BEHAVIORAL AND ELECTROPHYSIOLOGICAL CORRELATES OF ATTENTION AND CROSS-MODAL DISTRACTION

By

LINDSAY BELL

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Lindsay Bell

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Chair: Thomas Oakland
Cochair: Andreas Keil
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Attention refers to the selective allocation of processing resources. This allocation of resources is said to be greatly influenced by the presence of emotional stimuli within the perceptual array, as these stimuli may signal threat or reward. Accordingly, psychological models of visual attention predict that the processing of emotionally arousing stimuli will be enhanced compared to cues lacking such emotional relevance. Several prior neurocognitive studies have demonstrated an increased attentional response in the visual cortex related to the processing of emotional stimuli. However, the influence of emotional stimuli on behavioral response remains unclear.

The present study examined the neural and behavioral responses to a visual arithmetic task in the presence of distracters in order to investigate whether the presence of these stimuli influenced attentional processing. Participants completed a series of simple arithmetic problems while high arousal, low arousal, and no-information visual and auditory distracters were presented. The accuracy of responding to arithmetic problems was analyzed as well as the steady-state visual evoked potential elicited by the primary task. This event-related potential was employed as an electrophysiological measure of the allocation of attention, as the amplitude of the sinosuidal waveform is increased significantly with attention. The results of this study revealed that highly arousing distracters impaired the accuracy of responding to the arithmetic problems compared to low arousal and no-information distracters. The examination of the amplitude of the steady-state visual evoked potential revealed that high arousal auditory distracters withdrew attentional processing from the primary visual task, whereas high arousal visual distracters led to a visual facilitation effect. A discussion of these findings and their relationship to previous attentional processing studies is provided.

CHAPTER 1
INTRODUCTION

Attention is the cognitive process that involves focusing on one aspect of the environment while disregarding others. This phenomenon has been the focus of research and analysis in psychology and cognitive neuroscience since the 19th century. In fact, in his 1890 Principles of Psychology, William James claimed that everyone knows what attention is (James, 1890). He described this process as, "taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction, and Zerstreutheit in German," (pp., 403). James noted that, while millions of items and sensations are present in the environment; most never enter an individual's experience. A person's experience is defined by what the individual attends. Interest determines the items to which the individual attends, thereby giving accent and emphasis, light and shade, background and foreground, and intelligible perspectives to what otherwise would be utter chaos. In James's perspective, without selective attention, the experience of consciousness would be a "gray chaotic indiscriminateness," and perception would be impossible (pp., 404).

Titchener listed the discovery of attention as one of the three major achievements in experimental psychology (Titchener, 1908). He meant discovery to be the explicit formulation of a problem and the recognition of attention's separate status and importance. This discovery acknowledged attention to be the nerve of the whole psychological system. Titchener's claim has been sustained. We now know that attention plays a role in essentially every aspect of cognition, perception, and action. Attention guides behavior as it is involved in almost every action, whether simple or complex. For example, a pilot must selectively attend to the most important items from a complex array of choices in order to monitor instruments and fly successfully. When attempting to learn animal facts in school, students must chose to focus on the teacher rather than competing stimuli within the classroom and assign retrieval cues in order to later access the animal information. A family searching for a new home must attend to the features of the potential homes that they determine to be most important, such a price or location. Given that attention permeates so many facets of cognition, it has been a topic of extensive experimental research since the birth of the field of psychology.

Historical Overview of Attention Research

Several prominent psychologists of James' era offered additional conceptions of attention. For example, Titchener (1908) tried to extend the basic essence of attention as described by James by stating that the fundamental effect of attention is to increase clarity. Kulpe disagreed, arguing that attention enhanced the discriminability of sensations rather than their clarity. Still others believed that attention increased the intensity of stimuli. This debate among the leading psychologists of the time led to a wealth of experiments aimed at uncovering the true meaning and function of attention.

At the turn of the 19th century the primary means for studying attention was introspection, that is, the self-observation and reporting of conscious inner thoughts, desires, and sensations. This mental process involves a conscious effort that relies on thinking, reasoning, and examining one's own thoughts and feelings. This method was popularized by Wilhelm Wundt in his psychology laboratory in Leipzig, Germany in 1879, leading Wundt to be credited for introducing the experimental study of attention to psychology. While the method of introspection dates to Socrates, Wundt pioneered the use of this method in experimental psychology in order to gather information regarding how subjects' minds were working and to analyze the mind to its basic elements.

Introspection often was criticized for its subjectivity and unreliability, even by Wundt (1900), leading competing researchers to develop new methods for measuring attention objectively. Mental chronometry used response times of perceptual-motor tasks to gather information regarding the duration, content, and chronology of cognitive functions. Franciscus Donders began using mental chronometry in order to study attention as early as 1858 (Johnson & Proctor, 2004). These experiments addressed whether one could attend to more than one thing at a given time, that is, whether split attention was possible. This question seemingly was impossible to address using introspection. However, the use of mental chronometry revealed that people could receive intelligible input even while distracted. One such experiment involved participants responding to a red light with the right hand and a white light with the left hand. The mean reaction time for this task was significantly longer than that for a simple reaction task where the participant was asked to respond when a single stimulus was presented. Though this method was first reported in a dissertation by one of Donder's students (De Jagger, 1965), Donders formalized the use of this method, known as the subtractive method. This method separated three types of reactions: the simple reaction where participants respond to a single stimulus, the choice reaction where participants must select the reaction according to the stimulus, and the go or no-go reaction where participants respond to one stimulus but not another. Using this technique, Donders sought to identify the time required for a certain process by adding that process to a task and recording the reaction time, then subtracting the simple reaction time. This process presumably allowed for separate measures of the time required for stimulus identification and decision processes.

Reaction time flourished as a method of studying attention through the remainder of the century. Wundt became involved in the use and evaluation of this method, criticizing Donders for his use of the go or no-go task as a measure of stimulus identification because the participants are also required to make a decision regarding whether to respond. Exner (1882) claimed the performance of simple reaction time tasks was dependent largely on the preparation that occurs prior to the presentation of the stimulus. Merkel (1885) conducted experiments in which Arabic numerals 1-5 were assigned to the left hand and Roman numerals I-V to the right hand, and participants were instructed to respond to stimuli accordingly. He found the mean reaction time increased approximately two-fold when the number of alternatives was increased.

At the end of the century, Helmholtz (1894) noted that attention is necessary for the functioning of visual perception. Through the use of experiments involving the brief presentation of printed letters, he found that attention could be directed to a particular region of the page prior to the stimulus presentation, even when eyes are kept fixed at a central location. Helmholtz concluded that one can voluntarily concentrate attention on one part of the peripheral nervous system even without eye movements or changes of accommodation. Lotze opposed the view that attention is a more intense illumination of content, instead believing conscious attention occurs to varying degrees. Thus, lower processes such as simple sensory experience are not necessarily accompanied by higher processes such as the comparison of two sensory experiences. Pilsbury (1908) believed the conditions of attentional acts may be found in both the immediate and the past experiences of the individual. This claim was based on studies involving a concept known as task set. In these studies, participants performed best when they were required to make judgments that were consistent with the instructions that had been provided prior to the onset of the stimulus. Pilsbury also noted that the essence of attention was an increase in the clarity of one idea at the expense of others.

In addition, the study of interference (i.e., one attentional task will interfere with the simultaneous performance of another attentional task) was popularized toward the end of the 19^{th} century. Binet (1890) was among the first to claim that attention could be understood in terms of interference. The requirement to complete an addition task interfered with a ball-squeezing task when the squeezing was to be rhythmic and a specific number of times. In contrast, the addition task did not interfere when the ball squeezing task required less attention because the rhythm and number of repetitions did not have to be monitored. Welch (1898) built upon this connection between action and attention by finding that participants failed to maintain a strong grip while performing mentally demanding tasks.

The study of attention largely was neglected at the beginning of the 20^{th} century due to the behaviorist movement that limited psychological inquiry to observable phenomena. Behaviorists viewed attention as troublesome as it conflicted with the goal of explaining the behavior of every organism based on its objective history. During this period, notable advances were limited in number. First, Jersild (1927) conducted studies that required participants to make judgments about each stimulus in a list as a function of whether the participant was required to perform a single task or alternating tasks for each stimulus. The time to complete a task was often longer for lists when the participant was required to switch tasks compared to those when the participant performed a single task, a phenomenon referred to as task-switching costs. In addition, Telford (1931) discovered an effect referred to as the psychological refractory period. Telford required participants to make a simple reaction by pressing a key each time a specific tone was played. Tones were played in variable intervals. Reaction times to tones played in rapid succession were considerably longer than reaction times to tones separated by longer intervals. Thus, he concluded that judgments or simple associations serve as a barrier against immediate repetition (i.e., refractory phase). Mowrer, Rayman, and Bliss (1940) found preparatory sets (i.e., the act of adjustment that readies the participant for a particular stimulus) do not necessarily involve any physical adjustments (e.g., body posture or muscle attention) though participants' reaction times were dependent on the expectancy of one of two possible stimulus events.

Then, the 1950's ushered in the cognitive revolution. During this time, unobservable cognitive processes such as attention once again became legitimate objects of scientific study. Throughout the decade, several works from England were published that applied information theories to attention. Donald Broadbent, a student at Cambridge, became a prominent player in this wave of attention studies. Broadbent worked with Colin Cherry, professor of telecommunications, in order to study attention using a dichotic listening procedure. Participants received two channels of information, one to each ear, simultaneously through headphones. Participants who attended to one stream of information recalled very little content from the second message. Broadbent concluded that people who are confronted with two streams of information, due to their limited cognitive capacities, separate the information on the basis of physical characteristics. Thus, one message can be filtered out from an array of information while another is selected for further processing, a phenomena Broadbent labeled selective filtering (Broadbent, 1958).

Treisman (1960) later showed that, in some cases, the unattended message could be processed beyond the physical level in order to derive meaning. To account for the fact that the meaning of the unattended message can impact performance, Treisman developed what he referred to as the filter-attenuation theory. According to this theory, early selection by filtering precedes stimulus identification. However, the filter negatively impacts only the information on channels that are not attended. The attenuated signal from the unattended channel may be sufficient to process simple information such as a person's name. Deutsch and Deutsch (1963) proposed a competing theory, the late-selection theory, which proposed that unattended stimuli always are identified, though a bottleneck effect occurs in later processing.

During the 1960s, researchers began to investigate the neural correlates of attention. Wurtz of the National Institutes of Health trained macaque monkeys to perform attentional tasks (e.g., performing a visual saccade following a brief cue indicating where the visual saccade should be made). He then recorded electrical signals from single neurons while the monkeys performed these tasks. In addition to observing neural activity related to visual stimulus presentation and saccade generation, he found that attentional processes involved in the performance of these tasks were associated with increased firing in the superior colliculus.

Attention theory continued to progress during the 1970s. For example, Kahneman (1973) developed a unitary capacity or resource theory that proposes that attention is a single resource that may be divided among different tasks to varying degrees. The amount of this attentional resource allocated to a task is dependent on the level of arousal and demands of the task. When the resource is limited, voluntary allocation strategies influence which tasks and processes will be allocated attention. Unitary resource models imply that tasks should produce interference when they compete for a limited resource. In the later part of the decade, these models began to give way to multiple resource models following studies that demonstrated that performing two tasks simultaneously is easier when the tasks use different modalities. Wickens (1980) extended the multiple resource view to human factors by proposing different attentional resources support different sensory modalities, coding modes, and response modalities. This concept acknowledges that multiple task performance often is enhanced when tasks use different input and output modalities.

Space-based versus object-based approaches to attention also were investigated toward the end of the 20th century. In the space-based approach to visual attention, attention is comparable to a spotlight that directs attention to everything in its field. Consistent with Helmholtz's views, this spotlight is not necessarily the same as the direction of the gaze. Information presented within or close to the attended location is processed more efficiently than information presented farther away from the focus of attention.

Treisman and Gelade (1980) formulated that an influential variant of spotlight theory which became the feature integration theory. This theory explains results from visual search studies in which participants determine whether a target is present among distracters. This theory presumes that stimulus features are encoded into parallel feature maps across the visual field at a preattentive stage. The effectiveness of this search may be influenced by processing during the preattentive stage when a participant is required to search for a target that is distinguished from distracters by one feature. A second stage involves focusing attention on a specific location and combining features that occupy the location. The search for target objects that are distinguished from distractors by a combination of features requires attention to the conjunction of features. Performance on such tasks worsens as the number of distracters increases because attention must be moved sequentially across the search field until the target is identified.

Object-based models of attention regard objects as the principle unit of attention. These models were derived from findings which suggest that attending to two different objects results in slower processing. Duncan and Humphreys's (1989) object-based model of attention proposes that the first stage of selection involves the formation of a visual representation that is divided into object-like units that include meaning codes. The next stage is characterized by competitive interaction between inputs, thus guiding awareness and action.

Attention research also focuses on the concept of priming. In these studies, a priming stimulus that can be the same or different from some aspect of a target stimulus precedes the target stimulus. For example, Posner and Snyder (1975) found that when the prime is identical to the target stimulus, an automatic facilitation occurs without any cost for trials when the prime is different from the target stimulus. More recently, negative priming studies have demonstrated that participants responded more slowly when the stimulus that had to be ignored on the prime trials became the relevant stimulus on the following trial. Though the cause remains a source of controversy, negative priming has been attributed to inhibitory processes active at the prime trial affecting performance on the probe trial.

More recent attention research has focused on the identification of neuropsychological evidence regarding the mechanisms underlying attention. Several strides have been made in cognitive neuroscience due to the emergence of brain imaging technologies (Johnson & Proctor, 2004). These include positron emission tomography (PET), functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). PET and fMRI are used to create images of the brain while completing attentive tasks. PET is a nuclear medicine imaging technique that produces three-dimensional images of functional biological processes by detecting pairs of gamma rays that are introduced into the body on a biologically active molecule. FMRI measures the dynamic regulation of blood flow related to neural activity in the brain. Studies using each of these technologies require participants to complete a cognitive task inside a scanner. The neural activity associated with the task is isolated by subtracting the brain activity during task performance from the activity that was present during baseline testing. This computed brain activity is said to be associated with the specific cognitive activity being performed.

The most widely used psychophysiological measure, the EEG, utilizes electrodes placed on the scalp to measure voltage fluctuations within the brain. This method provides information regarding neural processing that occurs within a given time interval. Event-related potentials (ERPs) typically are calculated in order to narrow the range of activity examined at a specific moment. Several single-trial EEGs related to a specific external event (e.g., stimulus presentation) are averaged. This averaging technique serves to reduce random noise as well as electrical activity that is unrelated to stimulus processing, leading to a remaining waveform that represents only the electrocortical activity associated with the processing of the stimulus. This allows for the examination of the chronological progression of attentional processes. ERP components are designated by the letters N and P to signify whether the component is negative or positive and a number which indicates the serial order in the event sequence. Thus, the N1 is the first negative component. The magnitude and latency of such components may be associated with specific cognitive events. The P3 (third positive) component is the most widely examined ERP component is. This component's amplitude tends to peak between 330 to 600 ms following stimulus onset, which is assumed to reflect the termination of stimulus examination (Donchin, Ritter, & McCallum, 1978). However, some studies have demonstrated that this component is sensitive to variables believed to influence response-related processing (Verleger, 1997).

Modern Attention Capture Research

Since the beginning of the 21st century, attention researchers have distinguished two types of attention movements: endogenous and exogenous (Boot, Kramer, Becic, Wiegmann, & Kubose, 2007). Endogenous attention movements are those that are driven by the goals and intentions of the observer. In contrast, exogenous movements are driven by the stimulus properties of the environment. Although sometimes these forces work together to allow for the correct allocation of attention, at other times the goal-directed forces may be at odds with the stimulus-driven forces. Attention is said to be captured when an exogenous, stimulus-driven, shift of attention occurs despite the fact that this attention movement is in conflict with the current goals of the observer. In many circumstances, the drawing of attention away from the primary task can be detrimental because distraction may interrupt a crucial task that requires focused attention. For example, loud children may distract from a person's primary task of completing important calculus homework. At times (e.g., when a fire alarm alerts a crowd attending a theater performance) drawing attention away may be beneficial.

The onset of an additional object and the presence of a uniquely colored object have been found to capture attention. However, these findings are inconsistent across the various attention research paradigms. This inconsistency has led attention researchers to suggest that specialized neural mechanisms may be present that prioritize the occurrence of onsets. These mechanisms may have evolved because the onset of additional items within a visual array (e.g., the addition of a predator to the environment) may be especially relevant. Several visual search studies have demonstrated that onsets seem to be the most effective way of drawing the respondents' attention to a particular location (Boot, Kramer, & Peterson, 2005; Cole, Kentridge, & Heywood, 2005; Irwin et al., 2000).

Onset cues appear to be detected rapidly, accurately, and require little attentional resources to process. In fact, several studies have suggested that processing onset cues occurs automatically. For example, Jonides (1981) examined the ability of peripheral onset cues and central arrow cues to direct participant's attention to a search while they were required to maintain a series of digits in memory. The predictive cue's power to direct attention decreased when participants were required to complete this memory task. However, peripheral onset cues continued to capture attention. Other findings have shown that onset cues capture visual attention even when they do not predict the target location.

Interestingly, onset cues have been found to lose their power when a secondary auditory task is performed. In one study, participants were required to complete an irrelevant singleton search paradigm while also completing an auditory task in which they were required to listen to a string of digits and count the number of times two sequentially read numbers were identical (Boot, Brockmore, & Simons, 2005). This auditory task placed demands on both attention and working memory. During this dual-task condition, onsets lost their ability to capture attention. No prioritization of onset items was observed during the irrelevant singleton task when participants were required to attend to the auditory task. Further, the nature of the primary task determines the nature of one's "attentional set" and therefore may influence the types of features that effectively capture attention (Folk, Remington, & Wright, 1994). For example, an onset cue will not effectively capture attention if an observer is looking for a color singleton. Thus, although the attention capture strongly focuses on the ability of onset cues to capture attention, this literature also suggests that display complexity, onset eccentricity, primary task complexity, and task-induced sets may limit the effectiveness of this method for capturing attention.

Emotional Stimuli and Attention Capture

Emotionally arousing stimuli are strong competitors for processing resources in the visual cortex as rapid and effective analysis of sensory information that could be relevant to survival is critical to adaptive behavior. Psychological models of visual perception and attention purport that the processing of stimuli that may signal threat or reward should be enhanced even in the absence of explicit instruction. This attention directed toward emotionally arousing stimuli is referred to as "motivated attention." Stimuli that have an appetitive (e.g., erotica) or aversive (e.g., mutilated bodies) emotional impact provide ideal cues to drive this type of attention. Emotional content may contribute to stimuli's competition for resources that is, emotional stimuli may be processed efficiently and cause interference with concurrent non-emotional tasks (Keil et al., 2005).

Psychophysiological studies using fMRI technology have also supported the notion that emotionally-laden stimuli attract neural resources (Bradley et al., 2003; Pessoa & Ungerleider, 2004). One research group utilized this technique in order to examine visual cortex activity when participants examined affective versus neutral pictures (Bradley et al., 2003). Results indicated that the functional activation in the occipital cortex was greater when participants viewed pictures that were related to motivational (e.g., violent death, viewer-directed threat, and erotica) than when they viewed less emotionally intense pictures (e.g., happy families or angry faces) or neutral images (e.g., household objects and emotionless faces). The strength of the functional neural activity was related to the judged emotional arousal of the various picture contents, suggesting that more extensive visual system activation reflects motivated attention. That is, the fMRI is reflective of appetitive or aversive motivational engagement directing attention and thereby facilitating the visual processing of stimuli that could be relevant to survival.

FMRI studies in humans were reviewed for evidence related to neural competition as well as how that competition is biased by attention (Pessoa & Ungerleider, 2004). This review revealed that a crucial consequence of attention is enhancing the influence of behaviorally relevant stimuli at the expense of irrelevant stimuli at a neural level. That is, attention provides a mechanism for filtering distracting information, often attenuating the processing of information that lies outside of the central focus. Emotional stimuli are a key exception to this finding. These authors noted that emotional stimuli appear to be processed automatically. However, the brain regions that typically respond differently to faces of varying emotional content may do so only in the presence of sufficient processing resources (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002). Thus, the processing of emotional faces may be compromised in the presence of a highly demanding concurrent task, suggesting that the processing of emotional faces requires selective attention (Pessoa et al. 2002, 2005).

Phobic stimuli facilitate visual search regardless of the size of the search array, thus this allocation of resources occurs seemingly automatically (Ohman, Flykt, & Esteves, 2001). Additional evidence for this claim using electrophysiological evidence suggests preattentive facilitation of orienting towards stimuli that are related to fear (Pourtois, Thut, Grave de Peralta, Michel, & Vuilleumier, 2005). In conclusion, although emotional visual stimuli may attract attentional resources, this may not occur automatically. Whether these stimuli attract resources in an automatic fashion or whether emotional stimuli are consciously selected for attention remains unclear (Viulleumier, 2005).

Several studies have attempted to determine whether the interference between emotional visual stimuli and a concurrent cognitive task can be computed and analyzed. A recent study of the time-course of competition for visual processing resources between emotional pictures and a foreground task used EEG to study steady-state visual evoked potentials. This technique allows for the examination of motivated attention because the amplitude of the sinusoidal waveform of the steady-state visual evoked potentials provides a continuous measure of the allocation of visual resources to visual stimuli that are flickered at a fixed rate, as its amplitude is increased significantly with attention (Muller et al., 2008). This increases the signal-to-noise ratio based on EEG segments of several hundreds of milliseconds in duration (Keil et al., 2008). Researchers use a frequency tagging technique in which the stimulus of interest is flickered at a different frequency than the remaining components of the visual array in order to examine the brain activity related to a specific visual object. Then, using frequency domain approaches, the steady-state visual evoked potential that is elicited by the stimulus of interest is monitored. Utilizing this technique, arousing emotional pictures displayed in the background were found to withdraw processing resources from a visual detection task more effectively than neutral background pictures (Muller, Andersen, & Keil, 2008).

Additional studies utilized inverse modeling in order to identify cortical sources of the effect of attention on the steady-state visual evoked potential (Muller et al., 1998, 2006). Activity in the early visual areas as well as the temporal lobe was enhanced when a flickering stimulus was attended. A recent fMRI study provided a more detailed understanding of the sources of the steady-state visual evoked potential that is elicited by 6-Hz pattern-reversal stimulation (Di Russo et al., 2007). The primary visual cortex (V1), the middle temporal (V5), the midoccipital area (V3A), and ventral occipital (V4/V8) visual areas were found to contribute to the generation of the steady-state visual evoked potential. Another study found that attending to flickering stimuli appears to activate similar areas in the visual cortex as viewing a serious of emotional images (e.g., mutilated bodies and attractive nudes) from the standardized International Affective Picture System (Muller, Andersen, & Keil, 2008).

Desimone (1998) suggested that presenting stimuli concurrently will result in a strong competition for processing resources. If highly arousing background pictures consume processing resources, then a reduction in steady-state visual evoked potential amplitude elicited by the foreground task compared with neutral background pictures can be expected. Studying the time course of steady-state visual evoked potential amplitude changes after the onset of the distracting stimulus allows for the investigation of the duration of this competition for processing resources in the visual cortex as this ongoing waveform reflects neural change in attention (Muller et al., 1998). In Muller and associates' (2008) study, this competition for resources lasted several hundred milliseconds and was not solely the result of the quick orienting response toward the emotional stimulus. The decrease in steady-state visual evoked potential amplitude was extended temporally and may have reflected the time window of the first positive component. This decrease in amplitude suggests an early orientation mechanism that is followed by a sustained attention mechanism that enhances neural responses in the visual cortex in order to provide optimal analysis of the affective significance of emotional stimuli (Calvo & Lang, 2004; Pourtois et al., 2005).

A disproportionate number of studies that address attention capture related to emotional stimuli focus on negative stimuli due to the hypothesis that these stimuli are processed at a higher level of priority due to their threat-signaling potential. Attending to these stimuli may ensure survival. In fact, several studies have suggested evolutionarily developed pre-attentive threat-detection modules (Ohman, Flykt, & Esteves, 2001; Pratto & John, 1991). Still, some studies suggest that emotional stimuli in general may capture attention, and that this phenomenon may not be specific to negativity (Anderson, 2005; Arnell, Killman, & Fijavz, 2004; Schimmack, 2005). Although studies tend to find that appealing stimuli capture attention more weakly, the positive stimuli utilized in these studies tend to be less emotionally arousing than the negative stimuli (Bradley, Codispoti, Cuthbert, & Land, 2001). That is, the asymmetry in attention capture effects may be due to the arousal level of the stimuli rather than the positive or negative valence. In fact, several studies utilizing erotic stimuli have demonstrated that these stimuli tend to affect attention in a manner similar to arousing negative stimuli, suggesting that the arousal intensity of a stimulus is more important to the emotional modulation of attention than the valence (Anderson, 2005; Schimmack, 2005; Schupp, Junghofer, Weike, & Hamm, 2004).

The attention-capturing effect of aversive images interferes with performance of target detection tasks, even following the termination of the aversive image. When participants were shown an emotional negative distracter while searching for a target image embedded within a picture stream, performance detecting the target decreased when it followed the negative distracter (Most, Chun, Widders, & Zald, 2005). This decrease in performance was substantially greater when the distracter was negative rather than neutral. Most (2005) characterized this as “emotion-induced blindness” or “attentional rubbernecking.” Raymond, Shapiro, and Arnell (1992) described an “attentional blink” when they found similar results related to emotionally negative pictures capturing and holding attention. Recently, Most and colleagues (in press) investigated whether erotic stimuli would result in an attentional blink similar to that following emotionally aversive pictures. A robust “emotion-induced blindness” effect was observed when participants were confronted with erotic distracters during a rapid serial visual processing task (RSVP), which focuses on the ability of an observer to identify relevant information in a rapid stream of distracter items. This study provided further evidence that both positive and negative emotionally arousing stimuli cause attentional blinks.

The use of a rapid serial visual processing paradigm in which stimuli are presented sequentially at a high rate (e.g., 10 items per second) results in a decrease in the detection of the second of two targets within a stream of distractors when the second target is presented within about 500 ms of the first (Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992). A range of explanations of this attentional blink phenomena have been proposed, including a two-stage theory (Chun & Potter, 1995). In the initial stage, items are processed as a fairly high-level short-term representation, including conceptual and semantic activation (conceptual short-term memory). In the second stage, those items are transformed into a more complex form of memory that is necessary for response generation. Chun and Potter believe the first stage is vulnerable to interference and the second stage is limited in capacity. Thus, when attention is occupied by the first stimulus, the processing of the second stimulus suffers.

Also, the visual short-term memory buffer has been proposed to explain the attentional blink. According to Raymond, Shapiro, and Arnell (1995), items included in the rapid serial visual processing stream may enter this memory buffer, in which items compete for retrieval. If the first target is selected, the second will suffer from interference. If the first target demands too many processing resources, the second may be more easily overridden by the stream of distractors or fail to be represented in short-term memory at all. Finally, Di Lollo and associates (2005) suggest that the processing of the first target results in a temporary loss of control over the perceptual filter used to evaluate items and select targets based on specific features.

Electrophysiological studies tend to support a resource sharing account in which magnetocortical and electrocortical fields indicate a compromise exists between the two targets (Hommel et al., 2006). That is, resources are excessively allocated to the first target at the expense of processing the second target, resulting in greater neural responses to the first stimulus in trials when the second target is missed compared to trials in which the second target was correctly detected. Then, the neural response to the second target is expected to mirror this pattern, with smaller neural activity being evoked by incorrect second target trials than correct second target trials. Shapiro and colleagues (2006) demonstrated that relative increases in neural activity related to the first target are related to impaired reporting of the second target. Similarly, Kranczioch, Debener, Maye, and Engel (2007) found evidence that indicated support for this resource sharing theory as smaller P3 (third positive) components were observed for the first target in correct second target trials compared to incorrect trials. Keil, Ihssen, and Heim (2006) found that steady-state visual evoked potential amplitudes were enhanced following the first target in trials with missed second targets. In another study, these authors found a reduction in electrocortical responses to the first target when the second target was correctly identified. The predictive quality of this amplitude attenuation was sustained over time, which suggests a reduction of resources allocated to the distracter stream in trials when targets were correctly detected.

The fundamental concept of the attentional blink as an unavoidable processing limitation was challenged recently when Olivers and Niewwenhuis (2006) reported that the size of the attentional blink is modulated by the participant's general mental state. In one condition, the attentional blink phenomenon was not described to the participants and they were instructed to actively think about holidays or shopping to prepare for a meal with friends while attempting to identify two digits within a stream of letters. Under this condition, the identification of the second target improved 10 to 50 percent compared to a control condition in which participants simply were instructed to attend to the task at hand. Under another condition that included detecting an occasional yell presented within a tune, the detection accuracy for the second target improved to the extent that the attention blink nearly disappeared. The authors note that, while limited-capacity theories appear to account for these results by assuming that less resources were available for allocation to the first target in the free association and music conditions, several studies have demonstrated that the attentional blink is less substantial for the second target when fewer resources are allocated to the first (Chun & Potter, 1995; Sieffert & Di Lollo, 1997). This simple distribution of resources hypothesis fails to account for the finding that detection performance for the first target did not suffer. Thus, the authors proposed that the beneficial effects of the task-irrelevant mental activity may be the result of participants' more diffuse mental state under these conditions, as participants were required to adopt a more distributed mode of attention when required to manage the requirements of two tasks. Perhaps this more flexible mode of operation widens the attentional capacity and therefore benefits the processing of targets that are presented in rapid succession. The authors (Olivers & Nieuwenhuis, 2006) called their own hypothesis into question, noting that it still fails to explain why the detection of the first target does not suffer and criticizing that adopting a diffuse mental state would imply that less attentional resources are being applied to the rapid serial visual processing task. In addition, they note that this "diffuse mental set" is inadequately specific and therefore open to a range of interpretations.

This finding was explored further by conducting additional experiments in which the detection accuracy of the first target and second targets improved when participants were required to perform an additional task or view positive affective pictures (Olivers & Nieuwenhuis, 2006). The findings from the previous study were replicated. The authors proposed two hypotheses to address these findings: the over-investment hypothesis and the positive-affect hypothesis. The first suggests that an over-investment of attentional resources in the rapid serial visual processing stream results in a substantial increase in the probability of an attentional blink. This hypothesis predicts that tasks that remove attentional resources from the rapid serial visual processing stream may lead to decreases in the attentional blink. When participants were required to perform a short-term memory in conjunction with the attentional blink task, the attentional blink was reduced compared to a control condition that did not include an additional memory task. Further support for the over-investment hypothesis was found when participants who were instructed to concentrate less on the task experienced greater improvements in performance than those who were instructed to focus on the task.

The positive-affective hypothesis suggested that the reduction in attentional blink results from positive affect increasing cognitive flexibility. This hypothesis was supported by results indicating that the attentional blink decreased when the rapid serial visual processing streams were preceded by positive affective pictures than when they were preceded by neutral pictures. However, negatively affective pictures did not result in such improvements. Thus, the reduction in attentional blink that occurs when participants perform concurrent tasks may result from both cognitive and affective variables.

Although most attention research has focused on selective processing within single sensory modalities, in the real world, attention often must be divided between various input systems. In studies investigating cross-modal coordination and integration of processing, attention was covertly directed to the expected location of a target stimulus within the primary modality. On some trials, stimuli presented in the secondary modality were equally likely to be presented on the opposite side from the expected location of the stimulus in the primary modality. Participants' performance was increased for stimuli in the expected location, regardless of modality, suggesting that focusing attention within a primary modality influences the processing of information in the secondary modality. This enhancement of performance in the secondary modality may result from the effects of cross-modal attention on perceptual processes or of attentional modulations during post-perceptual stages. In addition, these cross-modal attentional effects may be influenced by the activity of a single supramodal system that regulates covert attentional orienting processes across modalities or the spatial synergies between various independent attentional control systems in each modality (Farah, Wong, Monheit, & Morrow, 1989; Spence & Driver, 1997). Thus, although these results suggest that attention across modalities is linked, which stages of attention are influenced by these cross-modal associations is unclear.

Event-related brain potentials provide a valuable measure of the processing stages affected by attentional selectivity as well as the control processes involved in directing spatial attention (Eimer, 2001). Measuring the event-related brain potentials elicited by stimuli presented at attended and unattended locations allows for the analysis of the effects of spatial attention. The event-related brain potentials waveforms are composed of successive components that reflect distinct stages in the processing of external events such that short-latency components elicited within modality-specific brain regions are influenced by differences in physical stimulus properties. In contrast to these "exogenous" components, long-latency event-related brain potentials components have a broader scalp distribution that is not modality-specific and are not influenced directly by differences in physical stimulus properties. These long-latency components are referred to as "endogenous" and typically are related to post-perceptual stages of processing (e.g., stimulus identification and classification as well as response selection and activation). Thus, examining how these event-related brain potential components are influenced by spatial attention may allow one to distinguish sensory-perceptual processing reflected in early components from the post-perceptual effects of attentional selectivity reflected in later event-related brain potentials components.

Several studies have utilized these measures to examine the effects of unimodal spatial attention in vision, audition, and touch on event-related brain potentials waveforms (Alho, 1992; Eimer, 1994; Garcia-Larrea, Lukaszuwicz, & Mauguiere, 1995). Results from each of theses studies have indicated the presence of both modality-specific and nonspecific effects. This suggests that spatial attention influences the sensory-specific perceptual stage as well as post-perceptual attentional processes. These event-related brain potentials measures also can be utilized in order to study cross-modal links in spatial attention as event-related brain potentials are systematically affected by unimodal spatial attention. If cross-modal links exist, differences in event-related brain potentials to stimuli of different modalities (visual, auditory, or tactile) at attended versus unattended locations should be demonstrated under conditions where attention is overtly directed to target stimuli in another sensory modality. The effects of such cross-modal attentional links would suggest that these links mediate perceptual processes in a modality-specific manner. In contrast, if cross-modal effects limited to later nonmodality-specific components would suggest that these links influence stages that occur beyond initial sensory processing of a stimulus. Results from a cross-modal study (Eimer, 2001) indicated that the systematic ERP effects of spatial attention were present in both the primary and secondary modalities, and that these cross-modal links affected relatively early sensory-specific ERP components. Thus, crossmodal links in spatial attention may affect sensory perceptual modality-specific processes rather than post-perceptual processes. Thus, whether attention is a modality-specific resource remains unclear.

Multiple-Resource Theory of Attention

The multiple-resource theory, as developed by Wickens (1980), served to unify two largely incongruent views of human performance capacity. These perspectives were Broadbent’s (1958) linear information processing model and more recent “resource” conceptualizations, which focused on a more energetic and fluid formulation of human attention (Kahnman, 1973). Wickens’s theory provided a synthesis of the literature supporting these disparate views, which resulted in a well-founded design heuristic and strengthened the impact of the theory (Kramer, Wiegmann, & Kirlik, 2007). According to Wickens (2002), the origins of this theory lie in the ‘single channel bottleneck’ concept of information processing. The bottleneck model implies a limited capacity to perform two high speed tasks concurrently as effectively as either task could be performed individually (Broadbent, 1958; Craik, 1948). This view implied that time is a limited resource that cannot be shared between tasks, a view formerly prominent in reaction time tasks that analyzed the performance of high speed tasks.

Moray (1967) was among the first to suggest that humans may posses a ‘limited capacity central processor’ that could be shared between tasks rather than an indivisible time resource. This concept was elaborated further by Kahneneman (1973) and Rolfe (1973) who agreed that capacity is limited, yet sharable, and the resources demanded by a task in order to achieve a target level of performance (task demand) are not fixed. Instead, these “resource models” assume that the limited mental resources can be allocated as necessary in order to achieve task demands that are jointly defined by the level of difficulty of the task and the level of performance required. Residual resources, or spare capacity, then can be allocated to additional tasks. Tasks that demand more resources may interfere with a concurrent task whereas tasks that do not demand resources are said to be automated. A task is referred to as resource limited when it requires all available resources in order to obtain ideal performance. In contrast, a task is said to be data limited when it requires only partial resources.

Several experiments have demonstrated the tradeoff between primary task demand and secondary task performance, many of which also have identified converging operations that illustrated the concept of resource demand. These studies served to document that the single channel bottleneck suggested by Keele (1973) did not entail the extreme limitations that were previously suggested. Several tasks characteristics, including the bandwidth of information, working memory load, and the skill level of the participant were assumed to influence resource demands. The characteristics served to prevent the constructs of ‘resource’ and ‘resource demand’ from becoming circular terms in reference to the prediction of dual task performance. That is, they avoid the circularity of claiming that a task creates additional interference because it has a higher resource demand and its resource demand is higher due of the greater interference it causes. Therefore, resources can be defined as energetic concepts, that may be described independently of its influence on dual task performance (Kahneman, 1973).

Although some studies have failed to identify the exact resource to which they refer as limited, this resource is most often time. In fact, some models (e.g., the original single channel model) treat time as the only limited resource that matters. However, if this were true, mindless tasks (e.g., tapping one’s fingers or listening to background music) would interfere with competing tasks just as much as more highly demanding tasks (e.g., note-taking or rehearsing a string of numbers). Of course, more heavily demanding tasks, though they may occupy the same amount of time, require more mental resources than mindless tasks.

Kahneman’s (1973) development of a general resource model of task interference stating that concurrent performance of two tasks may result in a decrease in performance levels for one or both tasks. During the following decade, evidence emerged that suggested that a substantial portion of the variance in dual task performance could not be attributed to the quantitative resource demands of the tasks alone. The resource allocation policy underlying the tasks (i.e., which task is favored) also failed to account for this variation in dual performance. Related studies suggested that qualitative differences in information processing demands may lead to differences in time-sharing efficiency (Wickens, 1976). These structures behaved as though they were supported by individual limited resources. For example, time-sharing between tasks was more efficient if the tasks placed demands on separate, rather than common, structures

(Kantowitz & Knight, 1976; Wickens, 1976). Furthermore, the time-shared dual task performance of two tasks that require visual processing is lower than dual task performance when the equivalent information for one of these tasks is provided auditorally (Treisman & Davies, 1973). Real-life experience in addition to results reported by Parkes and Coleman (1990) illustrates that a person driving an automobile will have greater success at driving and comprehension when listening rather than reading a set of instructions while driving. Thus, the visual and auditory systems behave as though they represent multiple resources. Wickens (1980) conducted a meta analysis of an extensive literature base in which structural differences between task pairs suggested that structural dichotomies (e.g., visual versus auditory processes) behaved as distinct resources. He then identified the unique structural dimensions of human information processing that met the criteria of both accounting for changes in time-sharing efficiency and being related to neuropsychological mechanisms which could define resources.

This set of dimensions provided the bases for the four-dimensional multiple resource model, often referred to as the "box model" (Wickens, 1980). In Wickens's box model, multiple attentional resources were identified on the bases of four key dimensions. Each of these dimensions has two discrete levels and therefore exists as a dichotomy. According to Wickens, if two tasks demand one level of a given dimension, they will interfere with each other more than if they demanded separate levels of the dimension. In addition, each dimension can be associated with distinct psychological mechanisms, as implied by the theoretical context of multiple resources.

The first of these dimensions, the processing stage, is essentially a temporal axis reflecting concern for the progression of encoding, decision making, and response. Wickens (2002) notes that the resources used for perceptual and cognitive activities appear to be the same, while these resources are functionally distinct from those involved in the selection and execution of responses. For example, increases in perceptual cognitive difficulty do not significantly alter the performance of a concurrent task whose demands largely are related to response performance. Conversely, variations in the difficulty of responding do not influence the performance of a task whose demands are largely perceptual and cognitive. Isreal and associates (1980) conducted studies in which the amplitude of the P3 components of evoked brain potentials that were elicited by a series of counted tones were assumed to be indicative of the allocation of perceptual and cognitive processing resources because the P3 component can be elicited in the absence of overt response. These studies demonstrated that the P3 is insensitive to manipulations of tracking difficulty that were related to response but is influenced by variation in display load.

Shallice and colleagues (1985) required participants to conduct a series of tasks involving speech recognition and production. An analysis of dual task performance in this study indicated that the resources involved in the perception and responses involved in these tasks were distinct. This stage dimension is associated with separate brain structures. Thus, speech and motor activities are associated with frontal regions of the brain, while perceptual and language comprehension activities are associated with the brain region posterior to the central sulcus (Wickens, 2002). According to the multiple resource model, increasing response demands should not interfere with perceptual cognitive demands; whereas substantial interference will occur if multiple perceptually or cognitively demanding tasks are required.

Wickens's second dimension, the perceptual modality, is divided into the visual and auditory senses. These differentiations largely were generated from post hoc interpretations of experimental data derived from procedures that employed a dual-task paradigm. Wickens (1980) noted occasions when two tasks did not interfere with each other's performance, a finding inconsistent with a unitary resource theory. He used these occurrences to develop the belief that cross-modal time-sharing is better than intra-modal time-sharing. That is, attention can be divided more efficiently between visual and auditory processes than between two visual channels or two auditory channels (Wickens, 2002). For example, Parkes and Coleman (1990) demonstrated that the visually demanding task of driving was best accomplished when route guidance was provided auditorally rather than visually. Whether the advantage of cross-modal over intra-model time-sharing results from peripheral factors that place the intra-modal conditions at a disadvantage or the actual separate perceptual cerebral resources is unclear. Examples of peripheral factors include two competing visual channels that are placed a great distance from each other that will require visual scanning between them, thus creating an additional scanning cost. Two auditory channels occupy overlapping temporal frequencies or visual channels are that too close together may create masking or confusion. Although the degree to which the advantage of separating visual and auditory displays is the result of entirely sensory phenomena or related to visual scanning and auditory masking during intra-modal tasks remains unclear, experiments that have carefully controlled for such peripheral factors continue to find cross-modal advantages (Wickens, 1980).

Visual channels compose the third dimension of Wicken's box theory, including two separate aspects of visual processing: focal and ambient vision resources. These visual channels support efficient time-sharing, are characterized by distinct brain structures, and are related to separate types of information processing (Leibowitz et al., 1982; Previc, 1998; Weinstein & Wickens, 1992). Focal vision most often is foveal and crucial to recognizing fine details and patterns (e.g., reading or sorting through small objects). Ambient vision largely is related to peripheral vision and is utilized for sensing orientation and the speed and direction the self is traveling through an environment. Thus, an individual who is reading a road sign while driving down the correct lane of the street is utilizing the paralleling processing capability of these two visual channels. Whether this successful parallel processing occurs because the two channels are, in fact, utilizing separate resources or because ambient vision is actually an automatic process that requires no resources remains unclear.

Wickens's fourth dimension, processing codes, distinguishes analogue/spatial processes from categorical/symbolic processes. This distinction can be associated with the two cerebral hemispheres (Polson & Friendman, 1988). According to Wickens (2002), this separation of spatial and verbal resources appears to account for the high levels of efficiency with which spatial responses (e.g., tracking, steering, or mouse movements) can be time-shared with verbal responses (e.g., speaking). Manual tracking and discrete verbal tasks performed concurrently are more effective when the discrete task requires vocal rather than manual responses (Sarno & Wickens, 1995; Tsang & Wickens, 1998; Wickens & Liu, 1988). Requiring manual control may negatively impact performance in a task environment that requires spatial working memory (e.g., driving), whereas voice control may negatively impact performance when the concurrent task requires verbal resources (Wickens & Liu, 1988). Goodman and associates (1999) applied the processing codes dimension to cell phone use while driving, noting the potential dangers of manual dialing while driving and advocating for voice dialing. Martin and colleagues (1988) applied the processing code dimension to the office setting, finding that this code dichotomy explains the greater disruption created by background music that contains lyrics in an office setting where verbal processing is employed.

Wickens's multiple resource model can be employed in both an informal intuitive fashion and a formal computational fashion in order to predict the performance of time-shared tasks.

This model may be utilized to guide designers in endeavors such as determining whether to use spatial or verbal materials to guide navigation, employ voice versus manual controls, or supply auditory versus visual information. When applied more formally, the model may be employed to compute the predicted level of interference between two tasks as it relates to those tasks' competition for shared resources (Wickens, 2002). The demand and conflict components of each task may be entered into a computational matrix to calculate total interference.

Wickens's model, which resolved several questions regarding the division of attention, built upon the concept of functional cerebral space (Kinsbourne & Kicks, 1978) and differentiation of resources (Navon & Gopher, 1979). However, some believe that a significant degree of the power of Wickens's theory was derived from the greater number of explanatory degrees of freedom that naturally arises in multiple-factor versus single-factor construct (Kantowitz, 1987). Of course, this argument is intrinsic to all elaborations of unitary-factor theories, such as the development of multiple-factor theories of intelligence. An additional argument against Wickens's model is that it fails to account for the engagement level of various activities. For example, a driver operating a motor vehicle may perform this task less effectively while talking on a cellular phone even though these tasks are quite separate in their resource demands. Strayer and Johnson (2001) claim that this interruption is the result of the drivers becoming highly engaged in the cellular phone conversation. In spite of these arguments, Wickens's multiple-resource theory continues to have a substantial impact in the area of human attention research and system design and will serve as the foundation for the current study.

The Present Study

This first goal of the present study is to quantify the degree and time course of resources that are withdrawn from a primary task involving an academic skill (i.e., simple arithmetic problems) when visual and auditory distracters are presented. Hypothesis 1 states that compared to no distracter trials, the steady-state visual evoked potential elicited by the primary task will be reduced in the presence of background pictures or sounds. Several prior studies have demonstrated that presenting stimuli concurrently will result in a strong competition for processing resources (Desimone, 1998). This competition for resources lasts several hundred milliseconds and does not appear to be solely the result of the quick orienting response toward the emotional stimulus (Muller, Andersen, & Keil, 2008). The decrease in steady-state visual evoked potential amplitude is extended temporally and may reflect the time window of the first positive event-related potential component. This decrease in amplitude suggests that an early orientation mechanism is followed by a sustained attention mechanism that enhances neural responses in the visual cortex in order to provide optimal analysis of the affective significance of emotional stimuli (Calvo & Lang, 2004; Pourtois et al., 2005).

This second goal of the present study is to identify the timing and location of brain processes involved in distracter effects such as arousal level or positive versus negative valence. Hypothesis 2 states that compared to low-arousal stimuli, high-arousal stimuli will reduce the steady-state visual evoked potential elicited by the primary task more effectively. This finding will be found in both positive and negative valence trials. Previous work has demonstrated that emotional content may contribute to stimuli's competition for resources. That is, emotional stimuli may be processed more efficiently than non-emotional stimuli and cause greater interference with concurrent non-emotional tasks (Keil et al., 2005). Prior work utilizing steady-state visual evoked potentials to examine the time-course of competition for processing resources found that arousing emotional pictures displayed in the background withdraw more processing resources from a visual detection task than neutral background pictures (Muller, Andersen, & Keil, 2008). Additionally, electrophysiological evidence suggests automatic facilitation of orienting towards stimuli that are related to fear (Pourtois, Thut, Grave de Peralta, Michel, & Vuilleumier, 2005). Though most studies that have addressed attention capture related to emotional stimuli have focused on negative stimuli, others have found that emotional stimuli in general may capture attention (Anderson, 2005; Arnell, Killman, & Fijavz, 2004; Schimmack, 2005). Some studies have found that appetitive stimuli capture attention more weakly. However, the positive stimuli utilized in these studies tend to be less emotionally arousing than the negative stimuli (Bradley, Codispoti, Cuthbert, & Land, 2001). Thus, the asymmetry in attention capture effects may be related to the arousal level of the stimuli rather than their valence. In fact, several studies utilizing erotic stimuli have demonstrated that these stimuli tend to influence attention in a manner similar to arousing negative stimuli, suggesting that the arousal intensity of stimuli is more important to the emotional modulation of attention than their valence (Anderson, 2005; Schimmack, 2005; Schupp, Junghofer, Weike, & Hamm, 2004).

The third goal of the present study is to examine the extent to which distraction varies with the modality (auditory versus visual) in which a distracter is presented. Hypothesis 3 states that compared to auditory distracters, visual distracters will create greater interference with the primary task. Several studies have demonstrated that distracters presented in a different modality from that of the primary task create less distraction (Parkes & Coleman, 1990; Wickens, 1980). Thus, attention seemingly can be divided more effectively between visual and auditory processes than between two visual channels.

CHAPTER 2
METHOD

Participants

Twenty individuals from the University of Florida and the surrounding area were recruited. The mean age of the sample was 23.4 years (SD=5.47). Twenty percent of the participants were male. The self-reported ethnic backgrounds were 10% Hispanic and 80% Caucasian. Student volunteers received class credit for participation. Informed consent was obtained from each participant. This study received prior approval from the University of Florida's Institutional Review Board.

Procedure

Participants were administered the Woodcock-Johnson Test of Achievement – III Math Fluency Subtest. This measure consists of 160 simple arithmetic problems, including addition, subtraction, and multiplication to be completed in three minutes or less. Only those problems which resulted in a single digit response were included so that response effort would be consistent across trials. The participant was instructed to complete these problems as quickly as possible. This measure of mathematics fluency has a .92 median internal consistency reliability in the adult range (Mather & Woodcock, 2001)

After completing this brief test of mathematics fluency, the 257-electrode EEG cap was placed on the participant's head and the following instructions were provided:

> Please remain as still as possible. Focus on the cross that appears on the screen in front of you prior to each trail. Once the math problems appear, calculate each and remember your three answers. When instructed, type in each of your answers using the number keys at the top of the keyboard. Please avoid anticipating the end of the trial. Do not look down at the keyboard until instructed.

Once the examiner left the room, the words "Please press the mouse key to start," appeared on the computer screen. Then, arithmetic problems that had been selected from the Woodcock-

Johnson Test of Achievement – II Math Fluency Subtest were presented centrally on a 19-inch computer monitor, flickering at a rate of 15 Hz. That is, the math problems appeared for 30 milliseconds, then the black screen appeared for 30 milliseconds. Therefore, each cycle lasted 60 milliseconds, resulting in approximately 15 cycles per second. The rate of flickering was synchronized to the retrace of the cathode ray tube (CRT) monitor in order to most closely approximate 15 Hz. Each math problem was presented for two seconds; therefore, each trial lasted six seconds.

During visual distracter trials, color pictures selected from the International Affective Picture System (IAPS; Lang et al. 1997) blinked on the computer screen during arithmetic problem presentation. Visual distracters rated as high arousal pleasant, low arousal pleasant, high arousal unpleasant, and low arousal unpleasant were included. Additionally, several trials served as controls in which no information was presented. During auditory distracter trials, auditory recordings that have been similarly categorized (11 per condition) were presented through speakers. Thus, each participant was exposed to ten experimental conditions as follows:

1. High-arousal pleasant visual distracter
2. Low-arousal pleasant visual distracter
3. High-arousal unpleasant visual distracter
4. Low-arousal unpleasant visual distracter
5. No-information visual control (grayscale)
6. High-arousal pleasant auditory distracter
7. Low-arousal pleasant auditory distracter
8. High-arousal unpleasant auditory distracter
9. Low-arousal unpleasant auditory distracter
10. No-information auditory control (tones)

Eleven trials were conducted under each of these ten conditions, resulting in a total of 110 trials. Following each trial, the words, “Please enter your answers using the keyboard,” appeared on the screen. The participant then entered his or her three responses using the keyboard prior to the initiation of the next trial.

Behavioral Response Measurement and Data Analysis

Participants’ responses to the arithmetic problems were recorded using MATLAB, the numerical computing environment and programming language through which the stimuli and arithmetic problems were presented. Then, a one-way analysis of variance (ANOVA) was applied in order to examine differences in behavioral response accuracy across conditions. For the purpose of this analysis, conditions were collapsed across pleasant and unpleasant. Therefore, two within subject factors were compared: modality (visual and auditory) and type of distracter (high-arousal, low-arousal, and no information). Given the directed hypotheses outlined above, a planned comparison, or contrast analysis, was conducted in order to determine whether high arousal conditions were associated with increased error rates.

The mean arousal and valence ratings for the stimuli selected from the International Affective Picture System and International Affective Digital Sounds (Lang et al. 1997) for each of the four arousal conditions in this study are provided in Table 1.

Table 2-1 Mean arousal and valence ratings of distracter stimuli

Condition	**Arousal**		**Valence**	
	Mean	SD	Mean	SD
High-arousal visual	6.089	0.62	3.85	1.92
Low-arousal visual	3.08	0.52	5.47	0.99
High-arousal auditory	7.08	0.73	4.51	2.50
Low-arousal auditory	3.9	0.70	6.01	0.81

Physiological Response Measurement and Data Analysis

Electrical activity of the brain was monitored through EEG recordings from 257 electrodes using an Electrodesics Inc. (EGI) high-density EEG system and digitized at a rate of 250 Hz using Cz as a recording reference. Impedances were maintained below 50 kOhm, as recommended for the Electrical Geodesics high-input impedance amplifiers. All channels were pre-processed on-line with .01 Hz high-pass and 60 Hz low-pass filtering.

Individual EEG trials were excluded from further analysis on the basis of blink or electromyography artifacts in the scalp channels and in cases when excessive eye movements occurred. As a result of the long epochs and these stringent rejection criteria, the mean rejection rate across all conditions was expected to be fairly high. Ultimately, an average of 43 percent of trials was rejected. In order to examine the time course of steady-state visual evoked potential amplitude changes, artifact-free EEG epochs were averaged separately and algebraically referenced to average mastoids by subtracting one-half of the average signal recorded from the right mastoids from the averaged signal at each scalp location. These averaged epochs are expected to extend from 100 ms before to 1,600 ms after stimulus onset. The 100 ms before stimulus onset served as a baseline, and the mean amplitude was subtracted from each data point before being transformed into a frequency domain.

Steady-state visual evoked potentials amplitudes then were extracted from the EEG signal using complex demodulation (Muller et al., 1994; Regan, 1989), thus allowing a modulating signal to be extracted from a carrier signal. This procedure results in a temporal resolution of 500 ms. Mean steady-state visual evoked potential amplitudes were then calculated across the viewing epoch. Voltage maps were plotted using the spherical spline algorithm utilized by Perrin (1996) in order to depict the topographical distribution of the maximum steady-state visual evoked potential amplitude across conditions as well as the effect of the various distracters.

A one-way analysis of variance (ANOVA) was applied in order to examine differences in electrophysiological response across conditions. Given the directed hypotheses outlined above, planned comparisons, or contrast analyses, were conducted in order to determine whether high arousal conditions were associated with increased withdrawal of resources from the primary arithmetic task.

CHAPTER 3
RESULTS

Accuracy of Behavioral Response

The mean error rates in response to arithmetic problems in the presence of stimuli at each arousal level are presented in Figure 3-1 for auditory distracters and Figure 3-2 for visual distracters. The results of the ANOVA addressing arithmetic response error rates indicated no main effect for visual versus auditory distracters. The main effect for distracter arousal (high arousal, low arousal, and no information) were statistically significant, F (2,38) = 4.80, p =.014. There was no significant interaction between distracter modality and arousal. A planned comparison, or contrast analysis, was conducted in order to determine whether high arousal conditions were associated with increased error rates. As expected, these results indicated a quadratic trend with regard to distracter arousal, F(1,19) = 6.81, p = 0.17. Then, a post-hoc ANOVA was conducted in order to test for statistical differences in the error rate associated with low arousal and no information conditions. These results indicated no significant difference between the low arousal and no arousal conditions.

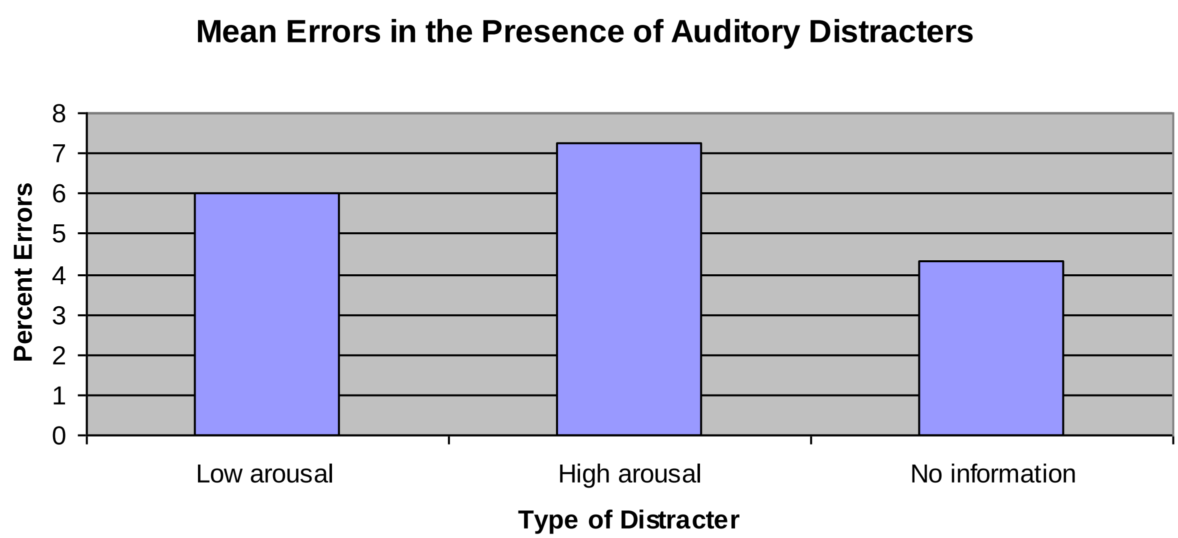


Figure 3-1. Mean errors in response to arithmetic problems in the presence of auditory distracters

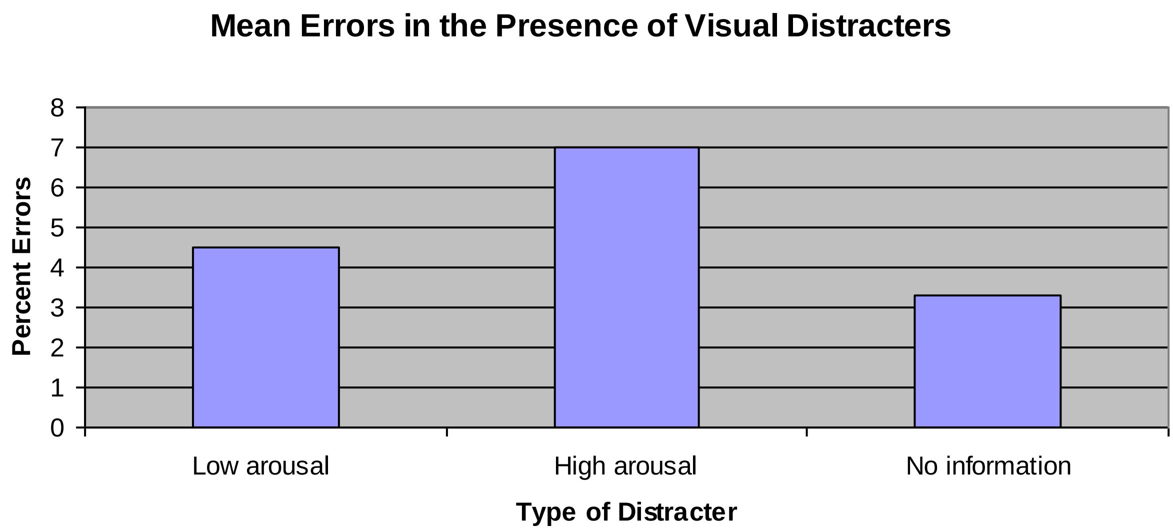


Figure 3-2. Mean errors in response to arithmetic problems in the presence of visual distracters

Electrophysiological Response

The steady-state visual evoked potentials were reliable across participants. The mean amplitudes of the steady-state visual evoked potential in the presence of auditory distracters are presented in Figure 3-3. The mean amplitudes in the presence of visual distracters are presented in Figure 3-4. The time course of the steady-state visual evoked potential amplitude in the frequency domain obtained by complex demodulation averaged across all subjects from the Oz electrode is presented for auditory distracters in Figure 3-5 and visual distracters in Figure 3-6. The grand mean topical distribution of the steady-state visual evoked potential amplitude in the presence of distracters at each arousal level is displayed for auditory distracters in Figure 3-7 and visual distracters in Figure 3-8.

The ANOVA that examined the electrophysiological response indicated no main effect for visual versus auditory distracters and no main effect for distracter arousal. The interaction between distracter modality and arousal was highly significant, $F(2,36) = 19.95$, $p =<.001$. A planned comparison was conducted to determine whether this interaction followed a linear or quadratic trend. The results indicated a significant quadratic trend, $F(1,18) = 24.19$, $p =<.001$.

That is, low arousal and no information distracters withdrew little attention from the primary arithmetic task across modalities, whereas high arousal distracters withdrew attention from the primary task in the auditory modality while providing a facilitating effect in the visual modality.

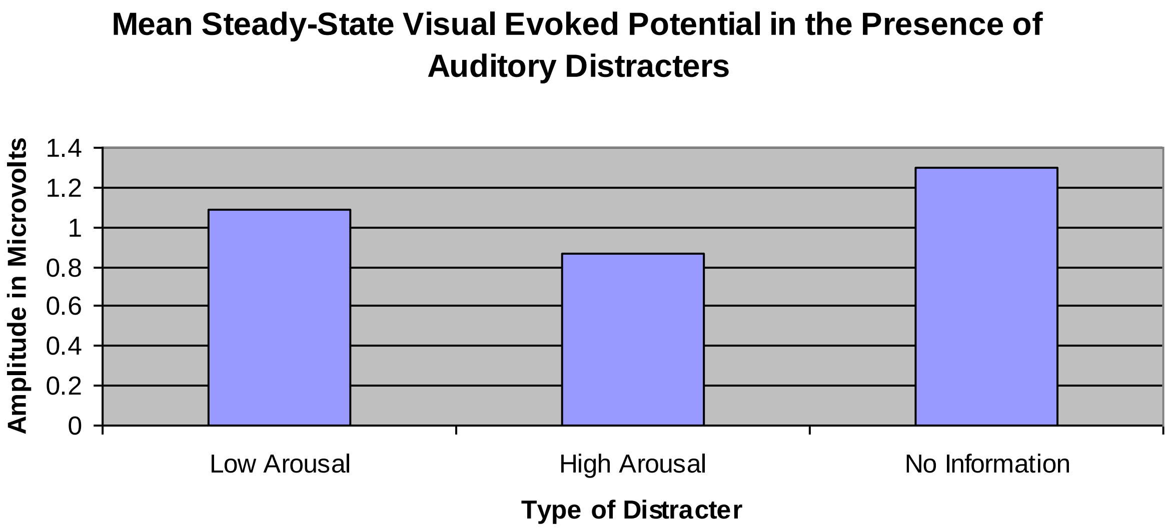


Figure 3-3. Mean amplitude of the steady-state visual evoked potential in the presence of auditory distracters

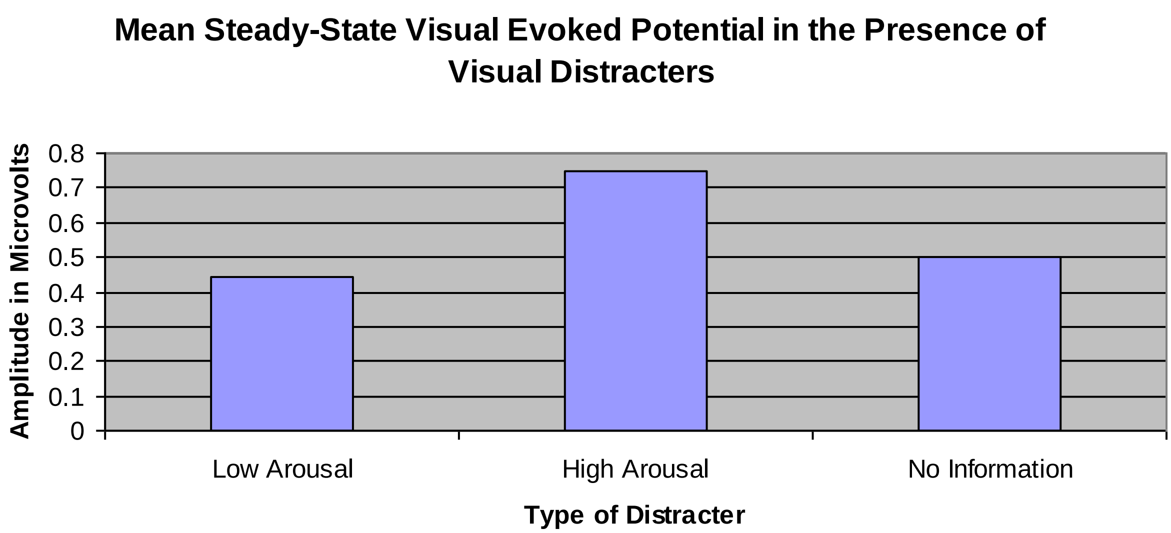


Figure 3-4. Mean amplitude of the steady-state visual evoked potential in the presence of visual distracters

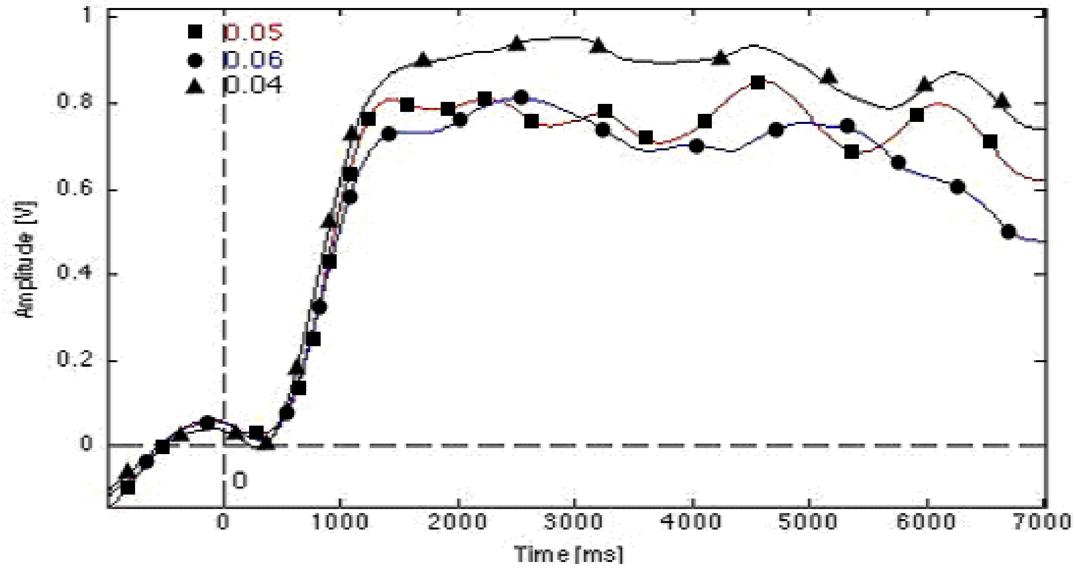


Figure 3-5. Time course of the steady-state visual evoked potential amplitude in the presence of auditory distracters in frequency domain obtained by complex demodulation averaged across all subjects from the Oz electrode. The line with squares is for low arousal distracters, the line with triangles is for high arousal distracters, and the line with circles is for no information distracters.

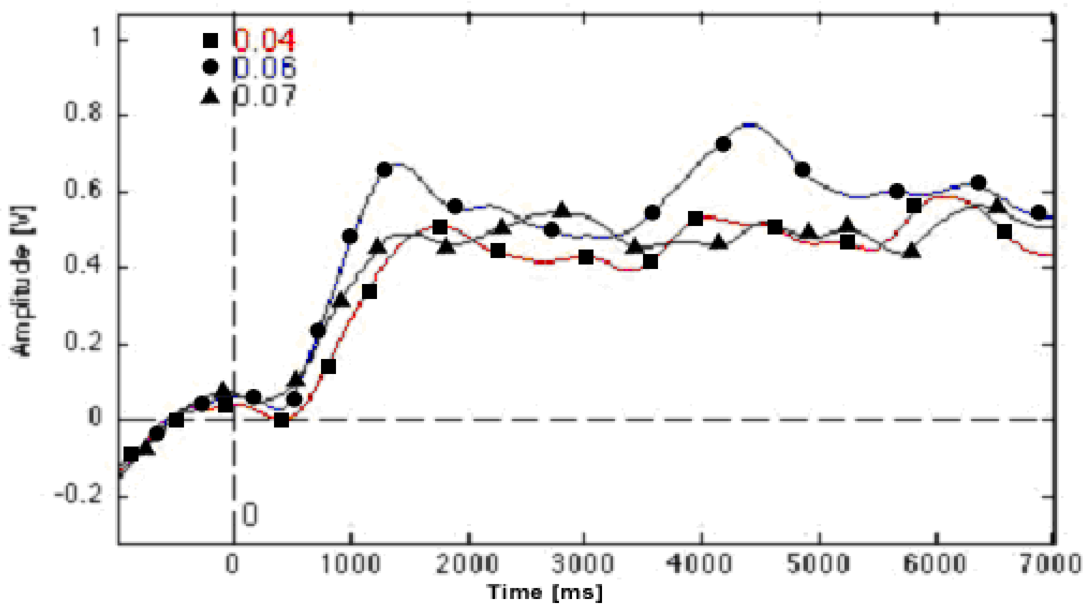
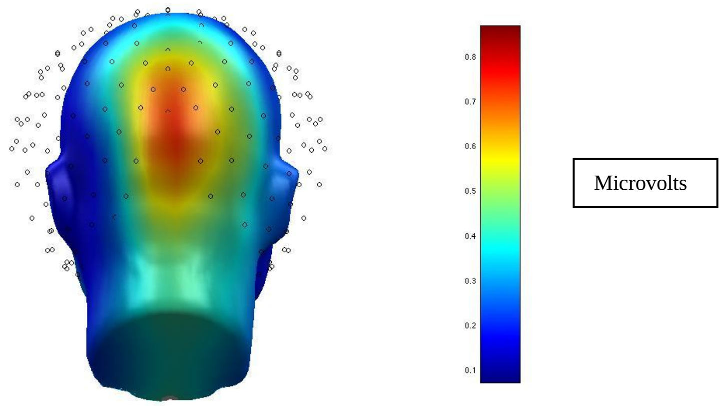
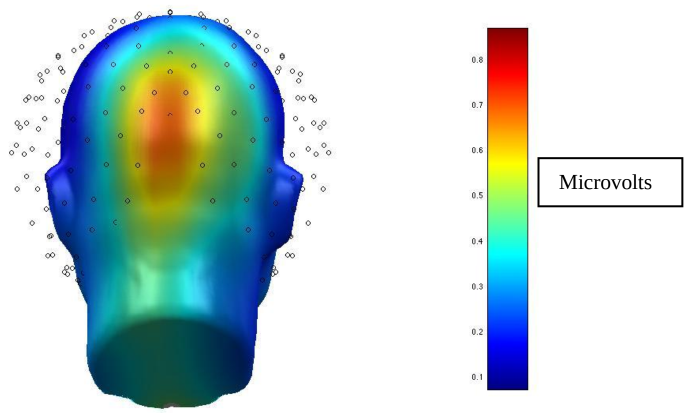


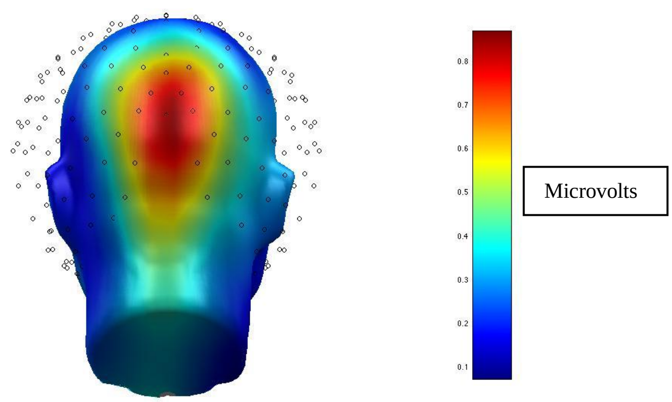
Figure 3-6. Time course of the steady-state visual evoked potential amplitude in the presence of visual distracters in frequency domain obtained by complex demodulation averaged across all subjects from the Oz electrode. The line with squares is for low arousal distracters, the line with triangles is for high arousal distracters, and the line with circles is for no information distracters.



Low Arousal

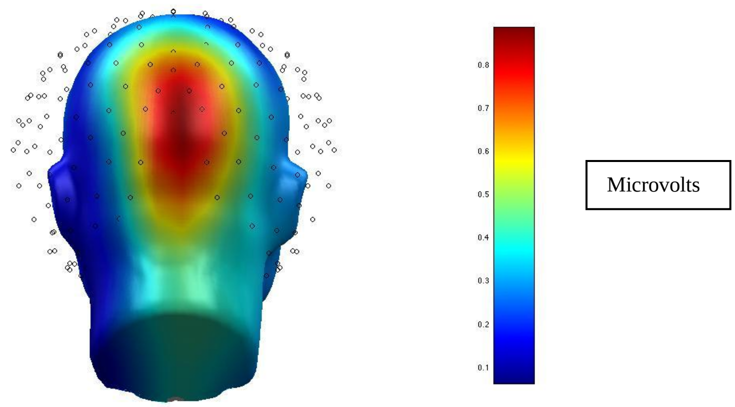


High Arousal

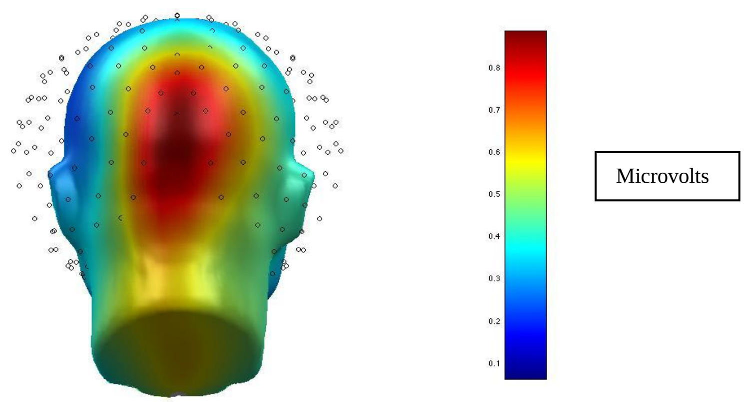


No Information

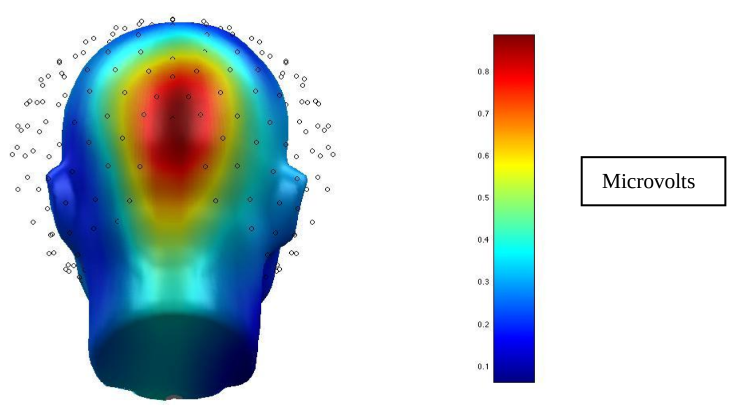
Figure 3-7. Grand mean topical distribution of steady-state visual evoked potential amplitude in the presence of auditory distracters at each arousal level



Low Arousal



High Arousal



No Information

Figure 3-8. Grand mean topical distribution of steady-state visual evoked potential amplitude in the presence of visual distracters at each arousal level

CHAPTER 4
DISCUSSION

This study examined the behavioral and neural responses to a visual arithmetic task in the presence of distracters in order to investigate whether the presence of these stimuli interefere with the attentional processing. Participants completed a series of simple arithmetic problems while high arousal, low arousal, and no-information visual and auditory distracters were presented. The accuracy of the responses to the arithmetic problems was analyzed and steady-state visual evoked potential elicited by the primary task served as dependent variables. This event-related potential was employed as an electrophysiological measure of the allocation of attention, as the amplitude of the sinosuidal waveform is increased significantly with attention attention (Mueller et al., 2008). The results of this study revealed that highly arousing distracters impair the accuracy of responding to the arithmetic problems compared to low arousal and no-information distracters. The examination of the amplitude of the steady-state visual evoked potential revealed that high arousal auditory distracters withdraw attentional processing from the primary visual task whereas high arousal visual distracters lead to a visual facilitation effect.

Influence of Distracters on Behavioral Response Error Rate

The results of the behavioral response accuracy analysis are consistent with expectations. That is, high arousal distracters lead to more errors in response to the arithmetic problems than low-arousal or no information distracters. This finding is consistent with previous studies that have demonstrated that emotional stimuli cause greater interference with concurrent non-emotional tasks than non-emotional stimuli because they are processed more efficiently (Keil et al., 2005). That is, the rapid processing of emotional stimuli appears to impair the cognitive processing of concurrent information (e.g., the arithmetic problems in the present study). Accordingly, these findings support a perspective called the competition hypothesis, which predicts poorer processing of tasks or stimuli that are presented in conjunction with motivationally relevant stimuli.

Several paradigms have provided similar evidence for behavioral response interference in the presence of emotional stimuli. One such paradigm, Stroop task, provides a test of reaction time in which the name of a color is printed in a different color ink and the participant must name the color that is written rather than name the color of the ink. Several modifications of this paradigm have been developed, including one in which participants must name the color of the ink, though a wide range of words are present, rather than only color names. Response times on this task are prolonged when the written word is aversive (McKenna & Sharma, 1995) or taboo-related (MacKay & Ahmetzanov, 2005).

An additional study measured the attentional interference resulting from background pictures while participants completed math problems or a line detection task (Schimmack, 2005). The results indicated that the most arousing pictures produced the strongest interference with the primary tasks. Another study employed a spatial-cueing paradigm in which participants were instructed to denote the side of the computer screen in which a positive, neutral, or threat-related target appeared (Fox et al., 2001). Greater latencies in response were found in trials in which emotional signals cued the opposite hemifield of a target location compared to trials in which these locations were denoted by neutral signals. This findings suggests that the emotional stimuli not only captured attention, but also interfered with the subsequent disengagement of attention. Furthermore, the processing of the target stimulus was impaired when emotional stimuli were displayed briefly in conjunction with a target stimulus. Other studies report that lexical decisions regarding neutral words are produced less rapidly when they were preceded by threat words (Calvo & Castillo, 2005) or arousing pictures (Ihssen, Heim, & Keil, 2007). Each of these studies produced findings similar to those found in the behavioral response accuracy analysis of the present study. That is, each suggests that emotional stimuli capture and hold attention, often at the cost of interfering with a concurrent or subsequent behavioral task.

However, findings indicating interference with a primary task in the presence of emotional stimuli have not been consistent across all paradigms. Additional studies in the field of cognitive neuroscience have used behavioral measures such as the dot probe as an assessment of selective attention in order to examine the influence of emotional distracters. This paradigm involves participants sitting in front of a computer screen with their chins resting in a chin rest. The participants are instructed to focus on a fixation cross that appears in the center of the screen while two stimuli appear on either side of the screen. One study using this paradigm displayed emotional words or pictures as well as neutral stimuli. Then, participants were asked to indicate the location of a dot that appeared on the screen following stimulus presentation. The presence of emotional stimuli was associated with both costs and benefits to performance on the dot-detection task (Mogg et al., 1997). Due to the inconsistency of previous behavioral findings, further investigation of the costs and benefits regarding the presence of emotional stimuli using neuroscientific methods is warranted in order to further explore the time course and neural mechanisms associated with the allocation of attention when viewing or hearing affective stimuli (Koster et al., 2004).

Electrophysiological Response to Auditory Distracters

The results of the electrophysiological analysis support the first and second hypotheses with regard to the presentation of auditory distracters. That is, the presentation of background sounds decrease the amplitude of the steady-state visual evoked potential elicited by the primary task (Hypothesis 1). This decrease in amplitude was greater for trials in which the distracter was highly arousing (Hypothesis 2). This finding is consistent with previous findings that suggest that the decrease in steady-state visual evoked potential amplitude is indicative of an early orienting mechanism and sustained attention mechanism that serve to prepare the cortex for analysis of the emotional stimuli (Calvo & Lang, 2004; Pourtois et al., 2005).

Therefore, the results of the electrophysiological analysis of steady-state visual evoked potentials in the presence of auditory distracters also support the competition hypothesis. These findings are consistent with those from prior neurocognitive studies that have demonstrated that presenting stimuli concurrently will result in a strong competition for processing resources (Desimone, 1998) and that this competition will be increased when the concurrent stimuli include emotional content (Keil et al., 2005).

Letter streams which were accompanied by either asynchronously presented streams of auditory, visual, and audiovisual objects were presented to participants who were asked to either attend to the letter streams or the visual, auditory, or audiovisual objects while the steady-state visual evoked potential associated with the letter-stream was measured (Talsma et al., 2006). The steady-state visual evoked potential was largest when auditory objects were attended compared to when visual or audiovisual objects were attended. These authors claimed that this study provides support for the notion that attentional capacity is greater across rather than within modalities. Interestingly, a study by the same research group (Talsma & Kok, 2002) measured event-related potentials to visual and auditory stimuli while participants were instructed to attend to a combination of stimulus modalities and spatial locations. The event-related potentials were compared for visual and auditory stimuli when those modalities were tended and unattended and at relevant or irrelevant spatial locations. The results indicated that intramodal spatial attention was expressed differently in visual versus auditory event-related potentials. Thus, the authors concluded that the stimulus attributes such as modality and spatial location may be processed differently across modalities.

Electrophysiological Response to Visual Distracters

The results of the electrophysiological analysis were contrary to our hypotheses with regard to visual distracters. The amplitude of the steady-state visual evoked potential elicited by the primary task was predicted to decrease when background pictures were present (Hypothesis 1) and this decrease in amplitude would be greater for trials in which the distracter was highly arousing (Hypothesis 2). On the contrary, we found an increase in the steady state visual evoked potential elicited by the primary task when highly arousing background pictures were displayed. Thus, these findings also were contrary to our third hypothesis, that predicted visual distracters would lead to a greater decrease in steady-state visual evoked potentials than auditory distracters. This hypothesis was founded on Wicken's Box Theory, which states that cross-modal time sharing is more effective than intra-modal time sharing (Wickens, 2002). That is, attention can be divided more easily between two tasks when those tasks draw upon separate modalities. Previous studies have found that stimuli tend to be less distracting when presented in a different modality from that of the primary task (Parkes & Coleman, 1990, Wickens, 1980). Therefore, visual distracters were predicted to lead to a greater decrease in the steady-state visual evoked potential elicited by the primary task than auditory distracters because the primary arithmetic task was visual in nature.

Previous findings have provided support for the competition hypothesis with regard to visual distracters in a manner similar to our behavioral and auditory distracter findings yet contrary to our visual distracter findings. Using methodology similar to the present study, EEG recordings measured the steady-state visual evoked potentials associated with rapidly flickering squares that were superimposed upon neutral and emotionally arousing pictures (Mueller et al., 2008). Behavioral response accuracy rates were recorded as the participants completed a foreground target detection task. The results of both the behavioral response and electrophysiological response indicated that emotional background pictures withdrew processing resources from the primary task. Contrary to our findings, the amplitude of the steady-state visual evoked potential decreased in the presence of these emotional background pictures.

A forced-choice lexical decision task was utilized to examine electrophysiological and behavioral interference resulting from task-irrelevant emotional pictures on subsequent word identification (Ihssen, Heim, & Keil, 2007). Pictures that varied in hedonic valence and emotional arousal preceded the word and pseudoword targets. The results of the behavioral analysis indicated impairment in the processing of target words in the presence of high-arousal versus low-arousal pictures; arousing pictures prolonged word reaction times. The results of the electrophysiological analysis indicated interference resulting from high-arousal pictures as reflected in a reduced first negative event related potential component as well as a suppression of the late positivity amplitude. Regional source modeling revealed early reduction effects that originated from inhibited cortical activity found in the area typically associated with orthographical processing, the posterior regions of the left inferior temporal cortex. Therefore, this study provided further evidence supporting the competition hypothesis.

Another series of studies provided support for the competition hypothesis when they analyzed the third positive event related potential component related to acoustic startle probes while emotional background stimuli were presented concurrently (Cuthbert, Schupp, Bradley, McManis, & Lang, 1998; Schupp, Cuthbert, et al., 2004). This event related potential component served as an indicator of attentional resource deployment. These studies indicated a reduction of third positive component amplitudes when pleasant or unpleasant arousing scenes versus nonarousing scenes were viewed. Thus, these results indicated an interference with attentional resources when emotional stimuli were present.

In contrast, the results of the present study provided support for the supplementation hypothesis. This hypothesis purports that the presence of emotionally arousing stimuli within a visual array serves to heighten attentional resources, thereby facilitating the processing of contiguous stimuli. This view predicts that emotional material in the perceptual array will enhance the processing of concurrent information. Support for this view can be observed in television commercials, magazines, and websites in which emotionally arousing content (e.g., cartoons, erotica, or threat images) are imbedded within the central information in order to attract attention. Thus, the supplementation hypothesis predicts our findings in which the presence of highly arousing emotional imagery facilitated visual processing.

Evidence supporting the supplementation hypothesis also can be found in recent work by Phelps and associates (2006) that sought to investigate emotional stimuli’s effect on contrast sensitivity, which is considered a dimension of early visual processing. Participants were asked to judge the orientation of a target stimulus while the emotional valence and attentional distribution of cues preceding the target stimulus were manipulated. All stimuli were presented centrally at a stimulus onset asynchrony of 125 milliseconds. Emotional events were found to facilitate subsequent visual processing as contrast thresholds were lower for grating patterns that were presented following the presentation of fearful faces compared to neutral faces. The authors of this study suggested that early visual processing was facilitated by emotion. That is, participants are said to perform better visually when emotional stimuli were present.

Other behavioral and electrophysiological studies have manipulated the distribution of visual spatial attention in order to study the transient yet nonselective facilitation elicited by motivationally relevant stimuli. For example, one study presented pairs of faces in the left and right visual hemifields (Pourtois et al., 2004). One face in each pair was fearful and the other was neutral. These pairs of faces were presented at stimulus onset asynchronies varying between 200 and 400 milliseconds. Following face presentation, participants were instructed to judge the orientation of unilateral bars that were presented at either horizontal or vertical orientation. The behavioral response analysis indicated faster discrimination responses to bars that replaced fearful versus neutral faces. In addition, the electrophysiological response analysis of visual evoked potentials associated with bars that appeared at the location of emotional faces indicated an increase in the lateral occipital first positive component compared to bars that appeared at the location of neutral faces. Thus, fear cues facilitated the processing of stimuli that were subsequently presented in the same spatial location.

Similar effects were demonstrated in studies using event-related fMRI methodology. The behavioral and physiological correlates of spatial attention modulation by emotion were explored by employing a fear conditioning paradigm combined with a covert spatial orienting task (Armony & Dolan, 2002). Participants were instructed to detect a peripheral target preceded by the brief presentation of a visual conditioned stimulus in the same or opposite visual field. A reaction time analysis found an interaction between attention shifts and the emotional content of the stimulus. Furthermore, the results of the electrophysiological analysis found conditioning-induced enhanced neural responses in the amygdala and extrastriate visual cortex. Thus, the presence of emotional stimuli enhanced activity in neural regions previously implicated in spatial attention.

General Discussion

The results of the behavioral and electrophysiological analysis regarding auditory distracters are consistent with our prediction that the presence of highly arousing distracters would interfere with the primary arithmetic task. Each of these findings is consistent with the competition hypothesis, which posits that the processing of concurrent or stimuli suffers in the presence of motivationally relevant stimuli, such as highly arousing sounds or pictures. Interestingly, the results of the electrophysiological analysis regarding visual distracters did not indicate interference with the primary task and instead revealed an enhancement of the steady-state visual evoked potential elicited by the primary task in the presence of highly arousing pictures. These results, in contrast to those from the behavioral and auditory distracter results, support the supplementation hypothesis, which purports that the processing of tasks and stimuli will be heightened in the presence of emotionally arousing stimuli. That is, the arousing pictures actually had a facilitation effect on the visual cortex, allowing the primary task to be processed more effectively.

The bulk of the recent research investigating the neural correlates of attentional response provides support for the supplementation hypothesis. Thus, the detection of motivationally relevant events, including emotional stimuli, in the perceptual environment appears to lead to a transient heightened attentional response. This heightened attentional response serves to temporarily tune the brain for maximally effective encoding of subsequent sensory input. Therefore, a quick glimpse of an emotionally arousing photograph, such as those flashed on the computer screen during the present study, seems to trigger a facilitated processing mode with regard to further incoming information.

Why then, does the effect only appear in the presence of visual distracters in the present study? The facilitation effect generated by the presence of emotional stimuli may be modality-specific. That is, the presence of highly arousing visual stimuli heightens the visual attentional response while the presence of highly arousing auditory stimuli heightens the auditory attentional response. However, this effect does not occur across modalities. The present study utilized the steady-state visual evoked potential as a measure of attention throughout the electrophysiological response analyses. Of course, this event-related potential measures visual attention. The presence of visual distracters heightened this response, and the auditory distracters detracted from this response. However, the auditory distracters may have been simultaneously heightening the auditory attentional response. Unfortunately, the present study did not collect a measure of the neural correlate of auditory attention, the auditory steady-state response. This response is a continuous oscillatory brain response that is elicited by repetitive sound modulations. This measure is analogous to the steady-state visual evoked potential that is elicited by rapidly flickering visual stimuli. In the present study, our primary task was visual in nature, thus the steady-state visual evoked potential was selected as the indicator of attentional resources.

A recent study that was completed by a team of leading attention researchers examined the auditory steady-state response and the steady-state visual evoked potentials elicited by repetitive visual and auditory stimuli (Saupe, Schröger, Søren, Andersen, & Müller, in press). This allowed for the examination of attentional modulation created by concurrently presented visual and auditory stimuli while participants were required to attend to one modality and ignore the other. Participants' attention was directed to either the visual or auditory modality for several seconds by means of target detection task. The amplitude of the steady-state response was found to be enhanced when the stimulus stream appeared in the modality that was being attended rather than in the modality that was being ignored. That is, the auditory steady-state response was enhanced when sounds were being attended compared to when a visual letter stream was being attended. Conversely, the steady-state visual evoked potential was enhanced when the visual letter stream was being attended compared to when the sounds were being attended. Prior studies that investigated the attentional modulation of the auditory steady-state response were limited to designs that included only auditory stimulation (Bidet-Caulet et al., 2007; Skosnik et al., 2007) or intermodal attention designs (Ross et al., 2004; Saupe et al., 2009). Studies investigating the attentional modulation of the steady-state visual evoked potential have used intramodal (Morgan et al., 1996a; Müller et al., 2006) and intermodal designs (Talsma et al., 2006). However, the study by this research team was the first examine the effects of intermodal attention on both the auditory steady-state response and the steady-state visual evoked potential, concurrently. The novel methodology employed in that study has broadened the opportunity for further research and understanding of the neural mechanisms of intermodal attention.

Implications

Proponents of resources sharing accounts or the competition hypothesis (Ihssen et al., 2007; Wicken, 1990) would predict that enhancing the emotional relevance of a stimulus will lead to greater interference with subsequent target processing and task performance. If this were the case, then when efficient attentional processing is warranted, the ideal environment would be void of competing emotional content in order to avoid attention capture by irrelevant stimuli. On the contrary, the present study provided support for the supplementation hypothesis with regard to visual stimuli. That is, the addition of emotional content enhanced the visual processing of the primary task. This finding is relevant to education in which teaching with media assistance is becoming increasingly common. The results of our electrophysiological analysis with regard to visual distracters would suggest that incorporating arousing pictures within textbooks or powerpoint lectures will facilitate the visual processing of the target information being presented. That is, students' processing of the information being presented may be enhanced if arousing elements are embedded into its presentation.

However, our behavioral findings suggest the inclusion of emotionally arousing stimuli may decrease performance of an academic task such as the arithmetic problems used in the present study. Thus, the findings from the present study are inconclusive as to whether emotionally arousing content will enhance attentional processing under all circumstances. However, previous work has found that the presence of emotionally arousing content facilitates motivated and instructed attention. In one study, the presence of emotionally arousing pictures were found to enhance the neural processing of grating targets (Keil et al., 2005). In addition, this research team found enhanced target detection in a stream of arousing pictures. The inconsistencies between the behavioral and electrophysiological findings of the present study as well as previous work may be due to the wide range of tasks and stimuli used, or the fact that attention is a multi-faceted phenomenon. Certain aspects of the attentional process may be influenced differently by stimuli of varying types and spatial locations. Thus, whether the enhancement of the neural processing of information will necessarily correspond to enhanced behavioral response in unclear.

Limitations

The non-inclusion of a neural measure of auditory attention, the auditory steady-state response, is a limitation of the present study. This measure is analogous to the steady-state visual evoked potential because it is a continuous neural response elicited by repetitive stimuli that reflects the allocation of attentional resources. In the present study, we selected the steady-state visual evoked potential as our electrophysiological measure of attention because the primary task was visual in nature. However, the inclusion of a recording of the auditory steady-state response would have allowed us to observe whether auditory distracters enhanced the auditory attentional response in the manner in which our visual distracters enhanced the visual attentional response.

Our inability to observe a dynamic change during the viewing epoch constitutes another limitation. In the present study, we were unable to examine the time-course of the steady-state visual evoked potential. Prior studies have suggested that specific components of the oscillatory response (e.g., the third positive component) are indicative of the source of the neural response. The present study, was unable to examine individual overlapping subcomponents of the steady-state visual evoked potential. Rather, we aimed to collect a reliable measure of the allocation of attention to the primary task. A significant increase in the number of trials may have allowed us to observe the individual subcomponents of the neural steady-state visual evoked potential. However, the present study was designed to avoid the introduction of fatigue as a confounding variable.

Future Directions

The findings of the present study as well as those by Saupe and associates suggest further investigation of the neural correlates of attention and distraction using both the steady-state visual evoked potential and auditory steady-state response is warranted. The results of the present study revealed a heightened attention response during a visual primary task when highly arousing visual stimuli were present. In contrast, the results of this study indicated a suppression of attentional response to the visual primary task in the presence of highly arousing auditory distractors. Future studies could address whether emotional content leads to a cortical facilitation response that is modality-specific. One possible methodology may be to replicate the present study with the addition of a recording of the auditory steady-state response. This would allow for the investigation of whether the auditory attentional response is heightened in the presence of highly arousing auditory stimuli.

As indicated by the results of the electrophysiological analysis regarding visual stimuli, perception and attention appear to be facilitated when connections to primitive motivational circuitry are activated. This enhancement is consistent across appetitive as well as defensive stimuli (Lang et al., 1997). This visual circuitry is said to involve visual analysis progressing along the ventral and dorsal streams, in which stimuli that are identified as emotionally relevant then are engaged in a defense circuit through which the lateral and basolateral nuclei of the amygdala receive threat- or reward-related cues from the visual system. Then, re-entrant projections from the amygdala feedback to the visual cortex, leading to a facilitation of attention and visual processing in the presence of emotional stimuli (Amaral et al., 1992). Future research may address whether emotionally arousing auditory stimuli lead to auditory facilitation in a similar manner.

Finally, the inconsistent findings regarding the influence of emotional distracters on task performance suggest that additional studies should examine the influence of emotionally relevant stimuli on a wide range of academic tasks. The current study found a decrease in response accuracy when highly arousing stimuli were present, whereas others have found an enhancement of performance (Ohman, Flykt, & Esteves, 2001). This may be related to characteristics related to the primary task. For example, the primary task in the present study placed demands not only on the visual system, but also on working memory, as three arithmetic problems were presented per trial and participants were required to retain the answers to the three problems to be entered at the end of the trial. Therefore, future efforts that investigate the stimuli and task characteristics that influence whether emotionally arousing stimuli interfere with or enhance primary task performance are warranted.

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BIOGRAPHICAL SKETCH

Lindsay Bell is originally from Toledo, Ohio and received her bachelor's degree in psychology from Purdue in 2001. Following graduation, she spent one year in Quito, Ecuador teaching English and Science classes to children in the fifth through eighth grades. When she returned, she matriculated into the School Psychology Program at the University of Florida. There, she developed an interest in neuropsychology and chose the field for her specialization. During her time at the University of Florida, Lindsay has supplemented the School Psychology Program's coursework requirements with a variety of neuropsychology courses in the Department of Psychology and College of Medicine.

Lindsay has also completed a variety of practicum experiences throughout her graduate training. Through school-based positions in Alachua and Marion County Schools, she provided assessment, intervention, and consultation services for children ages five through 18. Lindsay also worked with a rehabilitation psychologist at Southeastern Health Psychology to evaluate a wide range of patients suspected of neuropsychological deficits. Through this experience Lindsay aimed to cultivate the skills necessary to plan rehabilitative services for clients who have experienced traumatic brain injuries, stroke, dementia, or congenital neurological dysfunctions.

Lindsay's research pursuits have included two years working as a research assistant on a federally funded longitudinal study that investigated factors related to mental health service use, diagnosis, and outcomes related to attention-deficit/hyperactivity disorder (ADHD) called the ADHD: Detection and Service Use Study in the Department of Child and Adolescent Psychiatry. Through this study, Lindsay contributed to several state, national, and international conference presentations as well as four manuscripts for peer-refereed journals. Lindsay has also served as a research assistant for the Autism Genetics Study in the Department of Child and Adolescent Psychiatry, which seeks to identify behavioral-genetic links in individuals with Autism and related neurodevelopmental disorders. In this role, she conducted comprehensive assessments and generated psychological reports for participating families. Finally, Lindsay worked with Dr. Andreas Keil at the NIMH Center for the Study of Emotion and Attention throughout the development, execution, and completion of this dissertation project. In the following year, Lindsay will be completing her internship at the APACenter in Austin, Texas and receiving her doctorate in school psychology.