhaps due to the salience of the flanker and not necessarily the set size, per se. However, it is unclear how slippage would account for a Mexican hat distribution unless the further item were somehow more salient.

With regard to the flanker RTs, the pattern of flanker interference in the high load condition of the decomposed distance by load interaction was not significant, but a cubic trend is visually observable in the nonsignificant SOA x distance x load interaction, as seen in the right-hand panel of Figure 7. More data would need to be collected to determine whether this cubic effect would be significant in the high load condition of the three-way interaction. However, the cubic trend at the 114 ms condition in the two-way interaction of distance and SOA was significant. A Mexican hat-type distribution of flanker effects was not predicted for the SOA data, but closer examination shows that the cubic trend resulted from the averaging of low load flanker effects with high load flanker effects, producing the visually apparent rise in flanker interference at distance 3. Comparing the left hand and right hand sides of Figure 7, the rise in flanker interference at distance 3 has its origin in the high load condition. Although the three-way interaction containing this pattern did not quite attain significance, it is possible that more data collection would result in a gradient pattern under low perceptual load and a Mexican hat

distribution under high perceptual load, like the one observed by Caparos and Linnell (2009). In Figure 4, part of that pattern is observed with the high load showing a recovery at distance 4, but no decline after recovery. Perhaps our spatial extent was not enough to observe that second decline or possibly not enough data was collected to observe the effect. It is important to note that the analysis in the study conducted by Caparos and Linnell (2009) only computed RT differences of trials containing incompatible and neutral distractors as a function of distance. It is possible that their participants simply recognized the difference between incompatible and neutral and were able to automatically respond correctly when an incompatible distractor was presented.

Regarding perceptual load theory, the current study indeed found a strong perceptual load effect. Less flanker interference was observed in the high load conditions and more flanker interference was observed in the low load conditions. According to perceptual load theory, more flanker interference in the low load condition would be the result of resource spillover. However, it was also observed that preceuing the target's location by 114 ms significantly reduced the amount of flanker interference observed – especially at distance 2. Perceptual load theory may be underspecified with regard to the distribution of resource spill over. Importantly, perceptual load theory does not predict gradient patterns, which were found in the low load condition. Gaspelin et al. (2014) claim that items further from the focus of attention are less likely to receive attentional focus unless they are highly salient.

Returning to the possibility of the negative compatibility effect, the present study did not produce a significant negative compatibility effect. However, in the nonsignificant three-way interaction of distance, SOA, and load in the flanker data, a

negative compatibility effect is visually observable and, perhaps, if more data were to be collected to increase the statistical power, the negative compatibility effect may emerge. A negative compatibility effect was predicted to be observed in Müller et al.'s (2005) suppression zone where there is less flanker interference. Another reason for a negative compatibility effect in the suppression zone concerns the shifting of receptive fields. Baruch and Yeshurun (2014) suggest the largest impact on visual attention and selection is the shifting of receptive fields. They posit that the certain spatial locations attract attention which causes receptive fields to migrate to the attended location. If this is the case, when the receptive fields migrate, receptive fields become less dense in the location from which they migrated. This could result in less processing at the less-dense location simply because there are less receptive fields to process information. This could explain the suppression zone found in the Mexican hat model.

Conversely, Wyatt and Machado (2013) found a positive relationship between the strength of distractor inhibition and the intensity of that distractor or what they termed the reactive inhibition process. This finding supports the idea that inhibition is deployed reactively with respect to the distractor's intensity. This model would predict that the strongest negative compatibility effect should be observed at the nearest, most intense flanker position. However, the present study's visually apparent negative compatibility effect was contained in a nonsignificant interaction, meaning that the current study cannot offer relevant findings without further data collection.

Finally, important distinctions between the current study and other, previously-mentioned studies should be noted in order to conceptualize important differences between the current study and those completed prior. Müller et al. (2005) always placed

the target at the same location to avoid the splitting or shifting of attention. However, because they set up a paradigm ideal for endogenous cueing, using a constant time-course and predictable target location, they could not observe the distribution of attention in conditions using dynamic cueing of spatial locations. They also suggest that participants may shift attention to the center of a display when relevant information does not turn up at an expected location instead of shifting attention to the next most relevant element in the display. Instead, it is possible that subjects may simply zoom their gaze out in order to scan the visual field looking for the next most relevant area within the display. Therefore, by using a simple hemifield display with a fixed target location to prevent the shifting or splitting of attention, Müller et al. (2005) may have prevented their subjects from zooming out and scanning the environment to find the target. However, with the configuration of their display, one would not need to initially assume a broad focus of attention in order to identify a cued location (Erikson & St. James, 1986) before narrowing the focus of attention to the cued location, as is more typical of attentional control in the natural environment. Conversely, the present study extends the scope of Müller et al.'s study to examine situations combining endogenous with exogenous orienting and different time-courses of covert orienting.

Ultimately, it is important to note the differences between the displays and paradigms created and used by all different studies may affect how attention is distributed. For example, the display sizes of some studies, like Warner et al. (2014), Eriksen and St. James (1986), Gaspelin et al. (2014), and many others are much more compact in size compared to the array used by Müller et al. (2005). Also these studies used dynamically cued target positions rather than a fixed target position. These

differences create multiple factors that may ultimately determine the distribution of attention. An important limitation of the current study is that it lacks a neutral baseline. Instead, incompatible responses were compared to compatible responses in order to measure flanker interference. However, using a compatible flanker for comparison allowed for the possible observation of a negative compatibility effect in the suppression zone, although this was not clearly observed with the number of participants used in this study.

In summary, the current study is an attempt to clarify whether flanker interference declines monotonically with distance under low perceptual load or follows a Mexican hat-like distribution under high perceptual load. It was found that under conditions of low load, attentional selection followed a monotonically decreasing gradient. Overall, flanker effects were much smaller in the high load conditions and larger in low load conditions, supporting perceptual load theory's predictions. However, it was also discovered that precueing the target location by 114 ms significantly reduced RTs in low load conditions and reduced interference coming from flankers at distance two. In subsequent investigations, it would be worthwhile to increase the number of participants within the current study to determine if a Mexican-hat-type distribution would become observable in the high-load condition. In the future, it could also be beneficial to run similar experiments using a neutral baseline for a more complete measurement of flanker effects.

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APPENDIX

Appendix A

Consent Form: Course Credit

HUMAN PARTICIPANT CONSENT FORM

TITLE OF PROJECT: Visual Search and Salience
PRINCIPAL INVESTIGSTOR: Katie Rennie, Dept. of Psychology and Counseling, Pittsburg State University, 1701 S. Broadway, Pittsburg, KS 66762, (620) 235-4980
FACULTY ADVISOR: C. BRUCE WARNER
RESEARCH ASSISTANTS: Riegen Anderson, Courtney Hensler, Emily Loethen, Skyler Morris, Jocelyn Nino, Lucas Roecker
APPROVAL DATE: 2/22/2016
EXPIRATION DATE: 2/22/2017

INFORMED CONSENT

You are invited to participate in a study that is concerned with how rapidly and accurately people can search for an object presented on a computer screen. The experiment is expected to take 1 hour and 15 minutes of your time. During the experiment, you will receive the opportunity for frequent rest breaks and a mandated, intermediate break of 8 minutes. You were chosen for this experiment because you expressed interest in participating.

Your participation in this study is entirely voluntary, and you may withdraw your consent at any time.

PURPOSE OF RESEARCH

The purpose of this research is to investigate the time course of attention to visual objects and to spatial locations.

ALTERNATIVES

These are the alternatives available to you:
1. You could choose to participate in the study.
2. You could choose not to participate in this study.

PROCEDURES AND LENGTH OF STUDY

1. This experiment is expected to require up to 75 minutes (1 hour and 15 minutes) of your time. During the experiment, you will receive frequent rest breaks and a mandated, intermediate rest break of 8 minutes. You will be seated in front of a computer screen where you will place your chin in a chin rest like those found in an optometrist's office. Your job will be to search for letter T tilted 90 degrees to the left or right among other letter shapes. During the activity, you will make 1152 key presses. You will receive the opportunity for a 1 minute rest break after each group of 64 experimental observations. Half way through your participation, you will be required to take an 8-minute break. This is ensure you do not over exert your eyes and for the opportunity to stand and stretch, use facilities, or other necessary activities.

BENEFITS AND RISKS FOR PARTICIPATION

1. The information you provide may have benefits for science because this study will add to basic knowledge of human perception and attention. At the discretion of your instructor, you may receive course credit for your participation.
2. There are no anticipated legal, physical, or psychological risks of participation in this study.
3. **If you have experienced a seizure as a result of viewing flashing or rotating lights or have been advised by a medical professional that you might experience a seizure or other adverse reaction in response to flashing or rotating lights, then you should avoid participation in this study, because you will be exposed to such stimuli.** If you think you have experienced a research-related injury, please call Bruce Warner at 620-235-4980.

COMPENSATION

1. There is no monetary compensation, but you may receive course credit if your instructor provides it.

FREEDOM TO WITHDRAW WITHOUT PREJUDICE

1. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time.
2. At the discretion of the principal investigator, participants may be taken out of this study due to unanticipated circumstances.
3. The principal investigator may take participants out of the study if the study is cancelled.

CONFIDENTIALITY STATEMENT

1. All the data you provide will be kept confidential. A code number associated with your responses will identify you. You will put your name on this confidentiality agreement, which will be stored in locked file cabinets in offices that have limited access so that they are available only to the appropriate professional staff on the project.
2. Any data that may be published in scientific journals will not reveal the identity of participants.
3. Your name will not be associated in any way with the data or with the research findings from this study. Therefore, we will be unable to inform you about your individual performance. The researcher(s) will use a study number instead of your name.
4. The researchers will not share information about you with anyone not specified above unless required by law or unless you give written permission.

INVITATION TO QUESTION

1. If you have any questions, we expect you to ask us. If you have any additional questions later, the faculty advisor, Bruce Warner, will be happy to answer them. Please contact Bruce Warner at (620) 235-4980 or cwarner@pittstate.edu.
2. If you are not satisfied with the manner in which this study is being conducted or if you have any questions concerning your rights as a study participant, please contact Bruce Warner, Ph.D., or Jamie Wood, Ph.D., Department of Psychology and Counseling, Pittsburg State University, 620-235-4523, or Brian A. Peery, Research and Grants Coordinator, 106 Russ Hall, Pittsburg State University, 620-235-4175.

TERMS OF PARTICIPATION

I understand this project is research and that my participation is completely voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at

any time, and stop participating at any time without explanation or loss of academic standing to which I may otherwise be entitled.

I verify by my initials in the blank below that I do not have a history of seizures caused by flashing/moving lights, and that I have not been told by a physician to avoid flashing/moving lights and/or video games due to a risk of seizure.

____
Initials

I verify by my initials in the blank below that I am participating for credit and will NOT receive any monetary compensation.

____
Initials

I verify by my signature below that I have read and understand this consent form and willingly agree to participate in this study under the terms described, and I also acknowledge by my signature that I have received a signed and dated copy of this consent form.

____
Printed Name of the Participant

______________________________ ____________
Signature of Participant Date

____________________________________ ____________
Signature of Witness (Project Staff) Date

Appendix B

Consent Form: Monetary Compensation

HUMAN PARTICIPANT CONSENT FORM (MONETARY COMPENSATION)

TITLE OF PROJECT: Visual Search and Salience
PRINCIPAL INVESTIGSTOR: Katie Rennie, Dept. of Psychology and Counseling, Pittsburg State University, 1701 S. Broadway, Pittsburg, KS 66762, (620) 235-4980
FACULTY ADVISOR: C. BRUCE WARNER
RESEARCH ASSISTANTS: Riegen Anderson, Courtney Hensler, Emily Loethen, Skyler Morris, Jocelyn Nino, Lucas Roecker
APPROVAL DATE: 2/22/2016
EXPIRATION DATE: 2/22/2017

INFORMED CONSENT

You are invited to participate in a study that is concerned with how rapidly and accurately people can search for an object presented on a computer screen. The experiment is expected to take 1 hour and 15 minutes of your time. During the experiment, you will receive the opportunity for frequent rest breaks and a mandated, intermediate break of 8 minutes. You were chosen for this experiment because you expressed interest in participating.

You will receive a check for $25, which will be mailed to you by the State of Kansas after your information has been processed. To be clear, you will not receive a check unless you complete the session in an acceptable manner. We cannot use incomplete data sets.

Your participation in this study is entirely voluntary, and you may withdraw your consent at any time.

PURPOSE OF RESEARCH

The purpose of this research is to investigate the time course of attention to visual objects and to spatial locations.

ALTERNATIVES

These are the alternatives available to you:

3. You could choose to participate in the study.
4. You could choose not to participate in this study.

PROCEDURES AND LENGTH OF STUDY

2. This experiment is expected to require up to 75 minutes (1 hour and 15 minutes) of your time. During the experiment, you will receive frequent rest breaks and a mandated, intermediate rest break of 8 minutes. You will be seated in front of a computer screen where you will place your chin in a chin rest like those found in an optometrist’s office. Your job will be to search for letter T tilted 90 degrees to the left or right among other letter shapes. During the activity, you will make 1152 key presses. You will receive the opportunity for a 1 minute rest break after each group of 64 experimental observations. Half way through your participation, you will be required to take an 8-minute break. This

is ensure you do not over exert your eyes and for the opportunity to stand and stretch, use facilities, or other necessary activities.

BENEFITS AND RISKS FOR PARTICIPATION

4. The information you provide may have benefits for science because this study will add to basic knowledge of human perception and attention. In addition, you will receive $25.00 upon completion of the experiment. If you still desire to withdraw from the experiment, you will not receive any monetary compensation due to the incomplete data set being unusable.
5. There are no anticipated legal, physical, or psychological risks of participation in this study.
6. **If you have experienced a seizure as a result of viewing flashing or rotating lights or have been advised by a medical professional that you might experience a seizure or other adverse reaction in response to flashing or rotating lights, then you should avoid participation in this study, because you will be exposed to such stimuli.** If you think you have experienced a research-related injury, please call Bruce Warner at 620-235-4980.

COMPENSATION

2. There is a monetary compensation of $25.00 for your participation in this investigation. You reserve the right to withdraw your consent from participation at any time. However, if you do not complete the entire experiment you will not receive the monetary compensation due to the incomplete data set being unusable.
3. **Checks will be mailed out from Topeka by the State of Kansas to address on the W9 after they have been processed by the business office. Allow 2-4 weeks for this to happen.**

FREEDOM TO WITHDRAW WITHOUT PREJUDICE

4. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time.
5. At the discretion of the principal investigator, participants may be taken out of this study due to unanticipated circumstances.
6. The principal investigator may take participants out of the study if the study is cancelled.

CONFIDENTIALITY STATEMENT

5. All the data you provide will be kept confidential. A code number associated with your responses will identify you. You will put your name on this confidentiality agreement, which will be stored in locked file cabinets in offices that have limited access so that they are available only to the appropriate professional staff on the project. The Federal W-9 and Independent Contractor form that you complete will be quickly transferred to the department secretary for processing and stored securely. Our project staff will no longer have access to it.
6. Any data that may be published in scientific journals will not reveal the identity of participants.
7. Your name will not be associated in any way with the data or with the research findings from this study. Therefore, we will be unable to inform you about your individual performance. The researcher(s) will use a study number instead of your name.
8. The researchers will not share information about you with anyone not specified above unless required by law or unless you give written permission.

COMPENSATION OR MEDICAL TREATMENT AVAILABLE IF INJURY OCCURS

Only applies in research where more than minimal risk is involved.

In the event of injury, the Kansas Tort Claims Act provides for compensation if it can be demonstrated that the injury was caused by the negligent or wrongful act or omission of a state employee acting within the scope of his/her employment.

INVITATION TO QUESTION

3. If you have any questions, we expect you to ask us. If you have any additional questions later, the faculty advisor, Bruce Warner, will be happy to answer them. Please contact Bruce Warner at (620) 235-4980 or cwarner@pittstate.edu.
4. If you are not satisfied with the manner in which this study is being conducted or if you have any questions concerning your rights as a study participant, please contact Bruce Warner, Ph.D., or Jamie Wood, Ph.D., Department of Psychology and Counseling, Pittsburg State University, 620-235-4523, or Brian A. Peery, Research and Grants Coordinator, 106 Russ Hall, Pittsburg State University, 620-235-4175.

TERMS OF PARTICIPATION

I understand this project is research and that my participation is completely voluntary. I also understand that if I decide to participate in this study, I may withdraw my consent at any time, and stop participating at any time without explanation or loss of academic standing to which I may otherwise be entitled.

I verify by my initials in the blank below that I do not have a history of seizures caused by flashing/moving lights, and that I have not been told by a physician to avoid flashing/moving lights and/or video games due to a risk of seizure.

____
Initials

I verify by my initials in the blank below that I will receive a check for $25 ONLY if I complete the experiment. If I fail to complete it for any reason, I will not be entitled to compensation. This is because incomplete data sets are useless to the researcher.

____
Initials

I verify by my signature below that I have read and understand this consent form and willingly agree to participate in this study under the terms described, and I also acknowledge by my signature that I have received a signed and dated copy of this consent form.

____
Printed Name of the Participant

____ ____________
Signature of Participant Date

____ ____________
Signature of Witness (Project Staff) Date

Appendix C

Debriefing Sheet

VISUAL SEARCH AND SALIENCE DEBRIEFING

This experiment is intended to investigate the effects of stimulus salience in visual search. In this context, salience means that one stimulus stands out from others based upon some important difference such as its shape, brightness, color, or movement. Recent research has called into question whether stimulus salience can restrict attention to just the salient item.

In our experiment, we are examining the time course and spatial limits of salience effects. To investigate salience effects we asked you to view an array of shapes. One of the shapes was made more salient by virtue of the fact that it was cued by four dots and was a different color. We then measured your ability to attend to the salient item and ignore distracting items by repeatedly measuring your response time to the cued item.

We were not interested in your individual performance on any of these tasks, and we will not be able to tell you how you scored as an individual. Rather, we were interested in the average response times of the group. The full results of this experiment will likely not be available for several weeks. We hope the data will contribute to the growing body of literature concerning the effects of stimulus salience.

We sincerely thank you for your participation in our study. Should you have any questions concerning the study, or are curious about the research findings, please contact the faculty advisor, Bruce Warner, Ph.D., Department of Psychology and Counseling, Pittsburg State University, at 620-235-4980 or by email at cwarner@pittstate.edu. If you are not satisfied with the manner in which this study is being conducted or if you have any questions concerning your rights as a study participant, please contact Bruce Warner, Ph.D., or Jamie Wood, Ph.D., Department of Psychology and Counseling, Pittsburg State University, 620-235-4523, or Brian A. Peery, Research and Grants Coordinator, 106 Russ Hall, Pittsburg State University, 620-235-4175.

Appendix D

Researcher Opportunity Advertisement

RESEARCH OPPORTUNITY, EARN $25

You are invited to participate in an experiment conducted by Dr. Warner's Human Factors and Perception Lab. Participants will receive a $25 check for their service.

Your participation will help out a graduate student collecting her thesis data.

The experiment consists of **one session requiring an estimated 1:15 minutes**. During the session, you will make 1152 observations of visual stimuli and indicate choices by clicking one of two buttons. The task is similar to a simple video game. Frequent rest breaks will provided, plus an additional mandatory rest break of 8 minutes mid-session.

Due to the length of this experiment, **participants completing the session will receive a check for $25**. You will be required to fill out the necessary tax form (Federal W-9) for our accounting department in order to receive the check. If you choose not to complete the session, we cannot offer any compensation due to your data set being unusable.

In order to participate you must meet all of the following requirements:
(1) Be at least 18 years of age and no more than 35 years old
(2) Have normal (20/20) vision unaided or while wearing glasses or contacts
(3) Have no history of a seizure disorder or seizures provoked by flashing lights
(4) Have no history of ADHD
(5) Be a United States citizen to earn $25 (This requirement is due to the additional paperwork required to pay resident and non-resident aliens.)

If you wish to participate and meet the selection criteria above, please go to hfplab.youcanbook.me and choose an available time.

We will be running until the end of the semester and will post new slots periodically. Try back if there is no availability. ***Be aware that funds are limited, and when these run out, we not be able to accept any further participants for monetary compensation. So, reserve your session soon.***

Sign up at hfplab.youcanbook.me

Figure 1

Sample displays seen by participants for high and low load.

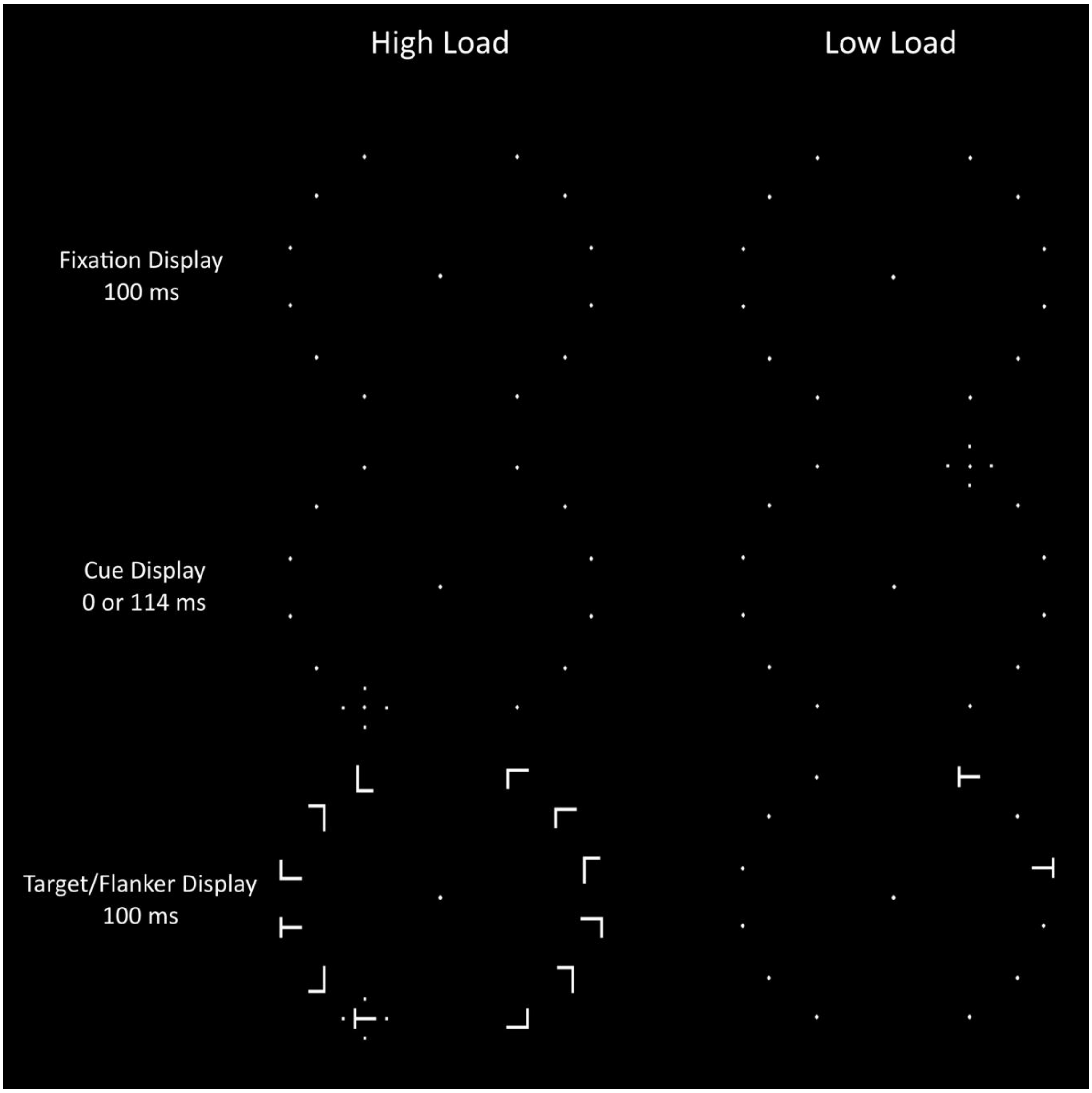
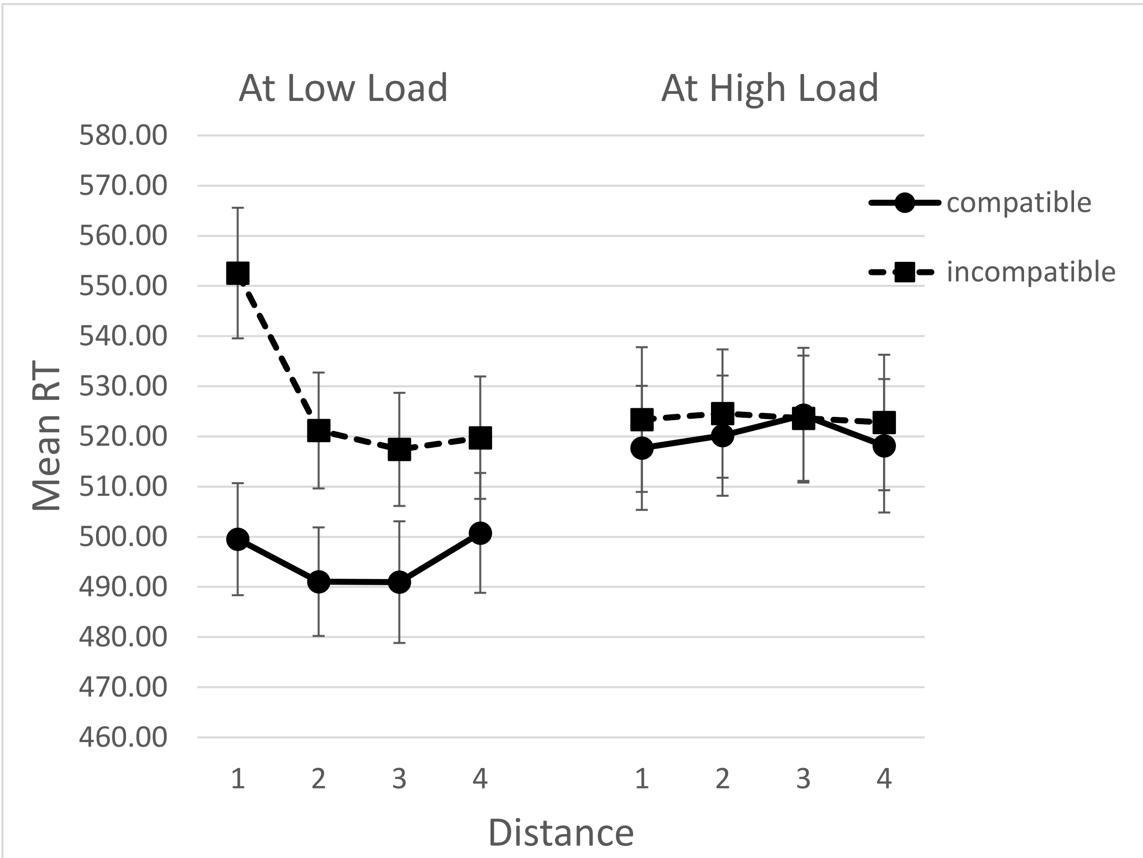


Figure 2

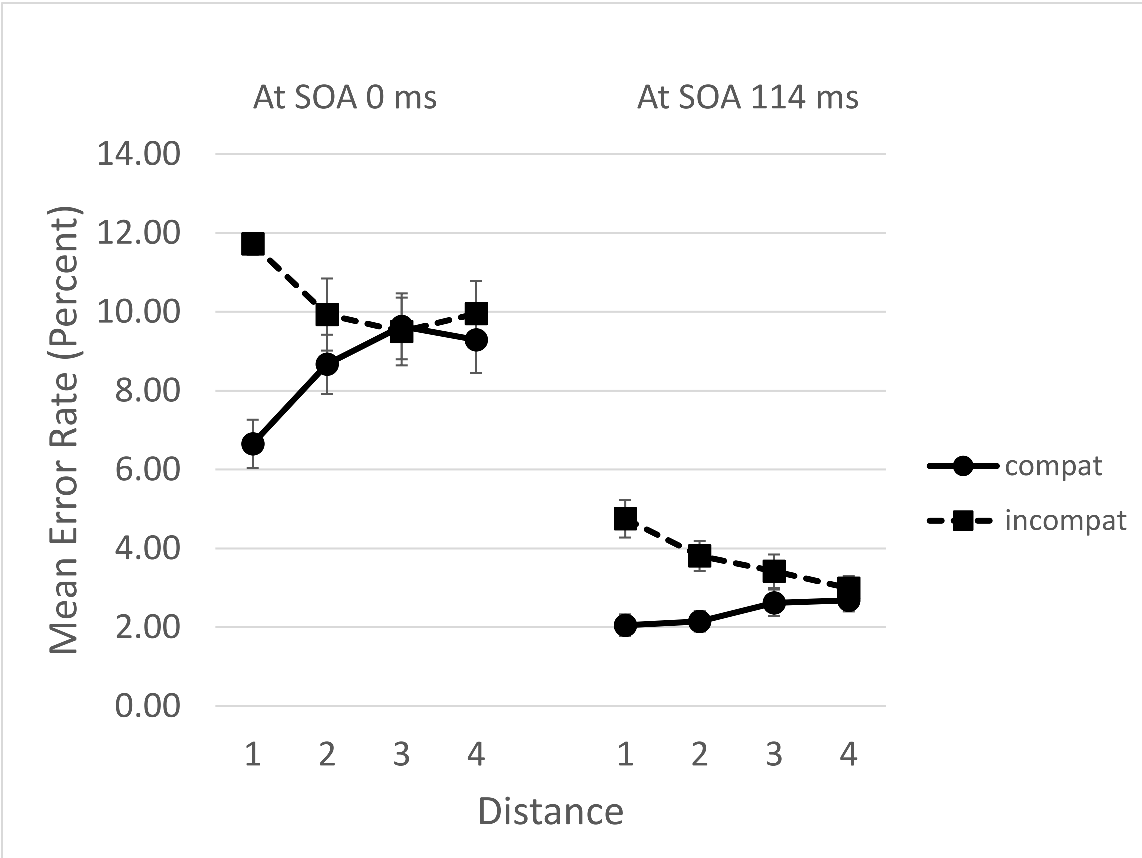
Raw RT Effects: distance x flanker compatibility x load.



Note: Significant three-way interaction of distance x flanker compatibility x load. Error bars are ± 1 SEM.

Figure 3

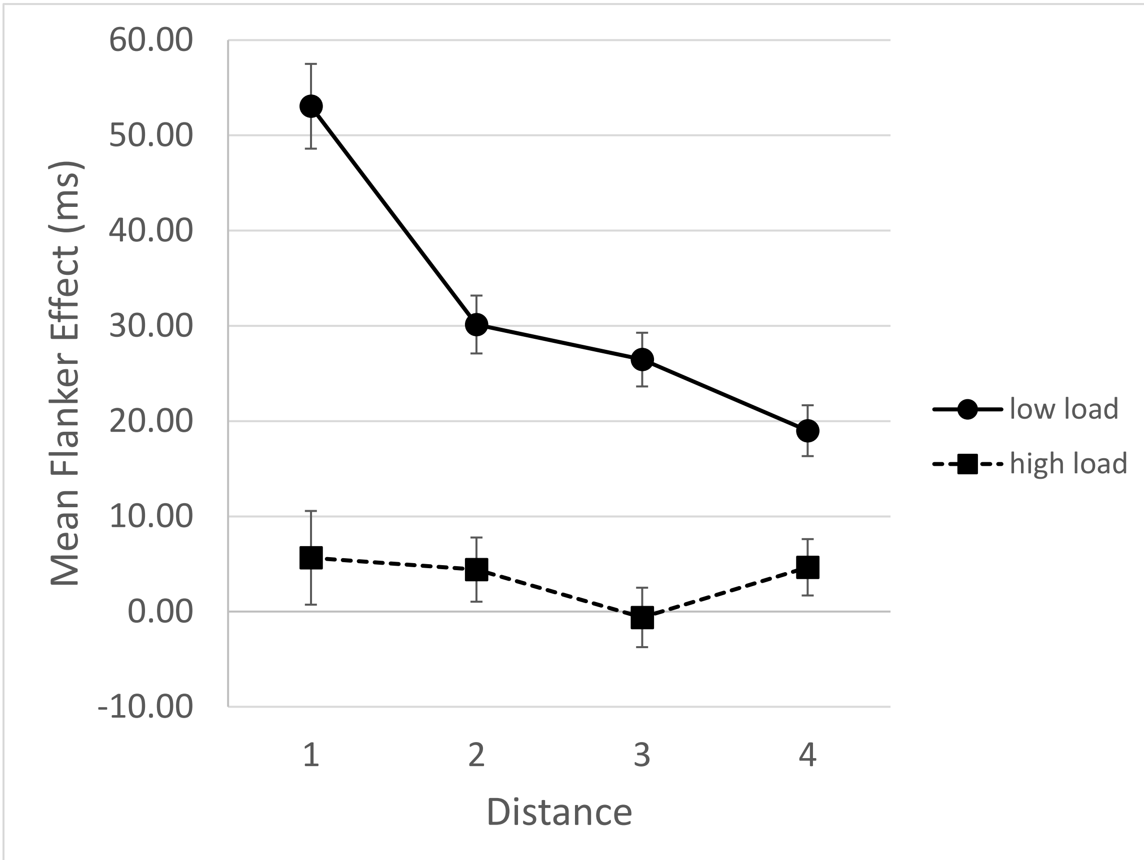
Raw Error: SOA x distance x flanker compatibility



Note: Significant three-way interaction of SOA x distance x flanker compatibility. Error bars are ± 1 SEM.

Figure 4

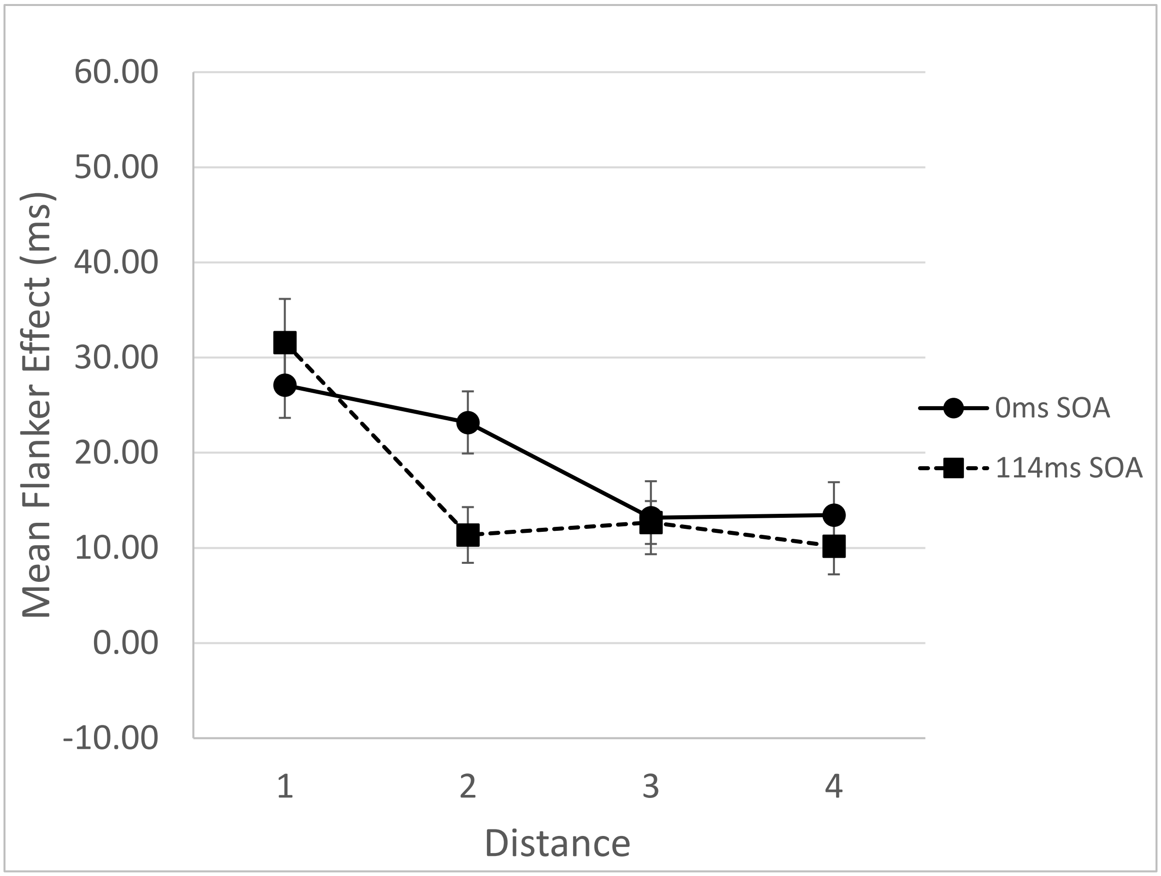
Flanker RT: Distance x load



Note: Significant two-way interaction of distance x load. Error bars are ± 1 SEM.

Figure 5

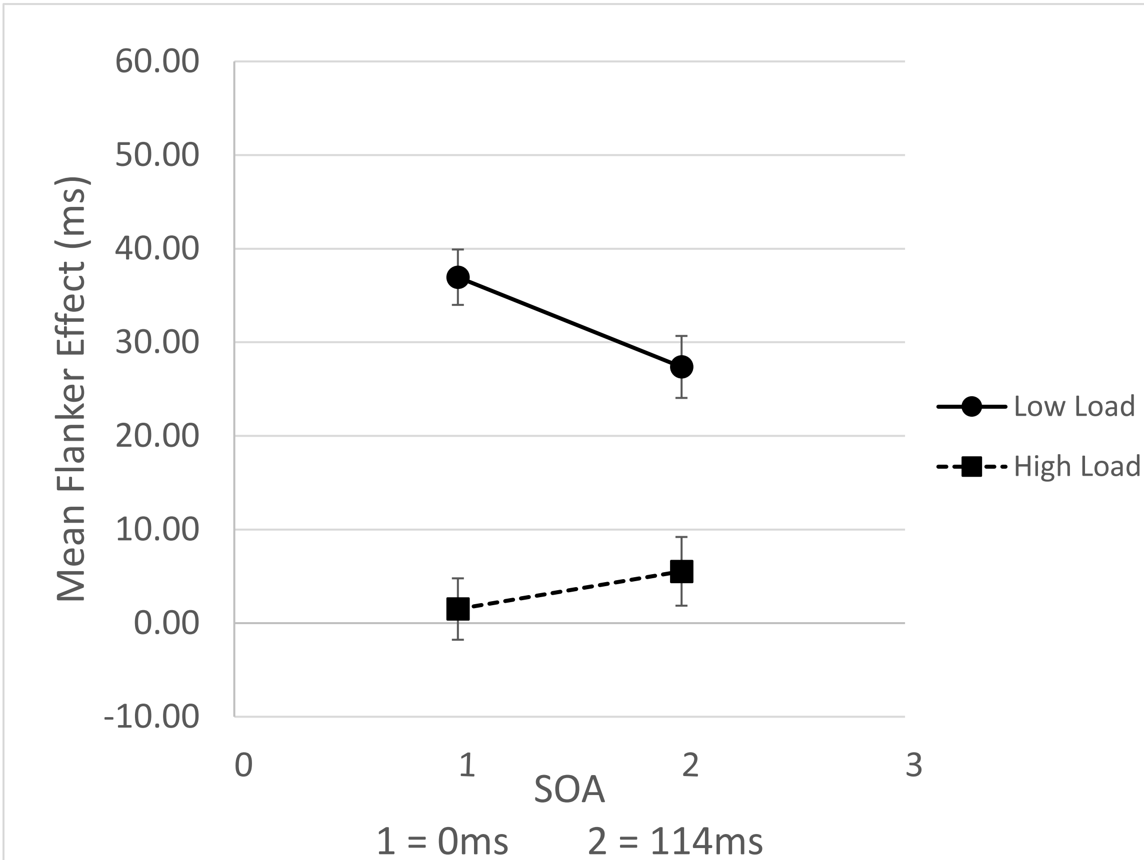
Flanker RT: Distance x SOA



Note: Significant two-way interaction of distance x SOA. Error bars are ± 1 SEM.

Figure 6

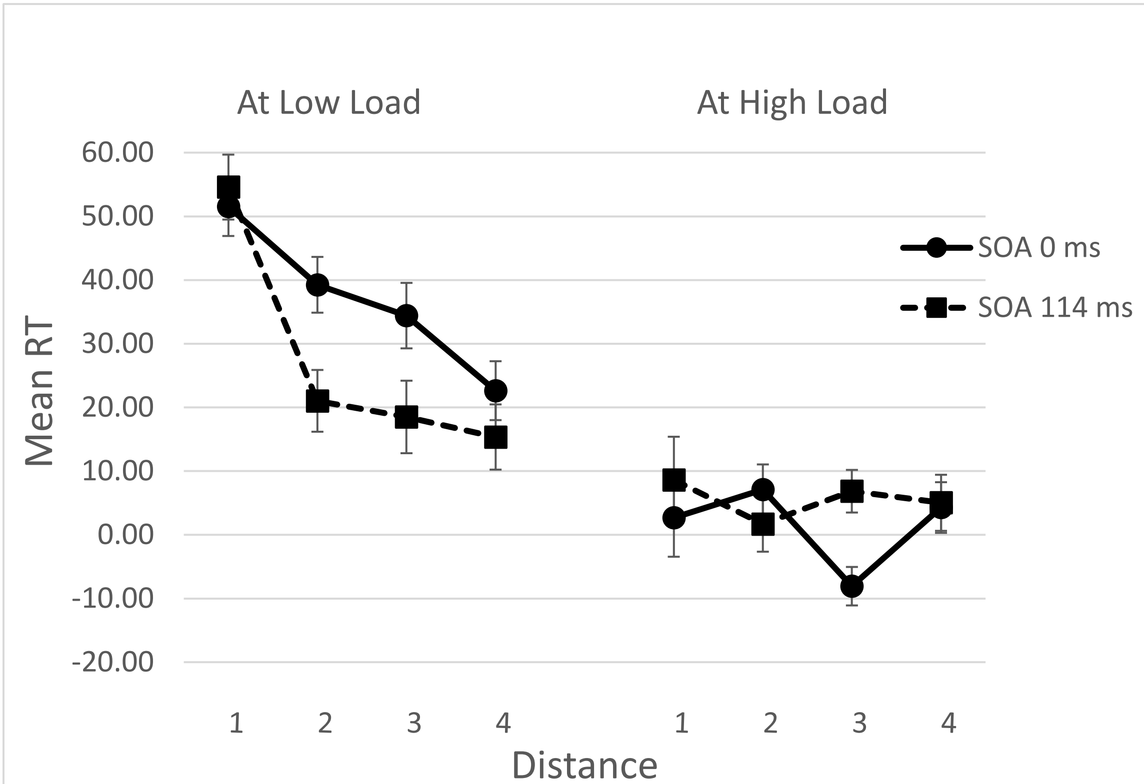
Flanker RT: SOA x load



Note: Significant two-way interaction of SOA x load. Error bars are ± 1 SEM.

Figure 7

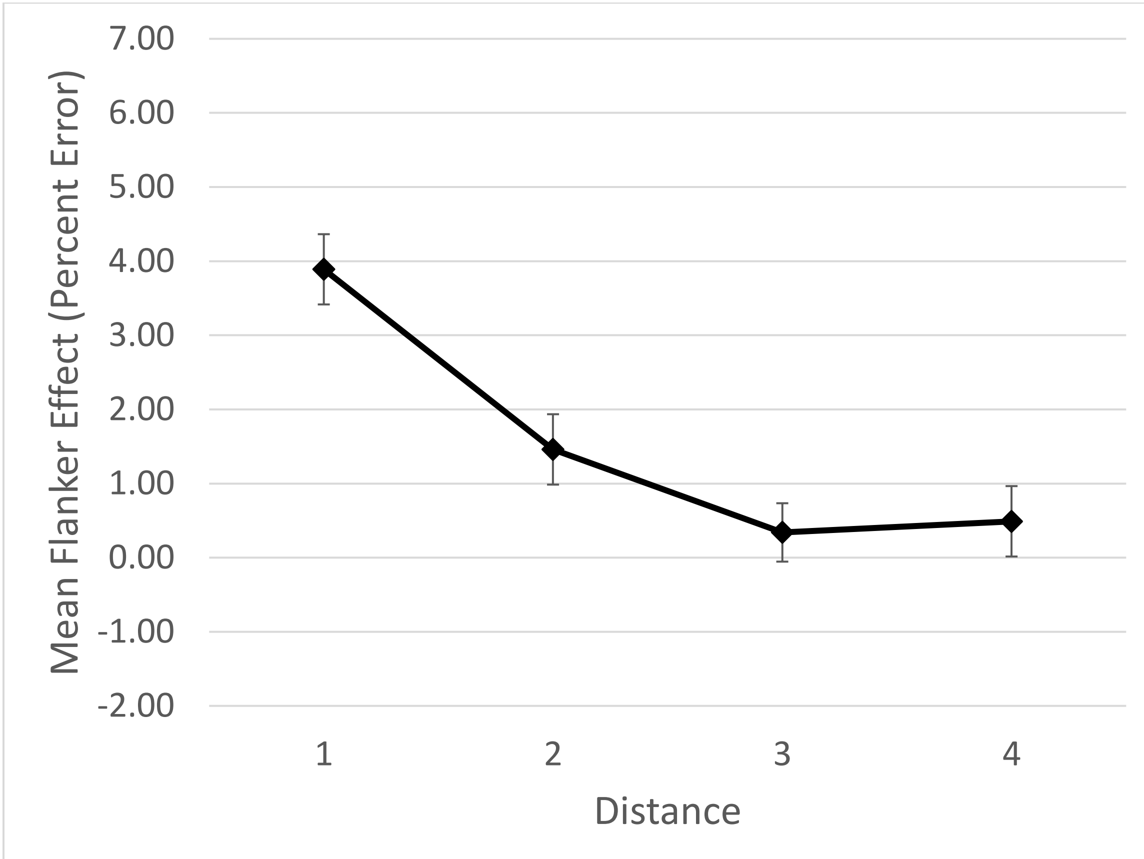
Flanker RT: SOA x distance x load



Note: Nonsignificant three-way interaction of SOA x distance x load. Error bars are ± 1 SEM.

Figure 8

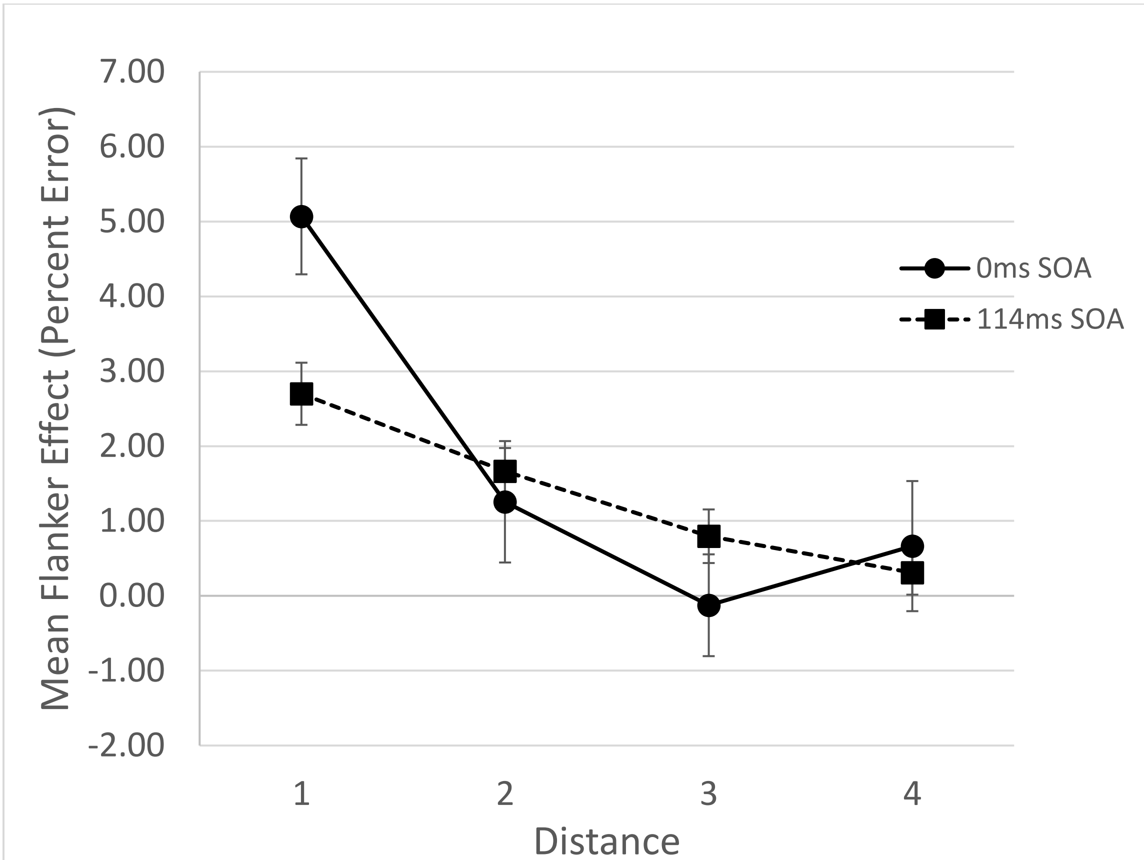
Flanker Error: Distance



Note: Significant main effect of distance. Error bars are ± 1 SEM.

Figure 9

Flanker Error: SOA x distance



Note: Significant two-way interaction of SOA x distance. Error bars are ± 1 SEM.

Table 1

Visual Angle measurements for all stimuli

	Degrees of Visual Angle
Placemarker and Fixation Dots	Width: 0.11° Height: 0.11°
T and L Stimuli	Width: 0.79° Height: 0.63°
Spot Cue	Width: 1.05° Height: 0.79°
Spotcue Spot Size	Width: 0.05° Height: 0.05°
Array Radius	4.7°
Target to Flanker Midpoint to Midpoint Distances	1.8°, 3.4°, 4.9°, and 6.2°