

## **Abstract**

# **Auditory and Visual Sustained Attention on Tasks with Varied Motivation and Cognitive Loads in Children With and Without ADHD**

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Attention Deficit Hyperactivity Disorder (ADHD) is a common condition that can make tasks difficult for the children affected, particularly in a school environment. Continuous performance tasks are one means of evaluating sustained attention in children with and without ADHD. Traditional continuous performance tasks performed without background noise have failed to separate children with ADHD from children without ADHD. It has been theorized that children with ADHD are more susceptible to the negative effects of reduced perceptual saliency, and require more motivation (feedback) than children without ADHD.

The following study aimed to test the effects of varying motivation and perceptual saliency on continuous performance tasks in children with and without ADHD and in adults without ADHD. Four sustained attention tasks were created: an auditory task with varied feedback, an auditory task with varied perceptual saliency, a visual task with varied feedback, and a visual task with varied perceptual saliency. Each task required the participants to respond to a target word or picture while ignoring non-target words and pictures. Error types (inattention, impulsivity, total errors, and reaction time) were recorded for each task, as well as changes in error rates across the testing session.

Results were analyzed using a repeated measures analysis of variance (ANOVA). Overall results indicated many differences between children and adults. In tasks with varied feedback, differences were found between the two groups of children in only the conditions with no feedback and when there was a longer delay between the response and feedback. In tasks with varied perceptual saliency, significant differences were found between the groups of children in the auditory task with a -5 signal to noise ratio. Differences in performance across tasks (vigilance decrements) were found in all three groups.

Overall, findings from this study were consistent with predictions that children with ADHD may need increased feedback to perform as well as peers without ADHD, and that they may have greater difficulty performing tasks with lowered perceptual saliency. This is an important consideration for ADHD management, diagnosis, and research. In addition, further research into the role of vigilance decrement in children with ADHD is warranted.



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in Children With and Without ADHD

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By  
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## **Chapter 1: Introduction and Literature review**

The current study will address sustained auditory and visual attention in children with ADHD and children without ADHD using tasks that offer varying levels of motivation and cognitive loads. As auditory processing and visual processing are developmental in nature, sustained attention will also be explored in young adults without ADHD, as that group is expected to demonstrate optimal performance. In order to consider auditory and visual attention, one must review the phenomenon of attention itself. The following discussion first addresses definitions, terms, theories, and measures of attention. Following that, Attention Deficit Hyperactivity Disorder (ADHD) will be discussed, including definitions, terms, and manifestations. Finally, a theoretical model and rationale for the current study will be presented.

### **ATTENTION**

#### **Definitions and Characteristics of Attention**

Attention is a complicated process that has been defined in many ways. According to Neisser (2009), *attention* can be defined as the way in which an individual chooses from all incoming information. Attention has also been defined as “the internal mechanisms that determine the significance of stimuli and thereby make it impossible to predict behavior by stimulus considerations alone” (Kahneman, 1973, pg. 2). In daily life an individual is constantly exposed to a wide variety of information. Attention is the process by which one chooses what incoming information to direct ones’ focus toward. In order for learning to occur, an individual must process the incoming information to which they are attending. Attention is therefore necessary for perceptual processing.

Kahneman (1973) described four main attributes of attention. First, attention is limited. An individual has a restricted amount of attentional resources, so not all inputs can be attended.

This limit, however, can change at different times. In other words, one's attentional capacity can be different from one moment or day to the next. Second, the amount of attention required depends on the demands of the tasks. Different amounts of attention are required for difficult tasks vs. simple tasks. Not all activities require an individual's full attentional capacity. Third, attention can be divided. An individual can attend to more than one input or source of information at the same time. Lastly, attention is selective and controllable. In other words, one can choose what to focus one's attention on.

Attention is a supra-modal factor that transcends sensory modalities (ASHA, 2005) and impacts performance on visual, auditory, and motor tasks. Attention can be shifted between these various modalities (Green, Doesburg, Ward, & McDonald, 2011). For example, an individual may focus his or her attention on an auditory stimulus, such as speech, and then subsequently look out a window, shifting his or her attention to a visual stimulus. Attention can be involuntary, and related to the amount of arousal. For example, hearing one's own name during a task typically results in a switching of attention to the source of the spoken name.

There are four main categories of attention discussed by psychologists: selective attention, divided attention, attention switching and sustained attention. Each will be defined and described herein.

An individual can either focus or divide his/her attention. According to Groome (2013, pg. 66) selective attention refers to the "conscious awareness of, and concentration upon, a particular source of stimulation or information". Selective attention is the ability of an individual to direct his or her attention to one designated stimulus such as a single target word or to a designated stimulus category such as digits when presented a sequence of digits and letters. According to Kahneman (1973, pg. 12), selective attention can be defined as "a constant

emphasis on a class of perceived events in preference to others”. Kahneman further states that “selective attention consists of the allocation of a limited capacity to the processing of chosen stimuli and to the preparation of chosen responses” and it also demonstrates an individual's “ability to resist distraction.” Selective attention requires an individual to focus on a single sensory input, a signal internal analyzer, or a single target while ignoring competing inputs, dimensions, or targets.

The spatial location or position of the target appears to be very important in selective attention. According to Logan (2004), the spatial position of a stimulus is the strongest cue allowing for stimulus detection and identification. This can be tested by varying the location of stimuli that an individual is required to attend. An individual will have better performance on a task if he or she is attending to a stimulus that is far away from a distractor, as opposed to a task where the distractor is near the stimulus. This could be important when considering the needs of children with ADHD in a classroom setting. If the proximity of the stimulus to the distractors is important in maintaining attention, these children may need to be far away from sources of distraction.

Researchers, such as Beck (1967), suggest two possible stages to selective attention: a pre-attentive mechanism that organizes the perceptual field prior to a focal attention stage. For example, in a school classroom students use the pre-attentive mechanism when they first tune out the background noise (e.g., chairs and desks moving, a lawnmower outside the window) and then use focal attention to listen to the words of the teacher. The speed of search of the focal target, e.g., the teacher's voice, depends on the ease with which the target can be discriminated from its background (Logan, 2004). In a research study, measures of reaction time (i.e., time from target onset to subject response) may be used to index that effect.

Divided attention is different from selective attention in that the required tasks are not associated solely with one source of information. Groome (2013) defines divided attention as an individual splitting his or her mental resources between multiple tasks at the same time. In other words, the tasks require that attention be split between multiple sources or categories of information at the same time. Researchers study how divided attention is used to focus on two simultaneous inputs, two simultaneous analyzers, or two simultaneous targets. Divided attention is an important skill, as many real-world situations require divided attention. In a school setting, for example, a child may need to attend to the teacher's voice while also attending to written work. In research studies, divided attention is often examined through the use of dual simultaneous tasks, which are typically more difficult than selective attention tasks.

Howard, Munro, & Plack (2010) noted that in most research on dual tasks studies assess performance on one single task as compared to performance on that same single task completed at the same time as another different task. When an individual is required to divide his or her attention between multiple tasks, his or her performance on both tasks can be reduced. Howard, Munro, & Plack (2010) found that in children (ages 9-12) accuracy on easy dual tasks in noise (i.e., repeating back words and remembering numbers to recall) was comparable to performance on each individual task. However, when the children were asked to recall numbers at a later time, their performance was decreased, especially with more challenging signal-to-noise ratios. In other words, the children had more difficulty recalling the digits when they also had another task to perform. Thus, the impact of dual task processing may not be immediate, as found in this study.

Hahn et al. (2008) studied divided attention (i.e., dual task performance) and selective attention in 25 adults ages 18-44. They found that when participants were required to divide

their attention on a task involving a circle with three varied colors (deciding whether the stimuli were the same or different), they displayed increased reaction times when compared to reaction times on the related selective attention tasks. On these selective and divided attention tasks, however, there were not significantly different accuracy scores (i.e., percent correct scores). Therefore, although reaction times increased on the dual task condition, accuracy was still maintained. This suggests that in dual tasks, adults can maintain the accuracy of their performance if they are given sufficient time to complete the tasks.

Attention switching involves changing selective focus from one source of information to another. This differs from divided attention in that the two tasks/targets are not simultaneous. In attention switching, one task/target is attended to, and then another different task/target is attended. For example, a child could focus his or her attention on playing a game and then switch his or her attention to a parent talking. On a research task, a subject might be pre-cued to respond to one stimulus target, type or category on selected stimulus trials and pre-cued to respond to another target, type, or category on other stimulus trials (e.g., trials 1, 2, 6, 9 be pre-cued with “report right ear” and on trials 3, 4, 5, 7, 8, 10 be pre-cued with “report left ear”). On these divided attention tasks in which adults were instructed to repeat back numbers presented to the right and left ear, using pre-cueing, the more complex the attention task, the more difficulty they had, as evidenced by a decrease in accuracy (Strouse, Wilson, & Brush, 2000). The task was made more difficult by increasing the length of the digit sequence that listeners were required to identify (i.e., one digit, two digits, or three digits).

Sustained attention is the ability to continue to attend to a stimulus over an extended period of time. Sustained attention tasks are generally around 15 minutes, but can be as long as 20 minutes (Greenberg & Waldman, 1993; Seidel & Joschko, 1990). Sustained attention is also

part of the *vigilance* network (Groome, 2013; Nigg, 2006), with *alerting* being the other part (Posner & Peterson, 1990). Vigilance is the ability to sustain attention throughout the duration of a task, while alerting is the initial cue that important information is coming. Vigilance is important in the real world. Children in school must maintain their attention to the teacher throughout the day. This can be a difficult task, as often attention must be maintained for extended periods of time, with minimal breaks. Children must maintain their attention, often with little or no external reinforcement to stay on task. The alerting function of the vigilance system can be impaired in children with ADHD (Nigg, 2006).

During a sustained attention task, subjects are not prompted or re-focused once the task has begun. The issue of re-orientation is very important when studying sustained attention. If a subject is given cues to stay on task, the task is no longer a sustained attention task. For a task to be a true evaluation of sustained attention, the individual must maintain his or her attention without any outside influences. When children with hyperactivity issues diagnosed by a physician complete a task with the tester physically present in the test room, their performance tends to be comparable to the performance of typical children with a tester in the room (Draeger, Prior, & Sanson, 1986). This suggests that the children with hyperactivity issues struggle with controlling their behavior internally, instead relying on external control to maintain appropriate behavior. The presence of the tester can be seen as external control to behavior. It is possible that when the children feel that they are being watched, or when an adult is present, they are better able to control their behavior. While the child's internal level of control was not impacted, the presence of the tester exerted an external control. It is possible that the children thought that they should please the tester, and therefore their performance improved. Given this interesting finding, experimental designs should allow for testing children without the tester immediately

present in the test room (e.g., on the other side of the audiometric sound booth but not within the sound booth).

Betts, McKay, Maruff, & Anderson (2006) evaluated sustained attention in children ages 5-12 without ADHD and examined performance in the following age groups: 5-6 years, 8-9 years and 11-12 years. They manipulated the cognitive task load during a computer based task, and studied the effects of age group and task load on attention. A low load task involved simply looking at two playing cards with children asked to indicate whether or not the cards were the same color (i.e., red or black suit). The high load task involved a six card display with children asked to indicate if there was a pair of cards among the six that matched in number, suit, and color. The researchers found that high load tasks resulted in poorer performance accuracy than low load tasks. They hypothesized that this was because high load tasks placed a greater cognitive demand on sustained attention, making them more difficult for the children. They also found that sustained attention improves with age. The youngest children had poorer performance than the older children; however, at around ages 8-9 years performance leveled off. In other words, at around ages 8-9, children had similar sustained attentional abilities as their older peers. Thus; grouping data across this age range (5-12 years) is not appropriate as there are significant differences between younger and older children.

Learning effects can be observed on sustained attention tasks. For example, if a subject is responding to a stimulus on a visual task and asked to ignore background speech babble, the subject's performance can improve over time. Eriksen (1958) found that performance over time can improve with practice. In Eriksen's study, participants were asked to discriminate among stimuli based on visual qualities, such as size of the stimuli. Half of the participants were told if their responses were correct each time, whereas the other half were not offered feedback. The

participants returned for testing over five one-hour sessions. Both groups had improved results over time, indicating that simply performing the task over time improved their performance. This practice effect was less apparent for more challenging discrimination tasks, but improvements still occurred from the beginning of the study to the end. When comparing the amount of improvement between the group with feedback and the group without feedback, the group with feedback had only a slightly greater improvement. This suggests that regardless of whether or not a participant is offered feedback, a practice effect can occur.

Reorientation is the ability to regain attention after distraction. Reorientation of attention after a period of selective listening on a given target is difficult and leads to errors for a few seconds after the reorientation cue, or reminder for an individual to regain their attention. Gumenyuk, Korzyukov, Alho, Escera, & Näätänen (2004) examined the effects of distraction on a sustained visual attention task in children in three age groups: 8-9, 10-11, and 12-13 years. The children completed a visual task, during which auditory stimuli were used to distract them. The auditory distractors included environmental sounds such as rain and car horns, played randomly during a constant presentation of a pure tone. A pure tone was constantly present during the task, whereas the auditory distractors occurred randomly. The younger children required a longer amount of time to reorient their attention to the visual task after the distraction (the novel environmental sound) as evidenced by increased reaction time and decreased accuracy. This suggests that there are age-related effects to the ability to reorient attention after distraction. When the children were distracted by a new auditory stimulus that differed from the constant pure tone, the younger children displayed greater difficulty in returning their attention to the visual task.

In the current study, sustained attention on auditory and visual tasks will be examined in children with and without ADHD. In addition to ADHD status, two other critical factors will be varied, the perceptual saliency of the target (using different noise conditions and different image contrast conditions) and the feedback offered (i.e., none, long delay, short delay, immediate). Having offered key definitions related to attention, the following section offers theories of attention in order to develop the theoretical basis for the current study.

### Theories of Attention

Numerous researchers have described attention and formulated theories of attention. These theories attempt to describe the processes and/or stages from perception of stimuli to attentional processing and response. The current discussion will address the main theories in chronologic order.

The Broadbent (1953) Filter Theory of Selective Attention views attention as a filtering mechanism. According to this theory, when a large amount of information is presented to an individual, it must be filtered so that it can be processed. The most important pieces of information can pass through, and only those pieces of information are perceived. This filtering process has also been called the Early Selection Model, or Bottleneck Model, as irrelevant stimuli are thrown out. The “bottleneck” is the point at which only selected sets of features can be processed. In a stimulus set, the filter identifies the relevant stimuli (Kahneman, 1973).

According to the Filter Theory of attention, all incoming information passes through a filter which removes the irrelevant information. Only the inputs or stimulus features that are deemed relevant are processed. The information is channeled through a specific sequence of processors: the S-system (short-term store), a selective filter, and lastly the P-system (limited

capacity channel). All stimuli enter the S-system, and then the information is filtered, and processed in the P-system. The information is processed serially and no parallel processing occurs. Processing focuses on selected features and away from irrelevant features due to a limited capacity. This theory spurred a great deal of thought and research, but it does not account for divided attention and is not supported by other research findings. While filter theory suggests that the unattended messages/stimuli are not attended to, research findings have demonstrated that there is some processing of the unattended information (Seitz & Watanabe, 2005).

Treisman (1969, pg. 283) examined the Early Selection/Filter Theory, and modified it to develop the Attenuation Model. She defined attention as “the selective aspect of perception and response.” She observed that the Filter Theory alone could not account for all findings from research on attention. Her Attenuation Theory includes an early filter, similar to the Early Selection Theory; however, this early filter simply attenuates the unattended information. The irrelevant information is not completely eliminated, as proposed in the Early Selection Theory, but rather it is attenuated. This theory allows for the parallel processing of multiple stimuli, unlike the Early Selection Theory. Additionally, according to the Attenuation Model, a single input can be easily processed whereas multiple inputs are more difficult because all inputs receive some level of processing. Analysis of stimulus features is accomplished by a number of different perceptual analyzers with both early and late analysis taking place. This model proposes that there are three different processes in attention selection. The implementation of these processes is dependent on the attention task. According to Treisman (1969), the three main types of selective attention processing are the following:

1. Selection of inputs: The individual selects which sensory data needs to be focused upon based on general stimulus characteristics (i.e., auditory or visual, the source, location, or direction), and then a decision stage follows with selection based on specific stimulus characteristics. The early selection based on general physical characteristics (including location) is similar to the figural emphasis stage in the model of attention offered by Kahnemann (1973). A task requiring selection of inputs would be one, such as the presentation of stimuli to both ears with the listener asked to identify only the stimuli in the right ear. The individual must limit his or her attention to the stimuli in the right ear.
2. Selection of analyzers: The individual selects one or more dimensions of the input stimuli to analyze and ignores other dimensions. The Stroop Test is an example of this, in which the names of colors are printed in different colored inks. The individual must name the color of the ink, not the printed words. This can also be called selection of attributes, as attributes are specified.
3. Selection of tests and targets: The individual selects a narrowly defined and specific target. The target is specified and rare/occasional during the task. An example of this type of task would be requiring an individual to identify one specific word in a list of words, such as during the Auditory Continuous Performance Test (Keith, 1994).

A fourth type of attention, selection of outputs, is discussed by Treisman but she emphasizes that this type is not very important compared to the other types because the task is uncommon. An example of selection of outputs would be a task in which the stimuli must be categorized in order to be selected and the stimuli themselves do not differ in a physical attribute. An example of this

type of task from Kahmemann (1973) is reading a list of digits. The listener can discriminate the digits from other stimuli.

A contrasting model of attention is the Late Selection Model (Deutch & Deutsch, 1963). According to this model, the selection of relevant information occurs late in the process, after all information is perceived. There is no limit to the amount of information that can be perceived, as it is automatic and does not necessarily require attention. After the perceptual stage, the information can be sorted so that the relevant and important information remains. A process of “importance weighting” occurs, in which attention is focused on the most important information and input. Essentially, all incoming information is perceived by the individual, regardless of importance. Selection of important and relevant information does not occur until after all information is perceived. This differs greatly from the Early Selection Model, as the Early Selection Model suggests early filtering of information. In the Late Selection Model, no such filtering occurs, and the most important information is ultimately focused on. This model does allow for divided attention, unlike the Early Selection Model. Because all incoming information is processed, and the individual can select what information to attend to, it is possible to attend to multiple inputs. This theory, however, does have some limitations. It does not account for how an individual might attend to multiple inputs on the same channel (e.g., two visual tasks), as all information is processed. Additionally, this theory does not explain why stimulus features are not always the most important aspect of selection. Sometimes the individual can attend to an input based on other factors besides the features of the incoming stimulus. Individuals use other factors besides stimulus features to decide where to direct their attention. This can include knowledge of the task, motivation, or relevance. It also oversimplifies perception, and does not fully explain focused attention. This theory has been criticized by Driver (2001) who observed

that studies in neuroscience have offered evidence against all stimuli being filtered using a late selection model. If all incoming stimuli are perceived, then why is an individual capable of focusing his or her attention on only one source of information? This model suggests that all inputs are attended.

Norman (1968) discusses two types of inputs that relate to the Late Selection Model: sensory inputs and pertinence inputs. Sensory inputs are the actual physical characteristics of the stimuli that the individual hears or sees. Pertinence inputs, however, are not physical in nature. Pertinence inputs relate to the relevance or importance of the information to the individual. More important information, with higher pertinence, is attended. This expands on the ideas presented by the Late Selection Model. All sensory inputs are perceived by the individual, regardless of importance. Pertinence inputs, however, direct late selection. After all the information is perceived on a basic level, the pertinence, or relevance, of each piece of information can then be assessed. Information with a higher pertinence level is ultimately used to direct attention. This attentional focus is the one most important or relevant to the individual.

Kahneman (1973) presented his own model of attention that has been called the Capacity Model. This model suggests that there is a limit to a person's mental capacity. Changes in arousal level are related to changes in difficulty of a task. When there is not a clear physical difference between the relevant and irrelevant information, selection is difficult or impossible. More difficult tasks result in increased arousal. The Capacity Model relates task difficulty to an individual's mental capacity and the effort required for performing a task. Any distractions present during the task also are viewed as competing for the limited mental resources of the individual. If there are multiple tasks, then as the difficulty of one task increases, the accuracy of performance on the other task will decrease. Capacity interference occurs when attentional

demands of other activities interfere with the chosen task, while structural interference occurs when multiple activities/tasks use the same mechanism of perception. Performing more than one task successfully depends on the effort associated with each individual activity. An individual can be unsuccessful at an activity either because he/she does not have the mental resources for the activity, or because he/she has given too much of his/her limited mental resources to other activities at the same time. According to Kahneman (1973), the stages of perceptual analysis include the following: sensory registration/temporary storage in sensory memory, unit formation (dividing the stimulus into groups), figural emphasis (the stage where attention begins), and activation of recognition units, perceptual interpretation/readiness, response selection, and response readiness. Attention is allocated at the stages of figural emphasis and response selection, which is similar to Broadbent's (1970, 1971) stimulus set (physical features drive the attention tasks) and response set (categories of stimuli drive the attention task). Figural selection allocates attention to objects rather than features. Kahneman's full model for perception and selective attention includes the following:

1. Stimuli are perceived with sensory registration and storage.
2. Stimuli are segmented into groups or units.
3. Figural emphasis/attention is directed toward units or groups to be analyzed (such as a letter, word, or shape). This requires attention and effort, and preferential attention is given to some units or groups.
4. Activation of Recognition Units occurs with a determination as to whether stimuli have critical target features with the greatest activation for stimuli meeting the greatest number of critical features.

5. Selection of Interpretations involves the decision as to whether the unit matches the target criteria. This stage is affected by perceptual readiness.
6. Response selection involves taking the required task action. This is affected by response readiness, and requires effort and attention to the response (Kahneman, 1973, page 67).

This model has been criticized, however. Some researchers believe that it is difficult to determine how stimuli are grouped, and that this model does not fully explain stimuli groupings, and that this model is too simple to thoroughly explain the complexities of attention.

Allport (1980) proposed the Module Model of attention as an alternative. This theory suggests that attention is controlled not by just one processing system, but by various “modules.” Each module controls attention to different types of tasks. Therefore, if an individual is completing multiple tasks that require attention from the same module, multitasking will be difficult. If he or she is completing tasks requiring attention from different modules, however, performance will not be impacted.

Johnson and Dark (1982) describe two theories of attention: intraperceptual theory and extraperceptual theory. They define intraperceptual theories as, “those that view attention as operating within the domain of perceptual processing” and extraperceptual theories as, “those that view attention as operating outside of this domain.” Extraperceptual processing is defined by them as, “...those forms of information processing that most theorists assign to a central processor of some sort” and can take many forms. In other words, intraperceptual theories propose that attention is part of the perceptual processing of incoming stimuli whereas extraperceptual theories propose that attention is not a part of perceptual processing but is a

consequence of a theorized central processor within the brain that focuses attention. Those supporting intraperceptual processing believe that attention is linked to the processing that occurs with all incoming stimuli. In contrast, those supporting extraperceptual processing argue that the mechanisms responsible for attention are not the same as those responsible for processing incoming information. In essence, attention and perception are viewed as two separate processes. Johnson and Dark (1982) argue for the intraperceptual theory due to a substantial amount of data supporting this theory. They found that when one is attempting to focus attention on a particular input and avoid focusing on a distractor, perceptual processing was improved, as reflected by accuracy of responses. They favor the intraperceptual theory because they believe that one must select and focus perception in order to attend to a specific stimulus rather than to a distractor. The brain is able to control its level of attention for the stimulus and for the distractor. Because the brain responds more to the stimulus than to the distractor, it follows that attention is directed internally, with greater internal resources given to the stimulus. If the extraperceptual theory were true, the brain would respond equally to both the stimulus and the distractor. This is because attention would be unrelated to the perception of the stimulus, making all inputs equal.

Johnson and Dark (1982) further discuss the importance of focusing attention away from irrelevant stimuli, or distractors, and instead focusing on targets. Attention must be directed towards the relevant inputs, even when the individual is also exposed to irrelevant distractors. Jones and Morris (1992) also discuss the impact of irrelevant stimuli on attention. They discuss how irrelevant background speech influences visual attention, as well. When there is irrelevant input present, the irrelevant input takes up mental space that could be occupied with something else. If there is a limit on an individual's mental capacity, irrelevant inputs can take up some of

that capacity and limit attention to the relevant inputs. Distractors can decrease an individual's ability to attend to important incoming inputs. In everyday life, distractors are plentiful and because of that attentional tasks with distractors might better reflect everyday attention.

Lavie, Hirst, Fockert, & Viding (2004) developed the load theory of attention. The load theory relates attention to the "perceptual load," i.e. the amount of information that must be perceived. When assessing selective attention, they propose that there are actually two separate strategies used. The first is the "perceptual selection mechanism," which is needed in situations in which an individual is confronted with a large amount of information to perceive. Because the amount of information exceeds the individual's perceptual load, he or she must focus his or her attention on the most crucial sources of information, and focus attention away from irrelevant stimuli, or distractors. Some stimuli are ignored, or not fully processed, because of the high perceptual load of the task at hand. The second strategy is the "cognitive control mechanism." The cognitive control mechanism is used to maintain one's attention away from distractors. One must have the cognitive abilities to actively choose the information processed. This mechanism is used when one is in a situation with fairly low levels of incoming information, such as an environment with limited background noise. Lavie et al. relate their theoretical model to the Yerkes-Dodson Law (Yerkes & Dodson, 1908), which relates to arousal level. They state that if a task is easy, performance will improve with background noise, but if it is difficult, performance will decrease with background noise. In the load theory of attention, early and late selection can both occur. The attention mechanism depends on the perceptual load of the task. If there is a large perceptual load (a lot of incoming information), early selection will take place. If there is a small perceptual load (not a lot of incoming information), however, late selection will take place. According to Lavie et al., this explains why some research supports early selection, and some

research supports late selection. If there is a smaller load, the irrelevant, or non-target, information can also be processed. The load involved in processing the relevant information determines the extent to which irrelevant information is processed. Distractors only interfere with processing if there is a low perceptual load. This applies to both selective attention and divided attention tasks. An individual's processing mechanism (early or late selection) is determined based on external events (load size), and not internal events. Even if the stimuli and distractors are the same, if an individual is given instructions that specify the relevant information, this can be used to increase the load for relevant information and decrease it for irrelevant information, manipulating the load. For example, if an individual is given directions to attend to input from the right ear only while information is presented to both ears, this increases the load for the right ear and decreases the load for the left ear. The individual is able to choose to focus their attention on the relevant stimulus, even if they are also exposed to another irrelevant stimulus. The individual weighs the importance load for the two incoming signals, and places greater importance on the relevant input than on the irrelevant input.

When reviewing theories of attention, it appears that different attentional mechanisms or processes occur depending on the nature of the attentional task. Theories that are based on the nature of the attentional task better explain the varied research findings. Attention has been studied in the auditory and visual modalities, and the literature related to visual attention and auditory attention follows.

### Visual Attention

Steinman & Steinman (1998) provide multiple definitions of visual attention. They first define visual attention as, "an enhancement of visual processing in a location that is attended."

They also define it as, “a filter that limits the amount of information that the visual pathways ultimately process. It determines which of the information that reaches our retinas will be available to the higher cortical areas that assemble our final perception of the visual world.” They lastly provide another definition of visual attention, as, “a mechanism that prioritizes our visual sensory input so that important or life-threatening information is enhanced, or processed more easily, and all other (relatively irrelevant) information is inhibited or ignored” (Steinman & Steinman, 1998).

Steinman & Steinman go on to discuss four important aspects of visual attention. They are: 1) engaging attention, 2) directing attention to a particular stimulus, 3) locking attention by focusing attention on the stimulus, and 4) suppressing irrelevant information. They go on to discuss how visual attentional abilities can be studied by researchers. Visual attention can be assessed through participants focusing their attention on a particular visual input, and then changing the visual input to be attended. In other words, the participants focus their attention on one visual stimulus or object, and then the incoming stimulus is changed to another stimulus to be attended. A target is presented and then a new target is presented. The individual must direct and then shift the focus of their attention to the new stimulus.

Visual attention can be thought of as a “spotlight” (Enns & Girgus, 1985). This means that within the visual field we can focus our attention on one particular target, much like a spotlight focuses light onto an actor on a stage. The size of this visual spotlight can be adjusted to fit the input. Our visual attention can narrow in on one very specific visual stimulus, or it can be expanded to include a larger visual field. Enns & Girgus (1985) studied visual attention in children and adults. In their first experiment, 15 children ages 6-8, 15 children ages 9-10, and 15 adults completed a task involving judgments related to four stimuli. These stimuli were

parenthesis in four different configurations: ((. )(, ( ), and )). The observer's task was to judge whether one side of the parenthesis curved either left or right, while ignoring the other parenthesis. The distance between the two parentheses was varied throughout the task. This variation of distance caused a difference in performance with poorer performance occurring when the non-target parenthesis was near to the target parenthesis. The researchers found that younger children are less able to change their "spotlight" of attention, or area that they are attending to, than adults. In other words, younger children had slower reaction times than adults and made more mistakes due to the irrelevant stimuli.

In their second experiment, Enns & Girgus (1985) tested 14 children ages 4-5, 14 children ages 6-8, and 14 adults to examine the extent to which children use the configuration properties of a stimulus to classify it. In this task, participants classified the direction of a target arrow when two arrows were presented at the same time. They were told to judge which way the designated target arrow was pointing. The distance between the two arrows was varied. They found that the children were more likely to process the configurations of stimuli, or overall shape, but only did so if they could see them in their first glance, when they didn't have to search for the stimuli. This provided support to the Separability Hypothesis (Shepp, 1978, 1983; Shepp, Burns, & McDonough, 1980), which states that children process the global features of a stimulus, rather than the smaller details that the experimenter changes (Enns & Girgus, 1985).

Enns & Cameron (1987) studied visual attention in three groups: 14 children ages 4-5 years, 14 children ages 6-7 years, and 14 adults. They suggested that visual attention requires three tasks: search, filtering, and priming. They defined search, also called orienting, as, "movements of attention in visual space." Filtering was defined as, "the ability to ignore

irrelevant stimuli or attributes in the visual field while a task-relevant stimulus or attribute is processed.” Priming was defined as, “maintaining or changing cognitive strategies over time” and as, “set expectancy” or “attention switching.” The participants were asked to indicate which way an arrow was pointing while ignoring a second distractor arrow. The position and spacing between the arrows was varied throughout the experimental task. The change in arrow positioning on the display was used to evaluate search abilities whereas the change in distance between arrows was used to evaluate filtering abilities. They found that reaction time improved with age, as well as search and filtering accuracy. Search abilities improved in children between 4 and 7 years, but then did not improve much between age 7 years and adulthood.

Itti & Koch (2001) offered a model of visual attention based on their review of the existing literature. They proposed that, “the most important function of selective visual attention is to direct our gaze rapidly towards objects of interest in our visual environment.” In other words, visual attention is used to quickly focus on visual stimuli. They discussed five important issues related to visual attention : 1) the perceptual saliency of an object which is dependent on the environment surrounding it, 2) the saliency of the stimulus is separate in the brain from the actual visual features of the object, 3) An individual’s attention is directed towards the most salient stimulus, so the individual will continue to direct his or her attention to the most salient stimulus until it is “disabled,” or its saliency is decreased, and is no longer the most salient, 4) Attention is related to eye movements, so an individual must control his or her eye movements to control attention and 5) an individual’s recognition of objects and the scene control the focus of visual attention. When individuals recognize their visual scenes and familiar objects, they focus their attention on them. The issue of the perceptual saliency of the visual target is critical in their model of visual attention. They state that future research is needed for modeling the interaction

between the difficulty of a task and various theories and models of attention. It is difficult to model visual attention when attention and task difficulty are so inter-related.

Posner and Petersen (1990) proposed a different theory of visual attention. They state three main points about visual attention:

1. Attention is processed separately from information in the brain. The systems processing attention and information are separate in the brain.
2. Attention is processed in multiple areas of the brain.
3. The areas of the brain that process attention can be divided into three different functions: orientation to physical events in the environment, identifying the source of information, and staying alert to new stimuli.

Theories of visual attention have been considered by researchers investigating auditory attention, and the discussion of the latter follows.

### Auditory Attention

Auditory attention can be defined as the way in which an individual chooses where to focus his/her awareness based on pitch, loudness, timbre, and the physical location of the sound source. (Andrews & Dowling, 1991). It has also been defined as the “ability to focus on relevant acoustic signals, particularly speech or linguistic stimuli, and sustain that attention for an age-appropriate amount of time” (Florida Department of Education, 2001). In other words, auditory attention is an individual’s ability to focus on stimuli presented in the auditory modality. This can include speech and environmental sounds. Auditory attention is important for children in the classroom, as the teacher’s voice is an auditory signal that must be attended.

Auditory attention in children was studied by Passow et. al (2013). These researchers aimed to study the differences in auditory attention between younger and older children. Twenty-four children ages 7-8 and 24 children ages 11-12 participated. These children performed a series of listening tasks in which single syllables were presented to either their right ear, their left ear, or both ears. The perceptual saliency of these stimuli was varied, and children were instructed to listen to just one ear for some of the testing, and both ears for other portions of the testing. These researchers found that the older children did better than the younger children at these tasks. This improved performance in the older children is related to improvements in perceptual saliency, as well as improvements in attention.

Auditory attention can be measured clinically. The Auditory Continuous Performance Test (ACPT; Keith, 1994) is a continuous performance test that is used clinically. This test was developed as a “measure that provides information to help [the clinician] determine if an attention problem is one of the underlying factors contributing to a child’s learning problems” (Keith, 1994, pg. 1). The Auditory Continuous Performance Test (ACPT) offers one means of assessing selective and sustained auditory attention in children. This test involves listening to a word list for an extended period of time in quiet and responding to the target word *dog*. Children must maintain their attention for the duration of the task without any prompting or reminding from the tester. This test aims to separate children with ADHD from children without ADHD. Unfortunately, however, there is limited data on use of the ACPT in identifying children with ADHD. Riccio, Cohen, Hynd, & Keith (1996) administered the ACPT to a sample of 30 children ages 9-12, some with co-occurring ADHD and Central Auditory Processing Disorder (CAPD) and others with only CAPD. The ACPT results did not consistently differentiate children with CAPD only from children with CAPD and ADHD. It was found that if the ACPT

total error score was used to indicate ADHD in these children, only 56.67% of the children would have been appropriately diagnosed as having ADHD. Investigating use of the ACPT in children with only ADHD would be useful in establishing the diagnostic utility of this test.

McGee, Clark, & Symons (2000) examined performance on the ACPT and the Conners' Continuous Performance Test (CCPT) (Conners, 1995) in 100 children ages 6-11 with and without ADHD, as well as children with reading disorders. They found that scores on the ACPT and the CCPT were similar (a strong correlation between scores on the two tests) in 65% of participants. Children with reading disorders displayed the poorest scores on the CCPT, however, which could suggest that some children with reading disorders could be misdiagnosed with ADHD, as the ACPT and CCPT are meant to be measures of attention, and to be used with children that are suspected of having ADHD.

A modified presentation of the ACPT in background noise was used in a study examining the possible benefits of low-gain directional hearing aid use in normal hearing school-age children with ADHD (Kuk, Jackson, Keenan, & Lau, 2008). In this study, the children were fit with directional hearing aids, which were worn while performing the ACPT listening task in speech spectrum noise in the soundfield. No hearing aid benefit was found but their data indicated that the ACPT in noise is a more challenging listening task than the traditional ACPT (i.e., based on observed differences in error rates when comparing the data from Kuk et al. to normative data published by Keith, 1994). The inclusion of background noise may better represent real world listening. The listening in noise task reduces the perceptual saliency of the target word, which might better differentiate performance for normal and ADHD children (Russell et al., in submission) in contrast to tasks with high perceptual saliency that may not.

Russell, Culbertson, Faucette, O'Brien, & Givens (in review) studied the ACPT in background noise. These researchers presented the ACPT with speech spectrum noise to children with and without ADHD. The children were tested once with the use of an FM system which improved the signal-to-noise ratio (i.e., level of stimulus words to level of noise), and once without an FM system. Total errors were counted, and the groups were compared. When the FM system was not used, the ADHD group had significantly more errors than the non-ADHD group. With use of the FM system, however, the groups were not significantly different. The ADHD group also showed a significant reduction in total errors with FM system use, while children without ADHD showed no significant improvement. These findings suggest that continuous performance tasks with reduced perceptual saliency may better differentiate between children with and without ADHD.

Sustained attention tasks, such as the ACPT and CCPT, are examples of continuous performance tasks commonly used to evaluate attention. The nature of continuous performance tasks will be discussed in the following section.

### **CONTINUOUS PERFORMANCE TASKS (CPTs)**

One method for evaluating attention is the use of continuous performance tasks (CPTs). CPTs require the performance of a designated task over an extended period of time. Originally from the field of psychology, these tests are used to evaluate both children and adults, and are designed to assess both selective and sustained attention. First developed in 1956, the CPT task was originally used to evaluate children with brain damage (Beck, Bransome, Mirsky, Rosvold, Sarason, 1956). On the Conners Continuous Performance Test (Conners, 1995) and the Auditory Continuous Performance Test (Keith, 1994), respondents are asked to respond to a single target across a timespan of approximately 15 minutes.

On CPTs, two types of errors are recorded: inattention errors and impulsivity errors, which are also known as errors of omission and errors of commission. Inattention errors involve the child failing to respond to the target stimulus when it is present. Impulsivity errors occur when the child responds when the target stimulus is not present. Theoretically, one would expect children with ADHD to perform more poorly than same-age peers without ADHD on CPTs. ADHD diagnosis is not made solely on the basis of one test, such as the CPT, however, and other information important in ADHD diagnosis includes parent report, teacher report, and the child's school records (Root & Resnick, 2003).

Various versions of the CPT have been reported in the literature, and CPT test characteristics impact performance. While performance on CPTs reflects selective and sustained attention, performance is also influenced by the perceptual saliency of the target, cognitive load, motivation and inter-stimulus interval. Each of these factors will be defined and its impact on CPT performance will be further described.

The perceptual saliency of a target stimulus can impact performance on CPTs. Perceptual saliency refers to the clarity of the stimulus and the term *saliency* is defined as, “standing out conspicuously” (Merriam-Webster, 2013). Saliency can be reduced by distorting the stimulus itself or by adding distortion in the background. For example, it is easier to identify words if there is no background noise, while the addition of background noise makes identification more difficult. In a study by Russell, Culbertson, Faucette, O'Brien, & Givens (in submission), children with ADHD (ages 8-12) exhibited poorer performance on the Auditory Continuous Performance Test (ACPT) when perceptual saliency was reduced using background noise. These children performed the task with the use of frequency modulating (FM) systems and also without FM systems. The FM systems delivered the stimulus words directly to the

child's ear, improving the signal-to-noise ratio and increasing the perceptual saliency of the target word. The children's error scores significantly improved when the FM system was used as compared with the non-FM condition.

One way to increase the cognitive load on a CPT is to use a working memory task. Working memory has been defined as, "a set of linked and interacting information processing components that maintain information in a short-term store (or retrieve information into that store) for the purpose of the active manipulation of the stored items" (Becker & Morris, 1999, pg. 1). It has also been defined as, "a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning" (Baddeley, 1992, pg. 1). A task with no working memory load might require a child to respond only when she sees the letter "B," while a working memory load task would require the child to respond to the letter "B" only if it follows after the letter "H." The child must remember the previous letter to correctly respond to the target letter. On a CPT, the working memory load refers to the amount of memory required for target identification. Brown, Turner, Mano, Bolden, & Thomas (2013) found that as the working memory demands of a continuous recognition task are increased, performance worsened. These researchers studied nonsense words. They had participants repeat back the nonsense words, and increased the number of syllables in these words. They found that the addition of each syllable negatively impacted participants' working memory.

Another major factor that can impact performance on CPTs is motivation. Motivation relates to the level of engagement in the activity. Motivation can be defined as "to be moved to do something" (Ryan & Deci, 2001, pg. 1). Motivation can be either internal or external. Internal motivation, also called intrinsic motivation, is defined by Coon & Mitterer (2010, pg.

378) as, “when we act without any obvious external rewards. We simply enjoy an activity or see it as an opportunity to explore, learn, and actualize our potentials.” Tasks that are intrinsically motivating include activities that an individual considers fun, and enjoyable. For example, a child may be intrinsically motivated to participate in a baseball game because he or she enjoys playing baseball. The child does not expect any sort of external reward, and is simply participating because the actual activity of playing baseball is motivating to him or her.

Motivation can also be external. External motivation, also called extrinsic motivation, is defined by Cherry (2013) as, “behavior that is driven by external rewards such as money, fame, grades, and praise.” The task itself is not motivating, but obtaining a reward that the child expects in exchange for task completion is motivating. If the child knows that he or she will receive no reward or the same reward regardless of the number of correct responses during a task, there is low motivation to perform well. If the child is told, however, that he or she will receive an extra reward for every correct response, there can be a much higher level of motivation. Response bias has been defined as, “the tendency to favor one response over another, irrespective of the stimulus features” (Jones, Moore, Amitay, & Shub, 2013, pg. 971). If a child is highly motivated to respond to the stimulus, in order to receive rewards, they will have a bias towards responding, regardless of whether the response is correct. If rewards are used on experimental tasks, then penalties may also be needed to limit or prevent false positive responding.

Motivation can impact performance on tests of sustained attention. CPT tasks are deliberately long, and often require the child to attend to low interest stimuli (i.e., often resulting in comments of “boring”) without feedback or reinforcement. Aase, Meyer, & Sagvolden (2006) studied the effect of task reinforcement on children with and without ADHD. Testing was conducted with both infrequent and frequent rewards for correct responses. When the children

were offered frequent rewards (i.e., a cartoon appearing on the screen), there was no difference in performance between the ADHD group and the normal controls. The frequency of the reinforcement in both conditions was determined using a multiple variable interval, in which reinforcers were varied around the mean time. When the reinforcement schedule was less frequent, however, the children with ADHD had greater decrements in sustained attention, as well as more performance variability in their responses. In other words, during a task with increased motivation (frequent rewards), the children with ADHD performed as well as their normal peers, while during a task with less motivation (infrequent rewards), their performance was worse than their peers. This suggests that motivation is an important factor related to sustained attention in children with ADHD.

Another factor that can impact CPT performance is the inter-stimulus interval. The inter-stimulus interval is the amount of time between the end of one stimulus and the onset of the next stimulus. Silverstein, Weinstein, & Turnbull (2004) found increased errors with a shorter inter-stimulus interval and with more frequently occurring target stimuli on continuous performance tasks in a study of 107 adults. In this study, participants responded to the letter “K” appearing on a computer screen. The inter-stimulus interval was varied (long, medium, and short inter-stimulus intervals). When the inter-stimulus interval was shorter, the participants had more errors.

Prior to discussing the use of continuous performance tests in evaluating sustained attention in children, it should be briefly noted that brain imaging studies have also been used to evaluate attention in children with and without ADHD. Recently, several brain imaging studies on sustained attention in children with ADHD have been performed. Research involving functional magnetic resonance imaging (fMRI) has suggested that when compared to children

without ADHD children with ADHD may have neural differences related to sustained attention (Wang, Yang, Xing, Chen, Liu, & Luo, 2013). Brain abnormalities related to sustained attention have also been found in boys with ADHD ages 11-17 by Christakou et al. (2013). They found that the boys with ADHD had decreased activation in some brain areas, such as the dorsolateral prefrontal cortex, and increased activation in other areas, such as the precuneus, when compared to normal controls. Further discussion of imaging studies will not be offered, as they are not included in the current study. The subsequent discussion will address use of continuous performance tests in children.

#### Use of Continuous Performance Tasks in Children

Generally, CPT tests involve the child watching for or listening for a specific target, such as one particular letter or word, and responding only to that target for an extended period of time. These tasks measure selective attention, as the child must selectively attend for the target and ignore and not respond to non-target stimuli. In addition, continuous performance tasks allow the clinician to assess sustained attention, or vigilance, because the entire task is usually ten minutes or longer without attempts to re-focus or re-instruct the respondent. Some children may have very few response errors at the beginning of testing. As the test progresses, however, and the child's attention may falter, and he or she may have more errors. The clinician can compare the child's performance at the beginning of testing with his or her performance at the end and determine whether there is a vigilance decrement, or "decline in signal detection over time" (Grier et al., 2003, pg. 349). As children with ADHD can struggle with sustained attention as well as selective attention, it follows that children with ADHD may have a greater number of errors towards the end of testing than at the beginning. In contrast, another pattern may emerge

as some children with ADHD might have sporadic periods of inattention and/or impulsivity throughout the task rather than a vigilance decrement over time.

Continuous performance tasks offer a great deal of information. One can examine the number of inattention (omission) errors, impulsivity (commission) errors, target reaction/response times, and distribution of errors across the timespan of the task. This can provide important diagnostic information for clinicians, as different error patterns may suggest different ADHD subtypes.

Clinical research by Tucha et al. (2009) found no significant difference between children with and without ADHD on a sustained attention task. Their 15-minute task involved pushing a button in response to a visual target stimulus (i.e., with an average ISI of 1000 ms). The participants in the ADHD group had more inattention and impulsivity errors than the normal participants. However, performance in both the ADHD group and the control group decreased over time, and both groups had comparable vigilance decrements. This suggests no sustained attention deficit in the ADHD participants. However, the target stimulus, a change in the pattern on a square presented by a computer screen, was not distorted or masked and had high perceptual saliency, a factor that may be related to the lack of differentiation between subject groups on vigilance decrement. As suggested in Nigg (2006), however, it is also possible that the cause of these difficulties is actually dysfunction in the alerting function of the vigilance system in children with ADHD. These children may have difficulty preparing for stimuli to occur, and difficulty preparing to respond to these stimuli

Continuous performance tasks have been used as measures of improvement over the course of treatment for ADHD in children (Wang et al. 2011). In the Wang et al. study, a computerized continuous performance test was completed by the children before attention

treatment (i.e., drug treatment and whatever treatment their psychiatrist prescribed), after three months of treatment, and after six months of treatment. Along with parent reports, this test was able to detect improvements in the children's attentional abilities over time.

Klein, Wendling, Huettner, Ruder, & Peper (2006) found increased intra-subject (within-subject) variability in 62 children ages 7-14 with ADHD on continuous performance tasks when compared to normal participants. They examined intra-subject variability in the reaction times of individuals responding over the course of a task on which participants responded to letters on a screen. This suggests that attention in children with ADHD is more sporadic during the task as compared to people without ADHD.

Epstein et al. (2003) found increased error rates for both inattention and impulsivity errors for children with ADHD than for normal controls on the Conners' Continuous Performance Task. These authors also found greater intra-subject variability in reaction times among those with ADHD. They state that the variation in reaction times was the measure that had the best relationship with ADHD symptoms. Mairena et al. (2012) found similar results, with variability in reaction times for children 8-12 years of age being related to parent-reported symptoms of ADHD. In other words, children with the most variable reaction times had the greatest prevalence of ADHD symptoms, as reported by parents.

#### Conners' Continuous Performance Task

One common continuous performance test is the Conners' Continuous Performance Test (CCPT) (Conners, 1995). This computer-based test requires the individual to respond to any letter that appears on a computer screen except the letter X. Both error types, inattention and impulsivity, are recorded during this test. Additionally, the individual's reaction time to targets is recorded on the CCPT. Reaction time measures allow the clinician even more information

about the individual's attention to further aid in analysis, as reaction times are related to ADHD symptoms, as stated earlier. Although not used in scoring, reaction time can still be examined by the clinician, as variability in RTs appears to be related to ADHD symptoms.

Different reaction times have been observed within groups of children with ADHD ages 7-13 years (Sjowall, Roth, Lindqvist, & Thorell, 2013). Some children with ADHD react quickly to stimuli, while others react slowly. These authors also found differences in executive functioning in children with ADHD compared to normal participants. Executive functioning was measured through tasks testing the children's memory, inhibition, and shifting. Working memory was tested through use of three memory games, one verbal, one in which children repeated digits, and one on the computer. Inhibition was measured through use of two tasks: one Go-No Go task, and one in which children labeled shapes. Finally, shifting was measured through a task in which children looked at shapes and labeled them using local or global features. Children with ADHD also had different levels on measures of emotional functioning, as measured by parent report, when compared to their non-ADHD peers. Emotional functioning related to the child's ability to handle emotion and his or her emotional responses. ADHD children had differences compared to non-ADHD children in three emotional functioning measures, "anger regulation, anger recognition, and regulation of happiness/exuberance."

As the CCPT is a measure of attention, one might expect children with ADHD to show significantly poorer performance on this measure and other continuous performance tasks. However, some research has found that children with ADHD and children without ADHD perform similarly on the CCPT. McGee, Clark, & Symons (2000) tested children with ADHD, children with reading disorders, children with both ADHD and reading disorders, and normal controls using the CCPT. They found that the children with ADHD did not have significantly

different scores on the CCPT than their normal peers. Interestingly, children with reading disorders did have significantly poorer scores than the normal controls. This suggests that the CCPT may not be a valid assessment of attentional difficulties in children with ADHD. As observed previously, easy CPTs such as the traditional CCPT may not challenge ADHD children whereas more difficult CPTs (e.g., those with reduced perceptual saliency) may challenge ADHD children and differentiate their performance from those of children without ADHD (Russell et al., in submission).

Soreni, Crosbie, Ickowicz, & Schachar (2009) used the Conners' Continuous Performance Task to examine the performance of 12 children with ADHD in three separate sessions, each separated by a week. Scores on the CCPT did not significantly vary across the three week time span. Thus, this study supported the short-term test-retest reliability of scores on the CCPT.

Variability in performance over longer periods of time in normal children on the CCPT-II, however, has been reported. Zabel, von Thomsen, Cole, Martin, & Mahone (2009) found that when normal children (ages 6-18) were tested with the CCPT-II and then tested again several months later, there was often a significant degree of variability between the two scores based on the 90% confidence intervals provided by the test manual. This finding suggests that this test may have limited long-term reliability. These researchers also suggest that if there is variation in the scores of children without ADHD, there may be even more concerns when testing children who do have ADHD using this test.

Soreni, Crosbie, Ickowicz, and Schachar (2009) found, however, that the CCPT can accurately and reliably measure inhibition control as indexed through use of impulsivity/commission errors over time. They examined CCPT performance in 12 children

ages 9-15 with ADHD. These children were tested three times, with seven days separating each session. While impulsivity errors were reliable over time, inattention/omission errors were not. That is unfortunate as omission errors are considered important in the diagnosis of ADHD, as they are reflective of inattention symptoms.

Before a discussion on ADHD is possible, it is important to understand what exactly ADHD is, as well as common symptoms and diagnosis methods.

## **ATTENTION DEFICIT/HYPERACTIVITY DISORDER (ADHD)**

### **Definition and Prevalence**

A precursor to the study of auditory attention in children with Attention Deficit/Hyperactivity Disorder (ADHD) is defining the disorder itself. An important source for defining disorders, the *Diagnostic and Statistical Manual of Mental Disorders*, or DSM, is the tool most frequently used by most mental health professionals (APA, 2011). This guide, written by the American Psychiatric Association, contains information that can be used by physicians and psychologists to diagnose mental disorders in children and adults. The DSM defines Attention Deficit Hyperactivity Disorder (ADHD) as a condition that makes focusing on everyday tasks difficult (APA, 2011).

More recently, Warikoo & Faraone (2013, pg. 1885) defined ADHD as “an early onset, clinically heterogeneous, complex neurobiological disorder, defined by persistent symptoms of inattention and hyperactivity/impulsivity that cause impairment in two or more settings according to DSM-IV-TR.” The Mayo Clinic has defined ADHD as, “a chronic condition that affects millions of children and often persists into adulthood. ADHD includes a combination of problems, such as difficulty sustaining attention, hyperactivity and impulsive behavior” (Mayo

Clinic, 2013, pg. 1885). Inattention is defined by Jones, Moore, Amitay, & Shub (2013, pg. 971) as “the complement of sustained attention. It expresses the fact that in a proportion of trials listeners appear to respond independently of the sensory information, possibly reflecting a lapse in concentration”. On a research task, inattention occurs on the trials during which a subject appears to respond independently of the sensory information, possibly reflecting a lapse in concentration. Impulsivity can be defined as, “an inability to inhibit responding” (Prior & Sanson, 1986, pg. 310). Hyperactivity is defined as “the state or condition of being excessively or pathologically active” (Merriam-Webster, 2013). Ross & Ross (1976, pg. 11-12) add that hyperactivity is a behavior that puts an individual, “into conflict with their environment.” ADHD is diagnosed based on the presence of inattention symptoms and/or hyperactive-impulsive symptoms with an onset before seven years of age and duration of at least six months (APA, 2011). While ADHD can occur in children and adults, the current review addresses only ADHD in children.

ADHD is a condition that impacts many children and their families. The estimated worldwide prevalence of ADHD in children is 5.29% (Polanczyk & Rohde, 2007). For the United States, the overall prevalence is estimated at 9.5% in children ages 4-17, which is 5.4 million children (Centers for Disease Control and Prevention, 2010). In children, ADHD can have a negative impact on many everyday activities requiring attention, including focusing on learning activities at school. The diagnosis of ADHD includes a designation of ADHD subtype or presentation.

### Theories of ADHD

A number of theories of ADHD have been presented. These theories attempt to explain the causes of ADHD. They also attempt to explain ADHD symptoms in children, and provide

insight on their ADHD-related behaviors. Johnson, Wiersma, & Kuntsi (2009) reviewed various ADHD theories and discussed their strengths and limitations. Many theories of ADHD can explain certain aspects of the disorder, but do not address all issues.

The first theory discussed by Johnson, Wiersma and Kuntsi (2009) is the Executive Dysfunction Theory (Barkley, 1997). This theory proposes a neural cause for ADHD. Essentially, it proposes that differences in the brains of children with ADHD cause a decreased level of executive control. Executive functions are, “neurocognitive processes that maintain an appropriate problem-solving set to attain a later goal” (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005, pg. 1336). These functions can include planning, working memory, and response inhibition. A deficit in executive control results in the behaviors characteristic of children with ADHD such as impulsivity. Willcutt, Doyle, Nigg, Faraone, & Pennington (2005) list four criteria that would need to be met if ADHD were caused by executive dysfunction alone:

1. Measures of executive functioning deficits would need to be the same across studies of ADHD. Other factors, such as cognitive abilities and age, would need to be controlled for.
2. Problems with executive functioning would have to be one of the causes for variation in the severity of ADHD symptoms in different individuals.
3. Most people with ADHD would need to display executive functioning difficulties.
4. Executive functioning problems must have the same cause as ADHD symptoms. The authors suggest that, because ADHD can be passed through families, executive functioning problems must also pass through families (pg. 1336).

These authors believe that executive functioning problems are one of the causes of ADHD symptoms, and cite research showing executive functioning weaknesses in individuals with ADHD. They do not believe, however, that executive dysfunction is the only reason for ADHD symptoms. They believe that executive dysfunction is just one of many factors causing ADHD symptoms. According to Johnson, Wiersma and Kuntsi (2009) this theory does not explain the hyperactivity symptoms of ADHD. They state that executive dysfunction can be the cause for response inhibition, explaining impulsivity symptoms. Response inhibition is defined by Richardson (2008, pg. 1) as, “a range of mechanisms that allow the suppression of previously activated cognitions and inappropriate actions and resistance to interference from irrelevant stimuli [Bjorklund & Harnishfegar, 1995]. Essentially, inhibitory control is the ability to suppress the processing or expression of information that would disrupt the efficient completion of the goal at hand [Dempster, 1992].” Response inhibition, however, is not characteristic of every child with ADHD. Additionally, this theory does not address motivation or state effects observed in children with ADHD.

The second theory reviewed by Johnson, Wiersma, and Kuntsi (2009) is the State Regulation Model (van der Meere & Sergeant, 1988). This theory proposes that ADHD symptoms are caused by the state of the child. Barkley (1997) argues that the state of the child can be directly related to whether a child responds, and to what the response is. He argues that once a child is in a certain state, such as boredom, s/he can try to modify his/her state into one that is more positive, impacting behavior. According to this theory, children with ADHD have a decreased energy and activation level than their peers. They have decreased effort, even if this is not intentional, explaining their difficulty with tasks. In other words, children with ADHD have an overall decrease in their effort, which results in them maintaining a less activated state than

non-ADHD children. According to these theorists, the event rate, or the frequency with which new events occur, can impact children with ADHD. Children with ADHD may need a higher event rate to maintain their arousal and effort. If effort is not maintained, the children have a decrease in their motivation, which leads to poor performance. Children will put more effort into tasks that they are motivated to do. If the child is not motivated to complete a task, such as schoolwork, s/he will have poorer performance than if motivation were higher. Therefore, variation in symptoms can be explained by examining the actual tasks. When children with ADHD are presented tasks that maintain their effort, such as those with a fast presentation rate, they will perform better than in tasks that are not as novel. Novelty-seeking is associated with impulsive behaviors (Wood, Rijdsdijk, Asherson, & Kuntsi, 2011).

The third theory discussed by Johnson, Wiersma, and Kuntsi (2009) is the Delay Aversion and Dual Pathway Theories discussed by (Sonuga-Barke, Taylor, Sembi, & Smith; 1992). The Delay Aversion Theory relates to the motivation of the child with ADHD. Delay aversion can be defined as the, “motivation to escape or avoid delay” (Antrop et al., 2006, pg. 1152). If the child is impatient and does not want to wait for a reward, s/he will act in a way to decrease the time to wait for a reward (Johnson, Wiersema, & Kuntsi, 2009). Thus, it is proposed that children will pass up a larger reward given to them in the future in favor of a smaller reward given to them sooner. However, children with ADHD are more likely to wait for the larger reward and not choose the immediate small reward if they have additional stimulation beyond the requirements of the task. Antrop et al. (2006) conducted a study in which children with ADHD and children without ADHD completed a computer task. During this task, they could choose to immediately earn one point, or wait for a delay and earn two points. They found that the children with ADHD chose the immediate, but lesser, reward more often than children

without ADHD. During some trials the computer screen was blank, but during other trials the screen displayed cartoons. The purpose of the cartoon was to provide the children with some stimulation while they waited for the next target. While the task was the same with and without the cartoon, the children had something to do to “pass the time” while they waited for the target. When the children with ADHD had additional stimulation (cartoons) they were more likely to wait for the larger reward.

The Dual Pathway Theory (Sonuga-Barke, 2002) is similar, proposing that in addition to delay aversion, these children also experience deficits in their inhibition, paralleling those described in the Executive Dysfunction theory proposed by Barkley. When given tasks requiring participants to stop an event that is already occurring, such as a visual signal, individuals with ADHD are less likely to stop the event, and also take longer to inhibit the event. In other words, individuals with ADHD have greater difficulty with stopping something that has already started. If a visual target is presented, for example, and the task is to inhibit that target, individuals with ADHD will not perform as well as individuals without ADHD. The key to the dual pathway theory is that Sonuga-Barke and colleagues posit that these are separate pathways to ADHD, and children may present with similar symptoms but have arrived there via different etiological pathways. In fact, Sonuga-Barke recently proposed yet another etiological pathway that implicates deficits in temporal processing (Sonuga-Barke, Bitsakou, & Thompson, 2010).

The final theory discussed by Johnson, Wiersma, and Kuntsi (2009) is the Dynamic Developmental Theory (Sagvolden, Johansen, Aase, & Russell, 2005). These researchers argue that there are two main components to ADHD symptoms: changes in reinforcement for behavior, and difficulty with changing behavior that has been reinforced in the past. This could be caused by insufficient dopamine in the brain. All children can understand that their actions have

consequences. For children with ADHD, however, the window of time during which behavior and its consequence can be perceived by the child as related may be shorter than the time window for normal children. These children may have difficulty understanding, therefore, what the consequence of their behavior will be. These children have greater difficulty understanding the cause and effect relationship between a behavior and its consequence. This theory also explains impulsivity. Children with ADHD may act impulsively because their time window is smaller than that of normal children, giving rise to shorter, impulsive behavior. This may relate to deficits in sustained attention as well, as sustained attention tasks by their very nature typically require longer time between rewards.

Many theories of ADHD have been presented. Although many researchers agree on what symptoms are present in individuals with ADHD, the cause of these symptoms is still debated. It is possible that multiple factors contribute to the behaviors characteristic of children with ADHD.

#### ADHD Subtypes/Presentation Specifiers

ADHD presentation is varied with different symptom clusters experienced by different children. Based on symptom presentation using the DSM-IV-TR, children were classified as having *Predominately Inattentive Type*, *Predominantly Hyperactive Type*, or *Combined Type*. The subtypes refer to the main symptoms experienced by the child and, at the time, were considered relatively stable presentations. Within subtypes, the severity of the symptoms can also vary between children. It should be noted that the DSM-5, released in 2013, altered the conception of subtypes (APA, 2013). Instead of using the term “subtype,” this version uses the term “presentation specifier.” The subtypes have been replaced with ADHD Predominately Inattentive Presentation, ADHD Predominately Hyperactive/Impulsive Presentation, and ADHD

Combined Presentation. This is the result of a growing body of evidence that ADHD subtypes are not, in fact, stable over time, but are better conceptualized as clinical descriptions of a child's current presentation of symptoms (Lahey et al., 2005). The way in which a child's ADHD manifests itself can even change within individual children over time, resulting in a change in presentation specifier at different ages.

Children with predominately inattentive presentation, experience symptoms such as daydreaming during the school day and they may often seem distractible (National Institute of Mental Health, 2012). They have difficulty focusing on schoolwork, and may not be able to concentrate in school. They experience difficulty with completing schoolwork on time, and can sometimes lose things such as homework, toys, and other objects. They become easily bored and distracted, and do not understand information as quickly as other children (NIMH, 2012).

Children with hyperactive/impulsive presentation experience an above-average level of hyperactivity in their daily lives. These children have difficulty sitting still, and may move around throughout the day. They may wiggle and move around even when they are not engaged in a physically active activity. This may occur at a time when movement is discouraged, such as during school. This subtype is also characterized by frequent talking and movement, and these children may not filter what they say. They may struggle with and avoid tasks that take a long time, and may interrupt others (NIMH, 2012).

Lastly, children with the combined presentation experience symptoms of both inattention and hyperactivity/impulsivity. This subtype of ADHD is the most common (Rohde et al., 1999). These children exhibit hyperactivity and difficulties attending during school and at home. The diagnosis of ADHD combined presentation requires observation of symptoms from both the inattention category and the hyperactivity/impulsivity category.

### ADHD Diagnosis

ADHD can be evaluated in a number of ways. Evaluation and diagnosis is overseen by a physician, clinical psychologist, or clinical social worker. The American Academy of Pediatrics (2011) released diagnostic and treatment guidelines for ADHD. According to those guidelines, clinicians first should evaluate any child between the ages of 4-18 years who has issues with behavior problems and/or trouble at school that occurs along with inattention, hyperactivity, or both (American Academy of Pediatrics, 2011). Secondly, clinicians are advised to take into account observational information from the child's parents and teachers, and relate that observational data back to the DSM diagnostic criteria for ADHD. Thirdly, clinicians must determine that the child's symptoms are not caused by another disorder. Some disorders may present similarly to ADHD. Therefore, the clinician must rule out other conditions related to the child's symptoms, such as bipolar disorder, depression, clinical anxiety, and autism. In addition, many disorders can co-exist with ADHD, and special care is advised in order to make sure that all conditions are diagnosed. Fourthly, clinicians must recognize that ADHD is a chronic condition. The guidelines also offer recommendations for treatment of ADHD, which will be discussed in a later section (American Academy of Pediatrics, 2011).

### ADHD Testing

There is no single assessment tool used in ADHD diagnosis. An assessment battery approach combining traditional testing with parent and teacher reports is the most commonly used method of ADHD diagnosis (Demaray, Schaefer, & Delong, 2003). This test battery provides the clinician with a comprehensive view of the child's symptoms, allowing the clinician to differentiate ADHD from other possible disorders. Important components of the overall

assessment include parent report, teacher report, and the child's school records (Root & Resnick, 2003). Often, parents are asked to use a rating scale to indicate the extent to which observed behaviors occur, as well as the severity of such behaviors. The key to proper diagnosis is not only documenting the presence of symptoms, but also documenting early onset (before age 14), severity and chronicity, and negative impact on daily functioning (i.e., functional impairment) (American Psychiatric Association, 2013).

### ADHD Rating Scales

Rating scales are often used in the evaluation of ADHD. The Foundation for Medical Practice Education (2008) has developed a scale called the ADHD Rating Scale. This scale is filled out by the child's parent and/or teacher. The scale contains items on inattention as well as on hyperactivity and impulsivity. The parent or teacher is asked to rate the child's behavior over the past six months, and rates symptoms from the DSM criteria, such as "Fails to give close attention to details or makes careless mistakes in schoolwork/homework." The parents or teacher can respond "always or very often," "often," "somewhat," or "rarely or never." Similarly, the Vanderbilt ADHD Diagnostic Teacher Rating Scale and Vanderbilt ADHD Diagnostic Parent Rating Scale rely on a teacher or parent report of the child's symptoms (Wolraich, 1998; Wolraich et al., 1998). In these assessments, teachers and parents rate the child's behaviors using the symptoms listed in the DSM, such as "Has difficulty sustaining attention to tasks or activities." They can rate specific behaviors as occurring "never," "occasionally," "often," or "very often." The Attention Deficit Disorders Evaluation Scale-3rd Ed. (ADDES-3) has two versions, the home version and the school version (McCarney & Arthaud, 2004). The ADDES-3 contains a behavior checklist containing items such as "Rushes through assignments with little or no regard for accuracy or quality of work," and also allows

parents and teachers to document specific concerns. The SNAP-IV Teacher and Parent Rating Scale (Swanson, 1992) is another tool in ADHD diagnosis. It contains statements about the child's behavior, with the teacher or parents rating each item (Swanson, 1992). Teachers or parents read statements related to ADHD behaviors, such as "Often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities," and then can respond with "not at all," "just a little," "quite a bit," or "very much" (Swanson, 1992). Generally, as has been discussed, the reports on the child's behaviors come from the child's teacher or parents and not from the child himself/herself.

### ADHD Management

Although there is no cure currently available for ADHD, symptoms can be managed in a number of different ways (Mayo Foundation for Medical Education and Research, 2013). Behavioral and medical treatments can be used to aid in attention in children with ADHD. These can include treatments such as counseling, medication, and behavioral strategies. Oftentimes, treatment types are combined, with children taking medication while also participating in therapy.

Counseling for ADHD can include behavior therapy, psychotherapy, and social skills training for children, as well as family therapy and parenting skills training for parents (Mayo Foundation for Medical Education and Research, 2013). Behavior therapy, the most common ADHD therapy, focuses on modifying the child's behavior. This type of therapy has been found to be effective in improving the child's behavior (Klein & Abikoff, 1997). Counseling focuses on teaching the child more appropriate behavior, and can combine rewards for positive behavior and punishments for negative behavior. This treatment is often used in children with mild

ADHD symptoms, as opposed to medication use (AACAP, 2007), but has little empirical support regarding its effectiveness in reducing ADHD symptoms.

Medications are also used to treat ADHD (AACAP, 2007). Stimulant medications, including Methylphenidate and Amphetamine preparations have been found to be very effective in treating children with ADHD. LeFever, Hannon, Dawson, Morrow & Morrow (1997) studied the prevalence of medication use to treat ADHD in children in grades 2-5. They found that ADHD medication use during the school day was 17% for Caucasian boys, 9% for African American boys, 7% for Caucasian girls, and 3% for African American girls.

Although ADHD medications often have side effects, these side effects can often be treated and medication use can be continued (Cortese et al., 2013). Side effects for ADHD medications can include loss of appetite, difficulty sleeping, mood problems such as irritability, weight loss, anxiety, headaches, nausea, and gastrointestinal problems (Collingwood, 2010). Loss of appetite can lead to long term growth problems, as well, such as decreased height (e.g., Swanson et al., 2007), although other researchers have not found medication use to negatively impact growth (e.g., Biederman et al., 2010).

Medications can be taken in a number of ways. Immediate-release medications are taken two or three times per day, as their effects can wear off over a few hours. Extended release medications, however, are generally administered once a day, as their effects are more lasting. Hodgkins, Shaw, Coghill, & Hechtman (2012) analyzed a number of studies comparing the efficacy of treatment of ADHD with amphetamines and Methylphenidate. They found that while some studies found one medication type to be more effective than the other, neither type has been shown, overall, to be the most effective for the treatment of ADHD. They emphasize that different patients can have different reactions to the different stimulant types.

Van der Oord, Prins, Oosterlaan, & Emmelkamp (2008) discuss the effectiveness of drug treatment for ADHD in their review article. They found that both use of methylphenidate and behavioral treatment approaches reduced ADHD symptoms overall. When methylphenidate was used, however, counseling did not further reduce ADHD symptoms such as behavior and performance in school and in social situations.

Atomoxetine has also been found to be effective in the treatment of children with ADHD. This drug is a norepinephrine (noradrenaline) reuptake inhibitor, as opposed to previously discussed drugs, which are stimulants. In children ages 6-16 with ADHD, Atomoxetine was found to reduce ADHD symptoms better than a placebo (Michelson et al., 2002). The children who took Atomoxetine showed improvements on a number of ADHD measures. On the ADHD Rating Scale-IV, their scores for both symptoms of inattention and hyperactivity/impulsivity were improved. On the Conners' Teacher Rating Scale and the Conners' Parent Rating Scale, results for children who took Atomoxetine showed significantly greater improvement over those taking a placebo.

## **RATIONALE FOR THE STUDY**

### **Processing Efficiency**

*Processing efficiency* may be a critical determinant of performance on perceptual tasks, such as CPTs. According to Hartley, Hill and Moore (2003), *processing efficiency* is defined as “all factors, aside from temporal resolution, that may affect detection on a task, such as attention, cognition, and motivational factors” (p. 140). In order to process information, one must attend to the information being presented. One must also have the cognitive resources required for processing the information. Additionally, one must be motivated to process the information; if an individual is not interested in a stimulus and does not believe that the stimulus is necessary,

they may not process it. Currently, however, there is not enough research to indicate the extent to which one or all three of these factors actually contributes to processing efficiency (Hill, Hartley, Glasberg, Moore, and Moore; 2004).

When backwards masking is compared in children of different ages, results differ for younger compared to older children. Hartley, Wright, Hogan, & Moore (2000) studied simultaneous and backwards masking in children ages 6-10, as well as in adults. During frequency resolution tasks involving responding to a tone presented in simultaneous noise, children and adults performed similarly. During backwards masking tasks, however, even the ten-year-old children performed worse than adults, with the 6-year-old children having thresholds that were 34 dB higher than adults. Hartley et al. found that as children mature and increase in age, their backwards masking thresholds improve. This also suggests that the true cause of lowered thresholds is processing efficiency, not decreased temporal resolution, as temporal resolution thresholds, or the ability to detect a tone in background noise in the simultaneous condition, is the same for children and adults.

Data from studies of backward masking have been used to support the theory that children have poorer processing efficiency. Hill & Moore (2002) studied the effects of backwards masking in children ages 9-10 and adults on tonal thresholds. The silent interval between the stimulus tone and the subsequent time-delayed masker was varied. The tonal threshold for children on this backward masking listening task was consistently higher than that of adults. Using this masking technique, the temporal window can be analyzed by examining the impact of changes in the length of delay between the stimulus tone and the masker. That temporal window can be defined as the time period during which different stimuli are perceived

as the same (Powers, Hillock, & Wallace, 2009). The temporal window can be mathematically modeled; and when these researchers modeled the temporal window both the results from the children and the results from adults fit similar temporal windows. Because of this, it is unlikely that temporal resolution led to poorer performance in the children. Lowered processing efficiency was proposed as the more likely explanation.

Stuart (2008) proposed that processing efficiency explained the results in his study of speech reception thresholds in 80 children ages 6-15 and adults. The sentences were presented in quiet and in two different types of background noise. During the background noise conditions, the noise was presented continuously on some tasks, and in an interrupted condition in other trials. He then compared thresholds in the interrupted and continuous noise conditions to find the “release from masking”. He found that children needed a better signal to noise ratio than adults for speech recognition thresholds. Temporal resolution did not explain his findings for thresholds in interrupted noise compared to continuous noise, however. The children experienced the same amount of release from masking as the adult group. This suggests that processing efficiency, rather than temporal resolution, was the reason for the elevated SNRs needed for threshold in children.

The issue of noise is important when considering processing efficiency on auditory tasks. There are two main sources of noise that can interfere with processing: external noise and internal noise. External noise is simply the noise that occurs in the environment, separate from the individual. In the aforementioned studies, the noises used were external noises. In a classroom, external noise could include people talking, papers rustling, and chairs moving. Internal noise can be defined as noise that is perceived by the individual, coming from an

internal source (Jones, Moore, Amitay, & Shub, 2013). It has also been defined by Buss, Hall, & Grose (2006, pg. 2) as, “variability in the neural representation of intensity.” There can also be variability in the neural representation of a signal. This noise is internal to the individual, and therefore differs between individuals. Internal noise can include various sources including the heartbeat and the spontaneous firing of neurons. It is also possible that internal noise can include factors such as attention.

Hurlbert (2000) discussed internal and external noise and how they might impact perceptual learning. She argued that if external noise is increased, it should be more difficult to elicit a response. This is because even when there is no external stimulus present, neurons will spontaneously fire (internal noise). But when external noise is present the neurons must increase their activation above that internal noise. They must increase their activity to simply override the background of external noise. According to Hurlbert (2000), internal noise levels cannot be reduced despite improvements in neurons. Perceptual learning does not decrease the noise internal to the person, but does allow them to perform better. She argued that perceptual learning is more related to signal detection than to internal noise. She discussed a study by Gold, Bennett, & Sekuler (1999) in which study participants looked at pictures of faces that varied in their perceptual saliency. Some of the faces were difficult to distinguish because they were presented in a high noise condition, i.e., they were blurred. Initially, participants struggled with distinguishing the faces. As the participants practiced the task, however, their ability to identify the faces improved. This suggests that the individuals improved in their ability to detect the stimulus, in this case a face, despite the external noise (i.e., blurring). The conclusion offered was that internal noise did not change but that participants learned how to identify the stimulus within the external noise.

It is possible that the amount of internal noise is different for children and adults. Buss, Hall, & Grose (2006) studied the concept of internal noise in eight children ages 5-10. A masker was used during a tone detection task. Once again, performance on these tasks can be related to internal and external noise. If external noise is the main reason for struggling on the task, when the frequency of the masker is fluctuated around the center frequency of the tone, performance should improve. If internal noise is the more important factor in performance, however, no change in performance would be expected with the changing masker. When the noise masker was fluctuated in frequency, the children's performance did not change, while the adults' performance did. This offers evidence to the theory that children have greater internal noise than adults. Buss, Hall, & Grose (2006) also performed a similar experiment involving 15 children ages 5-10 and adults. During this experiment they found similar results, suggesting increased internal noise in children.

In summary, several studies have supported the theory that children perform more poorly on challenging auditory tasks due to more limited processing efficiency. It has been proposed that the processing efficiency of children is impacted by the attention, motivation, and/or cognitive resources they bring to the designated task. The extent to which these factors impacts task performance requires further study.

The theory of processing efficiency suggests that one might predict task performance based on three factors: attention, motivation, and cognition. In the current proposed study, there will be two groups of children, those with diagnosed ADHD and those with no suspected or known ADHD and one group of young adults with no suspected or known ADHD. The factors of task motivation (using varied feedback conditions) and cognitive demand (using varied

perceptual saliency conditions) will be studied using analogous auditory and visual sustained attention tasks. The schematic (Figure 1.1) below illustrates the four sustained attention tasks, and the four different blocked conditions within each task.

Varied Perceptual Saliency Auditory Task

Game Number	Signal-To-Noise Ratio
1	No noise
2	+5
3	0
4	-5

Varied Perceptual Saliency Visual Task

Game Number	Contrast
1	No contrast reduction
2	Level 1 (slight contrast reduction)
3	Level 2 (moderate contrast reduction)
4	Level 3 (most contrast reduction)

Varied Feedback Auditory Task

Signal-to-noise ratio: -5 for all games

Game Number	Feedback
1	None (no points)
2	Immediate-points after every word
3	Short delay- points at the end of this game
4	Long delay- points at the end of all games

Varied Feedback Visual Task

Contrast Reduction: Level 3 (most contrast reduction)

Game Number	Feedback
1	None (no points)
2	Immediate- points after every picture
3	Short delay- points at the end of this game
4	Long delay- points at the end of all games

**Figure 1.1: Schematic of each task**

As Russell, Culbertson, Faucette, O'Brien, & Givens (in submission) have proposed, it may be that these challenging tasks produce findings that differentiate the performance of children with and without ADHD. The hope is that the development of these tasks might lead to a clinical measure of attention that consistently distinguishes children with ADHD from children without ADHD.

### **RESEARCH QUESTIONS**

In the current study, the following research questions will be addressed:

1. Within each of the 3 subject groups, is performance on challenging auditory and visual sustained attention tasks different when feedback is varied (i.e., none, long delay, short delay, and immediate)?
2. Within each of the 3 subject groups, is performance on auditory and visual sustained attention tasks different when the perceptual saliency of the stimuli is varied (i.e., no noise/contrast reduction, limited noise/contrast reduction, moderate noise/contrast reduction, high noise/contrast reduction)?
3. Are there performance differences across the 3 groups on auditory and visual sustained attention tasks when feedback is varied?
4. Are there performance differences across the 3 groups on auditory and visual sustained attention tasks when the perceptual saliency of the stimuli is varied?
5. Are there performance differences across modalities on the analogous tasks (i.e., auditory and visual tasks with varied feedback conditions; auditory and visual tasks with varied perceptual saliency conditions)?

6. Are there changes in performance over time (vigilance) on auditory and visual tasks within each of the four conditions within the task; from the beginning to the end of the entire task?

The specific performance measures on the tasks include: 1) inattention errors, 2) impulsivity errors, 3) total errors, 4) reaction times to targets, and 5) vigilance decrement (block 1 total error rate – block 4 total error rate).

## **Chapter 2: Research Methods**

### **PARTICIPANTS**

The number of required participants in each of the groups (children with ADHD; children without ADHD, and young adults without ADHD) was determined using a power analysis. This power analysis was based on previous research results from a study of continuous performance tasks in children with and without ADHD (Russell, Culbertson, Faucette, O'Brien, and Givens; in review). The data collected from that study was used to determine the number of participants that would be required to achieve significance at the .05 level. The number was determined to be 8-13 participants in each of the two groups of children, i.e., 8-13 children with ADHD and 8-13 children without ADHD. Based on the power analysis, the researcher chose a targeted study enrollment of 13 participants per group.

Twenty-six children ages 8 to 13 participated in this study. There were a total of 13 children with a diagnosis of ADHD as confirmed by parent report of diagnosis by a physician, psychologist, or counselor, and 13 children with no diagnosed or suspected ADHD. In addition, there was a group of 13 young normal adults, ages 18-30 years, with no suspected or diagnosed ADHD.

Participants were recruited through a variety of methods, including university email, fliers posted around the community and in the offices of psychologists, psychiatrists, and pediatricians, and through recruitment visits to community centers and physicians' offices. When scheduling, parents were advised that children with ADHD taking medications should not take their prescribed medication on the day of testing. Research sessions were conducted in a sound-treated room in the East Carolina Speech-Language and Hearing Clinic in the Communication Sciences and Disorders department.

This study was approved by the Institutional Review Board (IRB) at East Carolina University. For young adult participants, written IRB consent was completed prior to study participation. All parents of minor children provided written consent prior to their children participating in this study. All children provided written assent prior to participating, as well. The investigator emphasized to participants and parents that participation was optional. All participants were compensated for study completion with a \$20 Target gift card.

Several inclusionary criteria were determined based on case history questions. This case history information was recorded on a case history form for all participants, which can be seen in Appendix A. ADHD diagnosis or attention problems were ruled out for an adult participant by asking if s/he had ever received a diagnosis of ADHD from a physician, social worker or psychologist or experienced attention problems. A child was classified as ADHD if his/her parent/guardian stated that his/her child had a diagnosis of ADHD from a physician, social worker, or psychologist. A child was classified as non-ADHD if the parent/guardian confirmed that his/her child had no ADHD diagnosis and no suspected attention problems. All participants had no history of cognitive or speech delays or disorders, or auditory processing disorder as confirmed through parent/guardian report or self-report by adult participants. No participants had reportedly repeated a grade in school. The participants also had English as their first language by parent or self-report. There was verbal confirmation from the parents/guardians that children with ADHD receiving medication had not taken their medication on the day of the research session. Children with ADHD that had taken their medication, however, were still permitted to participate, but it was documented that they had taken their medication that day. Nine of the ADHD children had prescribed ADHD medications and of those five refrained from

taking these medications on the day of the study session as directed and four had taken their medications on the day of the study session.

After completing the case history questions, all participants completed hearing evaluation inclusionary measures including otoscopy, tympanometry, and air conduction thresholds. Otoscopy was performed using a hand-held Welch-Allen otoscope with a disposable speculum. This was used to rule out ear drainage, impacted cerumen, or structural abnormalities of the ear canals and tympanic membranes in both ears, as specified in the ASHA Guidelines for Audiologic Screening (1997). Tympanometry was also performed on all participants using a diagnostic tympanometer (GSI Tymptstar). In order to qualify for the study, the children were required to have normal tympanograms as specified by Hanks and Rose (1993) with static acoustic admittance values within 0.3-1.5 mmho, ear canal volumes within 0.6-1.5 cm<sup>3</sup>, and tympanometric width less than or equal to 200 daPa. Young adults were required to have normal tympanograms as specified by Margolis & Heller (1987), with static acoustic admittance values within 0.27-1.38 mmho, ear canal volumes within 0.63-1.46 cm<sup>3</sup>, and tympanometric widths between 51-114 daPa.

All participants completed a visual screening using the criteria from the American Association for Pediatric Ophthalmology and Strabismus (AAPOS, 2014). The vision screening was performed using corrected vision for participants who wore glasses. The participants were asked to stand 10 feet away from a Snellen Visual Acuity chart situated at eye level. They were asked to read the row of letters from the chart corresponding to 20/30 vision. All participants had visual acuity of at least 20/32 in both eyes. All participants with corrected vision wore their glasses on the day of testing; they wore their glasses during both the vision screening and during the actual testing.

Hearing loss was also ruled out. Air conduction thresholds were measured at octave frequencies from 250 – 8000 Hz in a sound treated booth using Etymotic ER-3A insert earphones connected to a diagnostic audiometer (GSI-61). All participants met the criteria for thresholds of 20 dB HL or better in both ears at all frequencies tested.

The Auditory Figure Ground SCAN test was performed on all participants (i.e., SCAN 3C for children and SCAN 3A for adults). This test involves listening to a list of recorded words. Background noise in the form of multi-talker babble was present during the words at a signal to noise ratio of +8. Participants were instructed to repeat back the recorded words and ignore the background noise. They were also encouraged to guess at any words that they had trouble understanding. The number of words correctly repeated was recorded for each ear separately, as well as a total number of correct words repeated. None of the participants' scores met the criteria for an Auditory Figure Ground deficit.

### **EXPERIMENTAL STIMULI**

Sustained attention was assessed in both the visual and auditory modalities through the use of analogous tasks developed specifically for this study. In each modality, there were two tasks, one in which the noise/distortion level was varied (to examine the impact of perceptual saliency) and one in which the feedback was varied (to examine the impact of motivation). All tasks were developed using Super Lab 5 (Cedrus, 2013).

Each of the four experimental tasks involved the presentation of 576 stimuli that included a randomized presentation of the target word/picture *dog* and 20 non-target words from the Peabody Picture Vocabulary Test, Fourth Edition (Dunn & Dunn, 2007) or the Preschool Language Scale, Fourth Edition (Zimmerman, Steiner, & Pond, 2002). The 20 non-target words were selected because they were within the expected vocabulary of a 4-7 year old child, were all

monosyllabic words, did not rhyme with dog, and could be easily depicted in pictures for the visual tasks. The target word was always *dog*, and the following 20 non-target foil words were used: fish, car, cat, shoe, bird, tree, grapes, mail, key, plant, game, barn, ring, nest, pear, coin, ship, map, house, and hat.

### **VISUAL IMAGES**

All of the visual images used were obtained from the image database [www.morguefile.com](http://www.morguefile.com), which offers free images that are not copyrighted. The images were selected because they were clear representations of the 21 associated words. The images were all equal in size.

Each picture was downloaded from the website and saved as its own individual jpg file onto a Dell laptop computer. Each jpg file was then opened in Microsoft Office 2010. This program was used for all edits to the images. For each of the 21 pictures, the image was saved in black and white to create an initial set of non-distorted images. This was accomplished through use of the Color settings bar in Microsoft Office 2010. The saturation setting was changed to -100 for all the images. This resulted in a black and white image without distortion of any kind. These images were then designated as the full contrast images.

Three sets of images with decreased contrast were then developed, creating three different levels of reduced contrast. Level 1 images were created by setting the contrast and brightness to -25, level 2 images were created by setting the contrast and brightness to -40, and level 3 images were created by setting the contrast and brightness to -50. These adjustments in brightness and contrast resulted in images with different contrast levels intended to make identification more difficult. The level 1 images had slightly reduced contrast, level 2 images

had moderately reduced contrast, and level 3 images had significantly reduced contrast. These three levels of reduced contrast were subjectively labeled by two members of the research team.

The pictures used in the familiarization block (described below) were also created using the 21 full contrast black and white pictures. Black Calibri 200 point font was used on Microsoft Paint to type the names of the pictures on the images. That way, the participants could see the images and read the names of the images that would be used during testing.

All images were presented through the SuperLab software. This software stretched the images so that they fit the entire screen. As all images were the same size, the level of stretching was also the same for all images. These images were presented to the participant during the visual portion of testing.

### **AUDITORY STIMULI**

For the auditory tasks, the words listed above were recorded by a female native English speaker, judged as having clear and articulate speech by the primary investigator. All recordings were completed in an audiometric sound booth with noise levels in the booth at or below the noise levels recommended by ANSI for audiological evaluation of hearing (as measured with a sound level meter) (ANSI S3.1--1999). A Behringer C-2 small-diaphragm matched pair cardioid (directional) condenser microphone was connected to the same Dell laptop computer used for all testing. The computer contained the Pratt software, and all recordings were conducted using this software. This recording set up was used for recordings, and all recordings were completed in the same recording session. The female speaker was seated in the center of the test booth with the microphone secured on a microphone stand at the level of her mouth and

at a distance 40 cm away from her mouth, and aimed directly toward her mouth. This distance was confirmed with a centimeter ruler.

The speaker was instructed to read each of the 21 words on the list with a natural style and with equal volume. The recording was conducted using the Pratt software program with a 16-bit resolution and a 44.1-kHz sampling rate. This program offered the speaker visual feedback on productions in order to prevent peak clipping and assist with the production of words approximately equal in volume. The average intensity levels for the words were approximately 70 dB SPL throughout the recording session, as indicated by the Pratt software display. The entire word list was read five times to establish a set of recorded words from which a best exemplar (i.e., well-articulated and appropriate volume) for each word could be selected.

The best recording of each word was selected for use in the study. The root square mean amplitude was calculated for the chosen word recordings in Matlab. Within Matlab, each of these recordings was then rescaled by equalizing the squared RMS value so that all words had the same intensity level. Those word files were used for the quiet (i.e., no noise) test condition.

In order to develop the word files with the words and noise at different signal-to-noise ratios, noise was added using Matlab. First, the average long-term spectrum level of the words was calculated. This was used as the reference level for determining the appropriate background noise levels to achieve the desired signal-to-noise ratios. A speech-shaped noise was added to the recorded words at various SNRs. The noise was added before the word onset, during the word, and after the word termination so that the entire recording totaled one second. The recorded words ranged in duration from X to & ms. The noise segments before and after the word segment corresponded to 1000 ms minus the word duration divided by two. For example, if a word was 460 ms then each of the noise segments was  $540/2$  or 270 ms. The noise segments

(before and after the word) were equal in duration. A cosine ramp was applied to the onset and offset of the noise to prevent audible clicks. The level of the word was adjusted based on the desired SNR relative to the part of the noise that overlapped with the word. Finally, the recorded words in noise were then normalized to the peak amplitude across all words. The following signal-to-noise ratios were established: no speech spectrum noise, SNR +5, SNR 0 and SNR -5. Each of the 21 words was saved in all four of these conditions.

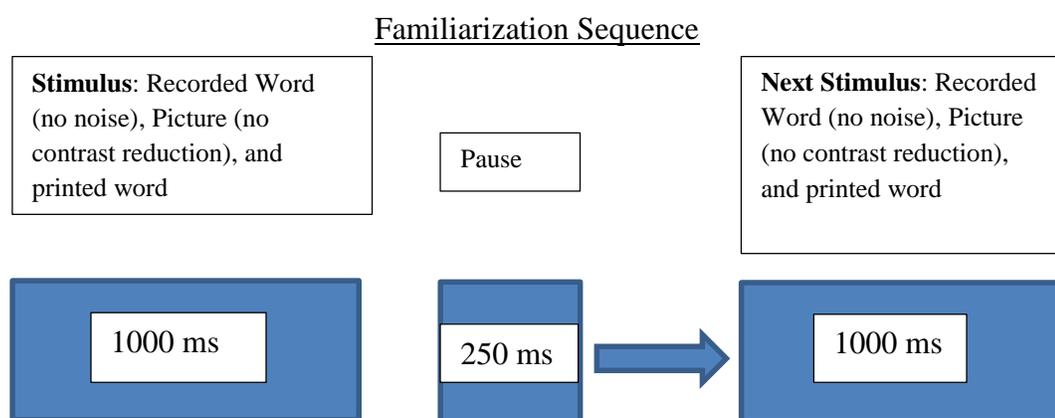
The Pratt software was used to generate a calibration pure tone for the word presentations during testing. The averaged peak amplitude of the words was established in Pratt and found to be 0.4994 Pa (87.95 dB SPL). A calibration tone was generated using the averaged peak amplitude level of the words according to ANSIS3.6-2004 (revision of ANSI S3.6-1996). A 1000 Hz pure tone was generated at this amplitude using the Pratt software and was recorded in a .wav file, to be used as a calibration tone. The 1000 Hz calibration tone was 30 seconds in duration. This tone was used to set the words at a calibrated level during test sessions.

### **EXPERIMENTAL STIMULUS FAMILIARIZATION AND TASK PRACTICE**

Prior to beginning the experimental tasks, the participants completed a stimulus familiarization block and a practice block. During familiarization and practice, participants were seated in a sound-isolated test booth directly facing a computer monitor at eye level. Task instructions were offered, as indicated below, and then insert earphones were inserted into both ears. During the familiarization and practice sessions, the researcher stood inside the booth with the participant.

The familiarization block was the first block that participants completed. During this block, each of the 21 stimulus word recordings in quiet was presented simultaneously with the full contrast visual image of that word along with the typed word on the picture (e.g., the word

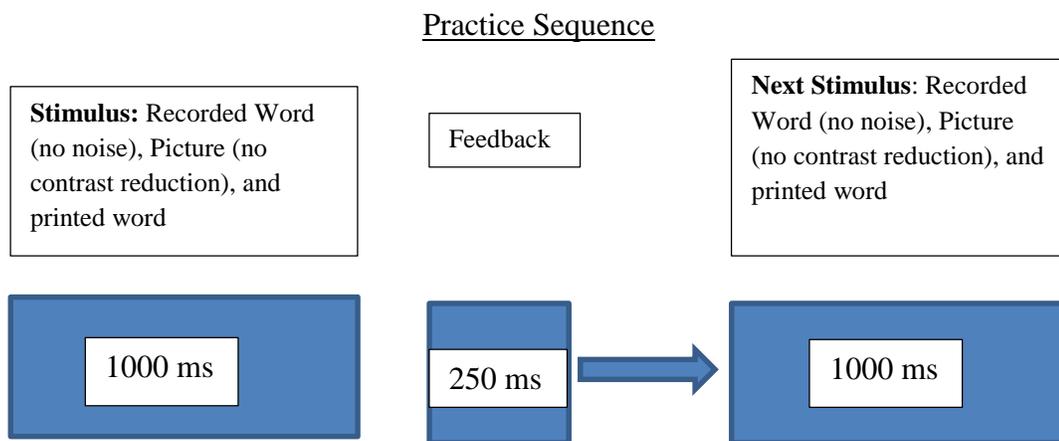
“cat” with the picture and written label of “cat”). These familiarization stimuli were each presented for one second, with a 250 ms pause in between each stimulus presentation. Participants were asked to attend to the stimuli but were not asked to respond to the stimuli during this section, as the purpose of this section was to simply familiarize them with the pictures and words. The 21 stimuli were presented once in alphabetical order. A schematic of the familiarization sequence is presented below in Figure 2.1.



**Figure 2.1: Familiarization Stimuli Sequence**

A practice session was used to familiarize the participants with the task they would be performing during testing, thus preventing a task learning effect. During this block, the participants were shown the familiarization stimuli once again in random order. The non-target words were presented one time, while dog was presented six times, in a ratio equivalent to the target/non-target ratio used during testing. During the practice block, however, the participants were instructed to press the space bar for *dog* and to do nothing when they saw/heard the other stimuli. All other keys on the keyboard were de-activated during the practice and test blocks. During the practice block, the participant would see/hear the stimulus for one second during which s/he might respond (i.e., space bar press or no press). Following that presentation, a

feedback notification was displayed for 250 ms, i.e., a green +1 was shown for a correct response and a red -1 was shown for an incorrect response. After the participant finished the practice block, a screen was displayed with black letters and the question, “Ready?” If the participant felt that he/she needed more practice before beginning the actual experimental tasks, he/she was able to repeat the practice session. Four participants asked to repeat the practice sequence. The practice sequence is illustrated in the schematic below (Figure 2.2).



**Figure 2.2: Practice Stimuli Sequence**

### EXPERIMENTAL ATTENTION TASKS

The schematic in Figure C below presents the format of the two auditory tasks and the two visual tasks with the conditions in a randomly ordered sequence as they might occur during a research session. Randomization of both tasks and conditions was done through use of a random number generator. Each task was assigned a number (1, 2, 3, and 4) and these numbers were placed in random order by a computerized random order generator. Following randomization of tasks, each condition within each task was also assigned a number (1, 2, 3, 4). These numbers were also randomized by a random order generator. In total, each participant’s test session

involved five randomizations: one randomization for the order of tasks, and one randomization for the order of conditions within each of the four tasks. Individual stimuli (i.e. words or pictures) were randomized by the SuperLab Pro software.

In the auditory modality there were two tasks, one varying in signal-to-noise ratio across blocks and one varying in feedback across blocks. In the visual modality there were two similar tasks, one varying in image contrast and one varying in feedback across blocks.

Auditory Varied Perceptual Saliency Task

Condition/Game Blocks	Signal-To-Noise Ratio
1	No noise
2	-5
3	0
4	+5

Visual Varied Perceptual Saliency Task

Condition/Game Blocks	Distortion Level
1	Full contrast
2	Level 2 (moderately reduced contrast)
3	Level 1 (slightly reduced contrast)
4	Level 3 (significantly reduced contrast)

Auditory Varied Feedback Task

Signal-to-noise ratio: -5 for all games

Condition/Game Blocks	Feedback
1	None (no points)
2	Short delay- points at the end of this game
3	Immediate-points after every word
4	Long delay- points at the end of all games

Visual Varied Feedback Task

Distortion: Level 3 (Significantly reduced contrast)

Condition/Game Blocks	Feedback
1	None (no points)
2	Short delay- points at the end of this game
3	Immediate-points after every word
4	Long delay- points at the end of all games

**Figure 2.3: Task Formats**

Each participant completed a series of four sustained attention tasks during which he or she heard a recorded word (auditory attention) or saw a picture of the word (visual attention). Two of the experimental tasks required a response to an auditory target, the spoken word *dog*.

On one auditory attention task, there were four randomly ordered blocks with different speech spectrum noise conditions in each block (i.e., no noise, +5 SNR, 0 SNR and -5 SNR). These different conditions were used to vary the perceptual saliency of the auditory stimuli. On the other auditory attention task, a single challenging SNR (-5 SNR) was used with four different feedback conditions in four randomly ordered blocks (no feedback, immediate trial-by-trial feedback, feedback at end of a block of 144 trials [576 total trials per task, divided by four blocks], and task end feedback). These different feedback conditions were intended to produce different levels of participant motivation.

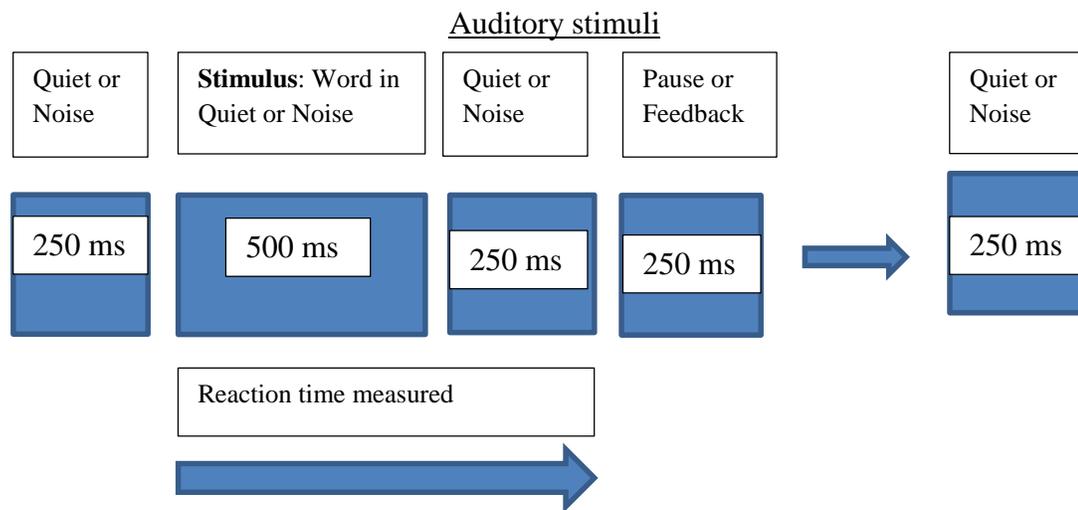
There were also two tasks that required responding to a visual target, a picture of a dog. On one of the visual tasks, there were four levels of contrast reduction (i.e., none, level 1, level 2, and level 3) each within one of four randomly ordered test blocks. These different contrast conditions were intended to vary the perceptual saliency of the visual images. On the other visual task, there was one level of challenging contrast reduction (i.e., level 3) and four levels of feedback (no feedback, immediate trial-by-trial feedback, feedback at end of a block of 576 trials, and task end feedback,) in four randomly ordered test blocks. Once again, the various feedback conditions were intended to produce different levels of participant motivation.

As stated above, each of the four sustained attention tasks (auditory feedback varied, visual feedback varied, auditory noise condition varied, visual contrast condition varied) included four test block conditions (i.e., levels of noise/contrast and levels of feedback). Each of the attention tasks contained 120 targets and 456 non-targets, with each block condition containing 30 targets and 114 non-targets. The total number of errors, inattention errors, impulsivity errors, and reaction time (time between stimulus presentation and the participant's space bar press) was recorded for all test blocks.

Prior to beginning the experimental tasks, the instructions were reviewed with each participant. (These instructions are offered in Appendix D). Participants were offered breaks in between the four sustained attention tasks, but not during an individual task. The tester did not provide the participants with any social reinforcement (i.e., no smiling, nodding, or talking during the testing).

### **STIMULUS PRESENTATIONS**

A grey screen was displayed throughout the auditory tasks. Following presentation of each word, either a grey screen or a grey screen with feedback indicators (depending on the condition) was displayed for 250 ms, to provide a pause between each stimulus presentation. In the immediate feedback condition, a feedback screen was displayed after each word was presented. This screen was grey with either a green +1 if the participant's response was correct, or a red -1 if the participant's response was incorrect. This screen took the place of the all grey screen used for the other feedback conditions. Reaction time to the button press was recorded from the stimulus onset to the end of the 1000 ms stimulus presentation segment. The stimulus presentation format for the auditory stimuli (i.e., assuming a 500 ms word duration) is displayed in the schematic below (Figure 2.4).

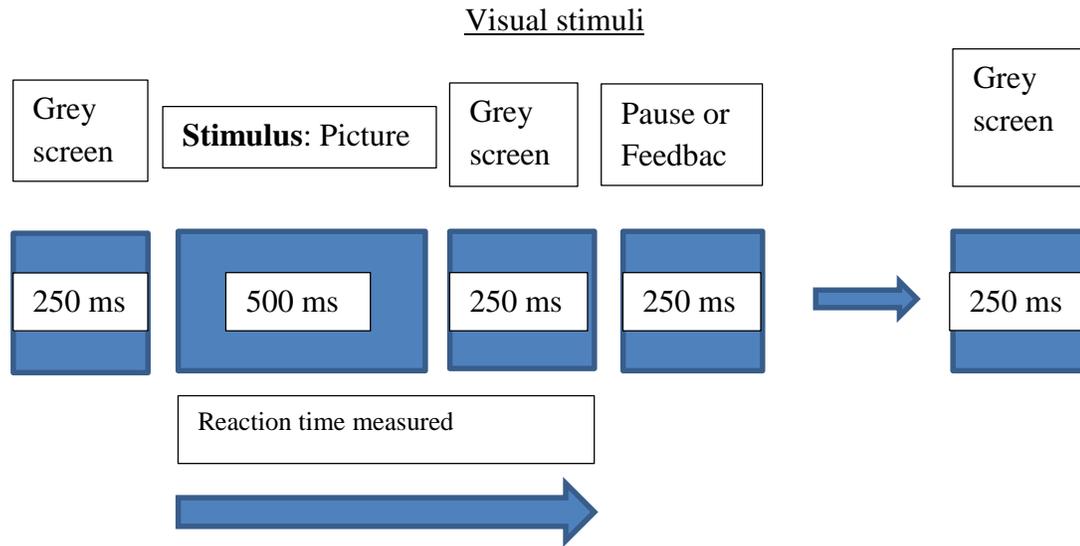


**Figure 2.4: Auditory Stimuli**

In the immediate feedback and short delay conditions, after all stimulus presentations were completed, a points screen was displayed for two seconds. This screen displayed the number of correct responses the participant had in that section. For example, if the participant made 130 correct responses, the number 130 would be displayed in black letters for two seconds before continuing to the next condition. Participants were instructed at the beginning of the session that they would be exchanging their points for a gift card at the end of all testing, and the more points they earned the more the gift card would be worth. This was used to vary participant motivation.

During all visual tasks, a gray screen was initially presented for 250 milliseconds prior to the visual image display. This was meant to mimic the onset of the background noise prior to the word in the auditory task. In other words, this screen was to alert the participant that a picture would soon be displayed. The picture was then displayed for 500 ms. Reaction time was measured from the onset of this picture to the end of the 1000 ms stimulus presentation segment. A gray screen was then displayed for 250 milliseconds after the picture. Following that, either a

gray screen or a feedback screen was displayed, just as in the auditory task. The pause/feedback screen was displayed for 250 milliseconds. This stimulus presentation is illustrated in the schematic below (Figure 2.5).



**Figure 2.5: Visual Stimuli**

At the end of each of the experimental tasks a screen was displayed saying, “Take a break.” During this time, participants took a break lasting as long as they wanted. After all four tasks were completed, a screen saying, “You have finished all games” appeared.

### **DATA FROM EXPERIMENTAL TASKS**

For both the auditory and the visual tasks, Super Lab Pro recorded the commission/impulsivity errors (response to non-target stimuli) and omission/inattention errors (failure to respond to target stimuli) as well as the reaction time, or time between the target stimulus and the response.

## **Chapter 3: Results**

The following sections will present demographics of the three participant groups (children with ADHD; children without ADHD; normal young adults) and will then present statistical results related to the research questions. For simplicity sake, the two groups with children will be labeled “ADHD Group” and “Non-ADHD Group” and the group with normal young adults will be labeled as the “Adult Group”.

All statistical analyses were performed using SPSS 20. All data sets for the Non-ADHD and adult groups include data from all 13 participants (i.e., no missing data). The results from the ADHD Group, however, only include data from the 9 participants that did not take their medication on the day of testing (i.e., with the exception of the analyses related to Research Question 3).

The means and standard deviations for performance measures were calculated and are presented in tables. A repeated measures Analysis of Variance (ANOVA) was performed on all data sets, and significance was determined using the  $p = 0.05$  level. Statistical testing used Greenhouse-Geisser test results for all  $p$  and  $F$  values. Post hoc testing was conducted using the Fisher’s Least Significant Difference (LSD).

### **DEMOGRAPHICS**

Each group (ADHD, Non-ADHD, and Adult) included 13 participants. Within the ADHD Group, 4 participants were designated as having a presentation of primarily inattentive, 2 as primarily hyperactive, and 7 as mixed. With respect to medication use in the ADHD Group, 9 were not on ADHD medications on the research session date (i.e., 4 not prescribed medications and 5 off of medications) while 4 were on medications. The data from the 9 participants off of medications on the day of testing were used in statistical analysis.

The demographic information on age, gender, race, and socioeconomic status of participants is presented in the tables below.

Ages

Group	Age Range in Years	Average Age
ADHD	8-13	9.8
Non-ADHD	8-13	9.9
Adults	19-30	25.4

**Table 3.1: Participant age distribution by group**

Gender

Group	Gender
ADHD	5 male 4 female
Non-ADHD	4 male 9 female
Adults	3 male 10 female

**Table 3.2: Participant gender distribution**

Race

Group	Race
ADHD	1 Black/African-American 8 White
Non-ADHD	1 Black/African-American 12 White
Adults	13 White

**Table 3.3: Participant racial distribution**

Participant demographics related to race and socio-economic status (SES) are similar for all three groups. A Pearson chi-square analysis was used to compare gender ( $p = 0.27$ ) and race ( $p = 0.50$ ) between the groups and age was compared using a one-way analysis of variance (ANOVA). Age distributions of the two groups of children are essentially the same, as confirmed by a chi square with one degree of freedom (1.35 chi square value). Overall, the majority of participants had parents with a college or graduate level education (education levels

ranged from some high school to graduate degree), and came from similar socio-economic backgrounds.

It should be noted, however, that gender may be a factor in analysis. Although the gender distributions of the three groups are not statistically different, there were more male participants than female participants in the ADHD Group; whereas there were more females than males in the Non-ADHD Group and the Adult Group. The reason this is of concern is that if this gender distribution had been observed in a larger sample it would have been significant.

### **DATA RELATED TO QUESTIONS 1 and 3**

Research questions 1 and 3 addressed whether performance on challenging auditory (-5 SNR) and visual (Level 3 reduced contrast) sustained attention tasks differed when feedback was varied (i.e., none, long delay, short delay, and immediate) within and between the participant groups. The data related to these questions is presented for impulsivity errors, inattention errors, total errors and reaction times to target.

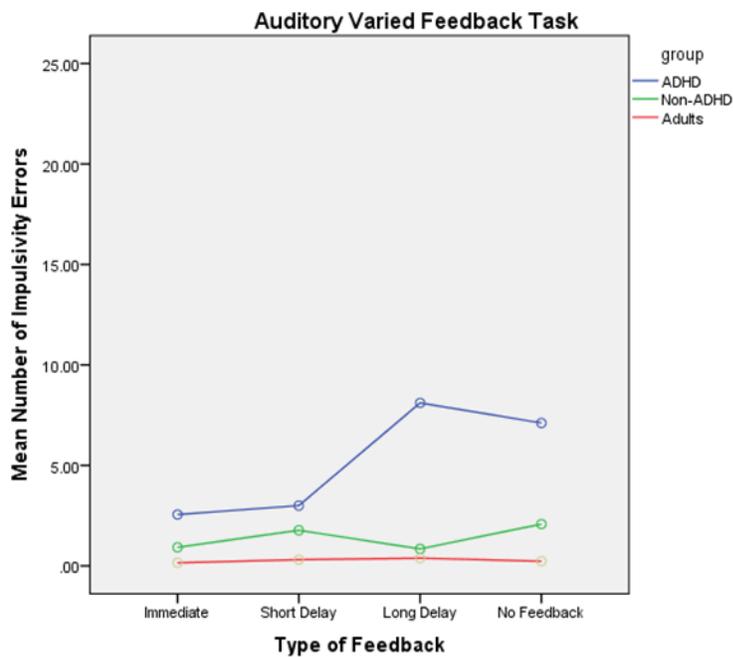
#### Impulsivity Errors

The group means for impulsivity errors for the most difficult auditory condition (-5 SNR) across feedback conditions are displayed in Table 3.4 below, along with standard deviations. These means and standard deviations are also displayed in Figure 3.1 below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory immediate feedback	2.5556	4.00347
	auditory short delay	3.0000	3.67423
	auditory long delay	8.1111	17.68081
	auditory no feedback	7.1111	9.18483
Non-ADHD	auditory immediate feedback	.9231	1.18754
	auditory short delay	1.7692	2.20431
	auditory long delay	.8462	.89872
	auditory no feedback	2.0769	4.29072
Adults	auditory immediate feedback	.1538	.37553
	auditory short delay	.3077	.63043
	auditory long delay	.3846	.86972
	auditory no feedback	.2308	.43853

**Table 3.4: Impulsivity errors on the challenging auditory task with varied feedback**



**Figure (3.1): Impulsivity errors on the challenging auditory task with varied feedback**

A repeated measures ANOVA was performed and no significant differences were found for impulsivity errors between the four feedback conditions within groups (ADHD Group  $F = 0.77$ ,  $p = 0.52$ , Non-ADHD Group  $F = 1.31$ ,  $p = 0.28$ , Adult Group  $F = 0.48$ ,  $p = 0.62$ ) for the most challenging auditory condition (-5 SNR).

Significant differences were found between the three participant groups for impulsivity errors on the challenging auditory task when comparing the different feedback conditions ( $F = 16.90$ ,  $p < 0.01$ ). The LSD test was used to analyze specific differences. In the immediate feedback condition, significant differences were found between the ADHD Group and the Adult Group ( $p = 0.01$ ) but not between the ADHD Group and Non-ADHD Group ( $p = 0.09$ ) nor between the Non-ADHD Group and the Adult Group ( $p = 0.36$ ). In the short delay condition there were also significant differences between the ADHD Group and the Adult Group ( $p = 0.01$ ) but not the ADHD and Non-ADHD Groups ( $p = 0.09$ ) nor between the Non-ADHD Group and the Adult Group ( $p = 0.11$ ). In the long delay condition, no significant differences between groups were observed for the ADHD and Non-ADHD Groups ( $p = 0.07$ ) and Non-ADHD and Adult Group ( $p = 0.89$ ). Significant differences were found between the ADHD Group and the Adult Group ( $p = 0.05$ ). In the no feedback condition, the ADHD Group and Adult Group had significantly different numbers of impulsivity errors ( $p < 0.01$ ) as did the ADHD and Non-ADHD Groups ( $p = 0.04$ ). The Non-ADHD Group and Adult Group ( $p = 0.38$ ) did not have significant differences for the no feedback condition.

Impulsivity errors on the visual low contrast task (Level 3) with varied feedback were also determined and are displayed in Table 3.5 and Figure 3.2 below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual immediate feedback	.8889	.60093
	visual short delay	1.4444	2.24227
	visual long delay	5.3333	11.66190
	visual no feedback	6.0000	16.51514
Non-ADHD	visual immediate feedback	1.4615	3.52646
	visual short delay	5.6154	18.75961
	visual long delay	.2308	.59914
	visual no feedback	2.9231	7.91056
Adults	visual immediate feedback	.0769	.27735
	visual short delay	.2308	.59914
	visual long delay	.0769	.27735
	visual no feedback	.3077	.63043

Table 3.5: Impulsivity errors on the challenging visual task with varied feedback

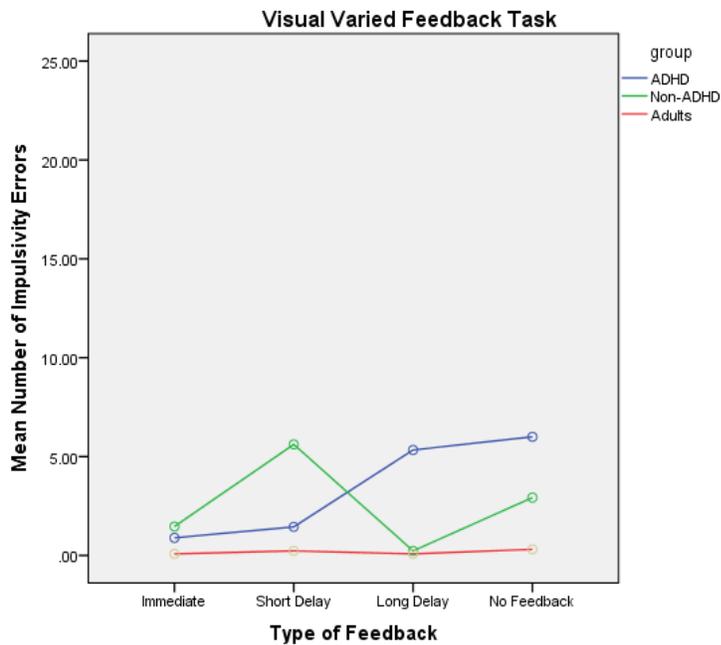


Figure 3.2: Impulsivity errors on the challenging visual task with varied feedback

A repeated measures ANOVA was used to analyze impulsivity errors across the varied feedback conditions for the lowest contrast visual task (Level 3 reduced contrast). Within groups, the type of feedback did not produce significant differences in the number of impulsivity errors (ADHD  $F = 1.00$ ,  $p = 0.34$ ; Non-ADHD  $F = 1.09$ ,  $p = 0.32$ ; Adult Group  $F = 0.81$ ,  $p = 0.44$ ).

Between groups, there were significant differences in the lowest contrast visual task for the ADHD children and adults ( $p = 0.05$ ) across the varied feedback conditions. Post-hoc LSD analysis revealed that the significant differences were in the visual long delay condition ( $p = 0.05$ ). Although not statistically significant, when comparing the ADHD Group and the Non-ADHD Group, a p-value of 0.053 was found.

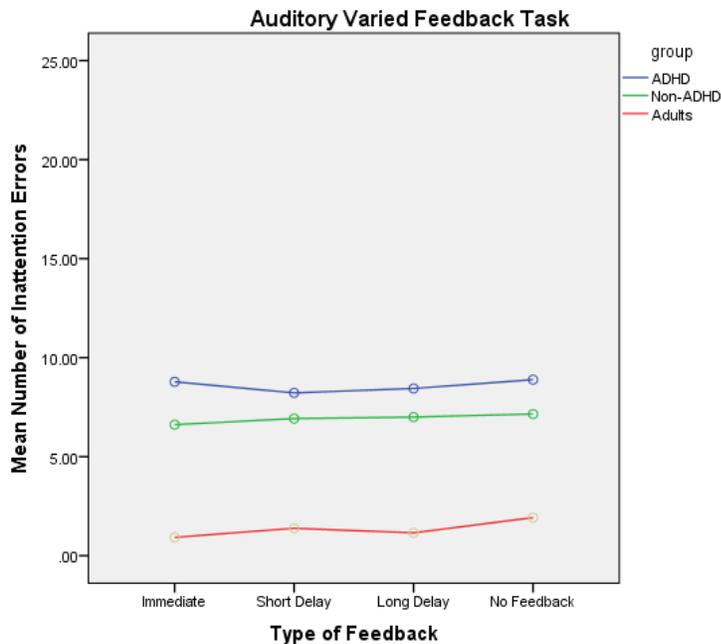
#### Inattention Errors

Means and standard deviations for inattention errors for the most challenging auditory attention task (-5 SNR) under different feedback conditions can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory immediate feedback	8.7778	7.10243
	auditory short delay	8.2222	5.28625
	auditory long delay	8.4444	4.55826
	auditory no feedback	8.8889	6.73507
Non-ADHD	auditory immediate feedback	6.6154	5.59074
	auditory short delay	6.9231	5.12285
	auditory long delay	7.0000	5.08265
	auditory no feedback	7.1538	3.62506
Adults	auditory immediate feedback	.9231	1.18754
	auditory short delay	1.3846	2.50128
	auditory long delay	1.1538	3.31276
	auditory no feedback	1.9231	2.21591

**Table 3.6: Inattention errors on the challenging auditory task with varied feedback**



**Figure 3.3: Inattention errors on the challenging auditory task with varied feedback**

No significant differences in inattention errors were found within groups when comparing the performance on the challenging auditory task under the various feedback conditions (ADHD Group  $F = 0.08$ ,  $p = 0.97$ ; Non-ADHD Group  $F = 0.08$ ,  $p = 0.94$ ; Adult Group  $F = 1.16$ ,  $p = 0.33$ ).

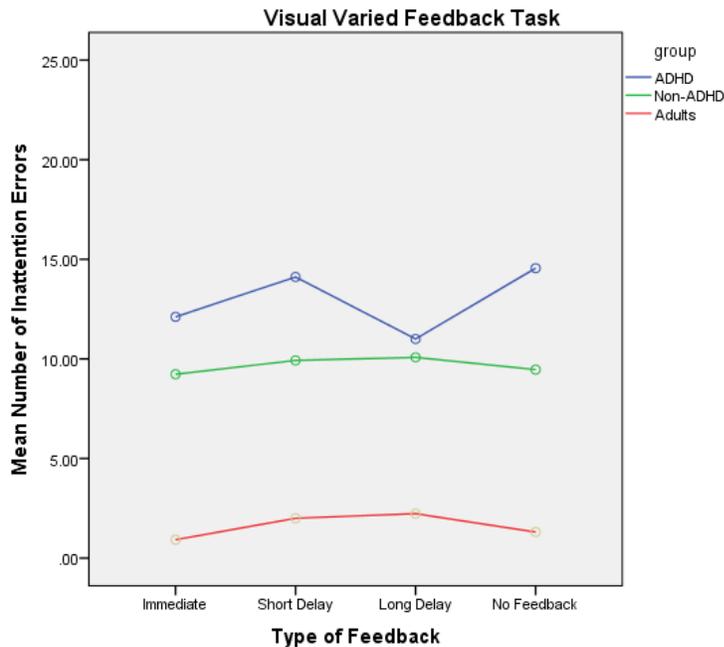
Between groups, significant differences in inattention errors for different feedback conditions were found ( $F = 10.55$ ,  $p < 0.01$ ). Differences between the children (ADHD Group and Non-ADHD Group) and adults were found, with  $p$  values of 0.01 or less in all feedback conditions. No significant differences between the ADHD Group and the Non-ADHD Group were found, however (i.e., immediate feedback  $p = 0.33$ , short delay  $p = 0.50$ , long delay  $p = 0.45$ , no feedback  $p = 0.35$ ).

Inattention errors on the challenging visual task under various feedback conditions and results can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual immediate feedback	12.1111	5.10990
	visual short delay	14.1111	8.68108
	visual long delay	11.0000	7.51665
	visual no feedback	14.5556	6.67291
Non-ADHD	visual immediate feedback	9.2308	4.81584
	visual short delay	9.9231	5.29877
	visual long delay	10.0769	4.95751
	visual no feedback	9.4615	4.87537
Adults	visual immediate feedback	.9231	1.44115
	visual short delay	2.0000	3.05505
	visual long delay	2.2308	3.37031
	visual no feedback	1.3077	1.54837

**Table 3.7: Inattention errors on the challenging visual task with varied feedback**



**Figure 3.4: Inattention errors on the challenging visual task with varied feedback**

Significant differences were not found within groups for inattention errors on the challenging visual task across feedback conditions (ADHD  $F = 1.84$ ,  $p = 0.17$ ; Non-ADHD  $F = 0.21$ ,  $p = 0.83$ ; Adult Group  $F = 1.93$ ,  $p = 0.18$ ).

Significant differences were found between groups when comparing the children (ADHD Group and Non-ADHD Group) and the Adult Group ( $F = 21.24$ ,  $p < 0.01$ ). P-values from the LSD comparing the ADHD Group and Non-ADHD Group to the adults were all 0.01 or less for all feedback conditions. Between the ADHD Group and Non-ADHD Group, significant differences were found only for the no feedback condition ( $p = 0.02$ ), but not for the immediate ( $p = 0.11$ ), short delay ( $p = 0.10$ ), and long delay ( $p = 0.69$ ) conditions.

#### Total Errors

Total errors represent the number of inattention errors combined with the number of impulsivity errors, and these were determined for the most challenging auditory sustained

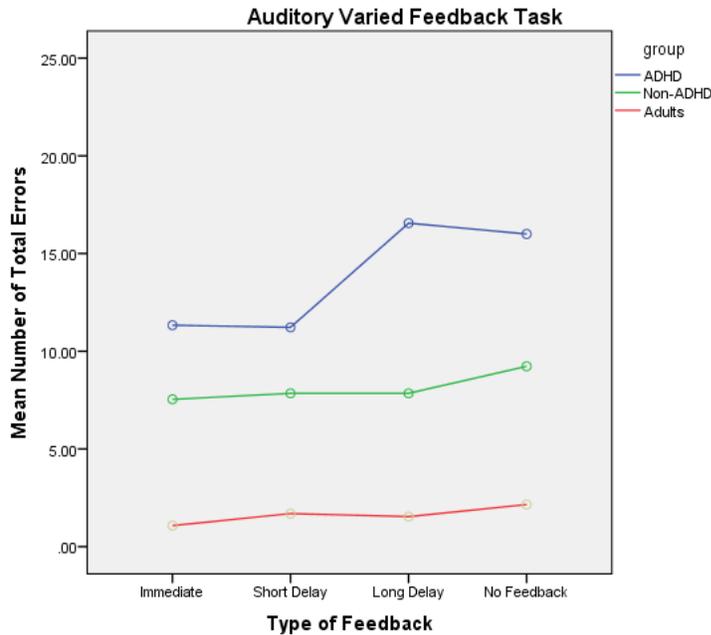
attention task (-5 SNR) and the most challenging visual sustained attention task (Level 3 reduced contrast) across varied conditions of feedback.

Total error rates were determined for the challenging auditory task with varied feedback conditions, and can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory immediate feedback	11.3333	9.02774
	auditory short delay	11.2222	7.82269
	auditory long delay	16.5556	18.82891
	auditory no feedback	16.0000	11.30265
Non-ADHD	auditory immediate feedback	7.5385	5.65119
	auditory short delay	7.8462	5.35173
	auditory long delay	7.8462	5.55047
	auditory no feedback	9.2308	6.32658
Adults	auditory immediate feedback	1.0769	1.25576
	auditory short delay	1.6923	2.86893
	auditory long delay	1.5385	4.13552
	auditory no feedback	2.1538	2.44425

**Table 3.8: Total errors on the challenging auditory task with varied feedback**



**Figure 3.5: Total errors on the challenging auditory task with varied feedback**

Within groups there was no significant change for total errors on the challenging auditory task for different feedback conditions (ADHD Group  $F = 1.80$ ,  $p = 0.25$ ; Non-ADHD Group  $F = 0.53$ ,  $p = 0.61$ ; Adult Group  $F = 0.81$ ,  $p = 0.50$ ).

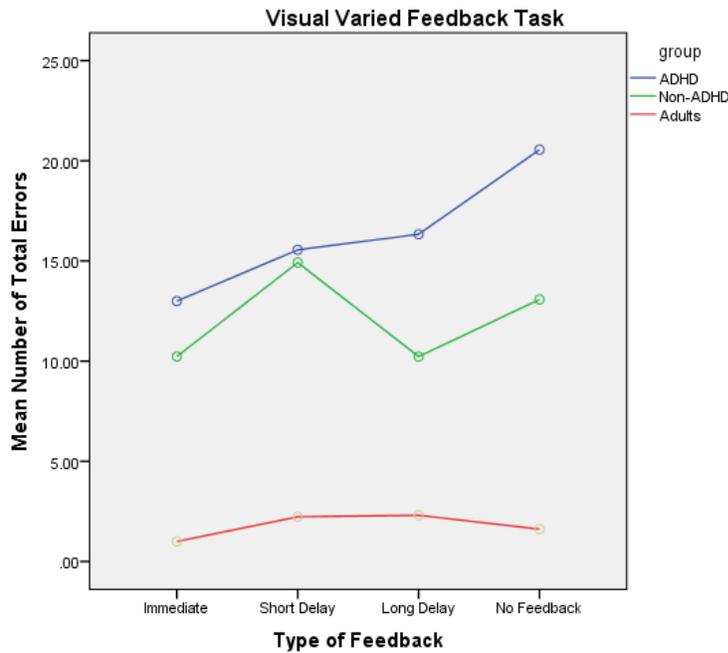
There were significant differences between groups when comparing total errors across feedback conditions ( $F = 61.26$ ,  $p < 0.01$ ). Thus, LSD follow-up testing was performed. When the ADHD Group was compared with the Non-ADHD Group, there were no significant differences for the immediate feedback ( $p = 0.14$ ), short delay ( $p = 0.16$ ), and long delay ( $p = 0.06$ ) conditions while there were significant differences for the no feedback condition ( $p = 0.03$ ). When the ADHD Group and Non-ADHD Group were compared with the adults, significant differences were found (ADHD Group and adults:  $p < 0.01$  for all conditions; Non-ADHD Group and adults: immediate feedback  $p < 0.01$ , short delay  $p = 0.01$ , no feedback  $p = 0.02$ ). No significant differences were found between the Non-ADHD Group and adults for the long delay condition ( $p = 0.13$ ).

Total error rates were also determined for the challenging visual task with varied feedback and the means and standard deviations can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual immediate feedback	13.0000	5.19615
	visual short delay	15.5556	9.18029
	visual long delay	16.3333	14.95828
	visual no feedback	20.5556	17.67138
Non-ADHD	visual immediate feedback	10.2308	6.96603
	visual short delay	14.9231	20.32019
	visual long delay	10.2308	5.26235
	visual no feedback	13.0769	9.86122
Adults	visual immediate feedback	1.0000	1.41421
	visual short delay	2.2308	3.03188
	visual long delay	2.3077	3.32627
	visual no feedback	1.6154	1.89466

**Table 3.9: Total errors on the challenging visual task with varied feedback**



**Figure 3.6: Total errors on the challenging visual task with varied feedback**

Within participant groups, no significant change in performance was found on the visual task across feedback conditions (ADHD Group  $F = 1.24$ ,  $p = 0.38$ ; Non-ADHD Group  $F = 1.10$ ,  $p = 0.33$ ; Adult Group  $F = 2.00$ ,  $p = 0.17$ ) for the challenging visual sustained attention task.

Between groups, significant differences were found ( $F = 11.83$ ,  $p < 0.01$ ) across the feedback conditions. Follow-up LSD testing indicated no significant differences were found for any condition between the ADHD Group and the Non-ADHD Group (immediate feedback  $p = 0.22$ , short delay  $p = 0.91$ , long delay  $p = 0.10$ , no feedback  $p = 0.12$ ). Significant differences were found between the ADHD Group and the Adult Group (immediate feedback  $p < 0.01$ , short delay  $p = 0.03$ , long delay  $p < 0.01$ , no feedback  $p < 0.01$ ) and the Non-ADHD Group and the Adult Group (immediate feedback  $p < 0.01$ , short delay  $p = 0.02$ , long delay  $p = 0.02$ , no feedback  $p = 0.01$ ).

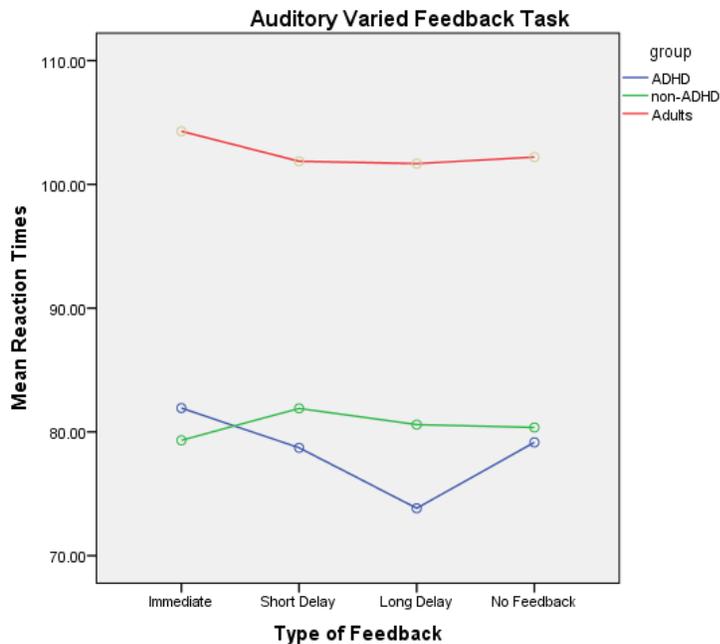
### Reaction Times

Reaction times on the challenging auditory and visual sustained attention tasks in varied feedback conditions were also compared using a repeated measures ANOVA. Reaction times were measured for all correct responses to the target stimulus. Reaction times for the auditory task can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory immediate feedback	81.9300	27.69169
	auditory short delay	78.7178	27.90228
	auditory long delay	73.8333	25.22530
	auditory no feedback	79.1567	25.72588
Non-ADHD	auditory immediate feedback	79.3200	31.45425
	auditory short delay	81.8992	28.61184
	auditory long delay	80.5892	28.06708
	auditory no feedback	80.3600	18.75546
Adults	auditory immediate feedback	104.2931	7.71991
	auditory short delay	101.8638	10.64752
	auditory long delay	101.6777	14.54247
	auditory no feedback	102.2023	11.89416

**Table 3.10: Reaction times on the challenging auditory task with varied feedback**



**Figure 3.7: Reaction times on the challenging auditory task with varied feedback**

Results indicated no differences in reaction times within groups on the challenging auditory task across feedback conditions (ADHD  $F = 0.78$ ,  $p = 0.54$ ; Non-ADHD  $F = 1.00$ ,  $p = 0.34$ ; Adult Group  $F = 0.23$ ,  $p = 0.84$ ).

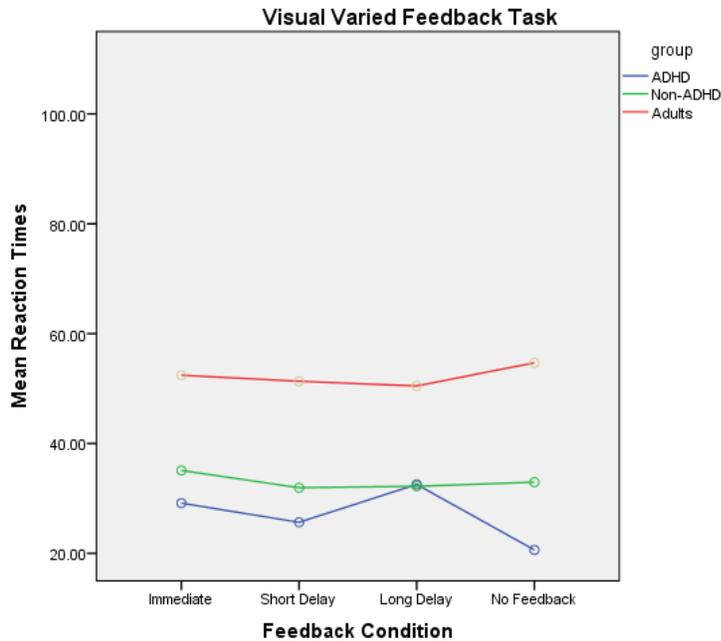
Significant differences between groups were found across various feedback conditions on the most challenging auditory task. Significant differences were found between the ADHD Group and the Adult Group for the immediate feedback condition ( $p = 0.04$ ), short delay condition ( $p = 0.03$ ), and long delay condition ( $p = 0.01$ ). Significant differences were found between the Non-ADHD Group and Adult Group for the immediate feedback condition ( $p < 0.01$ ), short delay condition ( $p = 0.03$ ) and long delay condition ( $p = 0.02$ ).

Reaction times for the challenging visual task with varied feedback conditions were also summarized and can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual immediate feedback	29.1456	16.03861
	visual short delay	25.6467	16.55441
	visual long delay	32.5444	19.32925
	visual no feedback	20.6244	15.04943
Non-ADHD	visual immediate feedback	35.0877	13.81470
	visual short delay	31.9431	16.30835
	visual long delay	32.2115	13.86695
	visual no feedback	32.9438	14.22570
Adults	visual immediate feedback	52.4238	4.63149
	visual short delay	51.3292	6.51547
	visual long delay	50.4700	7.59979
	visual no feedback	54.6854	3.11269

**Table 3.11: Reaction times on the challenging visual task with varied feedback**



**Figure 3.8: Reaction times on the challenging visual task with varied feedback**

Within groups, reaction times were not significantly different on the challenging visual task across varied feedback conditions for the ADHD Group ( $F = 2.77, p = 0.08$ ), Non-ADHD Group ( $F = 0.33, p = 0.74$ ), and the Adult Group ( $F = 2.04, p = 0.16$ ).

There were significant differences between groups in reactions times on the challenging visual task across feedback conditions ( $F = 17.02, p < 0.01$ ). There were no significant differences in reaction times between the two groups of children for the immediate feedback ( $p = 0.31$ ), short delay ( $p = 0.23$ ), and long delay ( $p = 0.84$ ) conditions whereas significant differences were found for the no feedback condition ( $p = 0.01$ ). Significant differences were found on all feedback conditions between the ADHD Group and the Adult Group ( $p < 0.01$  for all conditions) and for the Non-ADHD Group and Adult Group ( $p < 0.01$  for all conditions).

### **DATA RELATED TO QUESTIONS 2 and 4**

Research questions 2 and 4 addressed whether performance changed on the auditory and visual sustained attention tasks within or between each of the 3 groups when perceptual saliency of the stimuli was varied. It should be noted that no feedback was offered during these tasks. Findings will be organized according to error type.

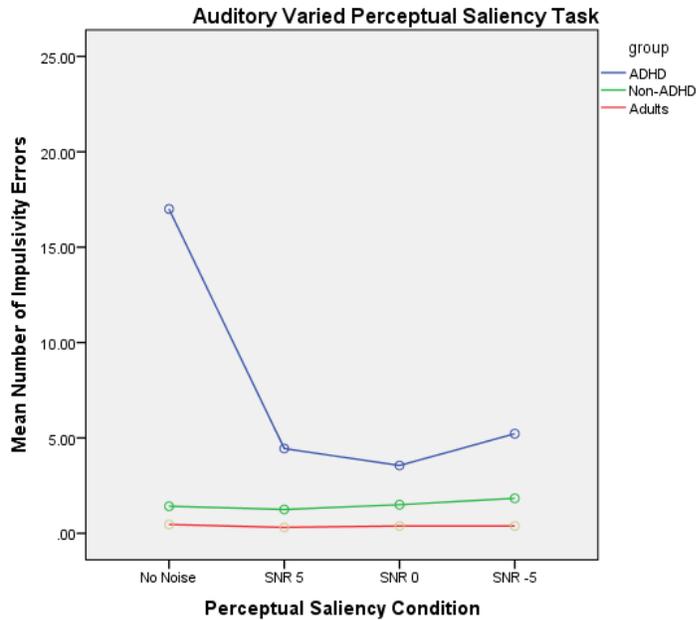
#### **Impulsivity Errors**

Impulsivity errors on the auditory attention task under varied conditions of perceptual saliency (no noise, +5 SNR, 0 SNR, and -5 SNR) were determined. Means and standard deviations for impulsivity errors can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory no noise	17.0000	41.87780
	auditory SNR 5	4.4444	5.98145
	auditory SNR 0	3.5556	5.70331
	auditory SNR -5	5.2222	6.37922
Non-ADHD	auditory no noise	1.4167	2.53909
	auditory SNR 5	3.5385	8.39261
	auditory SNR 0	2.3846	3.37980
	auditory SNR -5	1.6923	2.17503
Adults	auditory no noise	.4615	.66023
	auditory SNR 5	.3077	.63043
	auditory SNR 0	.3846	.50637
	auditory SNR -5	.3846	.65044

**Table 3.12: Impulsivity errors on the auditory task with varied perceptual saliency**



**Figure 3.9: Impulsivity errors on the auditory task with varied perceptual saliency**

When statistical testing was completed, results revealed no significant differences in impulsivity errors within groups (ADHD  $F = 1.08$ ,  $p = 0.33$ ; Non-ADHD  $F = 0.37$ ,  $p = 0.77$ ; Adult Group  $F = 0.13$ ,  $p = 0.95$ ) for auditory conditions across the four levels of perceptual saliency.

There were no overall significant differences in total impulsivity errors between groups across the four levels of perceptual saliency ( $F = 2.66$ ,  $p = 0.09$ ). Post-hoc LSD testing was performed to analyze each individual condition as well. Between groups, no differences in impulsivity errors were found between the ADHD and Non-ADHD Groups for the no noise ( $p = 0.11$ ), SNR 5 ( $p = 0.73$ ), and SNR 0 ( $p = 0.45$ ) conditions, whereas significant differences were found for the SNR -5 condition ( $p = 0.03$ ). No differences were found between the Non-ADHD Group and the Adult Group (no noise  $p = 0.91$ , SNR 5  $p = 0.16$ , SNR 0  $p = 0.15$ , SNR -5  $p = 0.36$ ). For the ADHD Group and the Adult Group, differences were found in the most difficult

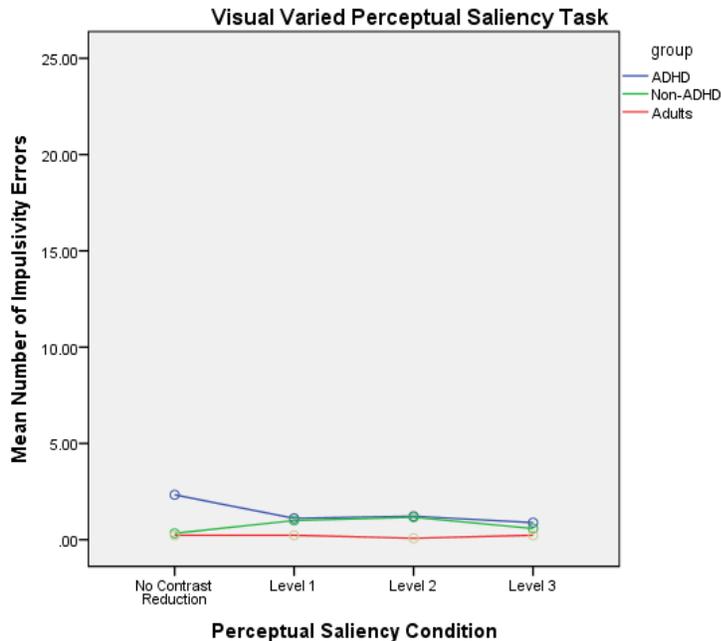
(0 SNR and -5 SNR) listening conditions ( $p = 0.05$ ,  $p < 0.01$ ), but not for the other conditions (no noise  $p = 0.91$ , SNR 5  $p = 0.16$ ).

Impulsivity error rates for varied visual perceptual saliency (i.e., full contrast image, level 1 reduced contrast, level 2 reduced contrast, and level 3 reduced contrast) conditions were compared. Means and standard deviations can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual no distortion	2.3333	3.35410
	visual level 1	1.1111	1.45297
	visual level 2	1.2222	1.92209
	visual level 3	.8889	1.16667
Non-ADHD	visual no distortion	.3333	.77850
	visual level 1	1.0000	1.53741
	visual level 2	1.1667	1.69670
	visual level 3	.5833	.66856
Adults	visual no distortion	.2308	.43853
	visual level 1	.2308	.59914
	visual level 2	.0769	.27735
	visual level 3	.2308	.59914

**Table 3.13: Impulsivity errors on the visual task with varied perceptual saliency**



**Figure 3.10: Impulsivity errors on the visual task with varied perceptual saliency**

Within groups, no differences in impulsivity errors were observed when perceptual saliency was varied on the visual attention task (ADHD  $F = 1.32$ ,  $p = 0.30$ ; Non-ADHD  $F = 0.37$ ,  $p = 0.69$ ; Adult Group  $F = 0.13$ ,  $p = 0.93$ ).

There was a significant difference between groups across the four levels of perceptual saliency ( $F = 4.29$ ,  $p = 0.02$ ). Between groups, differences were found only between the ADHD and Non-ADHD Groups for the no contrast reduction ( $p = 0.02$ ) condition, but not for the level 1 ( $p = 0.84$ ), level 2 ( $p = 0.93$ ), and level 3 ( $p = 0.40$ ) conditions. For the Non-ADHD Group and the Adult Group, significant differences were found for only the level 2 condition ( $p = 0.05$ ) but not for any of the other conditions (no contrast reduction  $p = 0.89$ , level 1  $p = 0.12$ , level 3  $p = 0.31$ ). Between the ADHD Group and the Adult Group, significant differences were found for the no contrast reduction condition ( $p = 0.01$ ), but not for the level 1 condition ( $p = 0.11$ ), level 2 ( $p = 0.07$ ) and level 3 condition ( $p = 0.07$ )

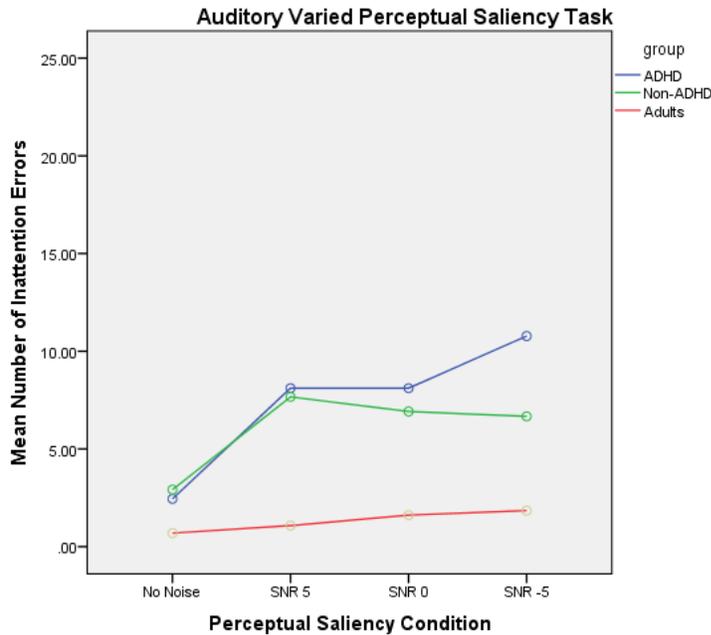
### Inattention Errors

Inattention errors based on varied auditory perceptual saliency conditions can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory no noise	2.4444	2.92024
	auditory SNR 5	8.1111	7.78531
	auditory SNR 0	8.1111	4.72875
	auditory SNR -5	10.7778	6.47645
Non-ADHD	auditory no noise	2.9167	2.50303
	auditory SNR 5	8.4615	6.39812
	auditory SNR 0	7.7692	4.74612
	auditory SNR -5	7.6154	5.10781
Adults	auditory no noise	.6923	1.10940
	auditory SNR 5	1.0769	1.75412
	auditory SNR 0	1.6154	2.18092
	auditory SNR -5	1.8462	2.99572

**Table 3.14: Inattention errors on the auditory task with varied perceptual saliency**



**Figure 3.11: Inattention errors on the auditory task with varied perceptual saliency**

When perceptual saliency conditions on the auditory task were compared within groups, significant differences in inattention errors were found for the ADHD Group ( $F = 8.60, p = 0.01$ ) and the Non-ADHD Group ( $F = 7.60, p < 0.01$ ). No within group differences were found in the Adult Group ( $F = 2.81, p = 0.08$ ) across the different acoustic saliency conditions. Follow up testing indicated significant differences for the ADHD group between the following conditions: SNR -5 and no noise ( $p > 0.01$ ), SNR 0 and no noise ( $p > 0.01$ ), and SNR 5 and no noise ( $p = 0.01$ ). Significant differences were found for the following conditions within the Non-ADHD group: SNR -5 and no noise ( $p > 0.01$ ), SNR 0 and no noise ( $p > 0.01$ ), and SNR 5 and no noise ( $p = 0.01$ ).

There were significant differences in inattention errors between groups ( $F = 9.39, p < 0.01$ ). No between group differences were found between the ADHD Group and Non-ADHD Group (no noise  $p = 0.63$ , SNR 5  $p = 0.89$ , SNR 0  $p = 0.84$ , SNR -5  $p = 0.14$ ). Significant differences were found for the ADHD Group and Adult Group (no noise  $p = 0.08$ , SNR 5  $p <$

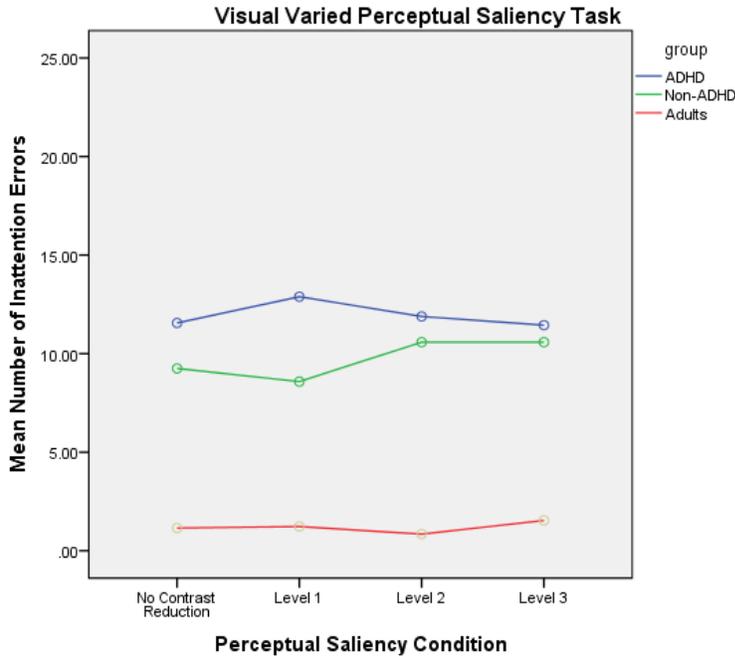
0.01, SNR 0 < 0.01, SNR -5 p < 0.01) and the Non-ADHD Group and Adult Group (no noise p = 0.02, SNR 5 p < 0.01, SNR 0 p < 0.01, SNR 0 p < 0.01, SNR -5 p = 0.01) for all conditions tested.

The number of inattention errors made when the perceptual saliency of the stimuli in the visual condition was varied can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual no contrast reduction	11.5556	5.54777
	visual level 1	12.8889	6.71648
	visual level 2	11.8889	6.43126
	vis3	11.4444	7.97043
Non-ADHD	visual no contrast reduction	9.2500	4.22385
	visual level 1	8.5833	5.10718
	visual level 2	10.5833	5.33357
	vis3	10.5833	4.46111
Adults	visual no contrast reduction	1.1538	1.34450
	visual level 1	1.2308	1.23517
	visual level 2	.8462	1.40512
	vis3	1.5385	1.56074

**Table 3.15: Inattention errors on the visual task with varied perceptual saliency**



**Figure 3.12: Inattention Errors on the Visual tasks with Varied Perceptual Saliency**

Within groups, no differences were found between the visual perceptual saliency conditions on the visual task (ADHD  $F = 0.64$ ,  $p = 0.62$ ; Non-ADHD  $F = 1.58$ ,  $p = 0.22$ , Adult Group  $F = 1.19$ ,  $p = 0.32$ ).

There were significant differences between groups ( $F = 22.29$ ,  $p < 0.01$ ). Between groups no differences were found between the two groups of children for the no contrast reduction ( $p = 0.19$ ), level 2 ( $p = 0.53$ ), and level 3 ( $p = 0.70$ ) conditions. Differences were found between these two groups only for the level 1 condition ( $p = 0.04$ ). Differences were found between both groups of children and the Adult Group ( $p < 0.01$  for all conditions).

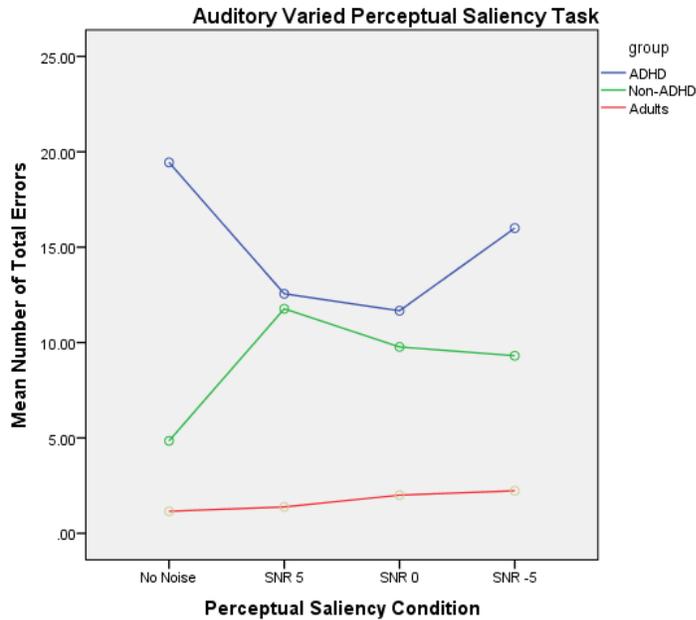
### Total Errors

Total errors were also compared for each group in the varied perceptual saliency conditions. The results of statistical analysis on the auditory varied perceptual saliency data can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory no noise	19.4444	42.53561
	auditory SNR 5	12.5556	12.10487
	auditory SNR 0	11.6667	9.65660
	auditory SNR -5	16.0000	11.06797
Non-ADHD	auditory no noise	4.8462	5.35173
	auditory SNR 5	11.7692	12.91739
	auditory SNR 0	9.7692	7.37285
	auditory SNR -5	9.3077	6.27674
Adults	auditory no noise	1.1538	1.62512
	auditory SNR 5	1.3846	1.85016
	auditory SNR 0	2.0000	2.51661
	auditory SNR -5	2.2308	3.32049

**Table 3.16: Total errors on the auditory task with varied perceptual saliency**



**Figure 3.13: Total errors on the auditory task with varied perceptual saliency**

Analysis within groups revealed no change in total errors across auditory perceptual saliency conditions (ADHD  $F = 2.72$ ,  $p = 0.14$ ; Non-ADHD  $F = 2.93$ ,  $p = 0.09$ ; Adult Group  $F = 1.79$ ,  $p = 0.18$ ).

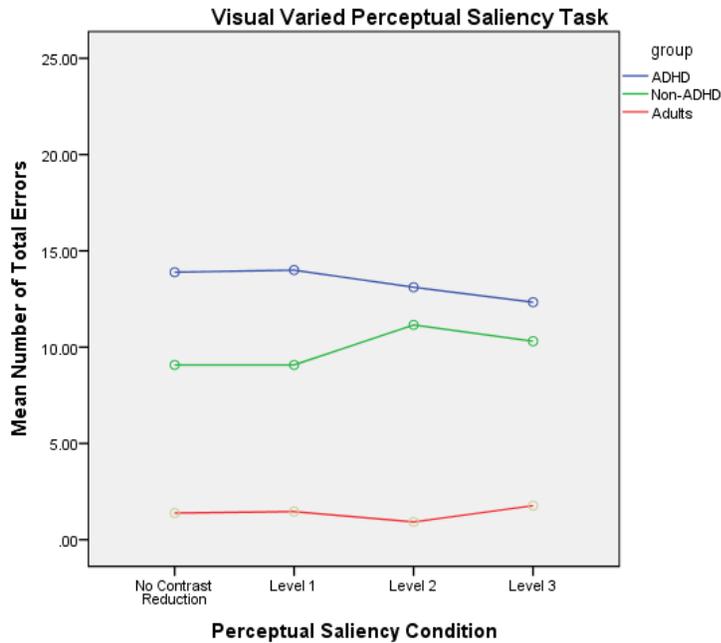
There were significant differences between groups ( $F = 5.06$ ,  $p = 0.01$ ) for total errors on different perceptual saliency conditions on the auditory task. Post hoc testing revealed no difference between the ADHD Group and Non-ADHD Group for the no noise ( $p = 0.13$ ), SNR 5 ( $p = 0.86$ ), and SNR 0 ( $p = 0.52$ ) conditions whereas significant differences were found for the SNR - 5 condition ( $p = 0.04$ ). Between the ADHD Group and the Adult Group, significant differences were found for the most challenging conditions (SNR 5  $p = 0.02$ , SNR 0  $p < 0.01$ , SNR -5  $p < 0.01$ ), but not for the no noise condition ( $p = 0.06$ ). Significant differences were also found between the Non-ADHD Group and the Adult Group for the SNR 5 ( $p < 0.01$ ), SNR 0 ( $p = 0.01$ ), and SNR -5 ( $p = 0.02$ ) conditions, but not for the no noise condition ( $p = 0.65$ ).

Total errors in the visual varied perceptual saliency condition were also determined and analyzed using a repeated measures ANOVA design. These results can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual no contrast reduction	13.8889	7.65579
	visual level 1	14.0000	6.89202
	visual level 2	13.1111	7.67210
	visual level 3	12.3333	8.24621
Non-ADHD	visual no contrast reduction	9.0769	4.99102
	visual level 1	9.0769	5.72220
	visual level 2	11.1538	6.47876
	visual level 3	10.3077	5.34454
Adults	visual no contrast reduction	1.3846	1.60927
	visual level 1	1.4615	1.39137
	visual level 2	.9231	1.38212
	visual level 3	1.7692	1.96443

**Table 3.17: Total errors on the visual task with varied perceptual saliency**



**Figure 3.14: Total errors on the visual task with varied perceptual saliency**

Analysis revealed no differences across perceptual saliency conditions on the visual task within groups (ADHD  $F = 1.39$ ,  $p = 0.33$ ; Non-ADHD  $F = 2.00$ ,  $p = 0.14$ ; Adult Group  $F = 1.90$ ,  $p = 0.18$ ).

There were significant differences between groups ( $F = 18.47$ ,  $p < 0.01$ ) on the visual task on different perceptual saliency conditions. Differences were found between the two groups of children for the no contrast reduction ( $p = 0.03$ ) and level 1 ( $p = 0.03$ ) conditions, but not for the level 2 ( $p = 0.43$ ), and level 3 ( $p = 0.40$ ) conditions. Differences were found between the two groups of children and the Adult Group, however ( $p < 0.01$  for all conditions).

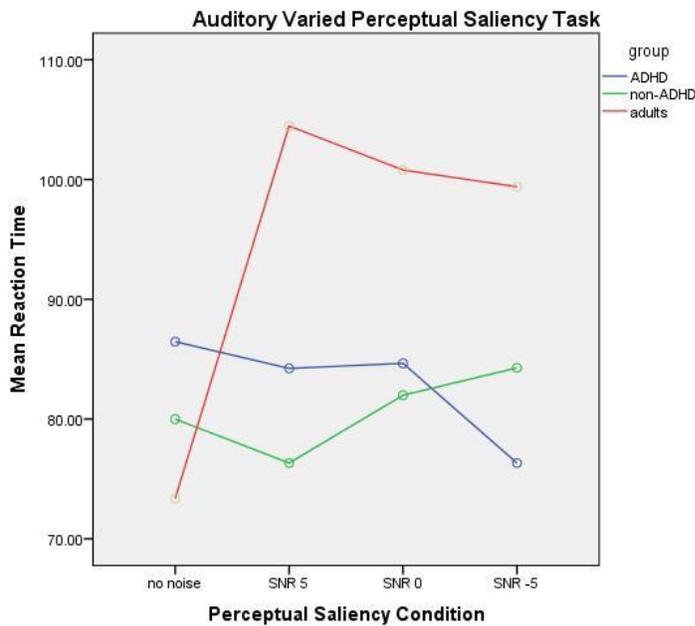
#### Reaction Times

Reaction times to targets in the varied auditory perceptual saliency condition were also calculated and compared using a repeated measures ANOVA. Results for this testing can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	auditory no noise	92.2500	22.79586
	auditory SNR 5	82.5467	25.54784
	auditory SNR 0	77.0256	28.78422
	audminus5	65.6011	28.67412
Non-ADHD	auditory no noise	79.9983	9.99481
	auditory SNR 5	71.0315	36.22692
	auditory SNR 0	76.8585	26.10171
	audminus5	78.3662	28.67029
Adults	auditory no noise	73.3523	9.05125
	auditory SNR 5	104.4646	7.89190
	auditory SNR 0	100.7923	8.73498
	audminus5	99.3946	12.98669

**Table 3.18: Reaction times to targets on the auditory task with varied perceptual saliency**



**Figure 3.15: Reaction times on the auditory task with varied perceptual saliency**

Reaction times within groups showed significant differences across perceptual saliency conditions on auditory tasks for the Adult Group ( $F = 65.75, p < 0.01$ ) but not for the children (ADHD  $F = 0.44, p = 0.61$ ; Non-ADHD  $F = 0.44, p = 0.66$ ). Follow up testing indicated that

significant differences within the adult group were found in the following conditions: SNR -5 and SNR 0 ( $p > 0.01$ ), SNR -5 and SNR 5 ( $p > 0.01$ ), and SNR 0 and SNR 5 ( $p > 0.01$ ).

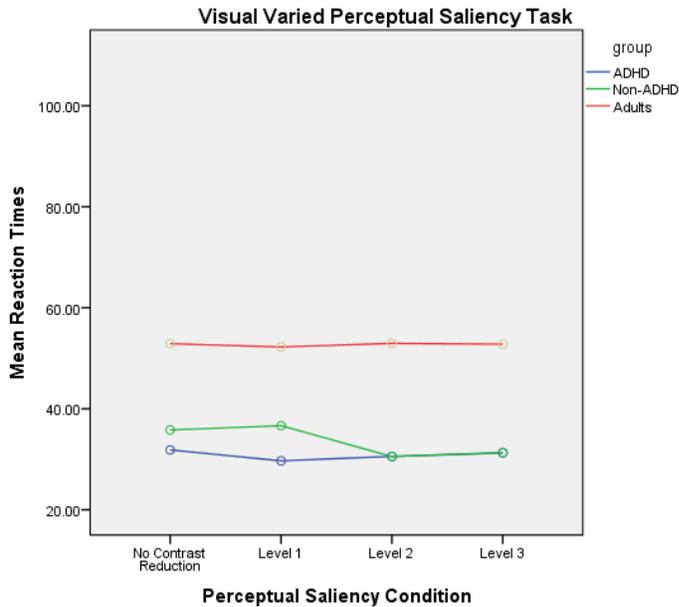
There were significant differences in reaction times between groups ( $F = 4.53, p = 0.02$ ) for different auditory perceptual saliency conditions. Significant differences in reaction times were found between the groups of children for the no noise ( $p = 0.05$ ) and SNR -5 ( $p = 0.04$ ) conditions. When the ADHD Group was compared with the Adult Group, significant differences were found for all conditions (no noise  $p = 0.01$ , SNR 5  $p = 0.04$ , SNR 0  $p = 0.01$ , SNR -5  $p < 0.01$ ). When the Non-ADHD Group was compared with the Adult Group, no difference in reaction time was found on the no noise condition ( $p = 0.25$ ) but differences were found on the other conditions (SNR 5  $p < 0.01$ , SNR 0  $p = 0.01$ , SNR -5  $p = 0.03$ ).

Reaction times for varying visual perceptual saliency conditions were also determined and compared. These results can be seen in the table and figure below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	visual no contrast reduction	31.8589	16.87464
	visual level 1	29.6933	11.82999
	visual level 2	30.5733	16.62021
	visual level 3	31.2644	16.12013
Non-ADHD	visual no contrast reduction	35.7992	11.70922
	visual level 1	36.6475	14.27768
	visual level 2	30.5442	14.64807
	visual level 3	31.3358	11.82951
Adults	visual no contrast reduction	52.8815	4.09755
	visual level 1	52.2431	3.03167
	visual level 2	52.9423	3.74874
	visual level 3	52.7992	3.25791

**Table 3.19: Reaction times on the visual task with varied perceptual saliency**



**Figure 3.16: Reaction times on the visual task with varied perceptual saliency**

Within groups analysis revealed no significant difference in reaction time across conditions with varied visual perceptual saliency (ADHD  $F = 0.50$ ,  $p = 0.63$ ; Non-ADHD  $F = 1.64$ ,  $p = 0.21$ ; Adult Group ( $F = 0.15$ ,  $p = 0.91$ ).

Significant differences were found between groups ( $F = 16.00$ ,  $p < 0.01$ ) for different conditions of visual perceptual saliency. Differences were not found between the two groups of children (no contrast reduction  $p = 0.38$ , level 1  $p = 0.15$ , level 2  $p = 0.97$ , level 3  $p = 0.88$ ). Significant differences were found between the Adult Group and both groups of children on all conditions, however ( $p < 0.01$ ).

### **DATA RELATED TO RESEARCH QUESTION 5**

Research Question 5 addressed whether there were performance differences across modalities on auditory and visual tasks with analogous feedback and perceptual saliency conditions. Data from all 39 participants (including the children in the ADHD group who had

taken their medication on the day of testing) were combined for each of the 16 test conditions and then analogous conditions were compared (e.g., auditory immediate feedback and visual immediate feedback).

### Impulsivity Errors

The data related to impulsivity errors for analogous challenging auditory (-5 SNR) and visual (level 3 contrast reduction) tasks for the various feedback conditions were examined. Table (NUMBER) offers the mean data per condition and standard deviations for the analogous auditory and visual tasks under the various feedback conditions.

Condition	Immediate feedback	Short delay	Long delay	No feedback
Auditory Mean (S.D.)	1.03 (2.10)	1.46 (2.37)	2.31 (5.80)	2.56 (5.55)
Visual Mean (S.D)	0.79 (2.10)	2.28 (10.87)	1.40 (5.80)	2.51 (9.08)

**Table 3.20: Mean and standard deviation of impulsivity errors for analogous challenging auditory and visual tasks**

When impulsivity errors were compared for the different feedback conditions, no differences were found between modalities (i.e. visual immediate vs. auditory immediate [ $F = 0.26, p = 0.62$ ], visual short delay vs. auditory short delay [ $F = 0.23, p = 0.63$ ], visual long delay vs. auditory long delay [ $F = 3.71, p = 0.06$ ] and visual no feedback vs. auditory no feedback [ $F < 0.01, p = 0.98$ ]).

For analogous auditory and visual tasks under varied perceptual saliency conditions, means and standard deviations for impulsivity errors can be seen below.

Condition	No distortion	Level 1	Level 2	Level 3
Auditory Mean (S.D.)	4.68 (20.73)	2.41 (1.21)	1.82 (1.42)	1.92 (0.89)
Visual Mean (S.D.)	0.76 (1.87)	0.68 (1.21)	0.76 (1.42)	0.61 (0.89)

**Table 3.21: Means and standard deviations for impulsivity errors on analogous auditory and visual tasks with varied perceptual saliency conditions**

Significant differences were found between some impulsivity error rates on analogous auditory and visual tasks. No significant differences were found between the no noise and no reduced contrast conditions ( $F = 1.38$ ,  $p = 0.25$ ), the SNR 5 and level 1 conditions ( $F = 3.47$ ,  $p = 0.07$ ), and the SNR 0 and level 2 conditions ( $F = 3.54$ ,  $p = 0.07$ ). Significant differences were found, however, between the most challenging conditions, SNR -5 and level 3 ( $F = 4.98$ ,  $p = 0.03$ ), with a higher rate observed for the auditory task.

#### Inattention Errors

Inattention errors for complementary visual and auditory tasks were compared (i.e. auditory immediate feedback vs. visual immediate feedback, auditory short delay vs. visual short delay, auditory long delay vs. visual long delay, auditory no feedback vs. visual no feedback, auditory no noise vs. visual no contrast reduction, auditory SNR 5 vs. visual level 1, auditory SNR 0 vs. visual level 2, and auditory SNR -5 vs. visual level 3). Means and standard deviations can be seen in the following table.

Condition	Immediate feedback	Short delay	Long delay	No feedback
Auditory Mean (S.D.)	4.77 (5.64)	5.28 (5.03)	4.97 (5.08)	5.49 (4.93)
Visual Mean (S.D.)	6.97 (5.93)	8.23 (7.31)	7.49 (6.41)	7.82 (6.78)

**Figure 3.22: Inattention errors on the analogous auditory and visual tasks with varied feedback**

Significant differences in inattention errors were found between all analogous varied feedback conditions (immediate feedback  $F = 9.95$ ,  $p < 0.01$ ; short delay  $F = 14.95$ ,  $p < 0.01$ ; long delay  $F = 10.76$ ,  $p < 0.01$ ; no feedback  $F = 8.61$ ,  $p < 0.01$ ).

When perceptual saliency conditions in the auditory and visual modalities were compared (i.e. auditory no noise vs. visual no contrast reduction [ $F = 27.63$ ,  $p = 0.46$ ], auditory SNR 5 vs. visual level 1 [ $F = 3.82$ ,  $p = 0.06$ ], auditory SNR 0 vs. visual level 2 [ $F = 6.97$ ,  $p = 0.01$ ], and auditory SNR -5 vs. visual level 3 [ $F = 3.52$ ,  $p = 0.07$ ]), significant differences were found between modalities for only the auditory SNR 0 vs. visual level 2 conditions.

### Total Errors

Total errors across modalities for the various feedback conditions were compared using the same analysis used for impulsivity and inattention errors. These error rates can be seen in the table below.

Condition	Immediate feedback	Short delay	Long delay	No feedback
Auditory Mean (S.D.)	5.79 (6.67)	6.46 (6.25)	7.28 (11.11)	8.05 (8.44)
Visual Mean (S.D.)	7.62 (6.82)	10.31 (13.80)	8.82 (9.52)	10.56 (12.38)

**Table 3.23: Total errors on the analogous auditory and visual tasks with varied feedback**

Significant differences were found between the auditory and visual immediate feedback conditions ( $F = 5.00$ ,  $p = 0.03$ ) and auditory and visual short delay conditions ( $F = 4.65$ ,  $p = 0.04$ ). Significant differences between modalities were not found for the auditory and visual long delay conditions ( $F = 2.94$ ,  $p = 0.09$ ), the auditory and visual no feedback conditions ( $F = 2.46$ ,  $p = 0.13$ ), the no contrast reduction and no noise conditions ( $F = 0.04$ ,  $p = 0.84$ ), the visual level 1 and auditory SNR 5 conditions ( $F = 0.03$ ,  $p = 0.86$ ), the visual level 2 and auditory SNR 0 conditions ( $F = 1.02$ ,  $p = 0.32$ ), and visual level 3 and auditory SNR -5 conditions ( $F < 0.01$ ,  $p = 1.00$ ).

### Reaction Times

Reaction times were compared across modalities for varied feedback conditions, which can be seen in the table below.

Condition	Immediate feedback	Short delay	Long delay	No feedback
Auditory Mean (S.D.)	91.10 (24.49)	90.15 (23.15)	89.61 (22.79)	255.75 (1023.02)
Visual Mean (S.D.)	41.00 (13.25)	37.80 (16.78)	40.10 (14.68)	38.41 (17.10)

**Table 3.24: Reaction times on analogous auditory and visual tasks with varied feedback**

Significant differences were found between reaction times on the visual and auditory immediate feedback conditions ( $F = 239.17$ ,  $p < 0.01$ ), visual and auditory short delay ( $F = 285.80$ ,  $p < 0.01$ ), and visual and auditory long delay ( $F = 257.68$ ,  $p < 0.01$ ). Reaction times were longer for the auditory tasks. Significant differences were not found between the visual and auditory no feedback conditions ( $F = 1.72$ ,  $p = 0.20$ ). However, the standard deviation for the auditory task with no feedback condition is noteworthy, and may be a contributing factor in the lack of significant differences between the modalities.

Differences were also found between perceptual saliency conditions, which can be seen in the table below.

Condition	No distortion	Level 1	Level 2	Level 3
Auditory Mean (S.D.)	79.76 (14.91)	84.92 (25.32)	87.51 (23.47)	86.64 (27.98)
Visual Mean (S.D.)	41.86 (13.50)	40.83 (14.27)	39.30 (14.82)	38.38 (15.18)

**Table 3.25: Reaction times on analogous auditory and visual tasks with varied perceptual saliency conditions**

Significant differences were found for reaction times between the visual no contrast reduction and auditory no noise ( $F = 77.29$ ,  $p < 0.01$ ), visual level 1 and auditory SNR 5 ( $F = 125.81$ ,  $p < 0.01$ ), visual level 2 and auditory SNR 0 ( $F = 197.28$ ,  $p < 0.01$ ), and visual level 3

and auditory SNR -5 ( $F = 138.84$ ,  $p < 0.01$ ) conditions. Significant differences were not found between reaction times for the visual and auditory no feedback conditions.

#### DATA RELATED TO QUESTION 6

Research question 6 addressed whether error rates changed over the course of testing within and across groups, both from the beginning to the end of the entire session (task 1 compared to task 4), and from the beginning to the end of each task (condition 1 performance on each task compared to condition 4 performance on each task). Vigilance (the ability to maintain performance over an extended period of time) was measured in two different ways. In the current study, one measure of vigilance was used to examine performance at the beginning and end of the research session, and this vigilance measure will be called “long term vigilance”. A second vigilance measure was used to examine performance at the beginning and end of a task and will be called “traditional vigilance” because it is most commonly reported in the literature and reflects performance changes across approximately 12 minutes.

In the current study, participants completed four tasks and each of the four tasks had four conditions within it. The long term vigilance measure involved the comparison of task 1 and task 4 performance, which results in a measure of early and late performance within the approximately 1.5 hour research session. The second vigilance measure compared early and late performance within each 12-minute task. Error numbers on the first condition within each of the four tasks (i.e., first 3 minutes of each task) were calculated and then averaged across conditions (i.e., task 1 condition 1 errors + task 2 condition 1 errors + task 3 condition 1 errors + task 4 condition 1 errors/4). The error numbers on the last condition of each of the four tasks (i.e., last 3 minutes of each task) were also averaged across the tasks (i.e., task 1 condition 4 errors + task 2 condition 4 errors + task 3 condition 4 errors + task 4 condition 4 errors/4). This compared

vigilance over a shorter period of time, approximately 12 minutes. This time frame is similar to the time frame used in most continuous performance tasks reported in the literature.

Differences in error rates for the two vigilance measures below were examined within and between groups. Impulsivity errors, inattention errors, and total errors will be discussed.

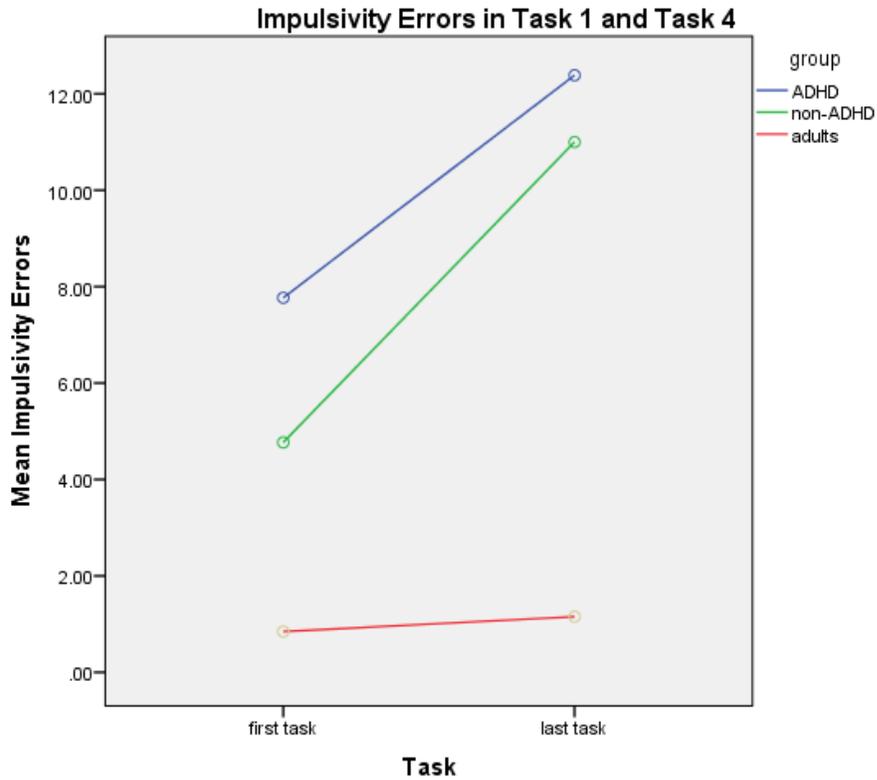
### Impulsivity Errors

Means and standard deviations for impulsivity errors from the first to the last condition (within tasks) and from the first to the last task (across the entire test session) can be seen in the table below.

<b>Descriptive Statistics</b>			
group		Mean	Std. Deviation
ADHD	Average of all first conditions	7.5000	14.69215
	Average of all last conditions	2.5833	2.70416
	Total errors in first task	10.0000	12.32883
	Total errors in last task	16.3333	23.98437
Non-ADHD	Average of all first conditions	1.7308	3.13160
	Average of all last conditions	.8333	.64280
	Total errors in first task	4.7692	5.87585
	Total errors in last task	11.0000	30.47677
Adults	Average of all first conditions	.1923	.23170
	Average of all last conditions	.2885	.40628
	Total errors in first task	.8462	1.06819
	Total errors in last task	1.1538	1.72463

**Table 3.26: Impulsivity errors from first task to last task**

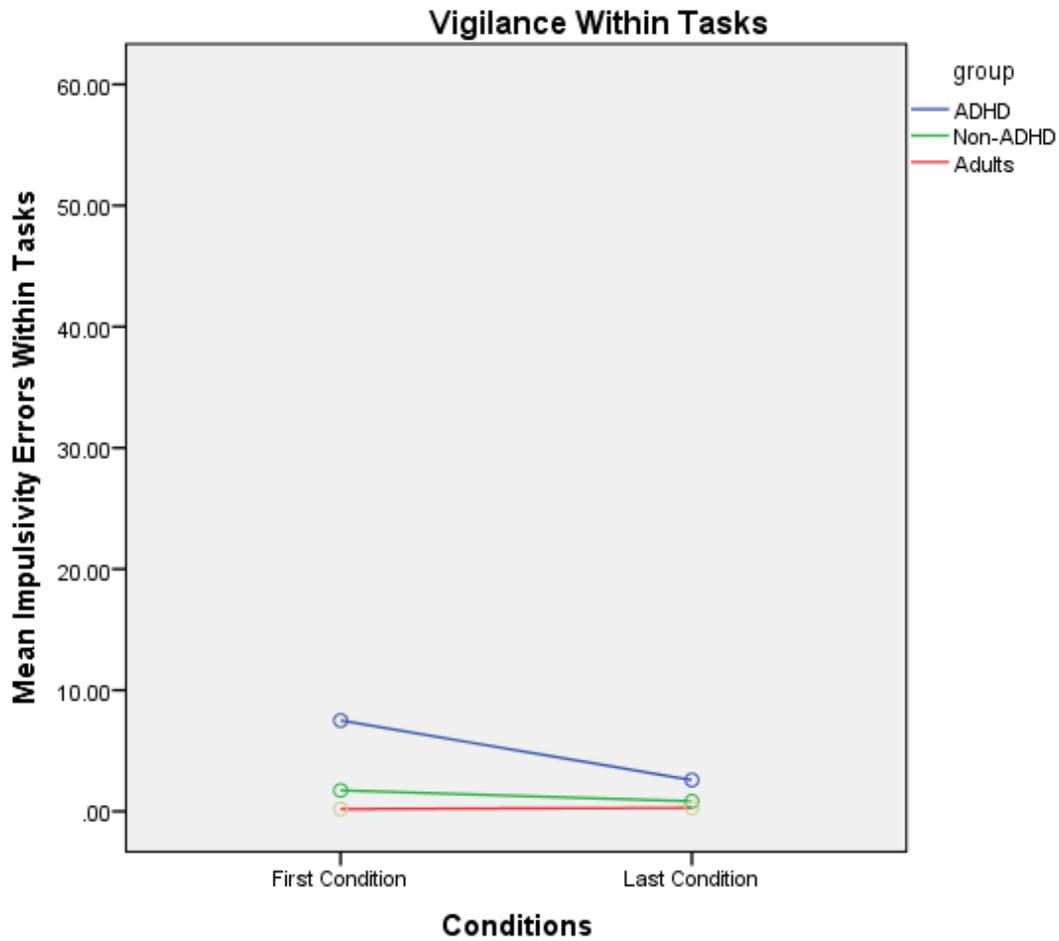
Figure 3.17 below presents the mean impulsivity errors for Task 1 and Task 4.



**Figure 3.17: Vigilance from first task to last task in session**

No differences in total impulsivity errors from task 1 to task 4 were found within any of the groups (ADHD  $F = 0.53$ ,  $p = 0.48$ ; Non-ADHD  $F = 0.53$ ,  $p = 0.48$ ; Adult Group  $F = 0.51$ ,  $p = 0.49$ ). Thus, no significant differences in impulsivity were found for long term vigilance.

Figure (NUMBER) below presents the mean averaged impulsivity errors for condition 1 (across tasks 1-4) and the mean averaged impulsivity errors for condition 4 (across tasks 1-4).



**Figure 3.18: Vigilance within tasks**

No significant differences in impulsivity errors were found between the first conditions and last conditions for any group (ADHD  $F = 1.54$ ,  $p = 0.24$ ; Non-ADHD  $F = 1.18$ ,  $p = 0.30$ ; adult Group  $F = 1.35$ ,  $p = 0.27$ ). Thus, no significant differences were found for traditional vigilance as reflected by impulsivity errors.

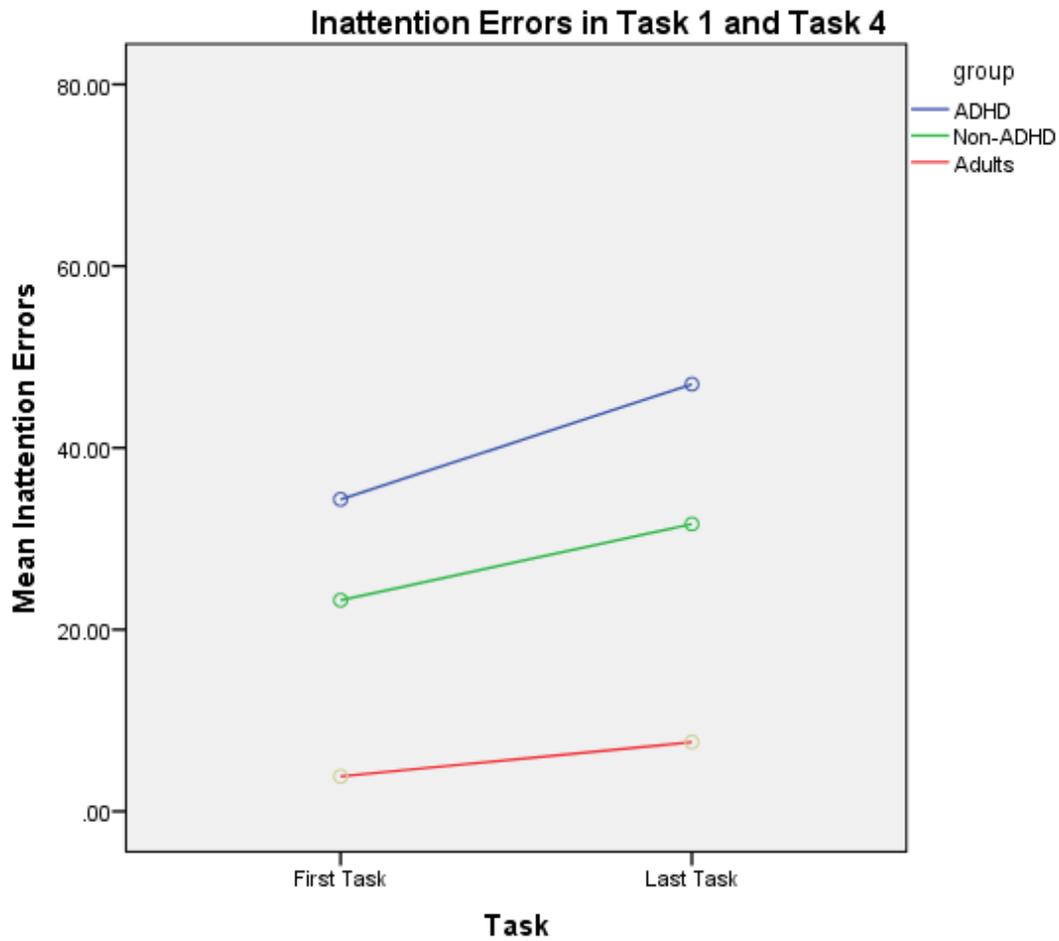
#### Inattention Errors

The inattention errors were determined using the same analysis as impulsivity errors. These errors are shown in the following table and figure.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	average of all first conditions	8.3889	6.21755
	average of all last conditions	11.7500	6.13901
	total errors in first task	34.3333	28.07579
	total errors in last task	47.0000	25.36730
Non-ADHD	average of all first conditions	6.5256	3.58646
	average of all last conditions	8.3526	4.28474
	total errors in first task	23.2308	14.94520
	total errors in last task	31.6154	21.03386
adults	average of all first conditions	1.2500	1.57123
	average of all last conditions	1.8462	1.84147
	total errors in first task	3.8462	4.05886
	total errors in last task	7.6154	8.78008

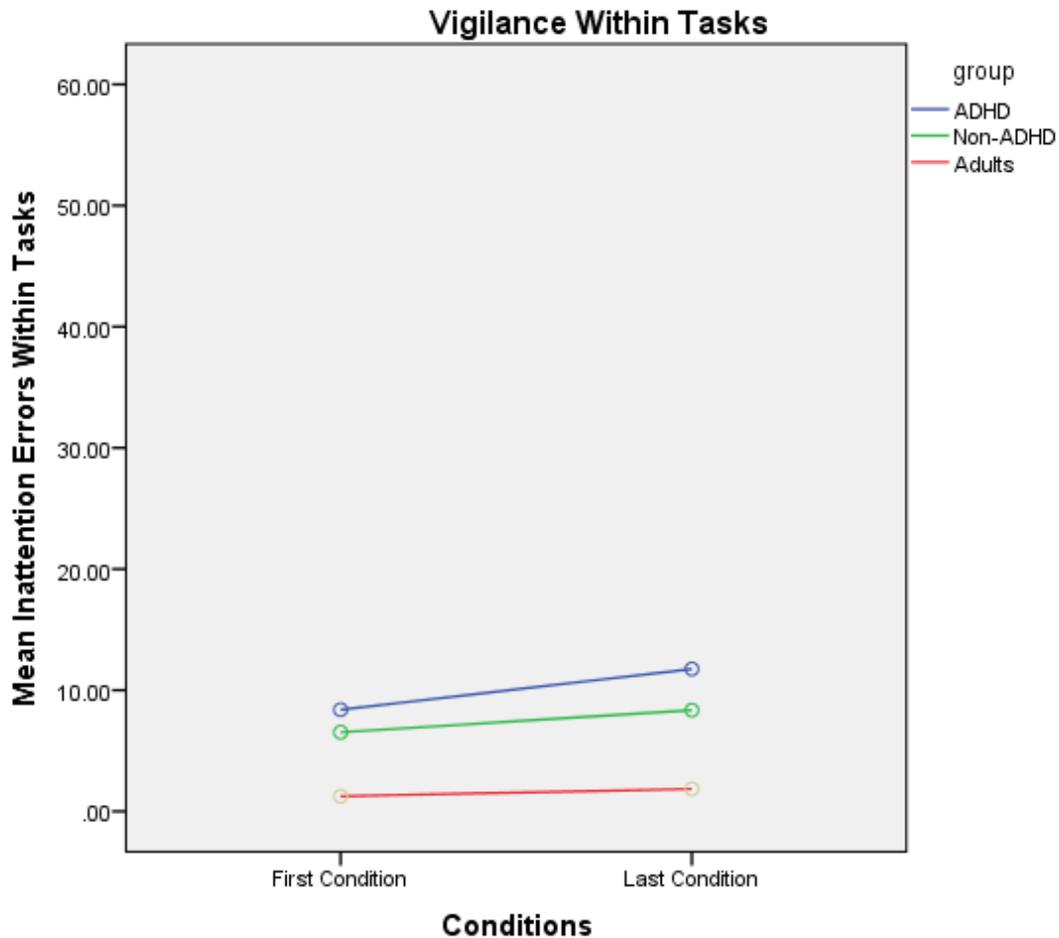
**Table 3.27: Mean inattention errors on the first and last tasks.**



**Figure 3.19: Vigilance from first task to last task in session**

When comparing all inattention errors from the first task to all errors on the last task, the ADHD Group ( $F = 6.27, p = 0.04$ ) and Adult Group ( $p = 0.04$ ) made more errors at the end of the session, while the Non-ADHD Group ( $F = 2.30, p = 0.16$ ) did not have a significant change. Thus, there was evidence for long term vigilance differences.

The figure below presents the averaged inattention errors across condition 1 for all tasks and the averaged inattention errors across condition 4 for all tasks.



**Figure 3.20: Vigilance statistics within each task**

Within subjects repeated measures ANOVA revealed that participants in all three groups made significantly more inattention errors at the end of each task than at the beginning (ADHD  $F = 11.84$ ,  $p < 0.01$ ; Non-ADHD  $F = 9.35$ ,  $p = 0.01$ ; Adult Group  $F = 10.94$ ,  $p < 0.01$ ). There were no differences in the amount of vigilance decrement that the three groups made (i.e., error rate at task end – error rate at task beginning), however.

#### Total Errors

Total errors for first task and last task and for averaged first and last conditions are offered in the table and figures below.

**Descriptive Statistics**

group		Mean	Std. Deviation
ADHD	averageallfirst	15.8889	17.3061
	average of all last conditions	57.3333	30.4426
	total errors in first task	44.3333	29.3981
	total errors in last task	63.3333	37.7690
Non-ADHD	averageallfirst	8.1346	6.07386
	average of all last conditions	36.0769	19.4742
	total errors in first task	28.0000	18.8282
	total errors in last task	42.6154	42.9545
Adults	averageallfirst	1.4423	1.70219
	average of all last conditions	8.5385	8.22208
	total errors in first task	4.6923	4.40425
	total errors in last task	8.7692	9.79076

**Table 3.28: Vigilance statistics total errors**

Figure 3.21 below presents the total errors for task 1 and task 4.

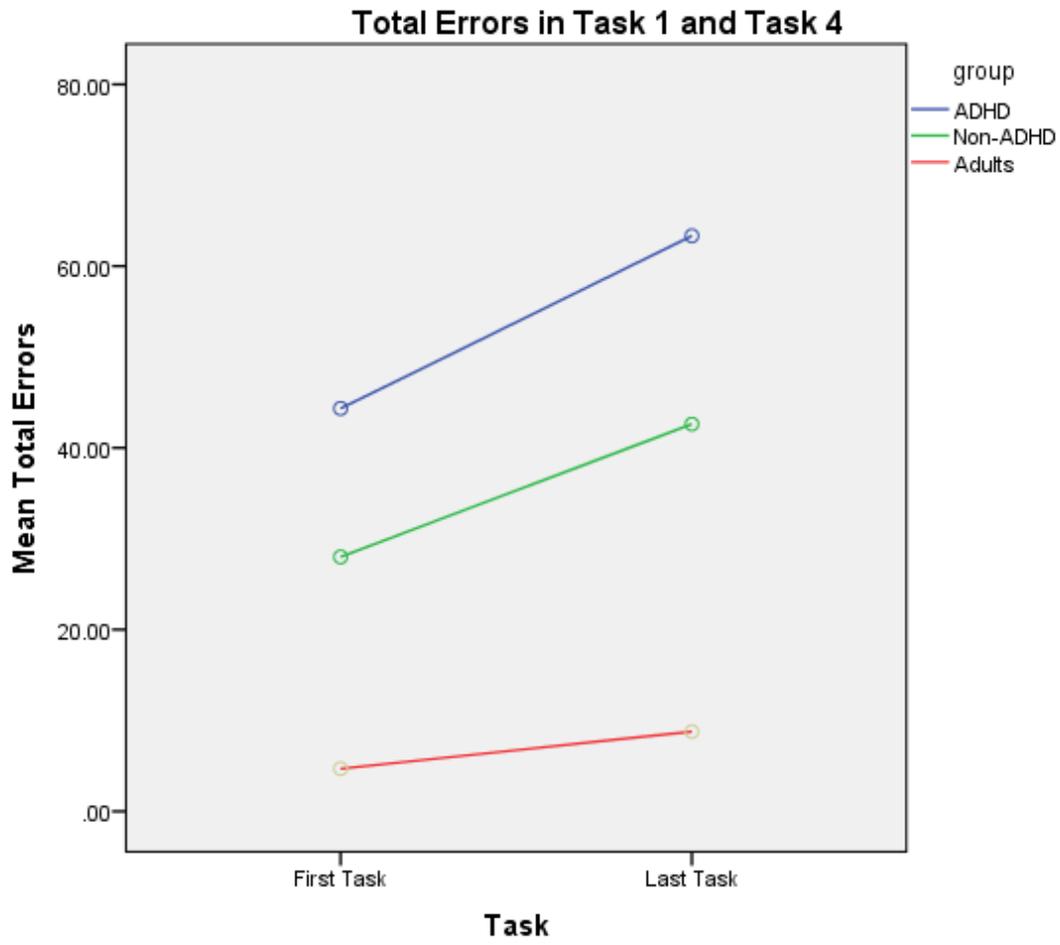
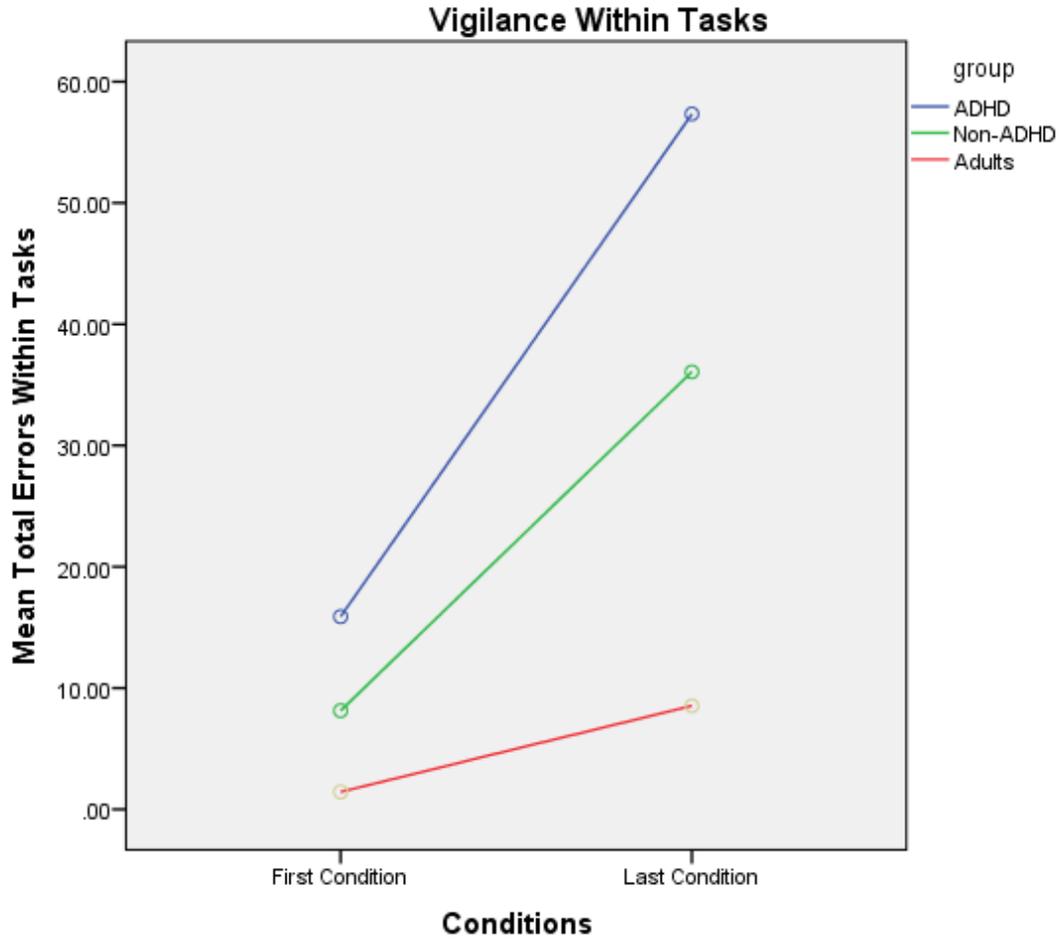


Figure 3.21: Vigilance statistics from the first and last task

Figure 3.22 below presents the averaged inattention errors across condition 1 for all tasks and the averaged inattention errors across condition 4 for all tasks.



**Figure 3.22: Averaged number of errors within the first and last conditions**

A repeated measures ANOVA revealed significant changes in total error numbers from the beginning of the entire session (task 1) to the end of the entire session (task 4) for the ADHD Group ( $F = 11.37$ ,  $p = 0.01$ ) and the Adult Group ( $F = 4.83$ ,  $p = 0.05$ ). There was not a significant difference from the 1<sup>st</sup> task to the 4<sup>th</sup> task for the Non-ADHD Group ( $F = 1.82$ ,  $p = 0.20$ ). There were no significant differences in the amount of vigilance decrement for the Adult vs. the ADHD Group ( $p = 0.24$ ).

The participants in all groups made significantly more errors in the last condition of each task than in the first condition of each task (ADHD  $F = 39.41$ ,  $p < 0.01$ ; Non-ADHD  $F = 4.68$ ,  $p < 0.01$ ; adults  $F = 15.03$ ,  $p < 0.01$ ).

## **Chapter 4: Discussion**

The following sections will offer discussion related to the findings of the present study. First, a discussion of participant behaviors during testing will be offered followed by discussion related to each of the research questions and summary of findings. Limitations of the study will be presented, and potential further research directions will be suggested.

According to the processing efficiency theory (Hartley, Hill and Moore, 2003), performance is determined by attention, cognitive demands of the task, and motivation. In the present study, attention varied between groups (ADHD children, Non-ADHD children, Non-ADHD adults). The use of different perceptual saliency conditions (created by adding background noise in auditory tasks and reduced visual contrast in visual tasks) was used to vary the cognitive demands of the task. Different feedback conditions were used to establish different levels of participant motivation. It was believed that attention status, perceptual saliency, and feedback would produce differences in performance. With respect to perceptual saliency, research has shown that adults perform significantly better on tasks with background noise than children (Hartley, Wright, Hogan, and Moore, 2000; Stuart, 2008). This finding was expected in the current study.

### **BEHAVIOR DURING TESTING**

During the testing session, the participants could see the tester through the window in the audiometric test booth. The participants were told that the tester could see and hear them throughout the session. This may have impacted participant behavior. Although this was a controlled testing environment, simply being aware that they could be watched may have influenced the participants' behavior. Overall, the adults were calm and focused during testing. They did not attempt to gain the tester's attention, and quietly performed the task without

complaining. Unlike the adults, many of the children (both those with and without ADHD) frequently looked at the researcher and attempted to gain her attention at times. Thus, many of the child participants demonstrated awareness that they were being observed throughout testing. This could be a factor in the current study in that while the researcher was not in the test side of the audiometric booth her presence was acknowledged by most of the children. Draeger, Prior and Sanson (1986) found that presence of the examiner had a much greater effect on the performance of hyperactive children on an auditory and visual attention task than on children in a normal control group. When the examiner was present, both groups had similar performance whereas when the examiner was absent the performance of the hyperactive group deteriorated significantly more than that of the control group. Thus, the awareness of being observed could potentially have enhanced the performance of the ADHD children in the current study.

Overall, children were more physically active than the adults during the experimental measures. Many children in the non-ADHD group remained in their seats and focused on the tasks like the adults, but some children in the non-ADHD group exhibited off-task behaviors. Some of the children in the non-ADHD group sang or danced during the test session, and one child put his head on the table during the session and did not continue to attend to the stimuli. Many children in the non-ADHD group complained about the tasks being too difficult or too boring. In the ADHD group, many children also displayed off-task behaviors. Several of them sang and danced during the tasks, and some got out of their chair to walk around near the computer. Many of the children in the ADHD group attempted to talk to the tester, and asked how long the session would be. Overall, the ADHD children displayed more off-task behaviors than the non-ADHD children. While off-track behaviors were not formally tracked, they may have impacted error rates, as will be discussed below.

### **RESEARCH QUESTIONS 1 AND 3**

Research questions 1 and 3 addressed whether performance on challenging auditory (-5 SNR) and visual (Level 3) sustained attention tasks differed within and between participant groups when feedback was varied (i.e., none, long delay, short delay, and immediate). First, the discussion will address different error types (i.e., impulsivity, inattention and total) and then will address reaction times.

According to Barkley's Model of ADHD (1997), poorer performance in children with ADHD is expected when there is either no feedback or a long delay between the stimulus and the feedback. Similarly, based on the Delay Aversion Theory (Sonuga-Barke, Taylor, Sembi, & Smith, 1992), children with ADHD were expected to respond best to stimuli with an immediate reward.

For the experimental tasks studied, it was expected that the most challenging conditions (-5 SNR and Level 3 reduced contrast) would produce high error rates in children that might be differentially affected by different feedback conditions and ADHD status. It was posited that more errors would occur in the no feedback conditions as participant motivation would be the lowest in those conditions and that performance would be better with shorter delays between stimulus presentations and feedback.

#### **Error Types and Rates**

Within all three participant groups (ADHD, non-ADHD, and adults), there were no significant differences in performance across varied feedback conditions for the most challenging auditory (-5 SNR) and visual (reduced contrast level 3) tasks. This was true for all error types (impulsivity errors, inattention errors, and total errors). Given this finding, it is

possible that either the feedback system was not effective in altering performance within experimental conditions (i.e., the presence of feedback instead may have sustained long-term performance and may have impacted or eliminated potential vigilance decrements) or that the expected error rates or related task difficulty did not necessitate “extra effort” or vigilance. Each of these possibilities will be further discussed.

Initially, there was some concern that the token system and gift cards might be too strong of a motivator and would not be realistic when compared with a real world situation. In a classroom setting, for example, children do not receive money as a reward for good behavior or for their performance. It may be, however, that the nature of the feedback system in the current study led to a lack of performance differences within experimental conditions. The reinforcement or reward system used in the current study is an example of a token system. In a token reward system, the participants do not earn a reward for each correct response. They instead earn “tokens,” in this case points, that later can be exchanged for a reward. Other reward systems have been found to impact motivation in ADHD children. In a study by Aase, Meyer, & Sagvolden (2006), children were offered an immediate reward for correct responses, i.e., they were shown a cartoon segment. Children with ADHD had significantly better performance when they were shown the cartoon than when they were not offered any rewards.

Again, in the current study the actual reward (i.e., gift card) was not immediate in any condition. The points earned during some of the conditions were simply tokens to be exchanged for the larger reward at a later time. The real reward for the participants was the gift card, or rather the purchase that the participant could use the gift card to buy. It is worth noting, however, that the immediate feedback condition could be considered, to some extent, a reward system in and of itself. The immediate feedback (+1 for a correct response and -1 for an

incorrect response) could be seen as a motivator, and simply seeing a +1 on the screen can be considered a reward. While the children were enthusiastic about the point system, even the immediate feedback condition did not significantly improve performance.

While the availability of points did not produce performance changes in tasks with different feedback conditions, the points may have helped motivate children to complete the entire set of tasks. The children often became frustrated with the sustained attention tasks, and frequently expressed boredom with the tasks. As stated, the child participants (from both the ADHD group and the non-ADHD group) enjoyed the points. Many of them would yell out their number of points, yell excitedly when they saw “+1,” and complain when they saw “-1” on the screen. Many of them asked after each block if they earned the same number of points as the other participants, and were concerned about their number of points. Again, although many of the child participants stated interest in the points and money to be earned on the gift card, the differing feedback conditions did not produce differences in performance. While the children may not have enjoyed the no feedback condition, the lack of feedback or points in that condition did not significantly change their performance. The adults did not generally state interest in the points and the money, although one adult participant commented that, “seeing my points right away kept me on track, and reminded me of how quickly I had to respond.” The feedback screen may have served as a prompt/reminder to respond before the next stimulus; however, even then the presence of the immediate feedback did not improve performance. Once again, the feedback system used in the current study did not improve performance; however, it may have reduced the possible vigilance decrements observed. In traditional CPT measures, no feedback is offered and a significant vigilance decrement can be observed in some children with ADHD. In the current

study, while there were some significant changes in vigilance, in no circumstance were the ADHD children found to have a significantly greater vigilance decrement.

Another possible reason that varied feedback did not produce performance changes may be due to the overall low error rates on the tasks. Prior to the study it was expected that the most challenging stimulus conditions (-5 SNR for auditory task; Level 3 contrast reduction) would result in a high error rate for the non-ADHD child participants, and an even higher rate for those with ADHD. In contrast, it was expected that the adult participants would have a lower error rate and that the feedback motivator would not have a significant impact. As can be seen in the tables within the Results sections, error rates for even the most challenging auditory and visual tasks under varied feedback conditions were fairly low for all participant groups (i.e., on a 576 trial task typically no more than 15 average errors in any of the groups). If these tasks were easy to begin with then differences based on feedback might not be expected. These low error rates indicate that the conditions were not that challenging and did not require “extra effort” or extra vigilance that the feedback was intended to motivate.

One important finding was that there were significant differences in impulsivity errors (auditory task), inattention errors (visual task) and total errors (auditory) between the groups of children with and without ADHD for the no feedback condition. This is worthy of further study, as the error types were mixed across tasks. While auditory tasks seem to produce many differences, this is worthy of future study.

Some have argued that children with ADHD have a reinforcement deficit. Due to a lack in internal reinforcement, they are more sensitive to external feedback, such as the feedback offered in many of the tasks in the current study. Traditional continuous performance tasks (CPTs) may include a response inhibition paradigm and do not provide feedback, both of which

can increase error rates. This could explain why CPTs may identify performance differences in children with and without ADHD better than the experimental paradigm used in the current study. However, the lower error rates in the current study also indicate that the primary difficulty of children with ADHD may not be sustained attention but may be response inhibition. In considering the findings of the current study and prior research, it appears that the difficulty or challenge of the task and the specific presence and nature of the feedback system all relate to whether the feedback system improves performance.

Feedback is also an important consideration in ADHD management. Effective feedback systems would be helpful in the classroom and at home. Perhaps a different type of feedback could be more effective, such as verbal praise or social reinforcement.

#### Reaction Times

To the researcher's knowledge there is no research relating feedback conditions to participant reaction times. In the current study, there was a penalty for incorrect responding and a point reward for correct responding. The inclusion of penalties and rewards would be expected to encourage participants to fully consider responses before making them. There is a known trade-off between speed and accuracy (Wood & Jennings, 1976) and it was expected that the adult participants would be aware of this trade-off while child participants might not be. It is also possible that the instruction set may have biased participants in regards to reaction time. Participants were instructed to react quickly, but maintain their accuracy.

There were no significant differences in reaction times within groups for the most challenging auditory and visual tasks across feedback conditions. While it was hypothesized that the varied feedback might affect reaction times, it seems that task difficulty had a greater effect on reaction time, at least for the adult group in the auditory task. Substantial differences in

reaction times were observed for the adults between the no noise condition and the tasks with background noise for the adults.

The main finding was that of significant differences between groups for the reaction times on the most challenging auditory and visual tasks across feedback conditions. On the auditory tasks, differences were found between both groups of children and the adult group but reaction times for the two groups of children did not differ, with the exception of in the visual condition with no feedback. It is possible that the children's reaction times did not vary because, overall, reaction time seems to be more influenced by age than ADHD status. Adults seem to understand the relationship between reaction time and performance, and sacrificed reaction time in order to respond correctly. On the visual tasks, the ADHD Group and Non-ADHD child groups had similar reaction times that were shorter than those of the adult group. Similarly, Epstein et al. (2003) reviewed three studies examining reaction times for ADHD and normal children on CPTs and no significant differences in mean RTs were found between the groups of children in any of those studies. Overall, it was proposed that reaction time does not have any relationship with ADHD status.

Overall, adults had longer reaction times than the children. There could be a variety of reasons for this. One possibility is that the adults took longer to respond because they spent time more carefully identifying the stimuli before responding. While the children responded quickly, they may have made more errors because of this, as they may have carelessly responded to non-target stimuli. This pattern of responding would also predict more impulsivity errors for the children, which was found. The adults, because they took extra time to respond, ensured better accuracy of their responses. There is a tradeoff between reaction time and accuracy (Wood & Jennings, 1976) with longer reaction times being associated with better accuracy. It is possible

that the adults understood the tradeoff between reaction time and accuracy, and sacrificed a faster reaction time to increase their accuracy.

The one exception to the finding of similar reaction times for the two child groups, however, was in the visual task when no feedback was provided. The children with ADHD had significantly shorter reaction times on these tasks than the children without ADHD.

### **RESEARCH QUESTIONS 2 AND 4**

Research question 2 addressed whether performance on auditory and visual sustained attention tasks differed within or between participant groups when the perceptual saliency of the stimuli was varied (i.e., no noise/contrast reduction, limited noise/contrast reduction, moderate noise/contrast reduction, high noise/contrast education). First, the discussion will address different error types (i.e., impulsivity, inattention and total) and then will address reaction times.

#### **Error Types and Rates**

Findings from prior studies (e.g., Russell, Culbertson, Faucette, O'Brien, & Givens, in review) have suggested that it is more difficult to maintain attention to stimuli with decreased perceptual saliency. Thus, performance differences across perceptual saliency conditions were expected. This was expected for both adults and children. It was theorized that adults would also struggle with conditions in which perceptual saliency was reduced, and, like children, have decreased performance.

The most difficult auditory condition (-5 signal-to-noise ratio) separated the two groups of children with respect to performance as indicated by differences in impulsivity errors and total errors. A poor SNR (i.e., -7 SNR) previously was found to differentiate the performance of ADHD and Non-ADHD children on auditory CPTs (Russell et al., in review), consistent with results from the current study. This differentiation was not found when comparing performance

of the two child groups on the visual task, and this may be related to the fact that the error rate was lower not allowing for differentiation of performance. The auditory task produced greater error rates, better allowing for differentiation of performance. As the auditory task differentiated the groups of children but the visual task did not, it is also possible that the visual task was not equally difficult to the auditory task. The tasks overall were judged to be difficult in the design phase of the study, while in reality the auditory task was more difficult than the visual task as evidenced by the error rates.

It is difficult to determine differences in performance with lower error rates. In tasks with lower error rates, a “ceiling effect” can be observed, in which the task is too simple for there to be any differentiation in groups. When performance differences are minimal, it is difficult to distinguish between groups.

It is possible that slightly more challenging signal-to-noise ratios (SNRs poorer than -5 SNR) or reduced contrast conditions (less contrast than level 3) might yield more errors, but there is a point at which if the perceptual saliency were further reduced, the words and pictures would be completely indistinguishable and the participants would simply not be able to identify the stimuli. At this point, the task would not be an attentional task at all, and testing would not yield valid results. Again, it may be that the low error rates for these different perceptual saliency conditions rendered some of the tasks fairly easy, not allowing for differential performance.

Real world tasks may present even more difficult challenges and distractions than those used in this study. In a classroom, children are required to do more than just detect a stimulus, they are required to process it and learn. There are also more distractions in the real world than there were in this study. Other children are moving and there is general classroom noise. It is

important to note that the current study utilized a target identification task. In other words, children were required to simply identify a target stimulus and respond. The majority of continuous performance tasks are simple target identification tasks, similar to the tasks used in the present study. Future studies might examine whether more challenging tasks show even greater differentiation between the performance of children with and without ADHD.

### Reaction Times

To the researchers' knowledge, there is no data in the literature relating the perceptual saliency of stimuli on sustained attention tasks with reaction times. However, it was expected that reaction times would be longest for the more challenging conditions (e.g., SNR 0, SNR -5, Level 2 contrast reduction, Level 3 contrast reduction). One would expect longer reaction times because of participant uncertainty in the more challenging conditions.

Within groups, there was no variation in reaction times for the auditory and visual perceptual saliency conditions, i.e., except for the Adult Group which appeared to have shorter reaction times in the no noise condition than in any of the noise conditions. Perhaps those shorter reaction times reflected the easier test condition and response certainty related to the easiest condition.

The reaction times for the two groups of children both differed significantly from the reaction times of the Adult group. The Adult group had longer reaction times, as they did in the varied feedback conditions. Perhaps adults realized the tradeoff between speed and accuracy and slowed their responses accordingly. There were differences in reaction times for the two groups of children in the auditory task for the no noise and the -5 signal to noise ratio tasks, with no consistent pattern of differences.

## **RESEARCH QUESTION 5**

Research Question 5 addressed whether there were performance differences across modalities on the analogous tasks (i.e., auditory and visual tasks with varied feedback conditions; auditory and visual tasks with varied perceptual saliency conditions). Comparable tasks were compared across modalities combining the data from all 3 groups. The tasks compared were the following: auditory vs. visual immediate feedback, auditory vs. visual short delay, auditory vs. visual long delay, auditory vs. visual no feedback, auditory no noise vs. visual no contrast reduction, auditory SNR 5 vs. visual level 1, auditory SNR 0 vs. visual level 2, and auditory SNR 5 vs. visual level 3. First, error types and rates will be discussed, followed by a discussion of reaction time data.

### **Error Types and Rates**

There is limited data comparing performance on analogous auditory and visual sustained attention tasks. A study by Corbett and Constantine (2006) found better performance on visual tasks than auditory tasks for children with and without ADHD. It was expected, however, in the current study that error rates would be similar for the comparable auditory and visual tasks, as the tasks were judged to be of similar difficulty levels.

Impulsivity errors differed only for visual and auditory tasks only at the most difficult level, (i.e., visual level 3 and auditory -5 SNR). Inattention errors varied for the immediate feedback, short delay, long delay, no feedback and level 2 reduced perceptual saliency (i.e., level 2 reduced contrast and SNR 0) conditions. Total errors varied between modalities for only the immediate feedback and short delay conditions. In all circumstances, performance was poorer on the visual tasks.

The pattern of differences above when all groups were combined also indicates that the visual tasks with distortion were more difficult than the auditory tasks with distortion. This is similar to the results found by other researchers. Overall, visual tasks produce greater error rates than auditory tasks when all groups were combined. There are several possible reasons for this. Firstly, visual tasks could just be more challenging than the auditory tasks overall, regardless of the task type. A second possibility is that the auditory and visual stimuli with distortion were judged to be the same level of difficulty, while that was not actually the case. It is possible that the amount of distortion was greater with the visual stimuli.

In the current study, participants differed in their opinions as to whether the auditory or visual tasks were more difficult. Both children and adults provided the tester with feedback as to which tasks they found to be most difficult. Some participants stated that the auditory tasks were less challenging than the visual tasks. They stated that during the auditory tasks they did not have to expend as much effort to respond accurately. They could look around the room, or allow their minds to wander during the auditory tasks. During the visual tasks, they felt that they had to concentrate more on the monitor to maintain accuracy.

Some other participants found the visual tasks to be less challenging than the auditory tasks. These participants felt that they benefited in having to watch the monitor. They stated that during the visual tasks, they had to focus their attention on the screen. This helped them to limit distractions by focusing their attention on the screen. During all of the testing, they were in the same environment, free of auditory distractors, so during the visual tasks there were not any kind of auditory distractions.

While the participants had varying opinion as to whether the auditory or visual tasks were different in their difficulty levels, it is unknown whether participant report had any relationship

to actual error rates. For example, one participant may report increased difficulty with auditory tasks, but in fact have greater error rates on visual tasks. Perhaps some individuals are simply auditory or visual learners, and find that they are able to perform tasks best in one modality. One could design a study in which participants were asked to estimate their performance, or error rates, on tasks in different modalities and then performance in those modalities could be compared to estimates based on actual error rates.

### Reaction Times

It should be noted that reaction time was significantly different across modalities for all conditions except one, the no feedback condition. The reasoning for this is unknown and warrants further study.

### **RESEARCH QUESTION 6**

Research question six addressed whether there were changes in performance over time (vigilance) on auditory and visual tasks within each of the four conditions within the task; and from the beginning to the end of the entire test session. Vigilance, the ability to maintain performance over an extended period of time, was measured in two different ways.

First, performance was compared within each 12-minute task and this was the traditional vigilance measure. Error numbers on the first condition within each of the four tasks (i.e., first 3 minutes of each task) were calculated. These error rates were then averaged across conditions. The error numbers on the last condition of each of the four tasks (i.e., last 3 minutes of each task) were also averaged across the tasks. This gave an average number of errors within the first few minutes of each of the four tasks as well as an averaged number of errors within the last few minutes of each task. This compared vigilance over a shorter period of time, approximately 12

minutes. This time frame is similar to the time frame used in most continuous performance tasks.

In addition, vigilance across the entire test session was compared and this was the long-term vigilance measure. Performance on all conditions of the first of the four tasks was compared to performance on all four conditions of the final task. This gave a long term comparison of performance, over the course of approximately an hour. This longer duration comparison is not used in continuous performance tasks.

It was expected that within all groups there would be a significant vigilance decrement, but with a larger decrement for the ADHD children on both measures of vigilance. This was expected because a greater than expected vigilance decrement is a sign of difficulties with sustained attention which is considered to be a hallmark of ADHD.

All three groups made significantly more inattention and total errors at the end of each task than at the beginning (i.e., and not for impulsivity errors). That 12-minute timeframe is comparable to the length of most CPTs reported in the literature. This finding is important in ADHD diagnostic testing. Previous studies mentioned (e.g., Nigg, 2006) have suggested that a significant vigilance decrement is common in children with ADHD. The findings from the present study suggest, however, that all participants have a significant vigilance decrement across the 12-minute timeframe.

A short term vigilance decrement was found for all three groups. Perhaps short term vigilance decrement cannot be used to reliably differentiate children with ADHD from children without ADHD. In fact, this finding calls to question whether children with ADHD have difficulties with sustained attention. Barkley (1997) proposed the Executive Dysfunction Theory which states that children with ADHD have an overall decrease in executive control and

not a sustained attention deficit. This is a controversial finding, as the tasks used in the current study are similar to those used in traditional continuous performance tasks. This finding is also controversial, as vigilance decrement is considered to be a hallmark sign of ADHD. This study, however, did not find a greater amount of vigilance decrement. An alternative explanation is that the use of a feedback system reduced the vigilance decrement measured in the current study.

Long-term vigilance will now be discussed. Long term vigilance decrement was measured from the beginning to the end of the entire 1.5 hour session (i.e., comparing task 1 and task 4 performance). In regards to beginning and end of session (long term) vigilance decrement, the adults and the non-ADHD children also performed significantly better at the beginning of each task than at the end, and not just the ADHD children. There was no difference, however, in the amount of vigilance decrement within groups. In other words, all three groups performed better at the beginning than at the end, but the change in performance was not significantly different between the groups.

Again, there were no significant differences in impulsivity errors from the beginning of the entire session to the end. Inattention errors changed significantly only for the ADHD group over the entire session, a very important finding, as this may be a possible way to separate the ADHD group from the Non-ADHD and Adult groups. For total errors, there was a significant increase in errors from beginning to end for the ADHD group and the Adult group, but not for the non-ADHD children. The overall pattern observed is a long-term vigilance decrement, exhibited by increased inattention errors for the ADHD group only. Thus, further investigation of long-term vigilance decrements may be warranted. When applying this finding to diagnostic testing, this study suggests a possible need for longer continuous performance tests. Sustained attention tasks of greater than 12-15 minutes may be needed to separate children with ADHD from those that do

not have ADHD. This would allow testers to separate the differences in vigilance decrement, as all groups experienced a short term vigilance decrement.

There were no significant differences in the amount of vigilance decrement when comparing the ADHD group and the adult group, however. In other words, when comparing the amount of change in performance between the two groups, a difference was not found. Inattention differences warrant further study, however, as those could differentiate the groups.

## **GENERAL FINDINGS**

### **Children and Adults**

Overall, the main finding of this study is that these sustained attention tasks can separate the performance of children from that of adults based on error numbers, but not differentiate consistently between children with and without ADHD. Overall, adults generally had lower error rates, including inattention errors, impulsivity errors, and total errors. Adults seem to represent a “best performance” group, in that in all tasks, adults performed better than both groups of children. The adults had overall fewer errors on all experimental tasks.

Sustained attention tasks can also separate children with and without ADHD in conditions in which feedback is limited or not present as evidenced by long term vigilance measures. These findings warrant future study, as they have ramifications on both ADHD diagnostic testing and management. In addition, changing perceptual saliency in these tasks can change error rates in children. This suggests that there is value in adding distortion to tasks, as tasks with distortion appear to be better able to differentiate children with ADHD from those without ADHD than tasks without distortion. This finding is important for future ADHD diagnostic testing.

One interesting finding was that overall, adults had longer reaction times than both groups of children. There could be a variety of reasons for this. One possibility is that the adults took longer to respond because they spent time more carefully identifying the stimuli before responding. While the children quickly responded, they may have made more errors because of this, as they may have carelessly responded to non-target stimuli. The adults, because they took extra time to respond, ensured better accuracy of their responses (Wood & Jennings, 1976). Perhaps, the adults realized the trade-off between quick responding and accuracy and that is why they had longer RTs and better accuracy.

One important finding was that there were significant differences between the adults and the two groups of children for almost all conditions and error types. This suggests that there were differences related to maturity. There is evidence that performance is age-related on other continuous performance tests reported in the literature (Conners, Epstein, Angold, & Klaric, 2003; Hagelthorn, Hiemenz, Pillion, & Mahone, 2003). The finding of age difference in performance is also consistent with processing efficiency theory.

#### Continuous Performance Tasks (CPTs)

Evidence presented from some earlier studies had suggested that continuous performance tasks do not consistently separate children with ADHD from children without ADHD (e.g., Tucha et al., 2009). The present study found similar results, especially when using shorter (approximately 10-12 minute) sustained attention tasks with limited feedback. Although there was a trend for children with ADHD to make more errors than children without ADHD, there was not a clear pattern of different error types across the different task types exhibited. The ADHD group had significantly higher error rates when feedback was not utilized, as well as in conditions in which a degraded auditory stimulus was used. No consistent pattern in errors

across visual tasks with degraded stimuli were found, however. This is an important finding also, as visual tasks are commonly used in ADHD diagnosis.

The main distinguishing factor between participants without ADHD (children and young adults) and the ADHD children on vigilance measures was the significant increase in inattention errors for the ADHD children on the long-term vigilance measure. The ADHD children had significantly more inattention errors at the end of the 1.5 hour research session when compared to initial performance. Perhaps, long-term vigilance decrement is a more important factor in ADHD children than the short-term vigilance measures included in most CPTs. This is an interesting finding, as this vigilance decrement was found in both ADHD children and adults. It warrants further study to determine if it can reliably separate all three groups.

It is also important to remember that CPT and sustained attention tasks differ in many ways from real-world attention tasks. In a real-world classroom setting, there are many different external factors (i.e., not associated with the stimulus) that can reduce perceptual saliency of the signal. In the real world, visual and auditory signals can be obscured in different ways (i.e., not simply by reduced contrast or steady noise as in the current study) such as by multiple and unpredictable external distractors, for example those caused by other children moving and talking. It is possible that in real-world settings perceptual saliency is even poorer than in the current research conditions and that there would be increased attention difficulties. Real-world attending also differs with respect to the potential foci of attention. First, unlike listening or watching for a single known target (i.e., picture of dog; spoken word “dog”), real-world attention involves listening and watching for known and unknown targets (i.e., visuals, words, phrases, and environmental noises). Because of all of the differences noted between CPT tasks and real-

world challenges, observation of children in real-world settings remains important in ADHD diagnosis.

### Limitations of the Study

This study had several limitations. Limitations of the study will be discussed in the following section, along with ways in which these limitations might be addressed.

The impact of gender on performance may have been a factor in the present study. There were no statistically significant differences in gender distributions between the groups; however, there were more males than females in the ADHD group, and more females than males in the two other groups. It is possible that gender may have impacted the participants' performance, and gender as a factor cannot be discounted. In future research, gender ratios should be noted, and attempts to gender balance the participant groups should be made.

A second limitation of the study is that despite parental advisement to not offer medications on the test date, some children participating in the study had taken their medication on the test date and their data had to be removed from most of the analyses. With the exception of comparing modalities, this study did not include children with ADHD who took their medication on the day of testing.

A third limitation of this study was that all case information was supplied by the parents for child participants, and by the individual for adult participants. No ADHD testing was conducted at the session; children with ADHD simply had a parent report of diagnosis. Future studies may want to include a confirmation of ADHD through a designated assessment battery.

Another weakness in the study is that the tasks were not demanding enough to result in high error rates. Thus, error rates for even the most challenging perceptual saliency conditions were low, making it difficult to differentiate the effects of feedback.

There was also a broad age range for the children participating in the present study (ages 8-13). More recent studies have shown children ages 8-9 differ in their performance from children ages 10 and older. It is possible that performance on these tasks is developmental in nature, and may have less to do with ADHD status than age. Findings may have been different if age groups had been separated, as younger children tend to perform more poorly than older children. The present study included poorer performers and better performers within all groups.

The presence of feedback in selected conditions throughout the experimental session may have limited the vigilance decrements observed. Most sustained attention and CPT studies have not used feedback (such as the Connors Continuous Performance Task).

A final limitation of the study is the number of F tests used. It is possible that because so many F tests were required, some of the variation found may have simply been random. As the number of F tests used increases, the possibility of simple random error also increases.

#### Further Research Directions

Further research could potentially look at ways of improving ADHD diagnostic testing. This study questions the use of some continuous performance task measures in identifying children with ADHD due to a lack of differences between the ADHD group and the Non-ADHD group. Further research could use a different task type, (e.g., with more real-world targets and distractors) and compare results from children with ADHD to results from children without ADHD. Further research could look at the role of distractors, and determine if children with ADHD perform differently from those without ADHD when there are distractors present.

Additionally, further research could investigate whether the participants perform differently when the tester is not visible (Corkum & Siegel, 1993). In the present study the tester could be seen through a window at all times, and participants were told that the tester could see

and hear them. If the tester were not present, it is possible that performance could have changed. The children may be more likely to display off-task behaviors when they knew that there was not an adult watching them. A possible future study could repeat the current study tasks, but with the tester out of the participant's view.

Further research could also examine the impact of ADHD medication use on performance. Some ADHD participants in the present study took their medication the day of testing, some did not take their medication the day of testing, and some were not prescribed medication for ADHD. The children that took their medication were not included in analysis, with the exception of comparing modalities, however. Further research could analyze the error rates of children in each of these groups to see if medication use impacts performance on these tasks.

Reaction time variability is another factor that might be further studied. Epstein et al. (2003) found that increased variability in reaction times was related to ADHD symptoms. They stated that this may be due to an inconsistent response pattern in children with ADHD.

Different types of feedback could also be examined. In the present study, participants were earning points in addition to earning a financial reward (greater value gift card). Further research could vary the reward and examine differences in performance.

Children could also be trained to maintain performance with increasing delays in feedback delivery. In the real world, feedback is often delayed or nonexistent. As children could be trained to accept limited or nonexistent feedback, performance could be examined.

Lastly, the relationship between continuous performance or sustained attention task performance and real world performance could be studied. Parent and teacher report could be compared to continuous performance task performance. Classroom behavior could also be

compared to continuous performance task performance. It is possible that there is a relationship between real world behavior and performance on these tasks.

## References

- Aase, Meyer, & Sagvolden. (2006, March). Moment-to-moment dynamics of ADHD behaviour in South African children. *Behav Brain Funct*, 28(2:11).
- Allport. (1980). Attention and performance. In Claxton, *Cognitive psychology: New directions* (pp. 112-153). London: Routledge & Kegan Paul.
- American Academy of Child and Adolescent Psychiatry. (2007). Practice Parameter for the Assessment and Treatment of Children and Adolescents With Attention Deficit/Hyperactivity Disorder. *J Am Acad Child Adolesc Psychiatry*, 4(7), 894-921.
- American Academy of Pediatrics Subcommittee on Attention Deficit/Hyperactivity Disorder. (2011). ADHD: Clinical Practice Guideline for the Diagnosis, Evaluation, and Treatment of Attention-Deficit/Hyperactivity Disorder in Children and Adolescents. *Pediatrics*, 28(5), 1-18. doi:10.1542/peds.2011-2654
- American Psychiatric Association. (2011). *Diagnostic and Statistical Manual of Mental Disorders IV*.
- American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.
- American Speech Language Hearing Association (ASHA). (2005). (Central) Auditory Processing Disorders [Technical report].
- American Speech-Language-Hearing Association. (2005). (Central) Auditory Processing Disorders. 1-20.
- Andrews, & Dowling. (1991). The development of perception of interleaved melodies and control of auditory attention. *Music Perception*, 8, 349–368.
- Antrop, Stock, Verte, Wiersema, Baeyens, & Roeyers. (2006). ADHD and delay aversion: the influence of non-temporal stimulation on choice for delayed rewards. *J Child Psychol Psychiatry*, 47(11), 1152-8. doi:1111/j.1469-7610.2006.01619.x
- Baddeley. (1992, Summer). Working Memory: The Interface between Memory and Cognition. *J Cogn Neurosci*, 4(3), 281-8. doi:10.1162/jocn.1992.4.3.281
- Barkley. (1997). Behavioral Inhibition, Sustained Attention, and Executive Functions: Constructing a Unifying Theory of ADHD. *Psychological Bulletin*, 121(1), 65-94.

- Beck, Bransome, Mirsky, Rosvold, & Sarason. (1956, October). A continuous performance test of brain damage. *J Consult Psychol*, 20(5), 343-50.
- Beck, J. (1967). Perceptual grouping produced by line figures. *Perception & Psychophysics*, 2, 491-495.
- Becker, & Morris. (1999, October). Working Memory(s). *Brain Cogn*, 41(1), 1-8.
- Betts, McKay, Maruff, & Anderson. (2006, June). The development of sustained attention in children: the effect of age and task load. *Child Neuropsychol*, 12(3), 205-21.
- Biederman, Spencer, Monuteaux, & Faraone. (2010). A naturalistic 10-year prospective study of height and weight in children with attention-deficit hyperactivity disorder grown up: sex and treatment effects. *J Pediatr*, 157(4), 635-40. doi:10.1016/j.jpeds.2010.04.025
- Bjorklund, & Harnishfegar. (1995). The evolution of inhibition mechanisms and their role in human cognition and behavior. In Dempster, & Brainerd, *Interference and inhibition in cognition* (pp. 142-69). San Diego: Academic Press.
- Broadbent. (1953). *Perception and Communication*. London: Pergamon Press.
- Broadbent. (1970). *Stimulus set and response set: Two kinds of selective attention*. New York: Appleton-Century-Crofts.
- Broadbent. (1971). *Decision and Stress*. London: Academic Press.
- Brown, Turner, Mano, Bolden, & Thomas. (2013, September). Experimental manipulation of working memory model parameters: an exercise in construct validity. *Psychol Assess*, 25(3), 844-58. doi:10.1037/a0032577
- Buss, & Hall, G. (2006). Development and the role of internal noise in detection and discrimination thresholds with narrow band stimuli. *J Acoust Soc Am.*, 120(5 part 1), 2777-2788.
- Centers for Disease Control and Prevention. (2010). *Attention Deficit/Hyperactivity Disorder (ADHD)*. Retrieved from Centers for Disease Control and Prevention: <http://www.cdc.gov/ncbddd/adhd/data.html>
- Cherry. (2013). *What Is Extrinsic Motivation?* Retrieved from About.com: <http://psychology.about.com/od/eindex/f/extrinsic-motivation.htm>
- Christakou, Murphy, Chantiluke, Cubillo, Smith, Giampietro, . . . Rubia. (2013, February). Disorder-specific functional abnormalities during sustained attention in youth with Attention Deficit Hyperactivity Disorder (ADHD) and with autism. *Mol Psychiatry*, 18(2), 236-44. doi:10.1038/mp.2011.185

- Collingwood. (2010). *Side Effects of ADHD Medications*. Retrieved from Psych Central: <http://psychcentral.com/lib/side-effects-of-adhd-medications/0003782>
- Conners. (1995). *Conners' Continuous Performance Test* (2nd ed.). Toronto, Canada: Multimedia Health Systems.
- Conners, Epstein, Angold, & Klaric. (2003). Continuous Performance Test Performance in a Normative Epidemiological Sample. *Journal of Abnormal Child Psychology*, 31(5), 555-562.
- Coon, & Mitterer. (2010). *Introduction to psychology: Gateways to mind and behavior with concept maps*. Belmont- California: Wadsworth.
- Corbett, & Constantine. (2006). Autism and attention deficit hyperactivity disorder: assessing attention and response control with the integrated visual and auditory continuous performance test. *Child Neuropsychology*, 1-40.
- Corkum, & Siegel. (1993). In the continuous performance task a valuable research tool for use with children with Attention-Deficit-Hyperactivity Disorder? *J Child Psychol. Psychiat.*, 34(7), 1217-1239.
- Cortese, Holtmann, Banaschewski, Buitelaar, Coghill, Danckaerts, . . . Sergeant. (2013). Practitioner review: current best practice in the management of adverse events during treatment with ADHD medications in children and adolescents. *J Child Psychol Psychiatry*, 54(3), 227-46. doi:10.1111/jcpp.12036
- Demaray, Schaefer, & Delong. (2003). Attention-Deficit/Hyperactivity Disorder (ADHD): A national survey of training and current assessment practices in the schools. *Psychology in the Schools*, 40(6), 583-597. doi:10.1002/pits.10129
- Dempster. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, 12, 45-75.
- Deutch, & Deutsch. (1963, January). Attention: Some Theoretical Considerations. *Psychological Review*, 70(1), 80-90. doi:10.1037/h0039515
- Draeger, Prior, & Sanson. (1986, September). Visual and auditory attention performance in hyperactive children: competence or compliance. *J Abnorm Child Psychol*, 14(3), 411-24.
- Driver. (2001). A selective review of selective attention research from the past century. *British Journal of Psychology*, 92, 53-78.
- Enns, & Cameron. (1987, August). Selective attention in young children: the relations between visual search, filtering, and priming. *J Exp Child Psychol*, 44(1), 38-63.

- Enns, & Girgus. (1985, October). Developmental changes in selective and integrative visual attention. *J Exp Child Psychol*, 40(2), 319-37.
- Epstein, Erkanli, Conners, Klaric, Costello, & Angold. (2003). Relations between Continuous Performance Test performance measures and ADHD behaviors. *J Abnorm Child Psychol*, 31(5), 543-54.
- Eriksen. (1958). Effects of practice with or without correction on discriminative learning. *Am J Psychol*, 71(2), 350-8.
- Florida Department of Education. (2001). *AIT Institute*. Retrieved from Central Auditory Processing Disorder (CAPD): Glossary of Terms:  
[http://www.aitinstitute.org/central\\_auditory\\_processing\\_disorder\\_glossary.htm](http://www.aitinstitute.org/central_auditory_processing_disorder_glossary.htm)
- Foundation for Medical Practice Education. (2008). *ADHD Rating Scale*. Retrieved from [www.fmpe.org](http://www.fmpe.org)
- Gold, Bennett, & Sekuler. (1999). Signal but not noise changes with perceptual learning. *Nature*, 402, 176–178.
- Green, Doesburg, Ward, & McDonald. (2011, March 9). Electrical neuroimaging of voluntary audiospatial attention: evidence for a supramodal attention control network. *J Neurosci*, 31(10), 3560-4. doi:10.1523/JNEUROSCI.5758-10.2011
- Greenberg, & Waldman. (1993, September). Developmental normative data on the test of variables of attention (T.O.V.A.). *J Child Psychol Psychiatry*, 34(6), 1019-30.
- Grier, Warm, Dember, Matthews, Galinsky, Szalma, & Parasuraman. (2003, Fall). The vigilance decrement reflects limitations in effortful attention, not mindlessness. *Hum Factors*, 45(3), 349-59.
- Groome, D. (2013). *An Introduction to Cognitive Psychology: Processes and Disorders*. Psychology Press.
- Gumenyuk, Korzyukov, Alho, Escera, & Näätänen. (2004, January). Effects of auditory distraction on electrophysiological brain activity and performance in children aged 8-13 years. *Psychophysiology*, 41(1), 30-6.
- Hagelthorn, Hiemenz, Pillion, & Mahone. (2003). Age and task parameters in continuous performance tests for preschoolers. *Percept Mot Skills*, 96(3 pt 1), 975-89.
- Hahn, Wolkenberg, Ross, Myers, Heishman, Stein, . . . Stein. (2008, June 18). Divided versus selective attention: evidence for common processing mechanisms. *Brain Res*, 1215, 137-46. doi:doi: 10.1016/j.brainres.2008.03.058

- Hartley, Hill, & Moore. (2003). The auditory basis of language impairments: temporal processing versus processing efficiency hypotheses. *Int J Pediatr Otorhinolaryngol*, 67, S137-42.
- Hartley, Wright, Hogan, & Moore. (2000). Age-related improvements in auditory backward and simultaneous masking in 6- to 10-year-old children. *J Speech Lang Hear Res*, 43(6), 1402-15.
- Hill, & Moore. (2002). A role for processing efficiency in auditory temporal processing. *ISCA*.
- Hill, Hartley, Glasberg, Moore, & Moore. (2004). Auditory processing efficiency and temporal resolution in children and adults. *J Speech Lang Hear Res*, 47(5), 1022-9.
- Hodgkins, Shaw, Coghill, & Hechtman. (2012). Amphetamine and methylphenidate medications for attention-deficit/hyperactivity disorder: complementary treatment options. *Eur Child Adolesc Psychiatry*, 21(9), 477-92. doi:10.1007/s00787-012-0286-5
- Howard, Munro, & Plack. (2010, December). Listening effort at signal-to-noise ratios that are typical of the school classroom. *Int J Audiol*, 49(12), 928-32. doi:10.3109/14992027.2010.520036
- Hurlbert. (2000). Visual perception: Learning to see through noise. *Current Biology*, 10(6), R231–R233.
- Itti, & Koch. (2001, March). Computational modelling of visual attention. *Nat Rev Neurosci*, 2(3), 198-203.
- Johnson, & Dark. (1982, June). In defense of intraperceptual theories of attention. *Journal of Experimental Psychology: Human Perception and Performance*, 8(3), 407-421.
- Johnson, Wiersema, & Kuntsi. (2009). What would Karl Popper say? Are current psychological theories of ADHD falsifiable? 5(15). doi:10.1186/1744-9081-5-15
- Jones, & Morris. (1992, September). Irrelevant speech and serial recall: implications for theories of attention and working memory. *Journal of Experimental Psychology: Human Perception and Performance*, 33(3), 407-421.
- Jones, Moore, Amitay, & Shub. (2013, February). Reduction of internal noise in auditory perceptual learning. *J Acoust Soc Am*, 133(2), 970-81. doi:10.1121/1.4773864
- Kahneman, D. (1973). *Attention and Effort*. Englewood Cliffs, New Jersey: Prentice Hall Incorporated.
- Keith. (1994). *Auditory Continuous Performance Test*. San Antonio, Texas: The Psychological Corporation Harcourt Brace & Company.

- Klein, & Abikoff. (1997). Behavior therapy and methylphenidate in the treatment of children with ADHD. *Journal of attention disorders*, 2(2), 89-114.
- Klein, Wendling, Huettner, Ruder, & Peper. (2006). Intra-subject variability in attention-deficit hyperactivity disorder. *Biol Psychiatry*, 60(10), 1088-97.
- Kuk, Jackson, Keenan, & Lau. (2008, June). Personal amplification for school-age children with auditory processing disorders. *J Am Acad Audiol*, 19(6), 465-80.
- Lahey, Pelham, Loney, Lee, & Willcutt. (2005). Instability of the DSM-IV Subtypes of ADHD from preschool through elementary school. *Arch Gen Psychiatry*, 62(8), 896-902.
- Lavie, Hirst, Fockert, & Viding. (2004, September). Load theory of selective attention and cognitive control. *J Exp Psychol Gen*, 133(3), 339-54.
- LeFever, Hannon, Dawson, Morrow, & Morrow. (1997). Prevalence of Medication Use for Attention Deficit Hyperactivity Disorder(ADHD): A Population-Based Study of Virginia School Children. *Pediatric Research*, 41, 14-14. doi:10.1203/00006450-199704001-00093
- Logan, G. (2004). Cumulative progress in formal theories of attention. *Annu Rev Psychol*, 55, 207-34.
- Mairena, Martino, D., Domínguez-Martín, Gómez-Guerrero, Gioia, Petkova, & Castellanos. (2012). Low frequency oscillations of response time explain parent ratings of inattention and hyperactivity/impulsivity. *Eur Child Adolesc Psychiatry*, 21(2), 101-9. doi:10.1007/s00787-011-0237-6
- Mayo Foundation for Medical Education and Research. (2013). *Attention deficit/hyperactivity Disorder (ADHD) in children*. Retrieved from Diseases and Conditions: <http://www.mayoclinic.org/diseases-conditions/adhd/basics/definition/con-20023647>
- McCarney, & Arthaud. (2004). *Attention Deficit Disorders Evaluation Scale-3rd Ed*. Hawthorne Educational Services, Inc.
- McGee, Clark, & Symons. (2000, October). Does the Conners' Continuous Performance Test aid in ADHD diagnosis? *J Abnorm Child Psychol*, 28(5), 415-24.
- Merriam-Webster. (2013). *Merriam-Webster*. Retrieved from <http://www.merriam-webster.com/>
- Michelson, Allen, Busner, Casat, Dunn, Kratochvil, . . . Harder. (2002). Once-daily atomoxetine treatment for children and adolescents with attention deficit hyperactivity disorder: a randomized, placebo-controlled study. *Am J Psychiatry*, 159(11), 1896-901.

- National Institute of Mental Health. (2012). *What is attention deficit hyperactivity disorder?* Retrieved from National Institutes of Health: [http://www.nimh.nih.gov/health/publications/attention-deficit-hyperactivity-disorder/index.shtml?utm\\_source=REFERENCES\\_R7](http://www.nimh.nih.gov/health/publications/attention-deficit-hyperactivity-disorder/index.shtml?utm_source=REFERENCES_R7)
- Neisser, U. (2009). *Cognitive Psychology*. Grolier Multimedia Encyclopedia.
- Nigg, (2006). *What Causes ADHD? Understanding What Goes Wrong and Why*. New York, NY: Guilford Press .
- Norman. (1968). Toward a theory of memory and attention. *Psychological Review*, 75(6), 522-536. doi:10.1037/h0026699
- Oord, V. d., Prins, Oosterlaan, & Emmelkamp. (2008). Efficacy of methylphenidate, psychosocial treatments and their combination in school-aged children with ADHD: a meta-analysis. *Clin Psychol Rev*, 28(5), 783-800.
- Parasuraman, & Davies. (1984). *Varieties of Attention*. Toronto: Academic Press.
- Passow, Muller, Westerhausen, Hugdahl, Wartenburger, Heekeren, . . . Li. (2013). Development of attentional control of verbal auditory perception from middle to late childhood: comparisons to healthy aging. *Developmental Psychology*, 49(10), 1982-1993. doi:10.1037/a0031207
- Polanczyk, & Rohde. (2007). Epidemiology of attention-deficit/hyperactivity disorder across the lifespan. *Curr Opin Psychiatry*, 20(4), 386-92.
- Posner, & Petersen. (1990). The attention system of the human brain. *Annu Rev Neurosci*, 13, 25-42.
- Powers, Hillock, & Wallace. (2009). Perceptual training narrows the temporal window of multisensory binding. *J Neurosci*, 29(39), 12265-74. doi:10.1523/JNEUROSCI.3501-09.2009
- Prior, & Sanson. (1986). Attention deficit disorder with hyperactivity: a critique. *J Child Psychol Psychiatry*, 27(3), 307-19.
- Riccio, Cohen, Hynd, & Keith. (1996, September). Validity of the Auditory Continuous Performance Test in differentiating central processing auditory disorders with and without ADHD. *J Learn Disabil*, 29(5), 561-6.
- Richardson. (2008). Inhibitory Control in Psychiatric Disorders—A Review of Neuropsychological and Neuroimaging Research. *Undergraduate Research Journal for the Human Sciences*, 7.

- Rohde, Biederman, Busnello, Zimmermann, Schmitz, Martins, & Tramontina. (1999). ADHD in a school sample of Brazilian adolescents: a study of prevalence, comorbid conditions, and impairments. *J Am Acad Child Adolesc Psychiatry, 38*(6), 617-22.
- Root, & Resnick. (2003). An update on the diagnosis and treatment of attention-deficit/hyperactivity disorder in children. *Professional Psychology: Research and Practice, 34*(1), 34-41.
- Ross, & Ross. (1976). *Hyperactivity: Research, Theory, Action*. New York: Wiley.
- Russell, Culbertson, Faucette, O'Brien, & Givens. (2013). FM Benefit in Children With and Without Attention Deficit Hyperactivity Disorder (ADHD) on Listening in Noise Tasks. *In submission*.
- Ryan, & Deci. (2001). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology, 25*, 54-67.
- Sagvolden, Johansen, Aase, & Russell. (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *Behav Brain Sci, 28*(3), 397-419.
- Seidel, & Joschko. (1990, April). Evidence of difficulties in sustained attention in children with ADDH. *J Abnorm Child Psychol, 18*(2), 217-29.
- Seitz, & Watanabe. (2005, July). A unified model for perceptual learning. *Trends Cogn Sci, 9*(7), 329-34.
- Shepp. (1978). From Perceived Stimuli to Dimensional Structure: A New Hypothesis About Perceptual Development. *Cognition and Categorization*.
- Shepp. (1983). The Analyzability of Multidimensional Objects: Some Constraints on Perceived Structure, the Development of Perceived Structure, and Attention. *Perception, cognition, and development, 39-75*.
- Shepp, Burns, & McDonough. (1980, September). Relationship of perceived stimulus structure and intelligence: further tests of a separability hypothesis. *Am J Ment Defic, 91*(2), 196-200.
- Silverstein, Weinstein, & Turnbull. (2004). Nonpatient CPT performance varying target frequency and interstimulus interval on five response measures. *Arch Clin Neuropsychol, 19*(8), 1017-25.

- Sjowall, Roth, Lindqvist, & Thorell. (2013). Multiple deficits in ADHD: executive dysfunction, delay aversion, reaction time variability, and emotional deficits. *J Child Psychol Psychiatry*, 54(6), 619-27. doi:10.1111/jcpp.12006
- Sonuga-Barke. (2002). Psychological heterogeneity in AD/HD--a dual pathway model of behaviour and cognition. *Behav Brain Res*, 130(1-2), 29-36.
- Sonuga-Barke, Bitsakou, & Thompson. (2010). Beyond the dual pathway model: evidence for the dissociation of timing, inhibitory, and delay-related impairments in attention-deficit/hyperactivity disorder. *J Am Acad Child Adolesc Psychiatry*, 49(4), 345-55.
- Sonuga-Barke, Taylor, Sembi, & Smith. (1992). Hyperactivity and delay aversion--I. The effect of delay on choice. *J Child Psychol Psychiatry*, 33(2), 387-98.
- Soreni, Crosbie, Ickowicz, & Schachar. (2009). Stop signal and Conners' continuous performance tasks: test--retest reliability of two inhibition measures in ADHD children. *J Atten Disord*, 13(2), 137-43. doi:10.1177/1087054708326110
- Soreni, Crosbie, Ickowicz, & Schachar. (2009). Stop signal and Conners' continuous performance tasks: test--retest reliability of two inhibition measures in ADHD children. *J Atten Disord*, 13(2), 137-43. doi:10.1177/1087054708326110
- Steinman, & Steinman. (1998, February). Vision and attention. I: Current models of visual attention. *Optom Vis Sci*, 75(2), 146-55.
- Strouse, Wilson, & Brush. (2000, June). Recognition of dichotic digits under pre-cued and post-cued response conditions in young and elderly listeners. *Br J Audiol*, 34(3), 141-51.
- Stuart. (2008). Reception thresholds for sentences in quiet, continuous noise, and interrupted noise in school-age children. *J Am Acad Audiol*, 19(2), 135-46.
- Swanson. (1992). *The SNAP-IV Teacher and Parent Rating Scale*.
- Swanson, Elliott, Greenhill, Wigal, Arnold, Vitiello, . . . Volkow. (2007). Effects of stimulant medication on growth rates across 3 years in the MTA follow-up. *J Am Acad Child Adolesc Psychiatry*, 46(8), 1015-27.
- Treisman. (1969, May). Strategies and models of selective attention. *Psychol Rev*, 76(3), 282-99.
- Tucha, Tucha, Walitza, Sontag, Laufkotter, Linder, & Lange. (2009). Vigilance and sustained attention in children and adults with ADHD. *J Atten Disord*, 12(5), 410-21. doi:10.1177/1087054708315065
- van der Meere, & Sergeant. (1988). Focused attention in pervasively hyperactive children. *Abnormal Child Psychology*, 16, 627-639.

- Wang, Huang, Chiang, Hsiao, Shang, & Chen. (2011, April 19). Clinical symptoms and performance on the Continuous Performance Test in children with attention deficit hyperactivity disorder between subtypes: a natural follow-up study for 6 months. *BMC Psychiatry*, *11*(65). doi:10.1186/1471-244X-11-65
- Wang, Yang, Xing, Chen, Liu, & Luo. (2013, November). Altered neural circuits related to sustained attention and executive control in children with ADHD: an event-related fMRI study. *Clin Neurophysiol*, *124*(11), 2181-90. doi:10.1016/j.clinph.2013.05.008
- Warikoo, & Faraone. (2013). Background, clinical features and treatment of attention deficit hyperactivity disorder in children. *Expert Opin Pharmacother*, *14*(14), 1885-906. doi:10.1517/14656566.2013.818977
- Willcutt, Doyle, Nigg, Faraone, & Pennington. (2005). Validity of the Executive Function Theory of Attention-Deficit/Hyperactivity Disorder: A Meta-Analytic Review. *Biol Psychiatry*, *57*, 1336–1346.
- Wolraich. (1998). Vanderbilt ADHD Diagnostic Parent Rating Scale.
- Wolraich. (1998). Vanderbilt ADHD Diagnostic Teacher Rating Scale.
- Wood, & Jennings. (1976). Speed-accuracy tradeoff functions in choice reaction time: experimental designs and computational procedures. *Perception and Psychophysics*, *19*(1), 92-102.
- Wood, Rijdsdijk, Asherson, & Kuntsi. (2011). Inferring Causation from Cross-Sectional Data: Examination of the Causal Relationship between Hyperactivity-Impulsivity and Novelty Seeking. *Front Genet*, *2*(6). doi:10.3389/fgene.2011.00006
- Yerkes, & Dodson. (1908). The Relation of Strength of Stimulus to Rapidity of Habit-Formation . *Journal of Comparative Neurology and Psychology*, *18*, 459-482.
- Zabel, Thomsen, v., Cole, Martin, & Mahone. (2009). Reliability concerns in the repeated computerized assessment of attention in children. *Clin Neuropsychol*, *23*(7), 1213-31. doi:10.1080/13854040902855358

## **APPENDIX A: IRB APPROVAL**



**EAST CAROLINA UNIVERSITY**  
**University & Medical Center Institutional Review Board Office**  
4N-70 Brody Medical Sciences Building · Mail Stop 682  
600 Moyer Boulevard · Greenville, NC 27834  
Office **252-744-2914** · Fax **252-744-2284** · [www.ecu.edu/irb](http://www.ecu.edu/irb)

Notification of Initial Approval: Expedited

From: Social/Behavioral IRB  
To: [Emily Russell](#)  
CC: [Deborah Culbertson](#)  
Date: 3/11/2014  
[UMCIRB 13-002775](#)  
Re: Auditory and Visual Sustained Attention on Tasks with Varied Motivation and Cognitive Loads in Children With and Without ADHD

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 3/11/2014 to 3/10/2015. The research study is eligible for review under expedited category #7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Name	Description
Assent	Consent Forms
attention study advertisement.docx	Recruitment Documents/Scripts
case history form.doc	Interview/Focus Group Scripts/Questions
Consent adults	Consent Forms
Consent parents	Consent Forms
data sheet	Data Collection Sheet
email ad.docx	Recruitment Documents/Scripts
HIPAA for parents	HIPAA Authorization
HIPAA form	HIPAA Authorization
Study protocol	Study Protocol or Grant Application

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

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IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418  
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418

## **APPENDIX B: HIPAA FORM**

**UMCIRB HIPAA Privacy Authorization**

East Carolina University (ECU)/Vidant Medical Center (VMC): Research Participant Authorization to Use and Disclose Protected Health Information for Research

**For use only with the research consent form for UMCIRB#: 13-002775**

**Principal Investigator: Emily Russell**

**Title: Auditory and Visual Sustained Attention in Young Adults without ADHD and in Children With and Without ADHD**

**Location where research will be conducted**

The members of the research team will conduct the research study at:

- East Carolina University (ECU)  VMC  ECU & VMC  Other

When taking part in research, protected health information (PHI) is collected, used, and shared with others who are involved in the research. Federal laws require that researchers and health care providers protect your PHI. Also, federal laws require that we get your permission to use collected PHI for the research. This permission is called authorization.

In order to complete the research project in which you have decided to take part, the research team needs to collect and use some of your PHI as described below.

**What types of protected health information (PHI) about me will be used or disclosed?**

(Select all that apply.)

**ECU Health Care Component:**

- ECU Physicians
- School of Dental Medicine
- Speech, Language, and Hearing Clinic
- Human Performance Lab
- Physical Therapy
- Student Health
- Other ECU Health Entity  
(please list):

**Vidant Health Entity:**

- Entire Vidant Health system
- Vidant Medical Center
- Other Vidant Health Entity  
(please list):

**Type of ECU Records:**

- Medical/clinic records
- Billing records
- Lab, Pathology and/or Radiology results results
- Mental Health records
- PHI previously collected for research
- Records generated during this study
- Other:

**Type of Vidant Records:**

- Medical/clinic records
- Billing records
- Lab, Pathology and/or Radiology
- Mental Health records
- PHI previously collected for research
- Records generated during this study
- Other:

**Who will use or disclose my PHI?**

- Principal Investigator
- Other members of the research team
- Other providers involved in your care during research procedures, outpatient/inpatient stays during which research is being performed, or physician office visits during which research is being performed.

**Who will receive my PHI?**

- Sponsor or other funding source to provide oversight for entire research project
- Research investigators to conduct and oversee the research project
- Principle Investigator and research team members to participate in the various research activities
- FDA or other regulatory agencies to provide regulatory oversight
- UMCIRB to provide continuing review of the research project
- Institutional officials in connection with duties for monitoring research activity
- Other providers involved in your care during research procedures, outpatient/inpatient stays during which research is being performed, or physician office visits during which research is being performed.
- Researchers at other sites—List sites:
- Data and Safety Monitoring Board and its staff
- Contract Research Organization and its staff
- Other

We will share only the PHI listed above with the individuals/agencies listed above. If we need to share other PHI or if we need to send PHI to other individuals/agencies not listed above, we will ask for your permission in writing again

**How my PHI may be released to others:**

ECU is required under law to protect your PHI. However, those individuals or agencies who receive your PHI may not be required by the Federal privacy laws to protect it and may share your PHI with others without your permission, if permitted by the laws governing them.

**What if I do not sign this form?**

You will not be eligible to participate in this study if you do not sign this Authorization form.

**How may I revoke (take back) my authorization?**

You have the right to stop sharing your PHI. To revoke (or take back) your authorization, you must give the Principal Investigator your request to revoke (or take back) your authorization in writing. If you request that we stop collecting your PHI for the study, you may be removed from the study. If you are removed from the study, it will not affect your ability to receive standard medical care or affect payment, health plan enrollment or benefit eligibility. PHI collected for the research study prior to revoking (or taking back) your Authorization will continue to be used for the purposes of the research

study. Also, the FDA (if involved with your study) can look at your PHI related to the study even if you withdraw this authorization.

**Restrictions on access to my PHI:**

You will not be able to see your PHI in your medical record related to this study until the study is complete. If it is necessary for your care, your PHI will be provided to you or your physician.

**How long may the PHI about me be used or disclosed for this study?**

Research information continues to be looked at after the study is finished so it is difficult to say when use of your PHI will stop. There is not an expiration date for this authorization to use and disclose your PHI for this study.

If you have questions about the sharing of PHI related to this research study, call the principal investigator Emily Russell at phone number 252-744-6130. Also, you may telephone the University and Medical Center Institutional Review Board at 252-744-2914. In addition, if you have concerns about confidentiality and privacy rights, you may phone the Privacy Officer at East Carolina University at 252-744-5200.

**Authorization**

To authorize the use and disclosure of your PHI for this study in the way that has been described in this form, please sign below and date when you signed this form. A signed copy of this Authorization will be given to you for your records.

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<b>Name of Participant or Authorized Representative (print)</b>	<b>Signature</b>	<b>Date</b>
---	------------------	-------------

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**If an Authorized Representative has signed on behalf of a Participant please print on the line above the authority of the Legal Representative to do so (*such as parent, court-appointed guardian, or power of attorney*).**

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<b>Person Obtaining Authorization</b>	<b>Signature</b>	<b>Date</b>
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## **APPENDIX C: CONSENT FORM FOR PARENTS**

East Carolina University



## **Informed Consent to Participate in Research**

Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Auditory and Visual Sustained Attention in Young Adults without ADHD and in Children With and Without ADHD

Principal Investigator: Emily Russell

Institution/Department or Division: Communication Sciences and Disorders

Address: Health Sciences Building, Greenville, NC, 27834

Telephone #: 252-744-6100

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Researchers at East Carolina University (ECU) study problems in society, health problems, environmental problems, behavior problems and the human condition. Our goal is to try to find ways to improve the lives of you and others. To do this, we need the help of volunteers who are willing to take part in research.

### **Why is this research being done?**

The purpose of this research is to understand the effects of varying feedback and cognitive load in continuous performance tasks for children with and without ADHD, and young adults without ADHD. The decision to take part in this research is yours to make. By doing this research, we hope to learn about factors that affect attention in those with and without ADHD.

### **Why am I being invited to take part in this research?**

Your child is being invited to take part in this research because he/she is between the ages of 8 and 13 and has a history of ADHD or no history of ADHD. If your child volunteers to take part in this research, he/she will be one of about 39 people to do so.

### **Are there reasons my child should not take part in this research?**

Your child should not participate if he/she has a history of cognitive impairments, speech delays, auditory processing disorder, or hearing loss.

### **What other choices does my child have if he/she does not take part in this research?**

Your child can choose not to participate.

### **Where is the research going to take place and how long will it last?**

The research procedures will be conducted at the Allied Health Sciences Building. Participants will be asked to come once and the total amount of time your child will be asked to volunteer for this study is an hour and a half.

### **What will my child be asked to do?**

Your child is being asked to do the following:

- have us look in his/her ears
- take a simple eardrum movement test (tympanometry)
- have a pure tone hearing test

- have a vision screening
- participate in one auditory processing screening assessment
- respond to a target word that is repeated in various levels of background noise with varied feedback/points
- respond to a target picture that is shown at varied levels of blurring with varied feedback/points

**What possible harms or discomforts might my child experience if he/she takes part in the research?**

It has been determined that the risks associated with this research are no more than what your child would experience in everyday life.

**What are the possible benefits my child may experience from taking part in this research?**

This research might help us learn more about the impact of varying task modality (auditory or visual), cognitive load (different levels of noise or blurring), and motivation (different points on different tasks) on attention. There may be no personal benefit from your child's participation but the information gained by doing this research may help others in the future.

**Will my child be paid for taking part in this research?**

If your child qualifies for this research and participates in the study, he/she will receive up to a \$20 gift card from Target. Participants completing the study will receive at least \$10 and can earn up to a \$20 gift card depending on points earned during the tasks/games. Those points will be explained before the tasks/games.

**What will it cost me to take part in this research?**

It will not cost you any money to be part of the research.

**Who will know that my child took part in this research and learn personal information about me or my child?**

To do this research, ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- Any agency of the federal, state, or local government that regulates human research. This includes the Department of Health and Human Services (DHHS), the North Carolina Department of Health, and the Office for Human Research
- The University & Medical Center Institutional Review Board (UMCIRB) and its staff, who have responsibility for overseeing your welfare during this research, and other ECU staff who oversee this research.

**How will you keep the information you collect about me or my child secure? How long will you keep it?**

The data will be kept in a locked cabinet in the research mentor's office. She will be the only one with access to this cabinet. The data will be kept for six years.

**What if I decide I do not want my child to continue in this research?**

If you decide you no longer want your child to be in this research after it has already started, you may stop at any time. You and your child will not be criticized for stopping. However, it is necessary that your child completes the study session in order to receive a gift card.



## **APPENDIX D: CONSENT FORM FOR YOUNG ADULTS**

*Title of Study:* Auditory and Visual Sustained Attention in Young Adults without ADHD and in Children With and Without ADHD

*East Carolina University*



## **Informed Consent to Participate in Research**

Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Auditory and Visual Sustained Attention in Young Adults without ADHD and in Children With and Without ADHD

Principal Investigator: Emily Russell

Institution/Department or Division: Communication Sciences and Disorders

Address: Health Sciences Building, Greenville, NC, 27834

Telephone #: 252-744-6100

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Researchers at East Carolina University (ECU) study problems in society, health problems, environmental problems, behavior problems and the human condition. Our goal is to try to find ways to improve the lives of you and others. To do this, we need the help of volunteers who are willing to take part in research.

### **Why is this research being done?**

The purpose of this research is to understand the effects of varying feedback and cognitive load in continuous performance tasks for children with and without ADHD, and young adults without ADHD. The decision to take part in this research is yours to make. By doing this research, we hope to learn about factors that affect attention in those with and without ADHD.

### **Why am I being invited to take part in this research?**

You are being invited to take part in this research because you are between the ages of 18 and 30 and have no history of ADHD. If you volunteer to take part in this research, you will be one of about 39 people to do so.

### **Are there reasons I should not take part in this research?**

You should not participate if you have a history of cognitive impairments, speech delays, auditory processing disorder, or hearing loss.

### **What other choices do I have if I do not take part in this research?**

You can choose not to participate.

### **Where is the research going to take place and how long will it last?**

The research procedures will be conducted at the Allied Health Sciences Building. Participants will be asked to come once and the total amount of time you will be asked to volunteer for this study is an hour and a half..

### **What will I be asked to do?**

You are being asked to do the following:

- have us look in your ears
- take a simple eardrum movement test (tympanometry)
- have a pure tone hearing test
- have a vision screening

*Title of Study:* Auditory and Visual Sustained Attention in Young Adults without ADHD and in Children With and Without ADHD

- participate in one auditory processing screening assessment
- respond to a target word that is repeated in various levels of background noise with varied feedback/points
- respond to a target picture that is shown at varied levels of blurring with varied feedback/points

**What possible harms or discomforts might I experience if I child take part in the research?**

It has been determined that the risks associated with this research are no more than what you would experience in everyday life.

**What are the possible benefits I child may experience from taking part in this research?**

This research might help us learn more about the impact of varying task modality (auditory or visual), cognitive load (different levels of noise or blurring), and motivation (different points on different tasks) on attention. There may be no personal benefit from your participation but the information gained by doing this research may help others in the future.

**Will I be paid for taking part in this research?**

If you qualify for this research and participate in the study, you will receive up to a \$20 gift card from Target. Participants completing the study will receive at least \$10 and can earn up to a \$20 gift card depending on points earned during the tasks/games. Those points will be explained before the tasks/games.

**What will it cost me to take part in this research?**

It will not cost you any money to be part of the research.

**Who will know that I took part in this research and learn personal information about me?**

To do this research, ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- Any agency of the federal, state, or local government that regulates human research. This includes the Department of Health and Human Services (DHHS), the North Carolina Department of Health, and the Office for Human Research
- The University & Medical Center Institutional Review Board (UMCIRB) and its staff, who have responsibility for overseeing your welfare during this research, and other ECU staff who oversee this research.

**How will you keep the information you collect about secure? How long will you keep it?**

The data will be kept in a locked cabinet in the research mentor's office. She will be the only one with access to this cabinet. The data will be kept for six years.

**What if I decide I do not want to continue in this research?**

If you decide you no longer want to be in this research after it has already started, you may stop at any time. You will not be criticized for stopping. However, it is necessary that you complete the study session in order to receive a gift card.

**Who should I contact if I have questions?**

The people conducting this study will be available to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator at 252-744-6130 (days, between 8:00 am and 4:00 pm).

If you have questions about your rights as someone taking part in research, you may call the Office for Human Research Integrity (OHRI) at phone number 252-744-2914 (days, 8:00 am-5:00 pm). If you would like to report a complaint or concern about this research study, you may call the Director of the OHRI, at 252-744-1971.



## **APPENDIX E: ASSENT FORM FOR CHILDREN**



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IRB Study # \_\_\_\_\_ *(The IRB office will fill this in, if this is a new submission)*

Title of Study: Auditory and Visual Sustained Attention in Young Adults without ADHD and Children With and Without ADHD

Person in charge of study: Emily Russell

Where they work: ECU Department of Communication Sciences and Disorders

Other people who work on the study: Dr. Deborah Culbertson

Study contact phone number: 252-744-6130

Study contact E-mail Address: russelle10@students.ecu.edu

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People at ECU study ways to make people's lives better. These studies are called research. This research is trying to find out if making words or pictures harder to hear or see, or if changing the amount of points you earn impacts how well you do on an attention task.

Your parent(s) need(s) to give permission for you to be in this research. You do not have to be in this research if you don't want to, even if your parent(s) has/have already given permission.

You may stop being in the study at any time. If you decide to stop, no one will be angry or upset with you.

**Why are you doing this research study?**

The reason for doing this research is to see what happens when you listen to words and see pictures.

**Why am I being asked to be in this research study?**

We are asking you to take part in this research because you are the right age.

**How many people will take part in this study?**

If you decide to be in this research, you will be one of about 39 people taking part in it.

**What will happen during this study?**

I will look in your ears, and then I will put a soft eartip in your ear and you will feel a small movement of your eardrum. I will check your hearing and sight and you will play some games on a computer.

This study will take place at ECU and will last about an hour and a half.

**Who will be told the things we learn about you in this study?**

Emily Russell and Dr. Culbertson will know about what we did during the study. A scientific journal will also know about what we learn from everyone, but you will not be named and no one will know who signed up for this study.

**What are the good things that might happen?**

Sometimes good things happen to people who take part in research. These are called “benefits.” The benefits to you of being in this study may be you will learn more about attention games, and how changing the game can make them harder or easier. You will also receive a gift card to Target.

**What are the bad things that might happen?**

Sometimes things we may not like happen to people in research studies. These things may even make them feel bad. These are called “risks.” There are no risks in this study. Things may also happen that the researchers do not know about right now. You should report any problems to your parents and to the researcher

**Will you get any money or gifts for being in this research study?**

You will receive a gift card from Target if you complete the study. If you finish all of the games you will receive at least a \$10 gift card and depending on the points you earn in the games you can earn up to \$20 on the gift card. The points will be explained before each of the games.

**Who should you ask if you have any questions?**

If you have questions about the research, you should ask the people listed on the first page of this form. If you have other questions about your rights while you are in this research study you may call the Institutional Review Board at 252-744-2914.

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If you decide to take part in this research, you should sign your name below. It means that you agree to take part in this research study.

\_\_\_\_\_  
Sign your name here if you want to be in the study

\_\_\_\_\_  
Date

\_\_\_\_\_  
Print your name here if you want to be in the study

\_\_\_\_\_  
Signature of Person Obtaining Assent

\_\_\_\_\_  
Date

\_\_\_\_\_  
Printed Name of Person Obtaining Assent

## **APPENDIX F: RESULTS FOR PARTICIPANTS DATA COLLECTION SHEET**

Unique Identifier: \_\_\_\_\_

**Results for Participants**

**Age:** \_\_\_\_\_

**Gender:**

Female                  Male

**How do you designate your/your child's race and/or origin?**

Black/African-American	Asian	Native Hawaiian/Other Pacific Islander
White/Caucasian	Hispanic/Latino	American Indian/Alaska Native
Two or more races	Other	

**Children: Has your child repeated a grade? Adults: Have you repeated a grade?**

Yes                  No

**Parents' highest level of education:**

**Mother**

Some high school	High school graduate	Some college
Associate's Degree	Bachelor's Degree	Some graduate school
Graduate Degree		

**Father**

Some high school	High school graduate	Some college
Associate's Degree	Bachelor's Degree	Some graduate school
Graduate Degree		

**ADHD diagnosis from a physician or psychologist:**                      yes                      no

If yes, what presentation?

- Predominantly hyperactive-impulsive
- Predominantly inattentive
- Combined hyperactive-impulsive and inattentive
- Don't know

If yes, are they currently taking medication for ADHD?                      Yes                      No

Medication type and dosage:

Did they take the medication today:                      Yes                      No

**Inclusion Criteria:**

English is first language?    Yes                      No

Cognitive deficits/delays?    Yes                      No

Speech-language deficits/delays?    Yes                      No

Auditory processing deficits?    Yes                      No

**Vision** (at least 20/32 in either eye)

Yes                      No

**Otoscopy** (normal or note conditions from protocol such as ear drainage, ear canal abnormalities such as obstructions, impacted cerumen or foreign objects, blood or other secretions, stenosis or atresia, otitis external, and perforations or other abnormalities of the tympanic membrane:

Left ear:

Right ear:

**Tympanometry** (normal child from Hanks and Rose: SAA: 0.3-1.5, ECV: 0.6-1.5; TW: ≤200; normal adult from Margolis & Heller, 1987: SAA: 0.27-1.38, ECV: 0.63-1.46, TW: 51-114)

Left ear:

SAA	ECV	TW

Right ear:

SAA	ECV	TW

**Hearing Thresholds**- 20 dB or better

Left ear:

0.25	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	8 kHz

Right ear:

0.25	0.5 kHz	1 kHz	2 kHz	3 kHz	4 kHz	8 kHz

**Scan-3 For Children or SCAN-3 for Adults AFG**

Auditory Figure-Ground at +8 dB SNR (Tracks 5-9)

RE Score	
LE Score	
AFG +8 Total Score	

age	normal	borderline	disordered
8	35 and up	30-34	29 and under
9	35 and up	32-34	30 and under
10-12	36 and up	33-35	32 and under

age	mean	2 SD
15-18	37.3	24.5-40.1
19-30	37.0	32.4-41.6

## **APPENDIX G: ATTENTION STUDY ADVERTISEMENT**



