

TESTING THE “INTERRUPT HYPOTHESIS”:  
DOES STARTLE DISRUPT COGNITIVE PROCESSING?

BY

J. ZACHARY REYNOLDS

A Thesis Submitted to the Graduate Faculty of

WAKE FOREST UNIVERSITY GRADUATE SCHOOL OF ARTS AND SCIENCES

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF ARTS

Psychology

December 2012

Winston-Salem, North Carolina

Approved By:

Terry D. Blumenthal, Ph.D., Advisor

James A. Schirillo, Ph.D., Chair

Janine M. Jennings, Ph.D.

Paul J. Laurienti, M.D., Ph.D.

## ACKNOWLEDGMENTS

I dedicate this manuscript to my mentor and advisor, Dr. Terry D. Blumenthal. This would not have been possible without his unyielding support, guidance, and patience. He has taught me a great deal about the startle reflex and how physiological measurements can give great insight into psychological processes. His approach to mentorship and teaching, as well as his dedication to the scientific method and the pursuit of truth, are truly inspirational.

**TABLE OF CONTENTS**

1. LIST OF FIGURES.....	iv
2. LIST OF ABBREVIATIONS .....	v
3. ABSTRACT.....	vi
4. INTRODUCTION.....	1
5. METHODS.....	24
6. RESULTS.....	31
7. DISCUSSION .....	50
8. REFERENCES.....	66
9. APPENDIX .....	72
10. CURRICULUM VITAE .....	73

## LIST OF FIGURES

Figure	Page
1.	(a) The four cue conditions; (b) The three congruency conditions ..... 15 in the original ANT (Fan et al., 2002)
2.	A typical trial with presentation of a spatial-cue, an acoustic startle ..... 15 stimulus, and a target with congruent flankers
3.	The experimental design matrix in which target location and direction ..... 26 have been collapsed. Each cell contains four trials, and 16 startle-alone trials were presented randomly throughout each block
4.	Startle stimulus by cue interaction on reaction time ..... 32
5.	Startle by congruency interaction for RT ..... 34
6.	A marginally significant cue by congruency interaction for RT ..... 36
7.	Cue by congruency interaction for accuracy ..... 37
8.	Three-way interaction for block by startle stimulus by congruency for ..... 39 accuracy
9.	Main effect of block for blink magnitude (i.e. habituation of the startle ..... 42 response)
10.	Marginally significant main effect of cue type for blink magnitude ..... 42
11.	Main effect of block for blink probability (i.e., habituation of the startle ..... 43 response)
12.	Main effect of cue for blink probability ..... 44
13.	Main effect of block for blink onset latency ..... 45
14.	Main effect of cue for blink onset latency ..... 46
15.	Main effect of cue for PPI of response magnitude ..... 47
16.	Main effect of cue for PPI of blink probability ..... 48
17.	Main effect of cue for PPI of blink onset latency ..... 49

## LIST OF ABBREVIATIONS

ADHD – Attention Deficit Hyperactivity Disorder

ANOVA – Analysis of Variance

ANT – Attention Networks Test

ASE – Accessory Stimulus Effect

CI – Confidence Interval

cm – Centimeter

dB – Decibels

EEG – Electroencephalogram

EMG – Electromyographic

fMRI – Functional Magnetic Resonance Imaging

GABA – Gamma-Aminobutyric Acid

Hz – Hertz

ITI – Intertrial Interval

IC – Inferior Colliculus

kHz – kiloHertz

*M* – Mean

$\mu$ V – Microvolt

ms – Millisecond

OOb – Orbicularis Oculi

PnC – Nucleus Reticularis Pontis Caudalis

PPI – Prepulse Inhibition

PPTg – Pedunculopontine Tegmental Nucleus

RT – Reaction Time

SC – Superior Colliculus

*SE* – Standard Error

SOA – Stimulus Onset Asynchrony

J. Zachary Reynolds

TESTING THE “INTERRUPT HYPOTHESIS”:

DOES STARTLE DISRUPT COGNITIVE PROCESSING?

Thesis under the direction of Terry D. Blumenthal, Ph.D., Professor of Psychology

The startle response is an automatic, defensive reflex that occurs in response to sudden transient change in the environment, and is characterized by physiological activity including muscle contraction in the face, neck, and shoulders. Prepulse inhibition (PPI) occurs when a stimulus is presented shortly before a startle stimulus resulting in attenuation of the response. Graham (1975) proposed the Interrupt and Protection Hypotheses to explain the role of PPI, positing that PPI occurs to protect processing of a prepulse from the disrupting effect of the startle response. Although these hypotheses have been assumed in the literature for several decades, little empirical support exists to justify the claim. The present study sought to address the Interrupt and Protection Hypotheses by combining the Attention Networks Test (ANT), a combined flanker and cue reaction time task that measures the efficiency of several attentional networks, with the startle paradigm. Startle stimuli were presented in the interval between the onset of the visual cue and the onset of the target and results were compared to control trials during which no startle stimulus was presented. No evidence was found to support the Interrupt Hypothesis, and since no interruption occurred, the Protection Hypothesis could not be evaluated.

## INTRODUCTION

The startle reflex is an automatic, defensive reflex that occurs in response to sudden, intense stimuli. It is characterized by a series of physiological responses including muscle contractions in the face, neck, shoulders, and skeletal muscles (Koch, 1999). Although the startle response and its elicitation are interesting phenomena, the modification of the startle reflex by extraneous stimuli and task demands is of most interest to psychophysicologists and has the greatest potential for practical application. The startle response was one of the earliest studied reflexes in the context of its implications for psychological processes with investigation into the underlying processes, functionality, and modification going back at least to the 1860s by Ivan Sechenov, a Russian physiologist (Hoffman, 1999). Unfortunately, the startle response did not enjoy immediate widespread popularity and remained relatively obscure until its modern resurgence in Frances Graham's presidential address to the Society of Psychophysiological Research in 1974. Graham's address highlighted the findings of recent investigations in her lab showing that the startle reflex and its modification could be used to investigate a much wider variety of psychological topics and lines of inquiry than previously supposed. In the last 35 years since this seminal event in the history of startle research, the startle response and its modification have been used to investigate questions regarding attention, emotion, cognition, psychological disorders, and the effects of various psychoactive substances.

The purpose of this thesis is to provide a brief literature review of the current knowledge regarding the startle response and to present findings from an original study that combined the startle paradigm with a computerized cognitive task, the Attention

Networks Test, to investigate whether or not startle interrupts cognitive processing. The Interrupt Hypothesis, proposed by Graham in 1974, has been largely assumed in the literature for several decades, though there is inadequate empirical support to justify the claim. This thesis aims to address the Interrupt Hypothesis by integrating previous research studies with the findings of an original research study conducted by the author. A summary of the basics of startle research will be discussed first to provide context for the primary impetus of this thesis.

### **The Startle Paradigm**

The startle response can be elicited with a number of different techniques, including presentation of auditory stimuli, cutaneous stimuli such as an air-puff to the face, electrical stimulation of the trigeminal nerve, or a physical tap to the glabella (forehead), or with visual stimuli (Berg & Balaban, 1999). Despite the variety of possible methods to elicit the startle response, the most commonly employed method by modern researchers is auditory elicitation with response measurement of electromyographic (EMG) activity in the orbicularis oculi muscle (OOc). The OOc is the muscle surrounding the eye that is responsible for eyelid closure. The advantages of this particular methodology are its relative ease of administration, noninvasiveness, and reliability. Whereas other methods may require more expensive equipment and/or simply measure the physical closing of the eyelid (as in the use of micropotentiometer or photoelectric measures), OOc EMG measurements are sensitive to weak activation of the muscle that may not be sufficient to cause eyelid closure (Blumenthal et al., 2005). In addition, EMG recording provides real-time levels of muscle activity and its subcomponents with millisecond accuracy.

A typical study measuring OOc EMG responses proceeds as follows. The participant is invited into the lab where EMG electrode and participant preparation begins. Because the electrical signals are relatively small in the OOc muscle (typically below 200  $\mu\text{V}$ ), it is very important to reduce the impedance between the skin and electrode in order to maximize detection of the electrical impulse produced by the muscle (Blumenthal et al., 2005). To obtain optimal recording of muscle activity, skin at the electrode site is first cleaned with an alcohol-soaked swab of cotton or gauze with a moderate degree of friction in order to remove any oils, makeup, or dead skin cells that may reduce the conductance of the signal. An adhesive electrode is then filled with conductive paste to carry the signal from the surface of the skin to the metal surface inside the electrode. For measurement of OOc muscle activation, two electrodes are placed directly below the lower eyelid on the skin overlaying the OOc, one beneath the pupil with the second a short distance (1 cm or less) laterally. A third, ground, electrode is usually placed on the temple, though it is sometimes placed on the forehead or mastoid. EMG is a differential measurement, in which the signal from one electrode is subtracted from the signal of the other, and any common activity received by both is rejected. With OOc EMG recording, properties of the blink, including probability, magnitude, onset latency, and amplitude can be measured and analyzed. As Blumenthal et al. (2005) note, although this methodology is good for excluding extraneous noise in the signal, it is important that participants be tested in as electrically neutral of an environment as possible. The use of a Faraday caged room and the exclusion of equipment with high levels of electromagnetic noise from the testing environment are highly recommended to achieve optimal measurements and reduce environmental noise.

After participant and electrode preparation, the next most important aspect of collecting valid and reliable data is definition of the stimulus parameters. Blink startle elicitation can be affected by subtle changes in intensity, rise time, duration, and bandwidth of the startle eliciting stimulus, as well as the inter-trial interval (ITI) and the number of trials presented during the session, so these parameters should be tightly controlled (Blumenthal et al., 2005). For bandwidth of an acoustic startle stimulus, research has shown that white noise (consisting of all the frequencies between 20 Hz and 20 kHz) is more effective than using pure tones, and thus white noise is the most commonly used eliciting stimulus. More intense startle stimuli also tend to produce responses with greater magnitude, amplitude, and probability, and shorter onset latency. Experimental evidence has shown that a startle response as measured by EMG activity of the OOc can be elicited with stimuli as quiet as 50 dB, but other studies show that the probability of eliciting a response drops below 50% around 85 dB. For this reason, most studies employ startle stimuli of approximately 100 dB (Blumenthal et al., 2005). This level of sound produces consistent startle responses as measured by OOc activity while minimizing participant discomfort and anxiety.

Rise time, or the amount of time it takes for the stimulus to reach full intensity, is another important consideration as a startle stimulus parameter, since the startle reflex is known (and defined) to be sensitive to sudden, transient changes in the environment (Graham, 1978). Stimuli with short or instantaneous rise times lead to responses with greater magnitude, probability, and amplitude, and a shorter onset latency when compared with stimuli with longer rise times. If rise times are too long, the transient change will not be sufficient to elicit a response even if the intensity of the stimulus

would have otherwise produced a response. Blumenthal (1988) found that startle stimuli of an intensity near the threshold of eliciting responses (80 and 85 dB) were particularly susceptible to variations in rise time. By presenting stimuli with rise times of 2.5 ms, 10 ms, and 25 ms, Blumenthal (1988) showed that longer rise times were associated with significantly lower response amplitude and probability, and greater onset latency.

Stimuli with longer durations also tend to elicit responses with greater probability and magnitude until the effect reaches asymptote at 50 ms, reflecting temporal summation of the auditory stimulus sufficient to elicit a response (Blumenthal & Berg, 1986). Therefore, the most commonly used duration for startle eliciting acoustic stimuli is 50 ms. This duration is generally sufficient to evoke the reflex while avoiding complete overlap with the response since blink onset latency is typically between 21-120 ms for blinks elicited by acoustic stimuli (Blumenthal et al., 2005).

### **Prepulse Inhibition (PPI)**

As previously mentioned, one of the most interesting aspects of the startle response is its amenability to modification by other stimuli in the local environment. Prepulse inhibition (PPI), in which a less intense stimulus presented shortly before the startle stimulus attenuates the response, is perhaps the most widely studied modulator of the startle reflex (Blumenthal, 1999). PPI occurs even on the first instance of the two stimuli occurring in sequence, which shows that it is automatic and not a learned response. Furthermore, PPI does not occur as a result of sensory masking, “refractoriness,” or lead stimulus induced muscle activity in the middle-ear. Prepulses can be presented as auditory, vibrotactile, and visual lead stimuli, affecting the startle response across modalities.

As is the case with parameters of the startle stimulus itself, the degree to which PPI occurs is determined by the parameters of the prepulse and its relation to the startle stimulus. Such parameters include the lead interval, duration, intensity, rise time, and modality. Lead interval, or the time between the onset of the prepulse and the onset of the startle stimulus, is one of the primary factors determining how the prepulse will affect the response. It has been shown through repeated testing that maximal inhibition for acoustic prepulses occurs around 120 ms (in the range between 60 ms and 240 ms), and when prepulses are presented outside this range the amount of inhibition decreases (Blumenthal, 1999). Studies on the effects of lead stimulus duration consistently show that inhibition increases as prepulse duration increases until it reaches a maximum between 20 and 50 ms. For intensity, more intense prepulses generally lead to greater startle inhibition, though there comes a point where prepulses become intense enough to elicit the startle response. In order to circumvent this, researchers can minimize the probability of eliciting a startle response with the prepulse by manipulating rise time. The rise time itself has not been shown to differentially affect the following startle response or the degree of inhibition (Blumenthal, 1999).

There are three main theories that are widely accepted to explain the function of prepulse inhibition, and as Blumenthal (1999) notes, “this phenomenon may have more than one function, so alternative explanations are not necessarily contradictory, exhaustive, or mutually exclusive” (pp. 64-65). These three theories are the Sensory Gating Hypothesis, the Protection of Preattentive Processing Hypothesis, and the Attentional Hypothesis, of which the last two are most important in the context of this paper.

The Protection of Preattentive Processing Hypothesis was first proposed by Graham in her seminal 1975 paper. This theory states that two automatic processes occur when a lead stimulus is presented in conjunction with a startle stimulus. The first process is identification of the lead stimulus and the second is inhibition of the startle response in order to protect the processing of the prepulse from the interrupting effects of the startle reflex. The Protection Hypothesis is partly based on the assumption that the startle response would disrupt processing of the prepulse if not for the protective effect of PPI. The purpose of the original study conducted by the author and discussed later in this manuscript was to evaluate the Interrupt Hypothesis.

The Attentional Hypothesis is an extension of the Protection Hypothesis, and asserts that controlled attentional processing of the prepulse impacts the degree of PPI and the startle response (Blumenthal, 1999). Filion, Dawson, and Schell (1993) investigated the role of attention on PPI by instructing participants to attend to certain auditory tones presented as prepulses and to ignore others. They found that both the ignored and attended prepulses inhibited the startle response, but there was more pronounced PPI for the attended prepulses presented at a stimulus onset asynchrony (SOA) of 120 ms. This finding shows that even though PPI occurs as an automatic process, it can be further modulated with the influence of controlled attention (Blumenthal, 1999).

The Sensory Gating hypothesis explains inhibition of startle as reducing the processing of repetitive or irrelevant stimuli in order to minimize distraction. This theory has been supported by the finding that patients with certain disorders such as schizophrenia, Huntington's disease, obsessive compulsive disorder, and Tourette's

syndrome all share PPI deficits, as well as the symptom of inability or difficulty in ignoring irrelevant stimuli in the environment. Interestingly, deficits in PPI have not been found for one of the most common attentional disorders, ADHD, implying that PPI is not necessarily a distinguishing feature of attentional dysregulation (Feifel, Minassian, & Perry, 2009).

### **The Physiology and Neural Correlates of Startle and PPI**

The majority of studies examining the physiology and neural correlates of startle have been conducted with rats and mice. Since the acoustic startle reflex has been found to be similar in mammals and elicited with the same stimulus parameters, these neuronal mechanisms in lower animals are assumed to be analogous to those in the human brain (Koch, 1999). Although the specific structures and mechanisms are still under investigation, it is thought that the primary structures involved in the acoustic startle response are neurons in the cochlear root, nucleus reticularis pontis caudalis (PnC), and motoneurons in the facial motor nucleus or the spinal cord (for the pinna reflex and whole body startle in rats, respectively; Davis, Walker, & Lee, 1999). The PnC is thought to be one of the most important brain areas involved in the startle reflex since it is both the mediator of the startle response as well as the center of reception from other areas of the brain that modulate the response, including aversive stimuli and prepulses (Koch, 1999). The key neurotransmitters involved in the startle reflex are glutamate, GABA, and glycine, where glutamate is excitatory, GABA is inhibitory, and glycine is inhibitory in the motor neurons in the spinal cord, but not in the PnC (Koch, 1999).

The neural components of PPI are less well understood than those of the startle response itself, though progress has been made in recent years. PPI is the result of

primarily automatic processes occurring in the midbrain, since it can be observed in sleeping humans as well as rats that have undergone surgical decerebration (Li, Du, Li, Wu, & Wu, 2009). The generally accepted circuitry of PPI that has been outlined from animal models suggests a serial pathway between the midbrain structures of the inferior colliculus (IC), the superior colliculus (SC), and the pedunculo-pontine tegmental nucleus (PPTg), though other research has suggested that other pathways may exist (Yeomans, Lee, Yeomans, Steidl, & Li, 2006). Research has shown that higher order processes like attention (e.g., Filion et al., 1993) can mediate the response, indicating that areas of the forebrain can also be involved. Research with laboratory rats has shown that axonal projections exist between midbrain structures that control PPI and the auditory cortex, amygdala, and lateral globus pallidus that mediate PPI (Li et al., 2009).

Yeomans et al. (2006) investigated the midbrain circuitry of startle elicitation and PPI through electrical stimulation of the SC and underlying structures in rats. This series of experiments led the authors to conclude that the previously discussed serial pathway leading to the PPTg should be revised in lieu of an alternative explanation. Yeomans et al. (2006) found evidence that PPI probably occurs through two convergent pathways, a fast pathway for auditory stimuli from the IC to the PPTg and a slower pathway from the SC to the PPTg which integrates the acoustic, tactile, and visual inputs that mediate PPI.

Animal research on the physiology of startle has also served to explain the evolutionary role of startle in mammals. In a study conducted by Yeomans, Li, Scott, and Frankland (2002), the researchers show that neural components involved in tactile, acoustic, and vestibular stimuli can elicit startle, and that simultaneous activation of these systems sum to produce larger startle responses. Drawing from these observations, the

authors provide support for the hypothesis that startle serves an evolutionary protective role in preparing and protecting the body (particularly the head and neck) from large blows or impacts, which would activate all three of these systems (Yeomans et al., 2002).

### **Previous Research Examining the Interrupt Hypothesis**

In her 1974 address to the Society for Psychophysiological Research, Frances Graham posed the question: “Is it possible that the inhibition [PPI], at least, reflects a wired-in negative feedback which reduces the distraction produced by reflexes such as startle, and thus protects what has been called preattentive stimulus processing?” (p. 246, Graham, 1975). This hypothesis implies that the startle response would otherwise interrupt processing if not for the protective effect of PPI. In a book chapter four years later, Graham (1978) reiterated her hypothesis, suggesting that startle serves a protective role as an interrupt system. Graham hypothesized that the role of the startle response is not dependent on the characteristics of the stimulus that activated the system, but on those of the stimulation that come afterward. In other words, she predicted that the primary function of the startle response is to disrupt ongoing processing as a defensive measure so that attentional resources can be directed to the current threat. The Interrupt Hypothesis seems to have face validity and has been assumed in the literature since first proposed by Graham . However, no empirical study has definitively confirmed that a startle stimulus or the resultant startle reflex actually does disrupt cognitive processing.

Norris and Blumenthal (1996) attempted to address the Interrupt Hypothesis by examining the relationship between prepulse processing and startle measurement using an identification-accuracy task. In this study, the authors presented auditory or vibrotactile prepulses of low or high frequency, followed on some trials by an auditory startle

stimulus with varying onset latency. Participants were asked to report the identity of the prepulse on each trial by pressing keys corresponding to “high tone,” “low tone,” or “no tone” on trials where no prepulse was presented. The authors found that accuracy on trials in which responses were inhibited by the prepulse was significantly greater than on trials where the responses were not inhibited. This was taken as evidence to support the Interrupt Hypothesis because identification accuracy was negatively associated with the presence of a startle response. Accuracy was higher on trials in which the startle response was inhibited, suggesting that the startle response failed to disrupt cognitive processing of the information content of the prepulse because the response was inhibited (Norris & Blumenthal, 1996).

Foss, Ison, Torre, and Wansack (1989a, 1989b), conducted a series of studies to investigate whether the introduction of a startle stimulus would disrupt participants’ task to aim a rifle. Their results showed that more intense stimuli led to greater disruption in the aiming task and habituation of the startle response was associated with less disruption of the aiming task but did not eliminate the effect. They did not find a significant correlation between EMG measurements of the eyeblink response and performance disruption. The authors noted that the disturbance of task performance lasted longer than that which would be expected from a disruption of only the motor component, and concluded that “performance disruption produced by startle-eliciting stimuli seems to involve a more cognitive deficit than would be expected of simple motor interference” (p. 318, Foss et al., 1989a). These findings show some preliminary support of the Interrupt Hypothesis, but also suggest that further investigation needs to be performed to determine

the relationship between the startle response and cognition as a component of task-related motor behavior.

Other studies combining the startle paradigm with performance tasks have found evidence that seems to argue against the Interrupt Hypothesis, though they were not specifically designed for this purpose. The StartReact Effect is a phenomenon in which reaction time decreases when a startle stimulus is presented simultaneously with the target stimulus during a reaction time task (Carlsen et al., 2009). This effect is notable in its seeming opposition to Graham's (1975) Interrupt Hypothesis, which states that startle should interrupt ongoing processing. If startle is theorized to serve as a defensive mechanism which interrupts current cognitive processing, then one would expect to find that startling stimuli presented during a task would lead to increased reaction time. Startling stimuli presented concurrently with the target stimulus in a reaction time task should slow down processing as the startle stimulus interrupts one or more steps in the cognitive processes occurring between perception and response to the target. However, the StartReact Effect shows the opposite effect: the presentation of a startle stimulus simultaneously with the target to which the participant must respond decreases reaction time on simple RT tasks. This finding has been replicated in numerous studies across a variety of tasks and participant groups (Carlsen, Chua, Inglis, Sanderson, & Franks, 2004; Carlsen et al., 2008; 2009; Carlsen, Lam, Maslovat, & Chua, 2011; Nijhuis et al., 2007; Valldeoriola et al., 1998).

Further research has shown that the StartReact Effect is not dependent on an overt startle response, since the reaction time quickening effect is still observed when the startle response is inhibited by a prepulse (Valls-Sole, Kofler, Kumru, Castellote, &

Sanegre, 2005) or eliminated through rise time manipulation (Lipp, Kaplan, & Purkis, 2006; Reynolds & Day, 2007). The finding that StartReact is not dependent on an overt startle response suggests that it is closely related to another phenomenon known as the Accessory Stimulus Effect (ASE). The Accessory Stimulus Effect states that reaction time to a target stimulus will decrease if it is paired with an additional stimulus in a different modality (Hackley & Valle-Inclan, 1998, 1999; Jepma, Wagenmakers, Band, & Nieuwenhuis, 2009). Similar to the StartReact Effect, the ASE shows that the introduction of a second stimulus decreases reaction time to the target stimulus. Despite the differences among these two phenomena, the consistent finding that RT is reduced when a startle stimulus is presented in conjunction with the target stimulus seems to contradict the Interrupt Hypothesis.

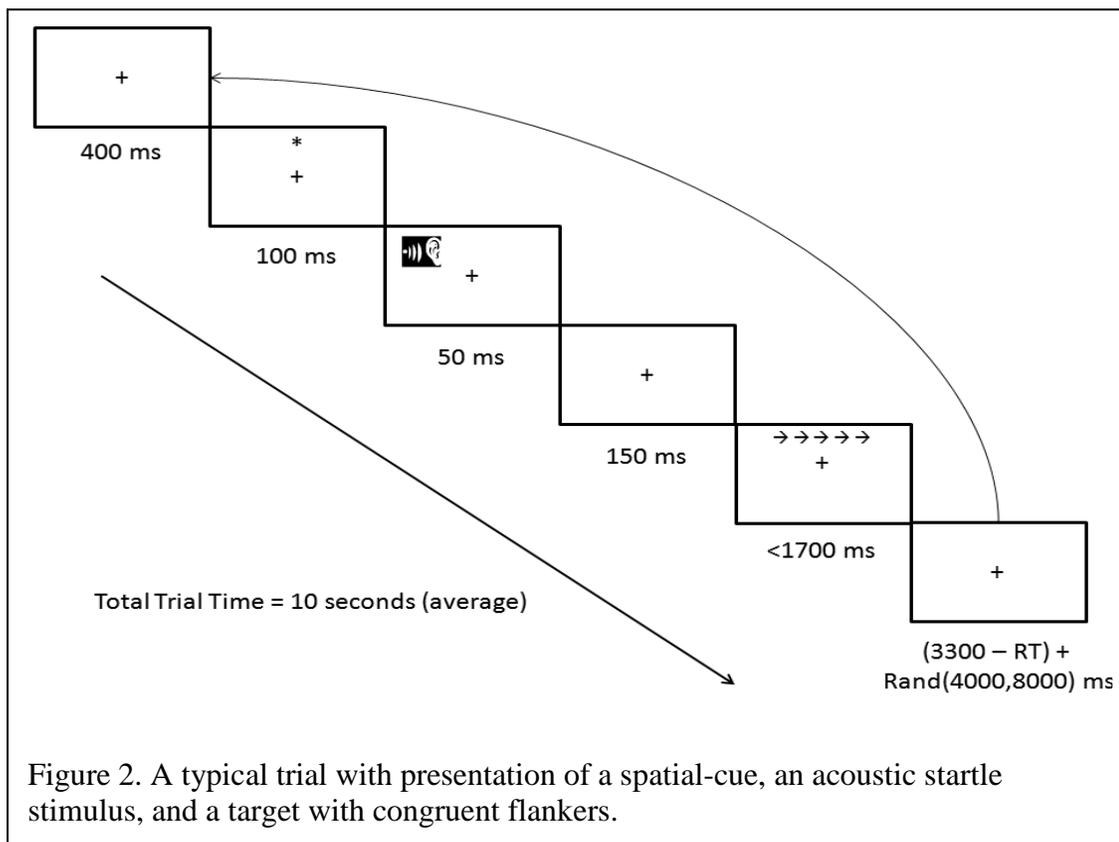
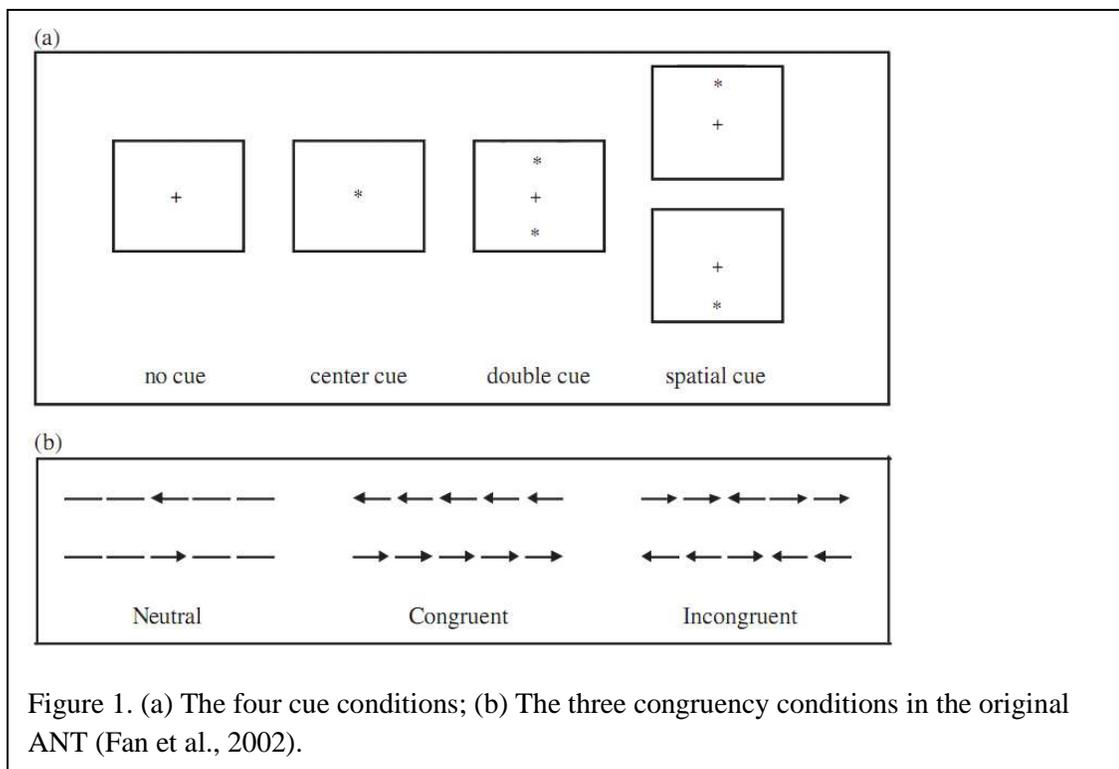
### **The Attention Networks Test**

The primary goal of the present study was to address this gap in the startle literature by providing direct evidence to support or argue against the Interrupt Hypothesis. This goal was accomplished by pairing startling acoustic stimuli with the Attention Networks Test (ANT) to determine how the addition of a startle stimulus (and/or the resultant startle response) impacted performance on the task.

The ANT was designed to be a short, but comprehensive task to evaluate and compare the efficiency of the alerting, orienting, and executive networks involved in attention (Fan, McClelland, Sommer, Raz, & Posner, 2002). The ANT combines a flanker task (Eriksen & Eriksen, 1974) with a cued reaction time task (Posner, 1980) in which participants are asked to indicate the direction of a target arrow in the display by pressing one of two buttons representing “right” or “left.” In the original task, there are

three flanker conditions: congruent, in which the flanker arrows surrounding the central arrow are pointed in the same direction; incongruent, in which the flanker arrows are pointed in the opposite direction of the target arrow; and neutral, in which the target arrows are presented with non-directional flanker lines (see Figures 1 and 2). The arrows can be presented in two different locations in the display, either above or below the fixation cross (+), and the target arrow can point either left or right. There are also four cue conditions, in which one, two, or no asterisks are presented before the target stimulus. These cues can be presented at the fixation cross (central-cue), at both locations where the arrows may appear (double-cue), or at one of the locations (spatial-cue), or no cue may appear (no-cue). Reaction time and accuracy are measured for each trial, and the efficiency of each attentional component is calculated from the reaction time data on correctly answered trials (MacLeod et al., 2010).

The ANT allows researchers to compare the efficiency of three separate components of attention by testing different trial types and performing subtractions or orthogonal contrasts between specific pairs (Fan et al., 2002). The alerting aspect of attention is essential for preparing the brain for incoming information and maintaining awareness for reception of the following stimuli, and it is thought to play a vital role in higher cognitive functioning. Orienting is proposed to be that which shifts attention toward the sensory information being received and selects the most important sensory signals for processing by the executive component. Executive control is involved in higher-level cognition and is responsible for goal-driven behavior, conflict resolution, planning, and decision making (Fan et al., 2009).



For the alerting network, efficiency is calculated by subtracting the average reaction time for the double-cue condition from the average reaction time of the no-cue condition. The double-cue and no-cue conditions are used to calculate alerting because no spatial information is given for where the arrows will occur in the display, and therefore attention must remain diffused between the locations (Fan et al., 2002). Because the no-cue condition provides no temporal information about when the target stimulus will appear, and the double-cue condition provides only temporal information, the double-cue reaction time is subtracted from the no-cue RT in order to parse out the effect of the temporal marker of the double-cue on reaction time. This shows efficiency of alerting because display of the double-cue should activate the alerting network in letting the subject know that the target is about to appear, thus decreasing reaction time.

For orienting, efficiency is calculated by subtracting the average reaction times of the spatial-cue condition from the center-cue condition (MacLeod et al., 2010). This calculation represents the orienting network because the spatial-cue condition provides spatial information about where the target will appear, thus causing attention to shift to that area, and producing a reduced reaction time. The center-cue and double-cue conditions are both considered to be alerting cues since they provide temporal information regarding the onset of the target but no predictive spatial information. One of each type of alerting cue is used to calculate the efficiency of the orienting and alerting networks so the comparisons are orthogonal and no mean RT value is used in the independent calculation of more than one attentional network (McConnell & Shore, 2011). For executive control, efficiency is calculated by subtracting reaction time of the congruent flanker trials from that of the incongruent flanker trials, regardless of cue

location (MacLeod et al., 2010). This calculation represents the executive component of attention because incongruent flankers produce conflict and executive attention must be used to resolve the conflict and inhibit the effect of the incongruent flankers.

In order to investigate whether the startle response disrupts processing, a task had to be chosen that would allow for the measurement of cognitive processing and would be amenable to the addition of a startle stimulus. The ANT was chosen to be combined with the startle paradigm to address the Interrupt Hypothesis because it allowed for the comparison of results on a number of different trial types with and without the addition of a startle stimulus. The visual cues presented in the ANT acted as relevant prepulses from which information had to be processed in order to gain the benefits of RT reduction. The extent of cue processing is evaluated from the ANT by comparing reaction time for different trial types, so disruption of cue/prepulse processing by the startle stimulus could be evaluated by examining the effect of a startle stimulus presented immediately after presentation of the visual cue.

### **Changes to the Original ANT**

The original ANT as proposed by Fan et al. (2002) was modified to accommodate the experimental hypotheses and to expedite the testing session. First, neutral flanker trials were removed to reduce the overall number of trials, conditions, and time needed to complete the session. Reaction time on neutral trials has been shown to be statistically similar to that on congruent trials and their inclusion provides unnecessary, redundant information (Callejas, Lupiàñez, Funes, & Tudela, 2005). Neutral trials were also removed in the study conducted by Callejas et al. (2005) for similar reasons. Furthermore, the focus of this study was to assess the effect of a startle response on the

processing of cue information, which facilitates the response to the target. Although effects of flanker congruency were assessed and analyzed, the focus of the study was on the effect of the startle response on the alerting and orienting networks. Second, the length of each trial was increased from four seconds to an average of ten seconds to allow for recovery of the startle response between trials. Third, acoustic startle stimuli were presented during the task in order to address the experimental question at hand. These startle stimuli were presented at the offset of the cue for 50 ms during the 200 ms fixation period between the offset of the cue and the onset of the target (see Figure 2). Fourth, two blocks of experimental trials were presented instead of the three contained in the original task. Given the sample size ( $n = 35$ ) and the number of trials presented across the two experimental blocks, a sufficient number of startled and non-startled trials were presented without the inclusion of a third block. It was also important to reduce the session time as much as possible to avoid fatigue effects. Fifth, sixteen “startle alone” trials (where no cues or targets were presented) were included among the other trial conditions in each block to assess baseline startle values for each participant. Sixth, the interval between the offset of the cue and the onset of the target was reduced from 400 ms to 200 ms to isolate the effect of the startle stimulus on the cue to earlier stages of processing. Callejas et al. (2005) reduced the SOA between the visual cue and target to 100 ms and the length of time for which the cues were presented to 50 ms, thus retaining a 50 ms interval of just the fixation cross between the offset of the cue and the onset of the target. Fan et al. (2009) reduced the SOA between the cues and target to 0 ms, such that the cues were presented for 100 ms which were then immediately followed by the target with no fixation interval in between. An intermediate interval was needed in this study to target

early stages of processing while reducing the probability that the eyelid would be closed when the target was presented. These changes allowed for a systematic test of the Interrupt Hypothesis.

### **Hypotheses**

This study design allowed for the direct comparison of results obtained from ANT trials without startle stimuli with trials conducted with the addition of an auditory startle stimulus between the visual cue and target. Separate analyses and hypotheses were made to confirm that the expected results of the control ANT trials (those without a startle stimulus) were similar to the results obtained in previous ANT research. Likewise, certain hypotheses are generally made and tested in studies utilizing the startle paradigm to confirm the methodological validity of the results before interpreting experimental findings. Given the validity of the startle measurements and ANT control trials as determined through consistency with previous research, it was hypothesized that the results of this study would provide evidence for the Interrupt Hypothesis by showing that the startle response disrupted processing of the cues. It was also expected that the results would provide support for the Protection Hypothesis such that RT would be negatively correlated with PPI, which if true, would indicate that increased PPI is associated with better task performance.

### **Standard Predictions for the ANT**

Standard predictions were made based on the results of previous ANT studies as follows. It was predicted that cues would have a significant effect on reaction time for non-startle trials, such that reaction time would decrease for each of the cue conditions with respect to the no-cue condition. Each cue condition provided information regarding

the timing of the following target (center-cue and double-cue), or the location and timing of the following target (spatial-cue; Fan et al., 2002). Thus, it was reasoned that these conditions would show decreased RT when compared with no-cue trials which contained neither temporal nor location information about the target. These hypotheses were made to determine and examine the effects of the alerting (center-cue and double-cue) and orienting (spatial-cue) visual cues.

Center-cue and double-cue conditions both provide temporal information but no spatial information for the subsequent target, thus activating the alerting network but not the orienting network. In order to maintain consistency with previous research that determined the efficiency of networks by making orthogonal contrasts between cue conditions, alerting was examined by comparing the double-cue condition to the no-cue condition, and orienting was examined by comparing the spatial-cue condition to the center-cue condition (Fan et al., 2002; Greene et al., 2008; Jennings, Dagenbach, Engle, & Funke, 2007). These comparisons assume that the double-cue and center-cue are equivalent in their effect on activating the alerting network. Some researchers have simplified the design of the ANT to exclude one of the two alerting cue conditions and including only the center-cue (Bish, Ferrante, McDonald-McGinn, Zackai, & Simon, 2005) or only the double-cue (Fan et al., 2009). Therefore, it was hypothesized that there would not be a significant difference in RT between center-cue and double-cue conditions.

The spatial-cue condition was expected to cause greater reduction in reaction time relative to the center-cue and double-cue conditions (Fan et al., 2002). The spatial-cue provided information about the location of the target in addition to the timing of its onset,

so it was expected that this condition would have the lowest average reaction time when compared with the other cue conditions as an effect of the combined engagement of the orienting and alerting networks.

No difference was expected for accuracy measurements on the no-startle trials regardless of cue condition. The cues contained no information regarding the direction of the target, so it was hypothesized that cue condition would not affect accuracy measurements.

A significant difference was expected in RT and accuracy measurements on the no-startle trials for congruent compared with incongruent flanker trial conditions. The incongruent flanker condition introduced conflict between the target arrow and the flanker arrows resolved by the executive component of attention, which was expected to result in an increased RT and error rate for incongruent trials.

### **Standard Startle Predictions**

It was hypothesized that startle magnitude would significantly decrease across blocks for startle-alone trials, showing habituation (see Figure 3).

It was predicted that there would be no significant difference in startle magnitude or onset latency between the startle-alone trials and the startled no-cue trials. Startle-alone trials and startled no-cue trials were indistinguishable until the target was presented 150 ms after the offset of the startle stimulus (see Figure 2), thus, it was not expected that there would be a significant difference for startle magnitude or onset latency between these trial types.

It was hypothesized that startle magnitude would be significantly smaller in startled cued trials compared with startle-alone and startled no-cue trials. This reduction

in startle magnitude would be PPI, where the visual cue would serve as a prepulse and inhibit the subsequent startle response.

### **Predictions for the Interaction of the ANT with Startle**

It was hypothesized that reaction time would be significantly greater for startled cued trials compared to non-startled cued trials. This hypothesis is a restatement of the Interrupt Hypothesis, which posits that a startle response will interrupt information processing. If startle impacted the processing of information from the cues which led to decreased RT for cued trials, then reaction time should have been greater for cued trials paired with a startle stimulus when compared to the same cued trials without a concomitant startle stimulus.

It was expected that the startle stimulus would cause RT to be greater for the spatial-cue condition than the other cue types. The spatial-cue condition contained an extra level of information that could have been disrupted (spatial and temporal) by the startle stimulus, so it was predicted that this condition would show a greater decrement in performance.

It was hypothesized that the startle stimulus would interrupt and disrupt task performance as measured by RT and accuracy, and would therefore not facilitate responding by acting as an auditory cue. Previous research (Callejas et al., 2005) showed that an auditory tone presented prior to the onset of the visual cue acted as an alerting cue, however, this auditory tone was not intense enough to elicit a startle response and was presented earlier in the trial. It was thought that the predicted interruption induced by the startle stimulus would override any possible facilitatory effect it might procure. The StartReact literature would predict that a startle stimulus presented at the same time as the

target would reduce RT, but the SOA of 200 ms between the startle stimulus and target in this study is outside the typical time range for which the StartReact effect is observed (Carlsen et al., 2004, 2008, 2009, 2011; Nijhuis et al., 2007; Valdeoriola et al., 1998).

It was hypothesized that there would be a negative correlation between RT on startled trials and the amount of PPI resulting from the visual cues, whereby larger degrees of PPI would be associated with faster reaction times. This correlation would be a test of the Protection Hypothesis, and it was hypothesized that a significant positive correlation would show that larger amounts of response inhibition are associated with shorter reaction times (due to less interruption), whereas reduced inhibition (i.e., larger startle responses) is associated with longer reaction times (due to more interruption).

## **METHODS**

### Participants

The study was approved by the Institutional Review Board at Wake Forest University, and each participant signed an informed consent form prior to the collection of any data. Forty six participants were recruited through the Sona Experiment Management System from the Introductory Psychology research pool at Wake Forest University. Each participant received one credit towards his/her Introductory Psychology research requirement after granting consent, regardless of whether or not exclusion criteria from a health history questionnaire were met. Initial exclusion criteria comprised only factors that would interfere with the person's ability to perform the task or to hear the sounds that would be presented, for example, uncorrected vision impairment, hearing impairment, recent illness that impacted hearing, or use of psychostimulant medication. Three participants were excluded from the study due to use of psychostimulant medication, two subjects were excluded due to recent ear infections, and one subject withdrew after granting consent. Data were collected for a total of 40 participants. However, an additional five participants were excluded during data analysis for various reasons discussed below. A total of 35 participants (19 females, 16 males) were included in the final analyses.

### **Apparatus and Materials**

An existing ANT experiment file (Fan et al., 2002) created with E-Prime software (version 2.0.8.90; Psychology Software Tools, Inc., Sharpsburg, PA) was obtained directly by email from Dr. Jin Fan, and then modified for this study. E-Prime software was used for the presentation of both auditory (i.e., startle stimuli) and visual stimuli

during the experiment. The ANT was presented on a 17" LCD monitor, and participants responded to the task (described below) by pressing either the left or right button on an immobilized computer mouse. A chinrest was used to standardize the viewing angle and distance from the computer monitor and to reduce excess head movement that could interfere with EMG measurements.

Each target trial of the ANT was presented pseudorandomly, and consisted of the following series of events (see Figure 2). A fixation cross remained at the center of the screen throughout the entire block. At the beginning of each trial, there was a 400 ms period containing only the fixation cross, immediately followed by one of four cue conditions (no-cue, central-cue, double-cue, spatial-cue) which remained on the screen for 100 ms. At the offset of the cue, either a 100 dB acoustic startle stimulus or a silent audio file was presented for 50 ms. After an additional 150 ms period (so that a total of 200 ms elapsed between the offset of the cue and the onset of the target), the target slide appeared for a maximum of 1,700 ms or until a response was made. After the response period there was a varying interval so that trials lasted an average of 10 seconds (ITI range of 8-12 sec). This was accomplished by subtracting the RT on each trial from the 1,700 ms response period and adding an interval that varied randomly in length from 5,600 ms to 9,600 ms. Startle-alone control trials were also interspersed randomly among ANT trials. In these startle-alone control trials, only the startle stimulus was presented over the headphones while the fixation cross remained on the screen. No cues or targets were displayed during control trials, which also lasted for an average of 10 seconds. Participants were explicitly told to ignore the sounds in all cases because sounds were irrelevant to the task.

Block	Flanker	Cue	No-Startle	Startle
Block 1	Congruent	No-Cue		
		Central-Cue		
		Double-Cue		
		Spatial-Cue		
	Incongruent	No-Cue		
		Central-Cue		
		Double-Cue		
		Spatial-Cue		
Block 2	Congruent	No-Cue		
		Central-Cue		
		Double-Cue		
		Spatial-Cue		
	Incongruent	No-Cue		
		Central-Cue		
		Double-Cue		
		Spatial-Cue		

Figure 3. The experimental design matrix in which target location and direction have been collapsed. Each cell contains four trials, and 16 startle-alone trials were presented randomly throughout each block.

Each experimental block of the modified ANT contained a total of 80 randomly presented trials, of which 32 were target trials paired with a startle stimulus (startle), 32 were target trials with no startle stimulus (no-startle), and 16 were no-target and no-cue control trials with only the presentation of a startle stimulus (startle-alone). The trial structure for the ANT (see Figure 3) was a 2 block x 2 startle (startle stimulus, no startle stimulus) x 2 flanker (congruent, incongruent) x 4 cue (no-cue, central-cue, double-cue,

or spatial-cue) factorial design (see Figure 3). Target direction and target location were counterbalanced and collapsed for analysis. The practice block contained 12 trials, of which half were startle and half were no-startle, and it did not contain any startle-alone trials. Feedback on accuracy and percent correct was given on the screen after each practice trial, but no feedback was given during the experimental blocks. The experimenter watched each participant perform the practice block on a duplicate monitor, and each participant was subsequently asked if he/she understood the directions or had any questions about the procedure. Any participant who responded with less than 50% accuracy ( $n = 2$ ) was given further instruction and subsequently asked to repeat the practice block. . Further instruction was also given for participants with less than 75% accuracy ( $n = 2$ ), but the practice block was not repeated in these instances, and one of these participants was excluded prior to analysis. Practice block data were saved for examination but not included in the primary analyses.

Acoustic startle stimuli consisting of broadband noise were produced with Audacity software (Free Software Foundation), and calibrated with a Quest 215 sound level meter to specifications of 100 dB(A), 50 ms duration, and <1 ms rise and fall times. After output from the computer, the startle stimuli were amplified with a Presonus HP4 amplifier and presented to both ears through Sennheiser PX200 headphones.

Startle responses were recorded by two electrodes (InVivoMetric E220X Ag/AgCl, 4 mm recording diameter) measuring electromyographic (EMG) activity of the orbicularis oculi muscle. These recording electrodes were filled with Synapse electrode paste and attached to the face with adhesive electrode collars (E401M). Before placing the electrodes, the skin below the left eye was cleaned with an alcohol soaked cotton

swab. The first electrode was placed directly below the left pupil between the top of the cheek and the lower eyelid, and the second was placed slightly higher and immediately lateral, with a spacing of <0.5 cm. Care was taken to make sure that the collars were not touching, which might induce movement artifacts. A third electrode was placed on the left temple to serve as a reference. The electrode wires were tucked behind the participant's left ear to minimize movement artifacts and plugged into a Biopac MEC100 extension cable which led into an adjacent room, where it was connected to a Biopac EMG100 amplifier (5000 Gain, filters passing 1-500 Hz). This signal was sampled by a Biopac MP150 work station at 1000 Hz, and the raw, filtered (28-500 Hz; to exclude movement artifacts and folding frequencies), rectified (to take the absolute value), and smoothed (averaged with a 5 sample boxcar filter) versions of the EMG signal were recorded with Acqknowledge software (Biopac Systems, Inc., Goleta, CA) and saved for analysis.

### **Procedure**

Upon entering the lab, participants were greeted by the experimenter and taken to the testing room. After recording the participant's student identification number, he/she was given an informed consent form to read and sign. This form briefed the participant on the procedure and format of the study, information regarding privacy and confidentiality, and any possible risks of participating. After agreeing to participate and signing the consent form, the participant was given a health history questionnaire to determine the presence of any exclusion criteria (i.e., use of psychostimulant medication, hearing loss, uncorrected vision, etc.). The experimenter left the room to evaluate this

form, and if any exclusion criteria were met, the experimenter dismissed the participant and granted full credit for participation.

After consent had been granted and health history had been evaluated, the experimenter placed three electrodes on the left side of the participant's face in preparation for startle response measurement. The experimenter then briefly instructed the participant on the task and the use of the mouse, which was placed in a comfortable location and immobilized. The participant was instructed to use his/her index finger for the left button and middle finger for the right button, and to respond as quickly and accurately as possible. A diagram of the trial structure was used as an aid to explain how to perform the task, and the experimenter asked each participant if he/she understood the instructions. The experimenter also explained that loud sounds would occasionally play over the earphones, but that these sounds were irrelevant to the task and should be ignored as much as possible.

After verbal instructions were given by the experimenter, headphones were placed on the participant's ears and he/she was directed to place his/her chin in the chinrest to minimize any unnecessary movement, and to pay attention to the computer monitor. Additional instructions about how to perform the task were displayed on the screen. The practice block containing 12 trials was then administered, providing feedback and accuracy information after each trial. The practice block took approximately three minutes to complete. Instructions then appeared asking the participant to let the experimenter know when he/she was finished with the practice block. Instructions telling the participant to inform the experimenter when he/she had finished a block appeared multiple times during each session. However, the experimenter monitored each

participant's task activity via a duplicate monitor in the control room and would re-enter the room at designated times whether prompted by the participant or not. Upon entering the room, the experimenter asked the participant whether he/she heard sounds through the earphones, and whether he/she understood the task or had any further questions about the task. If task accuracy was between 50% and 75% ( $n = 2$ ), the experimenter re-explained the task to address any lapses in understanding. If task accuracy was lower than 50% ( $n = 2$ ), the practice block was also re-administered. After the experimenter left the room, the participant followed instructions to complete the first block of experimental trials (80 trials total comprised of 32 startle trials, 32 non-startle trials, and 16 startle-alone trials). No feedback was given during the experimental blocks. Directions were then displayed asking the participant to inform the experimenter that he/she had finished the first block of experimental trials. The experimenter re-entered the room to check on the participant and gave him/her a brief period (no more than two minutes) to rest. The participant then completed the second block of 80 randomly presented experimental trials. After the participant finished the computer task, the experimenter removed the electrodes, debriefed the participant by explaining the goals and intent of the study, and provided a copy of the informed consent. Finally, each participant was thanked for participating and dismissed.

## **RESULTS**

### **Additional Participant Exclusion**

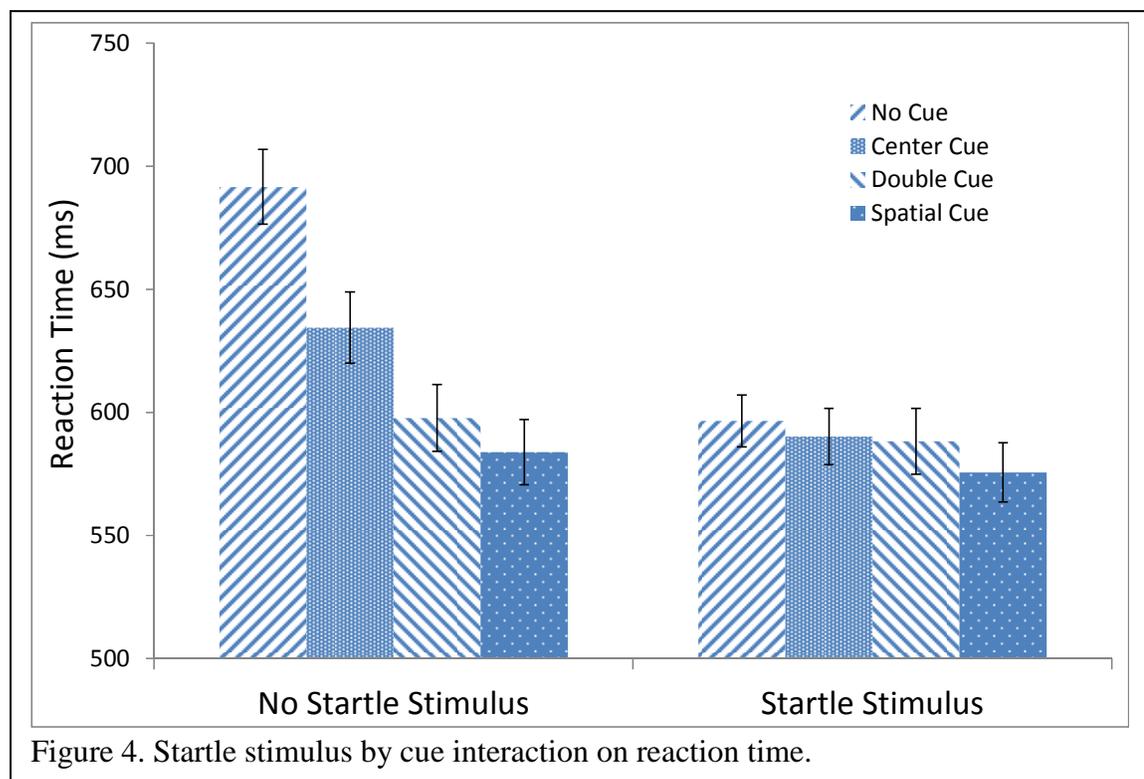
Although data were collected from a total of forty participants, an additional five participants were excluded from analysis for the following reasons. Two participants were deemed “non-responders” due to a low response rate (<20% for both experimental blocks) on the control startle trials. One participant was determined to be an outlier due to unusually variable startle responses for both control startle trials and task startle trials. An additional two participants were excluded as outliers based on low response accuracy on the ANT. In order to maintain consistency in the analyses, participants who were excluded based on startle criteria or task criteria were excluded from analysis for both sets of data. The final number of participants in the analyses was 35, including 19 females and 16 males.

### **ANT Analysis**

The ANT cognitive data were first analyzed by conducting a 2 block x 2 startle stimulus (startle stimulus, no-startle stimulus) x 4 cue (no-cue, center-cue, double-cue, spatial-cue) x 2 congruency (congruent, incongruent) repeated measures omnibus ANOVA separately on reaction time and accuracy. Follow-up comparisons were then conducted to examine significant interactions and to evaluate a priori hypotheses. Reaction time data were filtered so that any values below 200 ms and above 1700 ms were excluded. Target location (top, bottom), and target direction (left, right) were collapsed before all analyses. This and all other analyses were conducted using SPSS Software Version 19.0 (2010) with Greenhouse-Geisser corrections.

## Reaction Time

For the RT analysis, there were significant main effects of startle stimulus,  $F(1, 34) = 58.34, p < 0.001$ ; cue  $F(3, 102) = 43.22, p < .001$ ; and congruency,  $F(1, 34) = 305.29, p < .001$ . There were also significant interactions for startle stimulus by cue,  $F(3, 102) = 26.61, p < .001$ , and startle stimulus by congruency,  $F(1, 34) = 5.68, p = .023$ . There was a marginally significant interaction for cue by congruency,  $F(3, 102) = 2.61, p = .063$ .



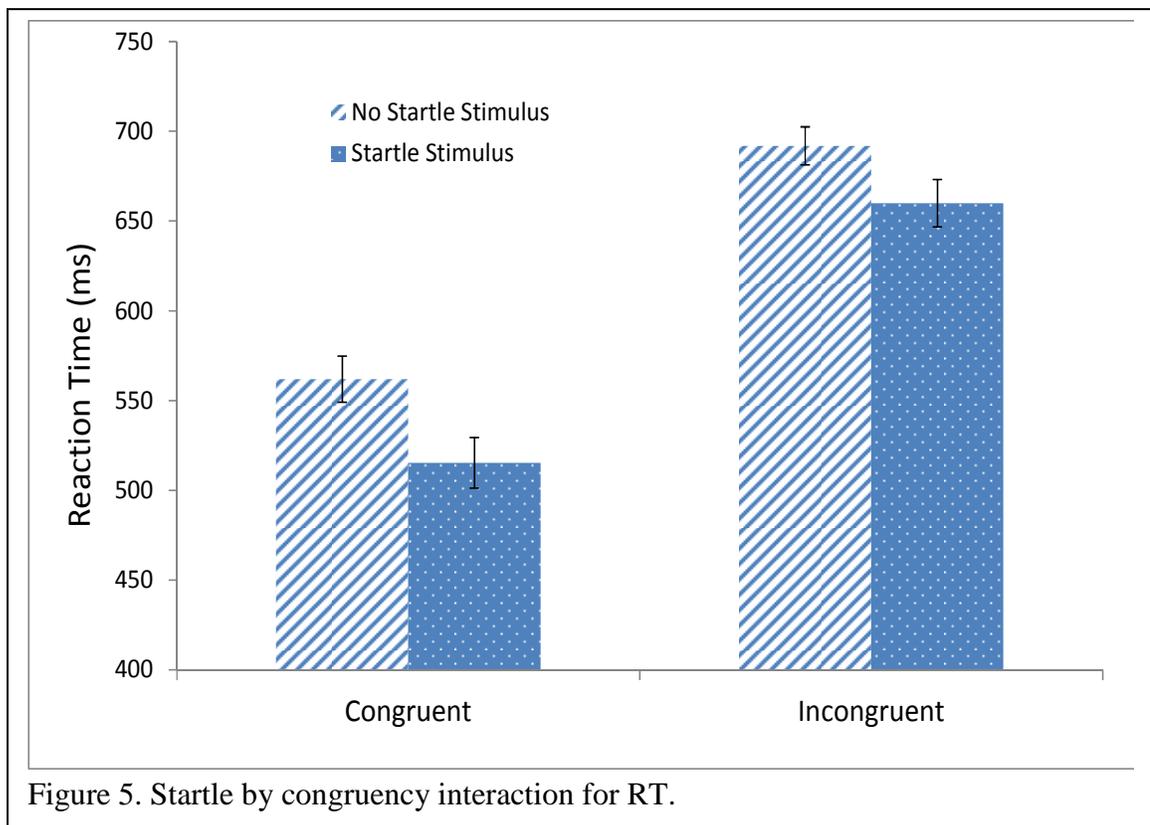
To explore the startle stimulus by cue interaction, pairwise comparisons were first conducted for each cue type across startle stimulus condition. This analysis showed that there was an effect of the startle stimulus on the no-cue,  $t(33) = 9.25, p < .001$ , and center-cue trials,  $t(33) = 5.29, p < .001$ . Reaction time was significantly lower for no-cue trials with a startle stimulus ( $M = 596.50, SE = 10.53$ ) compared to no-cue trials without a

startle stimulus ( $M = 691.60$ ,  $SE = 15.17$ ). Reaction time was also significantly lower for center-cue trials with a startle stimulus ( $M = 590.17$ ,  $SE = 11.45$ ) compared to center-cue trials without a startle stimulus ( $M = 634.48$ ,  $SE = 14.49$ ). There was not a significant effect of the startle stimulus on RT for double-cue,  $t(33) = 1.38$ ,  $p > .05$ , or spatial-cue trials  $t(33) = .97$ ,  $p > .05$ .

To further explore the startle stimulus by cue interaction, pairwise comparisons were also conducted at each level of the presence of a startle stimulus across cue type. For trials without a startle stimulus (equivalent to the original ANT design), there were significant differences in RT between all cue types,  $p < .001$ , except in the difference between the double-cue ( $M = 597.74$ ,  $SE = 13.55$ ) and spatial-cue ( $M = 583.87$ ,  $SE = 13.22$ ) conditions, which was not significant,  $t(33) = 1.63$ ,  $p > .05$ . This pattern did not carry over for the trials on which a startle stimulus was presented. Comparing across cues for trials with a startle stimulus, there were significant differences in RT between no-cue ( $M = 596.50$ ,  $SE = 10.53$ ) and spatial-cue ( $M = 575.69$ ,  $SE = 12.03$ ),  $t(33) = 3.29$ ,  $p = .002$ ; and between center-cue ( $M = 590.17$ ,  $SE = 11.45$ ) and spatial-cue trials,  $t(33) = 2.22$ ,  $p = .033$ . There was a marginally significant difference between double-cue and spatial-cue trials on RT,  $t(33) = 1.81$ ,  $p = .080$ . There were no significant differences between no-cue and center-cue,  $t(33) = 1.09$ ,  $p > .1$ ; no-cue and double-cue  $t(33) = 1.42$ ,  $p > .1$ ; or between center-cue and double-cue trials  $t(33) = .28$ ,  $p > .1$ .

To explore the startle stimulus by congruency interaction for RT, pairwise comparisons were conducted across startle stimulus conditions at each level of congruency (see Figure 5). For congruent trials, there was a significant difference between non-startled ( $M = 561.93$ ,  $SE = 12.90$ ) and startled ( $M = 691.92$ ,  $SE = 14.11$ )

trials,  $t(33) = 7.20, p < .001$ , such that responses were significantly faster for startled versus non-startled congruent trials. For incongruent trials, there was also a significant difference between startled ( $M = 515.38, SE = 10.57$ ) and non-startled ( $M = 659.93, SE = 13.21$ ) trials,  $t(33) = 5.87, p < .001$ , such that RT was speeded for startled versus non-startled incongruent trials. This interaction shows that the startle stimulus decreased reaction time more for congruent trials ( $MD = 46.55, SE = 6.47$ ) than incongruent trials ( $MD = 31.99, SE = 5.45$ ).



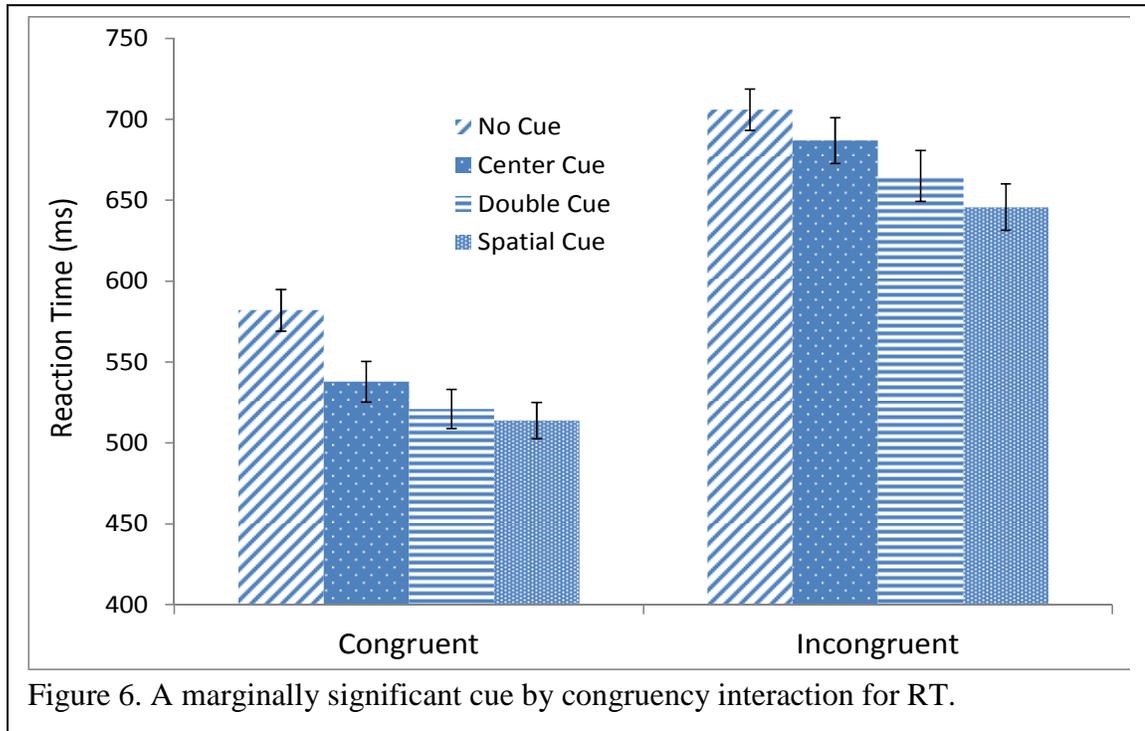
Pairwise comparisons were also conducted comparing the effect of startle stimuli on the difference between congruency conditions. For non-startled trials, there was a significant difference between congruent and incongruent conditions,  $t(33) = 15.18, p < .001$ . For startled trials, there was also a significant difference between RT in congruent and incongruent conditions,  $t(33) = 17.43, p < .001$ . These results confirm that RT was

significantly lower for congruent versus incongruent trials, however, there was a larger difference for those trials that included startle stimuli compared to those that had no startle stimulus.

The marginally significant cue by congruency interaction,  $F(3, 102) = 2.61, p = .063$ , was explored by conducting pairwise comparisons for congruency across cue type, as well as for cue type across congruency (see Figure 6). The pairwise comparisons for congruency across cue type showed that for the congruent trials, there were significant differences in RT for each cue type compared to every other cue, except for the difference between the double and spatial cues. For congruent trials, there was a significant difference in RT between no-cue ( $M = 582.06, SE = 12.89$ ) and center-cue ( $M = 537.79, SE = 12.47$ ),  $t(33) = 7.20, p < .001$ ; no-cue and double-cue ( $M = 520.98, SE = 12.08$ ),  $t(33) = 9.68, p < .001$ ; no-cue and spatial-cue ( $M = 513.79, SE = 11.25$ ),  $t(33) = 9.10, p < .001$ ; center-cue and double-cue,  $t(33) = 2.05, p = .048$ ; and center-cue and spatial-cue conditions,  $t(33) = 2.92, p = .006$ . The reaction time difference between double-cue and spatial-cue conditions for congruent trials was not significant,  $t(33) = 1.02, p > .3$ .

For incongruent trials in the comparison of congruency across cue type, RT was highest for the no-cue control condition and lowest for the orienting spatial-cue condition, with the center-cue and double-cue alerting conditions between the two. There was a significant difference in RT between no-cue ( $M = 706.05, SE = 12.81$ ) and center-cue ( $M = 686.86, SE = 14.12$ ),  $t(33) = 2.77, p = .009$ ; no-cue and double-cue ( $M = 665.02, SE = 15.70$ ),  $t(33) = 5.00, p < .001$ ; no-cue and spatial-cue ( $M = 645.77, SE = 14.45$ ),  $t(33) = 6.61, p < .001$ ; center-cue and double-cue,  $t(33) = 2.63, p = .013$ ; center-

cue and spatial-cue,  $t(33) = 4.72, p < .001$ ; and double-cue and spatial-cue conditions,  $t(33) = 2.31, p = .027$ .



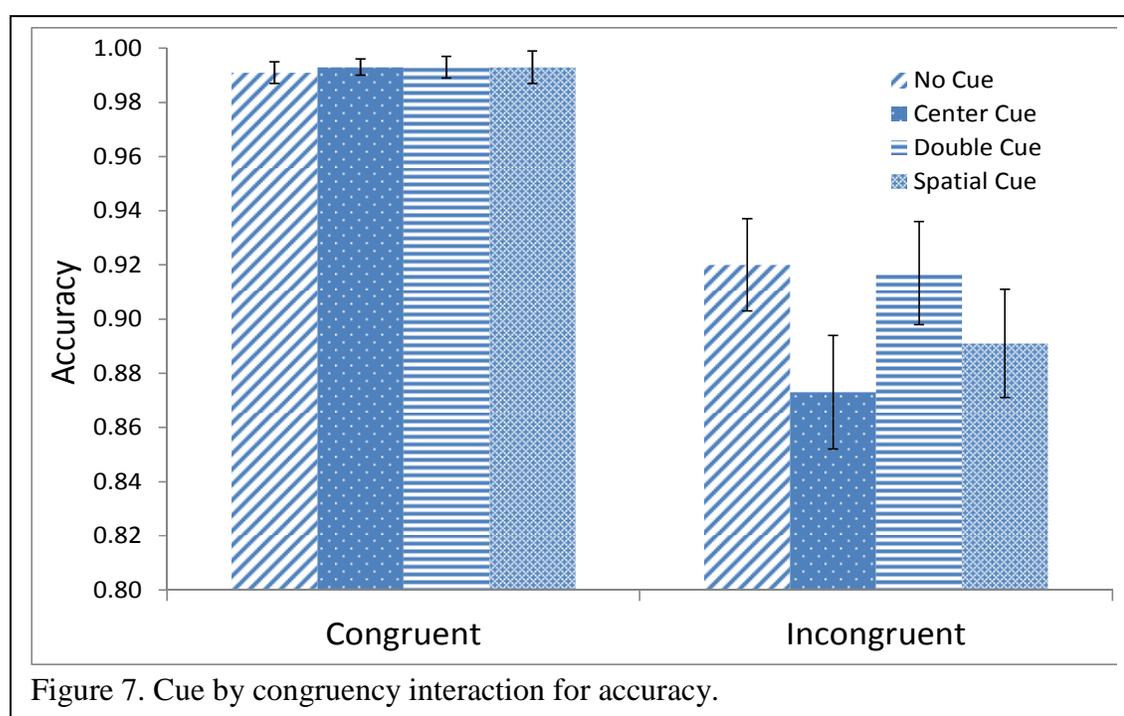
To further explore the marginally significant interaction for cue by congruency on RT, pairwise comparisons were conducted to examine the effect of cue on the difference between congruency types. This analysis showed that there was a significant difference for each cue type between the congruency conditions, such that incongruent trials consistently showed larger RTs. There was a significant difference between congruent and incongruent trial types for the no-cue,  $t(33) = 13.51, p < .001$ ; center-cue,  $t(33) = 14.78, p < .001$ ; double-cue,  $t(33) = 13.84, p < .001$ ; and spatial-cue,  $t(33) = 13.08, p < .001$ , conditions.

### Accuracy

Examination of the accuracy data revealed that there was a high degree of response accuracy, producing a ceiling effect, and low values for standard errors which

might have driven small differences between conditions to statistical significance.

Analysis of the accuracy data revealed main effects of cue,  $F(1, 34) = 3.70, p = .023$ ; and congruency,  $F(1, 34) = 36.76, p < .001$ ; as well as significant two-way interactions for cue by congruency,  $F(3, 102) = 4.57, p = .008$ ; and block by startle stimulus,  $F(1, 34) = 4.95, p = .033$ . There was also a significant three-way interaction for block by startle by congruency,  $F(1, 34) = 8.97, p = .005$ . Although these effects were found to be significant, small differences combined with low standard error may account for them.



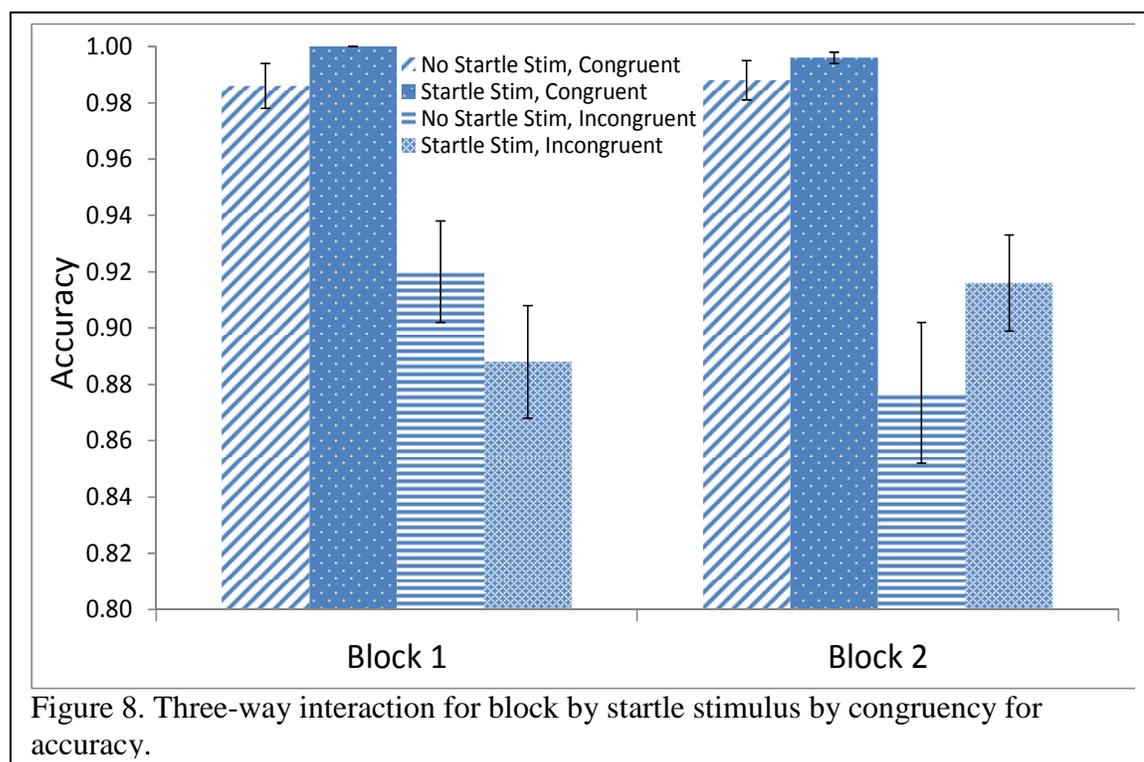
The two-way interaction of cue by congruency on accuracy was explored by conducting pairwise comparisons for cue type across congruency, as well as comparisons for congruency across cue type (see Figure 7). Comparing congruency across cue type, there were no significant differences in accuracy between cue types for congruent trials. For all cue types with a congruent target, the mean response accuracy was above 99%. This represents a ceiling effect, in which the low rate of response errors due to lack of

processing interference on congruent trials overrode the effect of cue type. For incongruent trials, there were significant differences between no-cue ( $M = .92, SE = .02$ ) and center-cue ( $M = .87, SE = .02$ ),  $t(33) = 4.18, p < .001$ ; center-cue and double-cue ( $M = .92, SE = .02$ ),  $t(33) = 2.87, p = .008$ ; and a marginally significant difference between no-cue and spatial-cue ( $M = .89, SE = .02$ ),  $t(33) = 1.93, p = .069$ . These results show that response accuracy was significantly lower in the center-cue condition than in the no-cue and double-cue conditions.

To further explore the cue by congruency interaction on accuracy, pairwise comparisons were conducted for cue type across congruency. For the comparison of accuracy between congruent and incongruent trials, there was a significant difference for no-cue,  $t(33) = 4.44, p < .001$ ; center-cue,  $t(33) = 6.00, p < .001$ ; double-cue  $t(33) = 4.47, p < .001$ ; and spatial-cue,  $t(33) = 6.00, p < .001$ . This analysis showed that accuracy was consistently and significantly higher for congruent compared to incongruent trials, as hypothesized.

The three-way interaction for block by startle stimulus by congruency was explored by conducting pairwise comparisons for startle stimulus and congruency across block, block and congruency across startle stimulus, and block and startle stimulus across congruency (see Figure 8). It must be noted in addition to the ceiling effect seen for congruent trials with high accuracy rates that standard errors were much higher for incongruent compared to congruent trials. This difference in standard errors impacted the statistical tests performed, and probably drove the significance of this interaction. For the startle stimulus and congruency across block analysis, the only significant difference was between block 1 and block 2 for no-startle-incongruent trials, in which

accuracy was higher in block 1 than block 2,  $t(33) = 2.10, p = .040$ . There was also a marginally significant difference between blocks for startle-incongruent trials, in which accuracy was higher in block 2 than block 1,  $t(33) = 1.81, p = .092$ .



For the block and congruency across startle stimulus analysis, the only significant difference was for block 1-incongruent trials, in which accuracy was significantly higher for trials with a startle stimulus compared to those without a startle stimulus,  $t(33) = 2.17, p = .035$ . There were also marginally significant differences in accuracy for block 1-congruent trials and block 1-incongruent trials, in which accuracy on congruent trials in block 1 with a startle stimulus were marginally significantly higher than trials with no startle stimulus,  $t(33) = 1.75, p = .073$ . Accuracy on incongruent trials in block 1 was marginally significantly lower for trials with a startle stimulus compared to those without a startle stimulus,  $t(33) = 1.88, p = .068$ .

The analysis for block and startle stimulus across congruency showed that accuracy on congruent trials was consistently and significantly higher than accuracy on incongruent trials independent of block or startle stimulus condition,  $t(33) = 4.71$ ,  $p < .001$ .

## **Startle Analysis**

### **Startle Response Scoring**

Startle responses were scored with a custom scoring program (Schulz et al., 2009) according to guidelines proposed by Blumenthal et al. (2005). For each startle trial, the program determined a 50 ms baseline period prior to the onset of the startle stimulus, as well as a window from 20-120 ms after stimulus onset during which a valid response would have occurred. Trials on which the onset of the response occurred outside of this window were excluded from analysis. Although the program could automatically score the data, each trial was inspected by a trained experimenter to determine: a) whether or not a response actually occurred, b) whether the program selected the correct onset, and c) whether the program selected the correct peak value. Trials on which no response occurred were marked as such, and included in the analysis. Those trials on which movement artifacts, extraneous noise, or spontaneous blinks occurred were marked as invalid or contaminated, and excluded from analysis. Latency was calculated as the difference between stimulus onset and blink onset. Blink probability was equal to one for trials on which a blink onset was determined, and zero for trials on valid/non-contaminated trials during which a blink did not occur (Blumenthal et al., 2005). Magnitude was calculated by taking the difference between peak voltage (within a 20-

150 ms window) and voltage at blink onset on trials in which a response did occur, and zero on trials in which a response did not occur.

### **Unstandardized Startle Analyses**

Analyses were first run on the uncorrected startle response data for blink magnitude, blink probability, and blink onset latency. These analyses show the effects of cue condition without standardizing the responses by comparison with control startle trials. This was done by conducting a 2 block x 4 cue (no-cue, center-cue, double-cue, spatial-cue) x 2 congruency (congruent, incongruent) repeated measures omnibus ANOVA separately for each of the measures (magnitude, probability, and latency). A *t*-test was also conducted to examine whether the startled no-cue condition acted as a true control condition by testing whether startle response magnitude for startle-alone trials was different from response magnitude for the startled no-cue condition.

**Magnitude.** Analysis of the unstandardized startle response data showed a significant main effect of block and a marginally significant main effect for cue type on blink magnitude. The main effect of block,  $F(1, 34) = 13.74, p < .001$ , indicates that average blink magnitude decreased from block 1 ( $M = 1.35, SE = .25$ ) to block 2 ( $M = .94, SE = .16$ ). This overall decrease in magnitude across blocks represents habituation of the startle response with repeated exposure to the startle stimulus (see Figure 9). The marginally significant main effect of cue,  $F(1, 34) = 2.67, p < .080$ , shows that blink magnitude was greatest for the center-cue ( $M = 1.21, SE = .22$ ), followed by no-cue ( $M = 1.18, SE = .21$ ), spatial-cue ( $M = 1.10, SE = .20$ ), and double-cue ( $M = 1.08, SE = .19$ ) (see Figure 10). There were no other significant main effects or interactions.

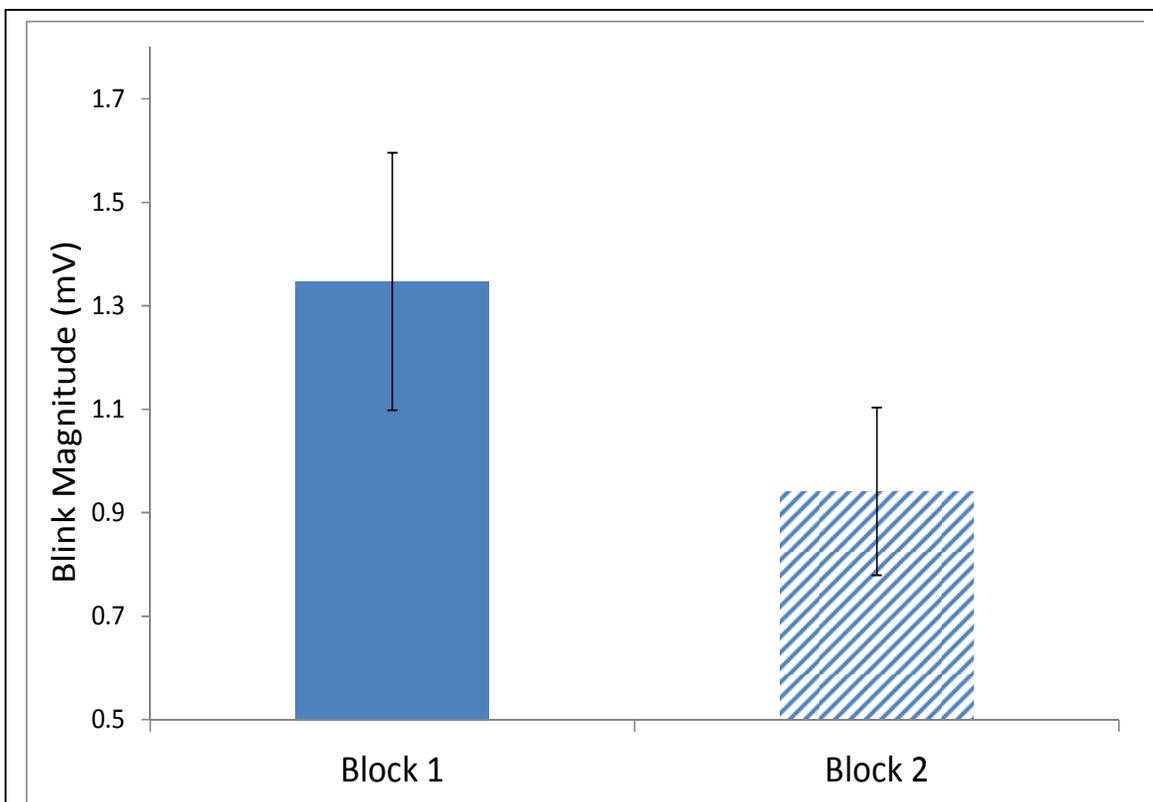


Figure 9. Main effect of block for blink magnitude (i.e. habituation of the startle response.)

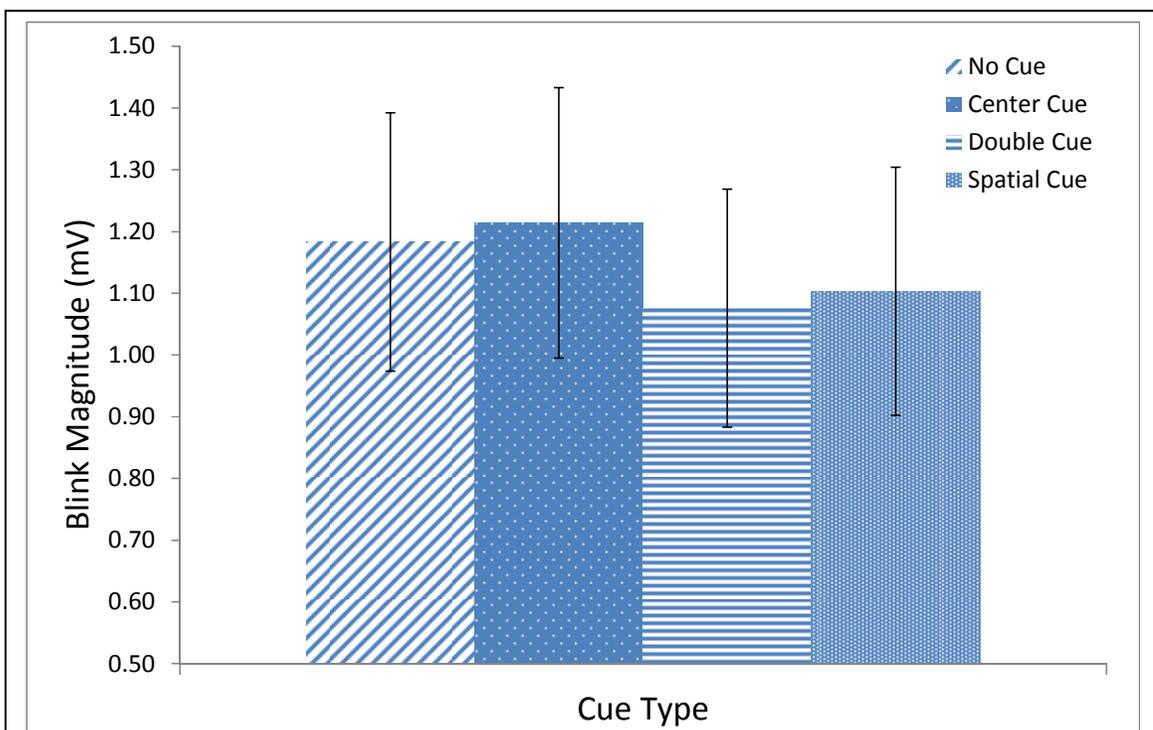
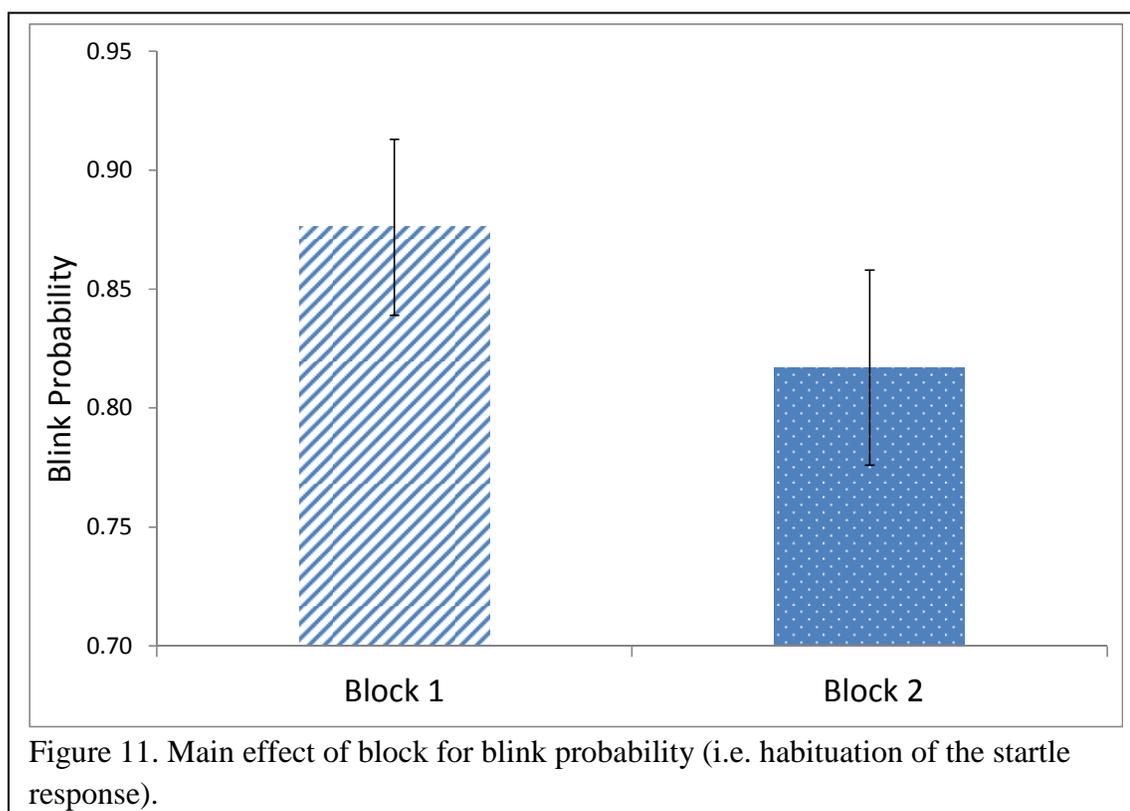
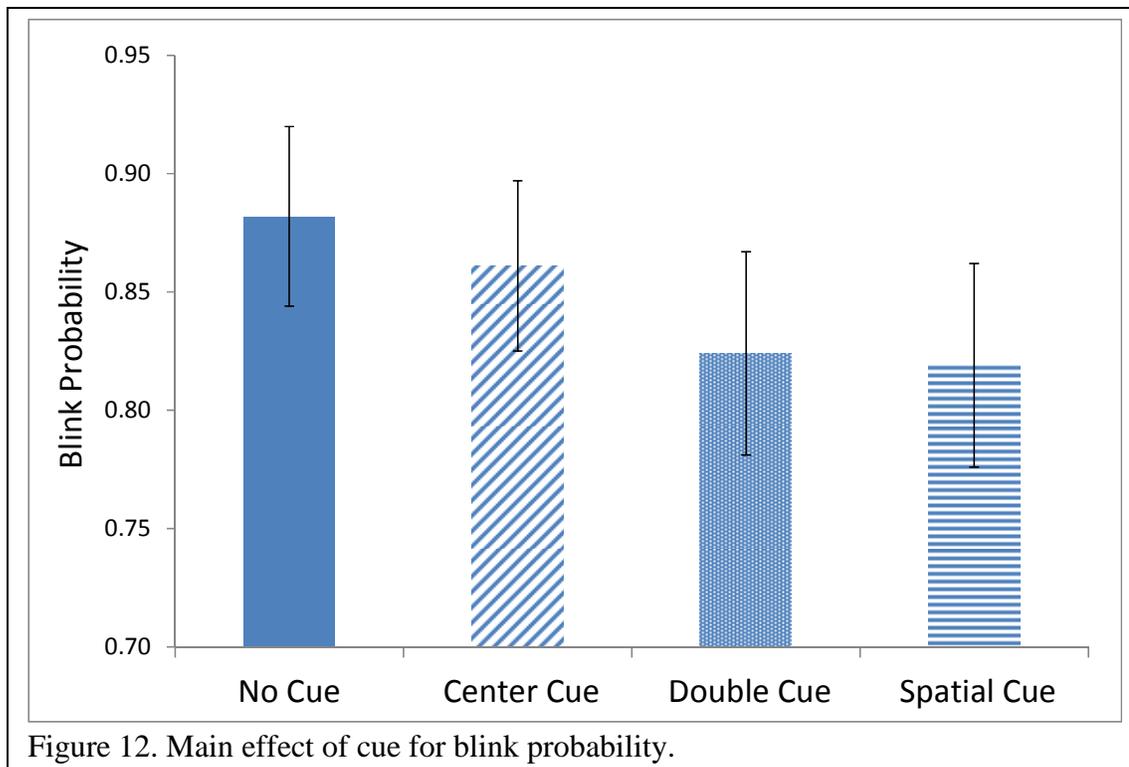


Figure 10. Marginally significant main effect of cue type for blink magnitude.

**Probability.** Analysis of the uncorrected startle data for probability indicated significant main effects of block,  $F(1, 34) = 10.96, p = .002$ , and cue,  $F(3, 102) = 4.04, p = .011$ . The main effect of block shows that blink probability significantly decreased from block 1 ( $M = .88, SE = .04$ ) to block 2 ( $M = .82, SE = .04$ ), further indicating habituation of the startle response across blocks (see Figure 11). The significant main effect of cue on blink probability shows that probability was greatest for the no-cue condition, which was subjectively indistinguishable from the startle-alone control trials, and lowest for the spatial-cue, such that the no-cue condition ( $M = .88, SE = .04$ ) showed the highest probability of response, followed by center-cue ( $M = .86, SE = .04$ ), double-cue ( $M = .82, SE = .04$ ), and spatial-cue ( $M = .82, SE = .04$ ) (see Figure 12). There were no other significant main effects or interactions.





**Latency.** Analysis of uncorrected startle response data showed significant main effects of block,  $F(1, 30) = 7.71, p = .009$ ; cue,  $F(3, 90) = 7.51, p < .001$ ; and congruency,  $F(1, 30) = 4.52, p = .042$ , on response latency (in ms). The main effect of block on response latency shows a small, but significant effect in the time of blink onset where block 1 latency ( $M = 40.2, SE = 1.3$ ) was shorter than block 2 ( $M = 41.6, SE = 1.2$ ) (see Figure 13). The main effect of cue on onset latency shows small but significant differences in latency for no-cue ( $M = 42.8, SE = 1.1$ ), center-cue ( $M = 41.1, SE = 1.2$ ), double-cue ( $M = 40.4, SE = 1.5$ ), and spatial-cue ( $M = 39.3, SE = 1.3$ ) (see Figure 14). The main effect of congruency on latency shows a statistically significant difference in response latency for incongruent ( $M = 40.5, SE = 1.2$ ) compared to congruent ( $M = 41.2, SE = 1.2$ ) trials. Overall, blink onset latency was slower for block 2 than block 1, shortest for spatial-cue and longest for no-cue, and longer for congruent compared to incongruent

trials. The significant differences between blocks and among cues are small, but likely represent real effects since this same pattern is also reflected in the blink probability data. However, the congruency difference is most likely a Type I error since the response occurred before the target was presented, and thus the congruency condition could not have impacted the startle response.

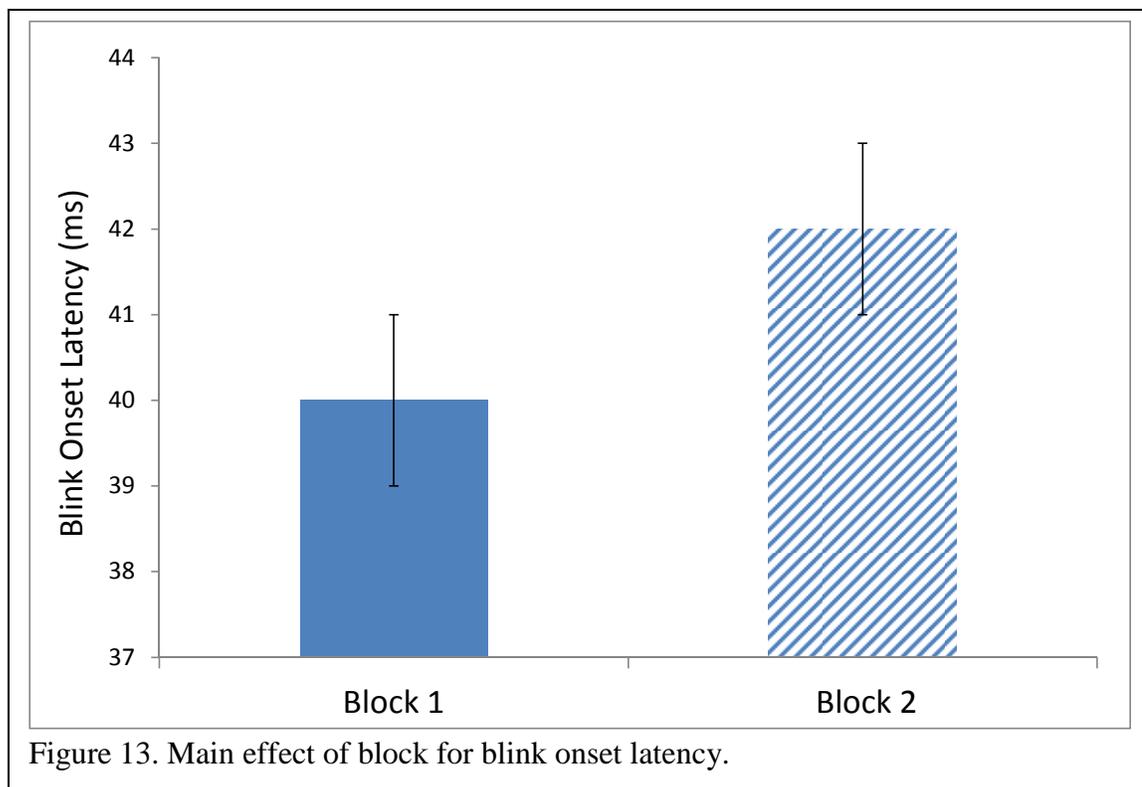
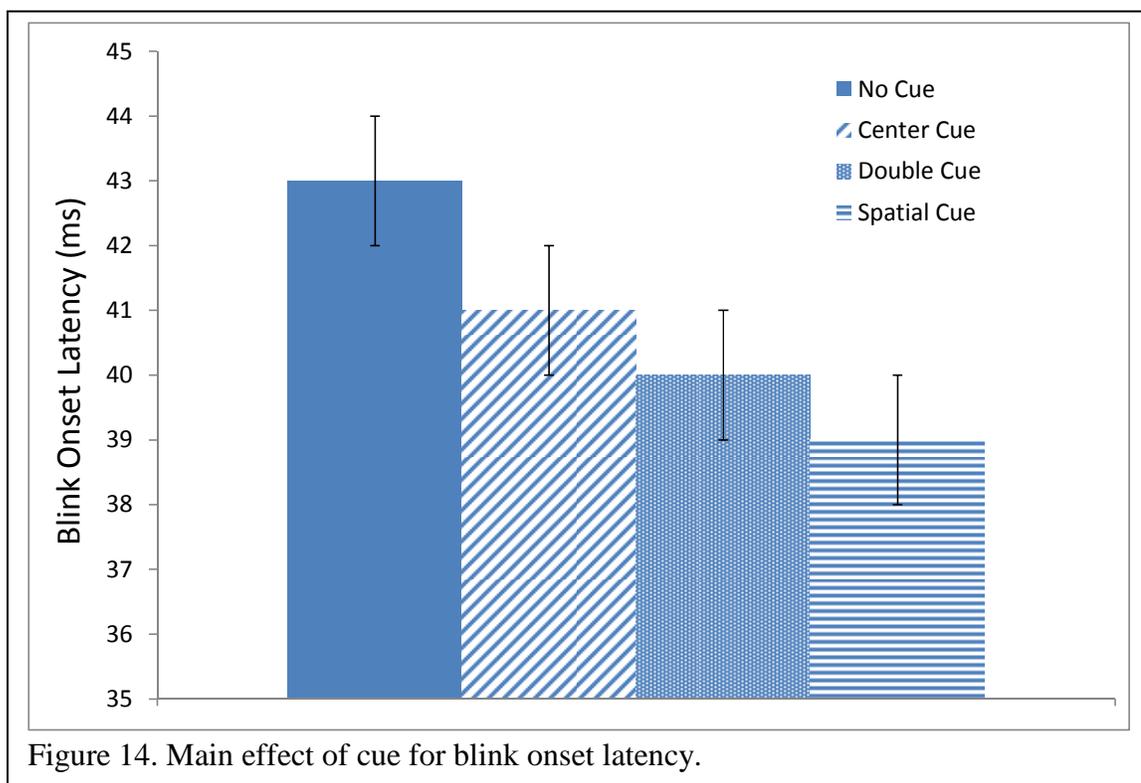


Figure 13. Main effect of block for blink onset latency.

### Analyses of PPI of Startle Data

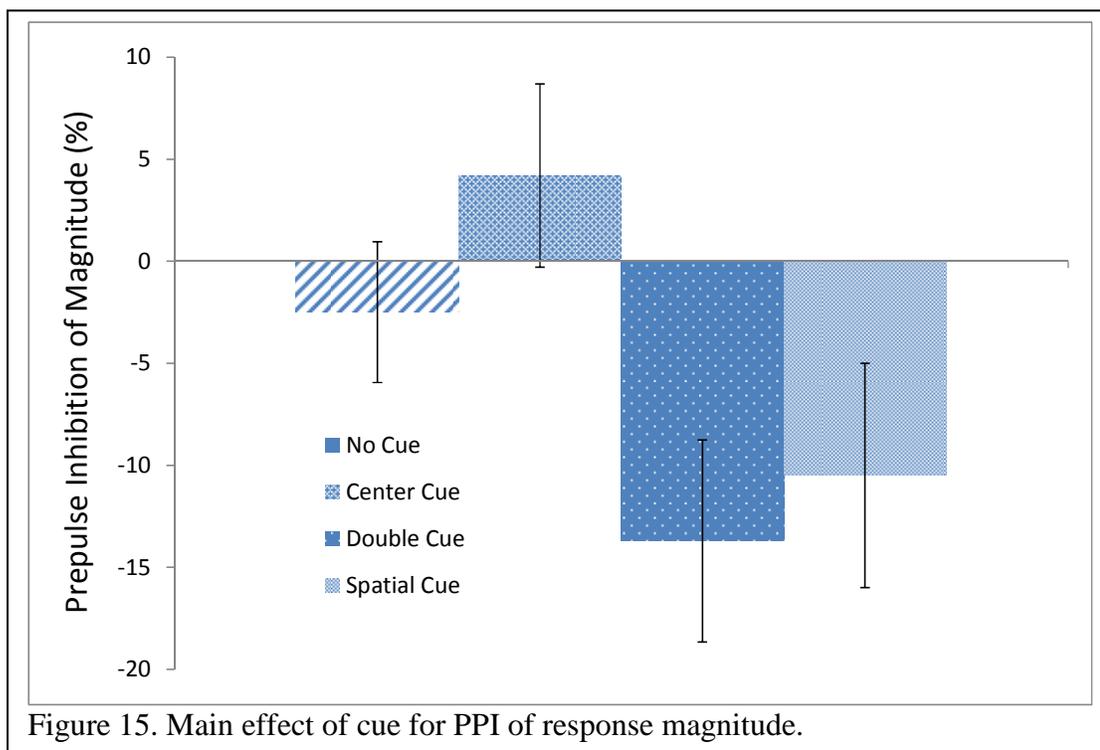
Calculations were performed to obtain PPI values for each of these variables, showing the pure effect of each cue condition on the startle response variables. The effect of cues on the startle variables was isolated by comparing the startle trials presented during the task to the control startle trials. For magnitude, the PPI value was obtained by subtracting the reactivity of the control (startle-alone) trials from the reactivity of the task trials, the result of which was then divided by the reactivity in the control condition. For

the probability and latency variables, the calculation consisted only of obtaining the difference between the task and control trials. After obtaining the PPI values for each of the startle variables, the 2 block x 4 cue (no-cue, center-cue, double-cue, spatial-cue) x 2 congruency (congruent, incongruent) repeated measures omnibus ANOVA was conducted a second time separately for magnitude, probability, and latency. An additional correlational analysis was conducted to examine the possible relationship between reaction time on startled trials with the PPI on cued trials to determine if the degree of response inhibition was related to RT.



**Magnitude.** Analysis of PPI data showed a significant main effect of cue,  $F(3, 102) = 4.72, p = .005$ , on PPI of response magnitude. The main effect of cue shows that PPI of blink magnitude was greatest for the double-cue ( $M = -.137, SE = .049$ ), followed by the spatial-cue ( $M = -.105, SE = .055$ ), and no-cue conditions ( $M = -.025, SE = .034$ )

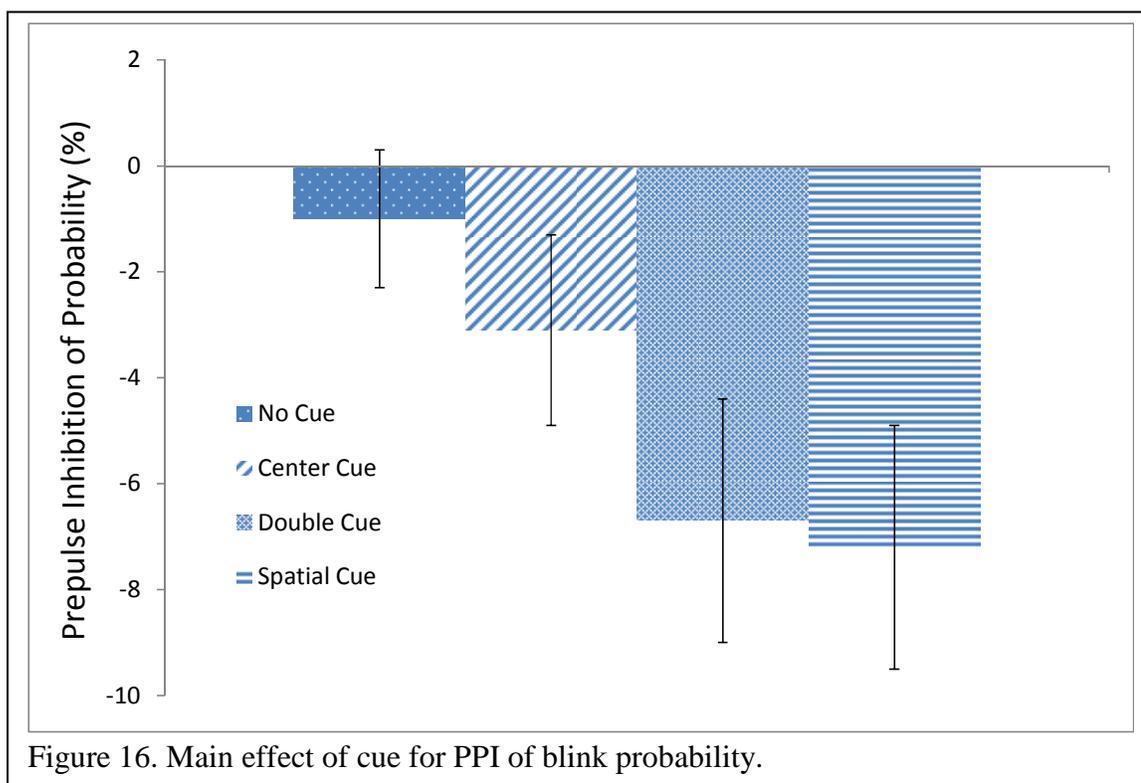
(see Figure 15). The center-cue condition actually showed a slightly positive mean ( $M = .042$ ,  $SE = .045$ ), suggesting prepulse facilitation. However, the double-cue condition showed the greatest amount of PPI and was the only condition that was significantly different from zero as expressed by the 95% CI [-.238, -.036].



**Probability.** Analysis of the standardized PPI probability data showed only a significant main effect of cue on probability,  $F(3, 102) = 4.04$ ,  $p = .011$  (see Figure 16). This main effect shows that blink probability inhibition was greatest for the spatial-cue ( $M = -.072$ ,  $SE = .023$ ), followed by the double-cue ( $M = -.067$ ,  $SE = .023$ ), center-cue ( $M = -.031$ ,  $SE = .018$ ), and no-cue ( $M = -.010$ ,  $SE = .013$ ) conditions.

**Latency.** Analysis of the PPI latency startle response data showed significant main effects of cue,  $F(3, 90) = 7.51$ ,  $p < .001$ , and congruency,  $F(1, 30) = 4.52$ ,  $p = .042$ . The main effect of cue on latency shows that the presence of cues facilitated the initiation of the startle response, and this facilitation was greater for the orienting spatial-cue

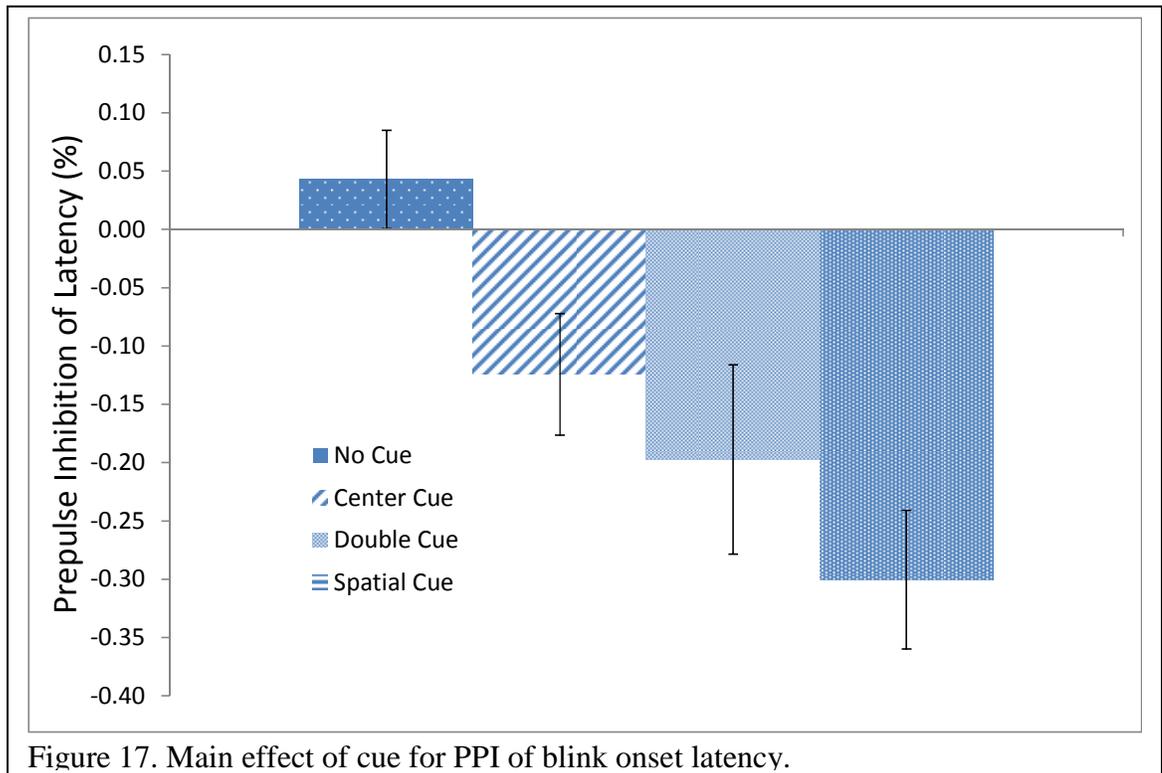
condition than either of the alerting cue conditions (see Figure 17). For the no-cue condition ( $M = .4$ ,  $SE = .4$ ), there was no difference in blink latency when compared to the control startle trials, as expected. For the center-cue ( $M = -1.2$ ,  $SE = .5$ ), double-cue ( $M = -2.0$ ,  $SE = .8$ ), and spatial-cue ( $M = -3.0$ ,  $SE = .6$ ) conditions, there were small, but significant, decreases in the onset latency of the startle response compared to control startle trials.



### Further Analyses

Examination of the analyses between startle-alone trials and startled no-cue trials for startle variables revealed no significant effects, indicating that these trials were subjectively and statistically indistinguishable and thus could be used interchangeably as true control trials. There were no significant correlations among RT and PPI of magnitude on startled-cued trials, indicating that the amount of response inhibition was

not related to RT. Exploratory correlations conducted between blink magnitude and accuracy for incongruent trials in block 1 and block 2 did not reach significance, showing that blink magnitude and accuracy were not related for incongruent trials.



## **DISCUSSION**

The startle response has been used in a variety of research settings to investigate the processes underlying various psychological phenomena, such as schizophrenia (Ludewig, Geyer, Etzenberger, & Vollenweider, 2002), emotional processing, cognition, and the effects of psychoactive substances. In order to fully utilize the startle response in the examination and treatment of such a wide variety of psychological applications, we must first attempt to understand how the startle response relates to these underlying processes. Though a large amount of literature exists on the topic of startle and cognition, many studies have drawn conclusions based on assumptions and hypotheses that have not been adequately tested in a systematic, empirical fashion. The present study aimed to address one such gap in the literature: the assumption of Graham's (1975) Interrupt Hypothesis. Combining the acoustic startle paradigm with the Attention Networks Test allowed for a preliminary test of the Interrupt Hypothesis.

### **ANT without Startle**

The initial analyses conducted were equivalent to the original ANT design, and were performed to examine the effects of cue type on reaction time and accuracy without the influence of the startle stimulus or startle response. It was predicted that cues would have a significant effect on RT for non-startle trials such that reaction time would be significantly faster for each of the cue conditions with respect to the no-cue condition due to the alerting and orienting effects of the different cue types. This hypothesis was supported by the data in that RT for each cue condition was significantly faster than in the no-cue condition. This observation indicates that the cues were indeed activating

attentional networks, and the difference in RT between cue types indicates that different networks were activated depending on the type of cue presented.

The alerting effect was observed, as predicted, in the comparison of the double-cue conditions with the no-cue condition. Reaction time was significantly faster for the double-cue condition than that for the no-cue condition. This shows the effect of alerting, in which the presence of a visual cue indicating the pending onset of the target stimulus was associated with decreased RT. The double-cue provides information about the timing of the target stimulus, which reduces RT, while attention must remain diffused across the two possible target locations. The no-cue condition does not provide timing information regarding the onset of the target, but also requires attention to remain diffused across the potential target locations. By comparing these two conditions, the effect of a visual cue which only provides temporal information regarding the onset of the target stimulus was isolated, providing a direct measurement of the alerting network. The significant alerting effect obtained in this study is consistent with previous ANT studies (e.g., Fan et al., 2002; Jennings et al., 2007).

The orienting effect was observed in the comparison of the spatial-cue condition to the center-cue condition as predicted. The center-cue condition provides temporal information regarding the onset of the target stimulus, whereas the spatial-cue condition provides information regarding the timing and location of the pending target. The difference between these two conditions isolates the effect of the orienting network from that of the alerting network. The significant difference in RT observed for the spatial-cue condition compared to the center-cue condition provided evidence for orienting network

activation consistent with the findings of previous research (e.g., Fan et al., 2002; Jennings et al., 2007).

The activation and efficiency of the executive attentional network was determined from the ANT by comparing RT and accuracy for congruent compared to incongruent flankers, regardless of cue condition. Incongruent flankers introduce conflict to the task of responding to the direction of the arrow which must be resolved via intervention of the executive network. It was hypothesized that RT would be slower and accuracy would be lower for the incongruent conditions compared to congruent flanker conditions. Both of these hypotheses were supported and the data aligned with the findings of prior research (Fan et al., 2002; Jennings et al., 2007). The significantly slower RT and lower accuracy for the incongruent trials shows that incongruent flankers made the task more difficult by introducing conflict which took extra time and attentional resources to resolve.

Given the findings of the original ANT study conducted by Fan and colleagues (2002) which showed no significant difference in RT between center-cue and double-cue, it was hypothesized that there would not be a significant difference in RT between center-cue and double-cue conditions. The reasoning behind this prediction was that both conditions provided predictive information about the timing of the target but neither condition provided specific predictive information about the location of the target, thus making them equivalent alerting cues. However, this hypothesis was not supported by the data obtained in this study. RT in the double-cue condition was significantly faster than RT in the center-cue condition, indicating that perhaps the double-cue condition provided some additional advantage over the center-cue. Though both cues necessitate the diffusion of attention across the possible target locations, the center-cue may divert

attention away from the potential target locations whereas the double-cue limits the possible target location to two specific areas of the screen. Alternatively, the double-cue condition could be interpreted as correctly predicting the location of the target 50% of the time, the advantage of which accumulated over many trials to an average net decrease in RT over the center-cue. Unfortunately, this interpretation cannot be verified with the current study design, though it could be tested in future studies with the addition of an eye-tracking camera and software. This finding is somewhat perplexing given its deviation from the results of other ANT studies (e.g., Fan et al., 2002; Greene et al., 2008; Jennings et al., 2007), so further investigation is warranted to determine the possible causes. The differences in startle measurements between center-cue and double-cue conditions discussed below provides further support that there is a functional difference between these two alerting cues.

Examination of the accuracy data for non-startled trials indicated that response accuracy was very high for congruent trials regardless of cue type, and accuracy was significantly higher for congruent compared to incongruent trials, as predicted. Responding to congruent trials did not require the same degree of processing as the incongruent trials, which necessitated activation of the executive network to resolve the flanker conflict. The shallower and more automatic response to congruent trials resulted in much higher accuracy for these trials compared to incongruent trials which had lower accuracy, possibly due to interference in processing of the target and/or a speed-accuracy tradeoff. This effect would be expected in studies utilizing the ANT in which participants are instructed to respond as quickly as possible, and the finding is corroborated by prior research (Fan et al., 2002, 2009; Jennings et al., 2007). However, most ANT studies do

not break down accuracy by block as was done in this study. With the additional factor of block in the analysis, accuracy decreased significantly for incongruent trials but was unaffected for congruent trials. This drop in accuracy for incongruent trials could be due to increased fatigue in block 2 over block 1, and would not be observed for congruent trials due to the less demanding nature of these trials.

### **ANT with Startle**

The design of this study allowed for a direct comparison between the original ANT methodology and the ANT with the addition of a startle stimulus. The aforementioned analyses, findings, and interpretations are consistent with the original ANT design. The following analyses and findings are original to this study and examine the effects that the addition of a startle stimulus had on measures of the ANT. Not only did the introduction of a startle stimulus affect performance on the ANT, but the startle responses were also affected by concurrent task performance. The Interrupt Hypothesis was examined in the context of these bidirectional effects. The results did not indicate that a startle-stimulus negatively impacted performance on the ANT, and therefore, no evidence was found to support Graham's Interrupt Hypothesis. Furthermore, since the Protection Hypothesis is dependent on the assumption that interruption occurs, it could not be evaluated. In direct contrast with the expected interruption and slowing of processing due to a startle stimulus, the results indicate that the presentation of a startle stimulus facilitated cognitive processing as indicated by reduced reaction time to the target.

When the ANT data were examined with the inclusion of the effect of the startle stimulus, it was clear that the startle stimulus significantly affected performance on the

task, though not in the hypothesized direction. Following the reasoning of the Interrupt Hypothesis, it was predicted that the presentation of startling stimuli during processing of predictive cues would interrupt this processing, resulting in increased reaction times. Since startle stimuli were presented immediately after the offset of the cue, the Interrupt Hypothesis would predict that the startle stimulus (or startle response) should disrupt the processing of the cue. The resultant disruption of cue processing should then be evident by an increase in reaction time to the target. However, the data in this study show the opposite effect: presentation of startle stimuli during the task tended to decrease RT to the target, facilitating processing rather than disrupting it. If the startle stimulus or response disrupted encoding of the cue, then the advantage procured by the alerting and/or orienting effects would be negatively impacted, resulting in decreased efficiency of the attentional networks and greater RT. Reaction time was significantly lower for the startled center-cue condition compared to its non-startled counterpart, and there was no significant difference (either increase or decrease) for the other visual cue conditions regardless of whether or not a startle stimulus was also presented.

In addition to the significant decrease in RT for the startled center-cue condition, there was also a significant decrease in reaction time for the startled no-cue condition. Since no visual cue was presented on these trials, there would be no visual cue for which to disrupt processing, so the decrease in RT must be due to the startle stimulus acting as an alerting cue itself. Even though the no-cue condition did not contain a cue for the startle stimulus to disrupt specifically, the startle stimulus was thought to be a generally disrupting and distracting influence during the performance of the ANT, so it was hypothesized that the startle stimulus would not act as an auditory cue. This hypothesis

was not supported. The significant decrease in RT between non-startled no-cue trials and startled no-cue trials shows that the startle stimulus acted as an alerting auditory cue, since no visual cue was presented before the onset of the startle stimulus and these trials were identical except for the presence or absence of a startle stimulus. Furthermore, the StartReact Effect cannot be used to explain the speeding of RT for trials on which a startle stimulus was presented because no facilitation was observed beyond what would be expected if the startle stimulus acted as an alerting cue. The interpretation that the startle stimulus maximized efficiency of the alerting network is supported by the observation that the difference in RT between the center-cue and double-cue conditions for the no-startle trials was eliminated with the addition of the startle-stimulus.

A study conducted by Callejas et al. (2005) examined the effect of an alerting tone presented during the ANT, but unlike the present study, the sound was presented prior to the presentation of the visual cue. This study found that a 50 ms non-startling auditory tone presented at a short (100 ms) SOA before the visual cue enhanced the orienting effect of the cue. The authors concluded that the tone acted as an alerting cue and that a highly activated alerting system increased the efficiency of the orienting system, thus arguing against the independence of the attentional networks (Callejas et al., 2005). However, this explanation cannot be applied to the current study, since the startle stimulus was presented after the visual stimuli in every cue condition. An alternative explanation for the present findings could be that the startle stimulus increased physiological arousal for a short period following its presentation, including the window during which the target was presented. Unfortunately this alternative explanation cannot be ruled out without additional information. Future studies could include measurement of

skin conductance response or subjective questionnaires to determine whether the startle stimulus increased arousal, which in turn, could lead to a decrease in RT.

It was hypothesized that the startle stimulus would differentially impact RT for the spatial-cue condition compared with the other cue conditions because the orienting cue contained an extra level of information which could potentially be disrupted by a startle stimulus. This hypothesis was not supported; the startled spatial-cue condition had the fastest mean RT out of all of the condition types. Reaction time for the startled spatial-cue condition was not significantly lower than the non-startled spatial-cue condition, providing evidence against the Interruption Hypothesis. If disruption of processing of the informational content of the cue was occurring, then it should be most evident in the condition in which the cue contained more information. The lack of a significant difference between startled and non-startled spatial-cue trials indicates that the startle stimulus did not disrupt processing of the cue as measured by reaction time, and the trend that the startle stimulus decreased RT implies that something else must be going on.

Examination of the relationships between startled-cued conditions indicated that the startle stimulus did not equally affect responding for each cue type. There were significant differences in RT among the startled-cue conditions, specifically between the no-cue and spatial-cue conditions and the center-cue and spatial-cue conditions, with an additional marginally significant difference between the double-cue and spatial-cue conditions. These differences show that the startle stimulus combined with the information present in each cue and did not simply drive the effect to asymptote. The most probable explanation for this effect is that the startle stimulus acted as an alerting

auditory cue, thus bringing RT of the startled no-cue condition to the same level as the center-cue and double-cue conditions. For the startled double-cue condition, the addition of the startle stimulus provided redundant information that did not produce any additional benefit to an already active alerting network. Comparing the center-cue condition for startled and non-startled trials supports this interpretation: whereas there was a significant difference in RT between non-startled center-cue and non-startled double-cue conditions, this significant difference was eliminated with the addition of the startle stimulus, which served to fully activate and maximize the efficiency of the alerting network for the center-cue condition. Since the startle stimulus could not provide any information to activate the orienting network, the significant reduction in RT for the startled spatial-cue condition compared to the other conditions must have been due to the visual orienting cue. Considering the effect of the startle stimulus acting as an auditory cue, it is interesting to note that even though the startle stimulus was presented 100 ms after the onset of the visual cue, it was still as effective in activating the alerting network as the most efficient alerting cue (double-cue). This finding implies that there could be a trade-off advantage of cue intensity versus time. This effect could be investigated in future studies that vary the intensity and SOA of an auditory cue in the interval between the offset of the visual cue and the onset of the target. Future studies might optimize PPI by increasing the SOA between the visual cue and startle stimulus to determine if interruption will occur at longer intervals.

The accuracy data were difficult to interpret due to the low error rates and variability, especially for congruent trials, which probably drove these effects to significance. For this reason, interpretation of the accuracy data was approached with

caution and the results should be deemed exploratory, with future research being necessary to substantiate these trends. Analysis of the accuracy data with inclusion of the startle stimulus revealed that the startle stimulus was associated with higher response accuracy for congruent trials. For incongruent trials, the startle stimulus resulted in a significant decrease in accuracy for block 1, but a significant increase in accuracy for block 2. These findings provide further support against the Interrupt Hypothesis, which would predict that accuracy should be lower for startled compared to non-startled trials. Although response accuracy was lower for startled incongruent trials in block 1, this trend reversed in block 2. In addition, congruent trials showed higher accuracy for startled compared to non-startled trials independent of block.

The change in the effect of the startle stimulus on response accuracy for incongruent trials from block 1 to block 2 could have been due to habituation of the startle response, which might have provided support for the Protection Hypothesis. If accuracy was lower in block 1 when response magnitudes were larger, and accuracy was higher in block 2 when blink magnitude was smaller, then the startle response may have been negatively impacting accuracy before habituation occurred. To examine this possibility, exploratory correlations were performed between startle response magnitude and accuracy for incongruent trials in block 1 and block 2. This analysis yielded no significant correlations, implying that this shift in response accuracy for startle condition across blocks was not the result of startle response habituation. Furthermore, this indicated that the observed effects on accuracy were the result of the startle stimuli and not the startle response.

### **Task Effects on the Startle Response**

In addition to examining the effects of the startle stimulus on ANT performance measures, analyses were conducted to examine the effects that performing the ANT had on the startle response. There is a rich body of research examining the effects of attention and performing a task on startle response measures, some of which was discussed in the Introduction to this manuscript (e.g., Filion et al., 1993). Prepulse inhibition (PPI) is commonly used to examine attenuation of the startle response as an effect of the prepulse, which is determined by comparing task trials to control trials. The prepulses in this study were the visual cues (center-cue, double-cue, and spatial-cue), whereas the startle-alone trials for each participant were used as controls. Individual variation in startle magnitude can be minimized with this methodology since the effect of the prepulse is standardized for participants using their own control trials. Examination of the unstandardized data can mask real effects of the prepulse due to individual variation but is still useful for identifying trends. Effects of the ANT on the startle response were examined for both unstandardized response data as well as PPI data.

Before exploring startle response data, certain analyses should always be conducted to verify that the data are legitimate. The startle reflex is known to habituate over time with repeated exposure to the same stimulus, so habituation should be found in almost any experimental paradigm utilizing the startle response. Therefore, a hypothesis was made predicting that startle magnitude would decrease significantly across blocks for startle-alone trials. Habituation was also evident from the significant main effect of block for blink probability, indicating that blink probability decreased from block 1 to block 2. Additionally, it was predicted that there would be no significant difference in startle

magnitude between startle-alone trials and startled no-cue trials, since these trials would be indistinguishable until the onset of the target stimulus. This hypothesis was supported, showing that there was no difference in these trials before presentation of the target and flanker arrows and that the startled no-cue trials could be used as true control trials.

Examination of the unstandardized startle data indicated that there were several trends that should be further explored by looking at PPI. There was a main effect of cue type on blink magnitude, which showed that blink magnitude was lower for the double-cue and spatial-cue conditions than the no-cue control condition. The main effect of cue type on blink probability suggested that blink probability was lower for double-cue and spatial-cue than the control condition. For blink onset latency, there was a main effect of cue, suggesting that latency was shorter for the orienting condition than the alerting conditions. These analyses served to inform the following interpretations of the standardized PPI data.

Examination of magnitude, probability, and latency for standardized PPI values produced a more accurate version of the effects of the ANT on startle response measures than the unstandardized data. Examination of the PPI of magnitude data revealed that PPI was only significantly different from zero for the double-cue condition, although there was a trend indicating that the spatial-cue may also inhibit startle magnitude to a lesser degree. This finding suggests that the PPI effect of the cues on magnitude may not be due to the information content of the cue, but rather to the number of items on the screen just prior to the presentation of the startle stimulus. The no-cue condition and center-cue condition both presented one item on the screen: the no-cue condition had the fixation cross displayed on the screen and the center-cue condition had an asterisk displayed on

top of the fixation cross. The spatial-cue condition had two items on the screen, the fixation cross and an asterisk at the top or bottom. The double-cue condition had three items on the screen, the fixation cross and two asterisks. The finding that the two conditions with one visual item (no-cue and center-cue) had less PPI of magnitude than the condition with two items (spatial-cue), which had less PPI than the condition with three items (double-cue) suggests that the number of visual elements displayed on the screen was responsible for these effects.

The interpretation that PPI effects in this study were due to the number of visual elements displayed on the screen can also be applied to the PPI effect seen for blink probability. Further examination of the possible relationship between cue type and blink probability revealed that only the double-cue and spatial-cue conditions had significant PPI of blink probability, and these two conditions were not significantly different from each other. The most probable explanation for this effect is that it is related to the number of items displayed on the screen, since there is no clear relationship between information content and the amount of PPI produced from the cues.

The PPI effects of the cues on blink onset latency were small, but statistically significant. These results showed that blink onset latency was shorter for trials with a visual cue than for trials without a visual cue, and that onset latency was shorter for the spatial-cue condition than the center-cue condition. These findings provide further support that the effect of the visual cues on the startle response is probably the result of the number of items displayed on the screen and not related to which attentional network was activated by the cue. The finding that the center-cue condition resulted in onset latency reduction that was significantly different from zero, whereas the no-cue condition

did not, indicates that a transient change in the screen also contributed to a reduction in latency.

### **Implications for the Interrupt Hypothesis**

The present study was designed to assess the veracity of Graham's (1975) Interrupt Hypothesis by combining the Attention Networks Test with the startle paradigm. The ANT is a well-documented cognitive task that allows for the measurement of multiple aspects of attention, including the alerting, orienting, and executive networks. Activation and efficiency of the alerting and orienting networks is determined by the processing and extraction of information from the presentation of visual cues, which in turn, affects reaction time to a visual target. Part of the difficulty in directly testing the Interrupt Hypothesis is the measurement of prepulse processing. Since the visual cue in the ANT is analogous to a prepulse in the startle paradigm, and processing of the visual cue in the ANT is determined by comparing the reaction times in different cue conditions, the ANT combined with startle was determined to be a potentially revealing method of testing the interruption of cognitive processing by a startle response.

If a startle response interrupts cognitive processing of a prepulse, as predicted by the Interrupt Hypothesis, then presentation of a startle stimulus immediately after the presentation of a visual cue in the ANT should have interrupted processing of the information leading to RT benefits from activation of the alerting and/or orienting networks. Slower reaction times in the startled conditions compared to the non-startled conditions should have resulted if interruption was occurring. However, the results of this study did not indicate that presentation of a startle stimulus during a cognitive task negatively impacted performance, and thus did not support the Interrupt Hypothesis.

Furthermore, the startle stimulus acted as an alerting cue that was as effective as the most efficient visual alerting cue, despite being presented 100 ms after the visual cue.

Another perceived benefit of using the ANT to address the Interrupt Hypothesis was the collection of response accuracy data in addition to RT data. The Interrupt Hypothesis would predict that disruption of prepulse processing should also decrease accuracy. A decrease in accuracy was seen in the data for incongruent trials in block 1 for startled compared to non-startled trials, but this trend reversed in block 2 such that accuracy was higher for startled vs. non-startled incongruent trials. Overall, there was no evidence that the startle stimulus led to a decrease in accuracy, and thus the Interrupt Hypothesis was not supported by the accuracy data, either.

The Protection Hypothesis is dependent on the assumption that the Interrupt Hypothesis is true, predicting that the role of PPI is to reduce the disrupting effect of the startle response on prepulse processing. Therefore, the Protection Hypothesis could not be evaluated, given the lack of evidence to support the veracity of the Interrupt Hypothesis. Future research will need to be conducted, perhaps with the use of a task utilizing measures other than RT before more definitive conclusions can be drawn.

### **Conclusion**

The results of this study failed to support the Interrupt Hypothesis, and since no evidence for interruption was obtained, the Protection Hypothesis could not be evaluated. However, extreme caution must be expressed and further studies must be conducted before it can be said that the Interrupt Hypothesis has been refuted.

The original study discussed in this manuscript was carefully designed with the express intent to determine whether or not a startle stimulus disrupts processing, but there

are some limitations to the study design. One of the primary reasons why it is difficult to attempt to refute the theory is that there is no clear way to measure a baseline of cognitive processing, interrupt it, and then determine the degree of interruption. It was determined that an attention task measuring differences in reaction time, like the ANT, would be an empirical method to accomplish this. Unfortunately, there are drawbacks to utilizing an RT measurement, such as the introduction of a motor component which adds an additional level of potential measurement error and variation. Future studies aiming to test the Interrupt Hypothesis should utilize alternative methods of measuring baseline cognitive processing during a task to compare with the same task performance when a startle stimulus is presented. EEG and fMRI data obtained during task performance with and without startle stimuli may provide further insight for the investigation of the interaction between the startle response and cognitive processing. Although the veracity of the Interrupt Hypothesis continues to be assumed in the literature, little evidence has been produced in terms of direct support. Understanding whether or not the Interrupt Hypothesis is a valid assumption could have important practical implications for research regarding schizophrenia and other conditions that show deficits in PPI. The study performed and discussed in this document adds to a growing body of research (e.g., the StartReact Effect) that seems to imply that perhaps the startle response does not disrupt processing. Future research should aim to resolve these inconsistencies.

## REFERENCES

- Berg, W. K., & Balaban, M. T. (1999). Startle elicitation: stimulus parameters, recording techniques, and quantification. In M. E. Dawson, & A. M. Schell, A. H. Böhmelt (Eds.), *Startle modification: Implications for neuroscience, cognitive science, and clinical science* (pp. 21-50). New York: Cambridge University Press.
- Bish, J. P., Ferrante, S. M., McDonald-McGinn, D., Zackai, E., & Simon, T. J. (2005). Maladaptive conflict monitoring as evidence for executive dysfunction in children with chromosome 22q11.2 deletion syndrome. *Developmental Science*, 8(1), 36–43.
- Blumenthal, T. D. (1988). The startle response to acoustic stimuli near startle threshold: Effects of stimulus rise and fall time, duration, and intensity. *Psychophysiology*, 25(5), 607–611.
- Blumenthal, T. D. (1999). Short lead interval startle modification. In M. E. Dawson, A. M. Schell, & A. H. Böhmelt (Eds.), *Startle modification: Implications for neuroscience, cognitive science, and clinical science* (pp. 51-71). New York: Cambridge University Press.
- Blumenthal, T. D., & Berg, W. K. (1986). Stimulus rise time, intensity, and bandwidth effects on acoustic startle amplitude and probability. *Psychophysiology*, 23(6), 635–641.
- Blumenthal, T. D., Cuthbert, B. N., Filion, D. L., Hackley, S., Lipp, O. V., & Van Boxtel, A. (2005). Committee report: Guidelines for human startle eyeblink electromyographic studies. *Psychophysiology*, 42(1), 1–15.

- Callejas, A., Lupiáñez, J., Funes, M. J., & Tudela, P. (2005). Modulations among the alerting, orienting and executive control networks. *Experimental Brain Research*, *167*, 27–37.
- Carlsen, A. N., Chua, R., Inglis, J. T., Sanderson, D. J., & Franks, I. M. (2004). Prepared movements are elicited early by startle. *Journal of Motor Behavior*, *36*(3), 253–264.
- Carlsen, A. N., Chua, R., Summers, J. J., Inglis, J. T., Sanderson, D. J., & Franks, I. M. (2009). Precues enable multiple response preprogramming: Evidence from startle. *Psychophysiology*, *46*(2), 241–251.
- Carlsen, A. N., Chua, R., Dakin, C. J., Sanderson, D. J., Inglis, J. T., & Franks, I. M. (2008). Startle reveals an absence of advance motor programming in a Go/No-go task. *Neuroscience Letters*, *434*(1), 61–65.
- Carlsen, A. N., Lam, M. Y., Maslovat, D., & Chua, R. (2011). Reaction time effects due to imperative stimulus modality are absent when a startle elicits a pre-programmed action. *Neuroscience Letters*, *500*(3), 177–181.
- Davis, M., Walker, D. L., & Lee, Y. (1999). Neurophysiology and neuropharmacology of startle and its affective modification. In M. E. Dawson, A. M. Schell, & A. H. Böhmelt (Eds.), *Startle modification: Implications for neuroscience, cognitive science, and clinical science* (pp. 95-113). New York: Cambridge University Press.
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non- search task. *Perception and Psychophysics*, *16*, 143–149.

- Fan, J., Gu, X., Guise, K. G., Liu, X., Fossella, J., Wang, H., & Posner, M. I. (2009). Testing the behavioral interaction and integration of attentional networks. *Brain and Cognition, 70*(2), 209–220.
- Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340–347.
- Feifel, D., Minassian, A., & Perry, W. (2009). Prepulse inhibition of startle in adults with ADHD. *Journal of psychiatric research, 43*(4), 484–489.
- Filion, D. L., Dawson, M. E., & Schell, A. M. (1993). Modification of the acoustic startle-reflex eyeblink: A tool for investigating early and late attentional processes. *Biological Psychology, 35*(3), 185–200.
- Foss, J. A., Ison, J. R., Torre, J. P., & Wansack, S. (1989). The acoustic startle response and disruption of aiming: I. Effect of stimulus repetition, intensity, and intensity changes. *Human Factors, 31*(3), 307-318.
- Foss, J. A., Ison, J. R., Torre, J. P., & Wansack, S. (1989). The acoustic startle response and disruption of aiming: II. Modulation by forewarning and preliminary stimuli. *Human Factors, 31*(3), 319-333.
- Graham, F. K. (1975). The more or less startling effects of weak prestimulation. *Psychophysiology, 12*(3), 238–248.
- Graham, F. K. (1978). Distinguishing among orienting, defense, and startle reflexes. In H. D. Kimmel, E. H. Van Olst, & J. F. Orlebeke (Eds.), *The orienting reflex in humans* (pp. 137-167). New York, NY: Lawrence Erlbaum Associates, Inc.

- Greene, D. J., Barnea, A., Herzberg, K., Rassis, A., Neta, M., Raz, A., & Zaidel, E. (2008). Measuring attention in the hemispheres: The lateralized attention network test (LANT). *Brain & Cognition*, *66*(1), 21–31.
- Hackley, S. A., & Valle-Inclan, F. (1998). Automatic alerting does not speed late motoric processes in a reaction-time task. *Nature*, *391*(6669), 786.
- Hackley, S. A., & Valle-Inclán, F. (1999). Accessory stimulus effects on response selection: does arousal speed decision making? *Journal of Cognitive Neuroscience*, *11*(3), 321–329.
- Hoffman, H. S. (1999). Prologue: A historical note on the “discovery” of startle modification. In M. E. Dawson, A. M. Schell, & A. H. Böhmelt (Eds.), *Startle modification: Implications for neuroscience, cognitive science, and clinical science* (pp. 1-5). New York: Cambridge University Press.
- Jennings, J. M., Dagenbach, D., Engle, C. M., & Funke, L. J. (2007). Age-related changes and the Attention Network Task: An examination of alerting, orienting, and executive function. *Aging, Neuropsychology & Cognition*, *14*(4), 353–369.
- Jepma, M., Wagenmakers, E. J., Band, G. P., & Nieuwenhuis, S. (2009). The effects of accessory stimuli on information processing: Evidence from electrophysiology and a diffusion model analysis. *Journal of Cognitive Neuroscience*, *21*(5), 847–864.
- Koch, M. (1999). The neurobiology of startle. *Progress in Neurobiology*, *59*(2), 107–128.
- Li, L., Du, Y., Li, N., Wu, X., & Wu, Y. (2009). Top-down modulation of prepulse inhibition of the startle reflex in humans and rats. *Neuroscience & Biobehavioral Reviews*, *33*(8), 1157–1167.

- Lipp, O. V., Kaplan, D. M., & Purkis, H. M. (2006). Reaction time facilitation by acoustic task-irrelevant stimuli is not related to startle. *Neuroscience Letters*, 409(2), 124–127.
- Ludewig, K., Geyer, M. A., Etzenberger, M., & Vollenweider, F. X. (2002). Stability of the acoustic startle reflex, prepulse inhibition and habituation in schizophrenia. *Schizophrenia Research*, 55(1-2), 129–137.
- MacLeod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, R. M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical considerations of the Attention Network Test. *Neuropsychology*, 24(5), 637–651.
- Nijhuis, L. B. O., Janssen, L., Bloem, B. R., Van Dijk, J. G., Gielen, S. C., Borm, G. F., & Overeem, S. (2007). Choice reaction times for human head rotations are shortened by startling acoustic stimuli, irrespective of stimulus direction. *The Journal of Physiology*, 584(1), 97–109.
- Norris, C. M., & Blumenthal, T. D. (1996). A relationship between inhibition of the acoustic startle response and the protection of prepulse processing. *Psychobiology*, 24(2), 160-168.
- Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology*, 32(1), 3–25.
- Reynolds, R. F., & Day, B. L. (2007). Fast visuomotor processing made faster by sound. *The Journal of Physiology*, 583(3), 1107–1115.
- Schulz, A., Lass-Hennemann, J., Nees, F., Blumenthal, T. D., Berger, W., & Schachinger, H. (2009). Cardiac modulation of startle eye blink. *Psychophysiology*, 46(2), 234–240.

- Valldeoriola, F., Valls-Solé, J., Tolosa, E., Ventura, P. J., Nobbe, F. A., & Martí, M. J. (1998). Effects of a startling acoustic stimulus on reaction time in different parkinsonian syndromes. *Neurology*, *51*(5), 1315–1320.
- Valls-Solé, J., Kofler, M., Kumru, H., Castellote, J. M., & Sanegre, M. T. (2005). Startle-induced reaction time shortening is not modified by prepulse inhibition. *Experimental Brain Research*, *165*(4), 541–548.
- Yeomans, J. S., Lee, J., Yeomans, M. H., Steidl, S., & Li, L. (2006). Midbrain pathways for prepulse inhibition and startle activation in rat. *Neuroscience*, *142*(4), 921–929.
- Yeomans, J. S., Li, L., Scott, B. W., & Frankland, P. W. (2002). Tactile, acoustic and vestibular systems sum to elicit the startle reflex. *Neuroscience & Biobehavioral Reviews*, *26*(1), 1–11.

## APPENDIX

**Health History Questionnaire**

Instructions: The data we collect can be influenced by a number of factors, so we would like some information concerning your health history. These questions will allow us to better understand and interpret your responses, and we will *not* report any individual responses to these questions, only group averages. There are no right or wrong answers. If you do not wish to answer a particular question, just leave it blank. Please feel free to ask us to clarify any of these questions on this form.

<p><b>Age:</b> ____ Years, ____ Months      _</p> <p><b>Sex/ Gender:</b> ____ Male    ____ Female_</p> <p><b>Dominant Hand:</b> ____ Right    ____ Left</p>
---

Have you had any colds or ear infections in the last year? If so, please provide details.

Have you ever suffered a severe hearing loss, either temporary or permanent? If so, please provide details.

Have you had any problems with vision? If so, please provide details.

Do you wear corrective lenses (e.g., glasses or contacts)? If so, are you wearing them now?

Are you currently taking any medications? If so, what problem is it treating, what is the dosage, and how long have you been taking it?

<p><b>In the past 4 hours, have you consumed:</b></p> <p><b>Caffeine:</b> <input type="checkbox"/> Yes    <input type="checkbox"/> No  Amount/ number (oz./liters/cups/ other): _____  Form of consumption: _____</p> <p><b>Tobacco:</b> <input type="checkbox"/> Yes    <input type="checkbox"/> No  Amount/number: _____  Form of consumption: _____</p> <p><b>Alcohol:</b> <input type="checkbox"/> Yes    <input type="checkbox"/> No  Amount/number (bottle/shots/ other): _____  Form of consumption: _____</p>
---

## CURRICULUM VITAE

**EDUCATION**

**Wake Forest University - Winston Salem, NC** August 2010 – December 2012

- Candidate for M.A. in Psychology
- Thesis: “Testing the ‘Interrupt Hypothesis’: does startle disrupt cognitive processing?”

**University of the South - Sewanee, TN** January 2005 – May 2008

- B.A. in Psychology

**University of Colorado - Boulder, CO** August 2004 – December 2004

- Honors Program
- Baker Residential Academic Program

**AWARDS/GRANTS**

**Wake Forest University - Winston Salem, NC** August 2010- December 2012

- Full Tuition Merit Based Scholarship

**Student Alumni Travel Fund, Wake Forest University** August 2011

- Awarded money from the Student Alumni Travel Fund to attend the 2011 Annual Conference for the Society of Psychophysiological Research

**RESEARCH EXPERIENCE**

**Wake Forest University - Winston Salem, NC** August 2010 – Present

Research Assistant & Master’s Student, Department of Psychology

Dr. Terry D. Blumenthal (Advisor)

- Executed two independent projects utilizing physiological measurement of the startle reflex, including design, recruitment, participant preparation, data collection, data analysis and interpretation
- Helped design and collect data on multiple collaborative studies conducted within the laboratory
- Helped to train and lead undergraduate students on laboratory procedures, methods and data collection

**Wake Forest School of Medicine - Winston Salem, NC** August 2010 – May 2012

Research Assistant, Department of Physiology and Pharmacology

Dr. Anthony Liguori

- Managed advertising, recruitment, and screening of participants for two research projects examining binge drinking behavior in the young adult population and assisted in data collection
- Administered the Wechsler Abbreviated Scale of Intelligence (WASI) and the abbreviated Structured Clinical Interview for DSM-IV (SCID) to recruited participants and made decisions regarding

**Wake Forest University - Winston Salem, NC** October 2009 – May 2010

Research Assistant, Department of Psychology

Dr. Dale Dagenbach

- Assisted in data collection and discussion of results in a research team setting, co-authored project proposal and documentation for submission to IRB

- Helped complete experiment comparing the effects of decision fatigue on self-regulation tasks in young adults versus older adults; designed experimental task using E-Prime Software

**Vanderbilt University - Nashville, TN**

May 2009 - July 2009

Research Assistant, Psychology Department

Dr. David Cole

- Collaborated on a longitudinal study on the effects of non-physical bullying on depression in children in middle Tennessee using surveys from students, teachers, and parents
- Organized, entered, and analyzed raw data using Excel and SPSS

**University of the South - Sewanee, TN**

January 2007 – May 2008

Research Assistant, Psychology Department

Dr. Helen Bateman

- Designed, tested, and distributed surveys for a study on alcohol use in college settings
- Collected, entered, and analyzed data using SPSS, and interpreted results with other students
- Executed study on the effect of music on the emotional state of young children recruited from the local community culminating in a formal research paper and presentation

**PUBLICATIONS**

Blumenthal, T. D., Spence, T. E., Reynolds, J. Z., Brown, S., Meekins, K., Massey, A., & Firan, A. (2011). Speeding Reaction Time with a Startle Stimulus [Abstract]. *Psychophysiology*, 48, p. S22.

**CONFERENCE PRESENTATIONS**

Reynolds, J. Z., & Blumenthal, T. D. (November, 2012). *Acoustic startle stimuli speed reaction time on the Attentional Networks Test*. Talk presented at the annual meeting of the Psychonomic Society, Minneapolis, MN.

Blumenthal, T. D., Spence, T. E., Reynolds, J. Z., Brown, S., Meekins, K., Massey, A., & Firan, A. (September, 2011). *Prepulse inhibition of startle varies with attention task difficulty*. Poster presented at the annual convention of the Society for Psychophysiological Research, Boston, MA.

Blumenthal, T. D., Spence, T. E., Reynolds, J. Z., Brown, S., Meekins, K., Massey, A., & Firan, A. (May, 2011). *Prepulse inhibition of startle varies with attention task difficulty*. Poster presented at the annual convention of the Association for Psychological Science, Washington, D.C.

Reynolds, J. Z. & Blumenthal, T. D. (April, 2011). *Is the “energy” in energy drinks just caffeine? An information processing approach*. Poster presented at the annual Wake Forest Department of Psychology Graduate Research Day, Winston Salem, NC.

Blumenthal, T. D., Spence, T. E., Reynolds, J. Z., Brown, S., Meekins, K., Massey, A., & Firan, A. (March, 2011). *Prepulse inhibition of startle varies with attention task difficulty*. Poster presented at the annual SYNAPSE Conference, Winston Salem, NC.

Blumenthal, T. D., Spence, T. E., Reynolds, J. Z., Brown, S., Meekins, K., Massey, A., & Firan, A. (February, 2011). *Prepulse inhibition of startle varies with attention task difficulty*. Poster presented at the annual North Carolina Cognition Conference, Greensboro, NC.

Bateman, H. V., & Reynolds, J. Z. (May, 2009). *Do I fit in? Social acceptance and alcohol use in college settings*. Poster presented at the annual convention of the Association for Psychological Science, San Francisco, CA.

Bateman, H. V., & Reynolds, J. Z. (May, 2008). *Psychological sense of community in college: Relationship to stress, social acceptance, and drinking behavior*. Poster presented at the annual convention of the Association for Psychological Science, Chicago, IL.