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A Preliminary Investigation of the Validity of Time-Based Measures of Sustained Attention for Children

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A PRELIMINARY INVESTIGATION OF THE VALIDITY OF TIME-BASED

MEASURES OF SUSTAINED ATTENTION FOR CHILDREN

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A PRELIMINARY INVESTIGATION OF THE VALIDITY OF TIME-BASED

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This dissertation, by Michael Kulfan, has been approved by the committee members signed below who recommend that it be accepted by the faculty of the Antioch University Seattle at Seattle, WA in partial fulfillment of requirements for the degree of

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DEDICATION

I dedicate this paper to my partner and wife Alexa. Without her unwavering support and tireless effort in many of the more important aspects of our lives, this paper would not have been possible. To my son Griffin, who has never known a father without a looming dissertation: Dad is finally done! I hereby re-dedicate my weekends and evenings to my family.

ABSTRACT

A PRELIMINARY INVESTIGATION OF THE VALIDITY OF TIME-BASED MEASURES OF SUSTAINED ATTENTION FOR CHILDREN

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This study is a preliminary investigation of the validity of using time-based measures to quantify sustained attention in children ages 6-12. Problems with sustained attention negatively affect childhood learning and development. The prevalence of disorders known to impact sustained attention performance continue to rise in the United States. Currently, commercially available, objective measures of sustained attention use normative comparisons that provide limited information about the effect such problems have on child performance in natural settings. We reviewed test data from 290 charts of children ages 6-12 referred for neuropsychological evaluation. The Test of Everyday Attention for Children (TEA-Ch) is an ecologically oriented measure of attention; however, the test provides only normative data about child sustained attention. We examined the validity of two time-based scores derived from the Code Transmission subtest of the TEA-Ch. The Code Transmission Time on Task (CT-TOT) estimates the total time a child spends processing the subtest stimulus and the Code Transmission Longest Duration (CT-LD) estimates the maximum duration of a child's sustained attention before an attentional lapse. We correlated CT-TOT and CT-LD scores with age, criterion sustained attention measures from the TEA-Ch, and a measure of intelligence. Analysis of the data revealed significant differences in performance on the time-based measures by age-band. Correlations reached significance for both measures with the four criterion measures, with the CT-TOT achieving higher correlations with all criterion measures. Correlations were non-significant between both measures and intelligence. Overall, the findings of the present study suggest that the CT-TOT may provide additional, valid performance-based information about children's sustained attention that, to date, is missing from any commercially available measure of sustained attention for children. The electronic version of this dissertation is available in the open-access OhioLink ETD Center, www.ohiolink.edu/etd.

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Chapter I: Introduction

Sustained attention refers to any continuous direction of conscious awareness towards specific phenomena and plays a critical role in the continuous, conscious processing of information (Mirsky, Anthony, Duncan, Ahearn & Kellam, 1991; Robertson, Manly, Andrade, Baddeley and Yiend, 1997). The ability to sustain attention is a fundamental precursor to higher order cognitive tasks, including explicit learning and memory formation (Douglas, 1983). Studies of children's performance on higher-level cognitive tasks suggest that problems associated with sustained attention undermine children's motivation and ability to cope with complex intellectual problems (Douglas, 1983). Sustained attention is also necessary for skill and knowledge acquisition in normal development and central for effective learning and functioning in school and the world in general (Curtindale, Laurie-Rose, Bennett-Murphy & Hull, 2007; Swanson & Cooney, 1989; The NICHD Early Child Care Research Network, 2003).

Sustained auditory attention is vital to processing language in general and has been implicated as a causal mechanism of specific language impairment in children (Finneran, Francis & Leonard, 2009; Gianvecchio & French, 2002; Montgomery, Evans & Gillam, 2009). The ability to sustain attention to auditory information over time and detect particular stimuli is critical to perform numerous tasks, including understanding class lectures and lesson plans presented orally (Demeter, Hernandez-Garcia & Sarter, 2011). Studies of the impact of sustained auditory attention on academic performance indicate that poor sustained attention has a greater impact on children’s ability to comprehend stories than other aspects of ADHD, has a significantly negative impact on academic achievement and a child’s ability to perform complex academic tasks (Flory, et al., 2006; Steinmayr, Ziegler & Träuble, 2010). Murphy, Laurie-Rose, Brinkman, and

McNamara (2007) found that sustained attention performance mediates sociability in pre-school children. A considerable number of research investigations show a causal link between childhood psychological and neurological disorders and impaired sustained attention (Catroppa, Anderson, & Stargatt, 1999; Douglas, 2004; Leckman, Bloch, Scahill, & King, 2009).

Many children in the United States have behavioral, developmental, and neurologic disorders that disrupt sustained attention. Childhood disorders widely known to disrupt sustained include ADHD, Tourette's Syndrome (TS), and traumatic brain injuries (TBI) (Barkley, 2006; Catroppa & Anderson, 2003; Sherman, et al., 1998). A brief description of each of these disorders follows, along with prevalence rates among children in the United States.

Attention Deficit/Hyperactivity Disorder (ADHD) represents a persistent pattern of inattention and/or hyperactivity-impulsivity that is more frequently displayed and more severe than is typically observed in individuals at a comparable age (APA, 2000). The primary symptoms of ADHD include limited ability to direct and sustain attention, problems with impulse-control, and general restlessness across situations and settings. Three primary subtypes of ADHD differentiate children by the features of the disorder expressed in the behaviors of the individual. ADHD, Predominantly Inattentive Type describes children with marked problems with inattention, distraction, and forgetfulness. The primary feature of ADHD, Predominantly Hyperactive-Impulsive Type is excessive, restless energy that manifests in off-task and/or contextually inappropriate behaviors. ADHD, Combined Type includes features from both of the other ADHD subtypes. All subtypes of this behavioral disorder manifest across different social, educational, and recreational situations. Symptoms of ADHD tend to worsen in situations, where a child must sustain attention or apply mental effort to features of their experience that lack intrinsic appeal. Barkley (2006) suggested that the most disruptive feature of all sub-types of ADHD is the impact that this disorder has on a child's ability to sustain attention.

According to the National Institute of Mental Health (NIMH, 2008), Attention Deficit/Hyperactivity Disorder (ADHD) is one of the most common mental disorders in children and adolescents. As of 2007, 9.5 % (5.4 million) of American children ages 4-17 had a diagnosis of ADHD (Pastor & Reuben, 2008). In addition, the prevalence rate of ADHD diagnosis increased by approximately 3 % each year between 1996 and 2007. This trend suggests that we will continue to see a rise in the number of children impacted by ADHD in the years ahead.

Tourette's syndrome (TS) is an inheritable neurologic disorder marked by persistent multiple motor tics and at least one vocal tic (APA, 2000; Scahill, Bitsko, Visser, & Blumberg, 2009). Secondary symptoms of TS include hyperactivity and marked inattentiveness (APA, 2000). The onset of TS occurs prior to age 18 and usually begins within the first decade of life. (APA, 2000; Leckman, et al., 2009). A 2007 Center for Disease Control (CDC) investigation of the prevalence of Tourette's Syndrome in the United States in children ages 6-17, estimated a lifetime diagnosis of 3.0 per 1,000 (151,000) (Scahill, et al., 2009).

Tourette's Syndrome often co-occurs with ADHD (Robertson, 2006). Some researchers suspect that these disorders may share a common etiology, especially with children diagnosed with the Hyperactive subtype of ADHD. The childhood literature indicates that TS has a negative impact on sustained attention, although not as pronounced as the impact of ADHD (Sherman, et al., 1998). Sherman, et al. conducted a between-groups study of children diagnosed with TS, ADHD and comorbid ADHD and TS to investigate their impact on sustained attention. Children ages 7-15 grouped into diagnostic groups listed above and a clinical control sample completed two, 15-minute sustained attention subtests. The children with TS performed markedly worse than controls on the measure of sustained attention, although not as poorly as children with comorbid TS and ADHD or ADHD alone. The findings provide evidence of the impact that TS has on children's sustained attention. Children with comorbid ADHD and TS diagnoses are at even greater risk of experiencing problems with sustained attention.

According to the Center for Disease Control and Prevention traumatic brain injury results from a bump, blow, or jolt to the head or a penetrating head injury that disrupts the normal function of the brain (Faul, Xu, Wald, & Coronado, 2010). Severity of TBI depends on the nature and intensity of the injury and ranges from mild to severe. Mild symptoms cause a brief change in mental status or consciousness, and severe symptoms include an extended period of unconsciousness or amnesia after the injury. Extensive research exists linking sustained attention problems with pediatric traumatic brain injury (TBI) (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005; Catroppa, Anderson, Morse, Haritou, & Rosenfeld, 2007). Research indicates that TBI has short and long-lasting impacts on the sustained attention capacities of children. Thirty months, five and 10 years following TBI, children continue to exhibit significant performance differences on various measures of sustained attention (Anderson, et al., 2005; Catroppa, et al., 2007). The severity of TBI mediates the impact on sustained attention (Catroppa, et al., 2007). Children diagnosed with more severe forms of TBI show greater subsequent problems with sustained attention.

Traumatic brain injury (TBI) is one of the most common causes of death and long-term disability in children (Yeates et al., 2010). Just over half a million children 0 to 14 years of age sustain a TBI requiring medical care each year in the United States (Faul, et al., 2010; Langlois, Rutland- Brown, & Thomas, 2005). The majority of TBIs are concussions or other forms of mild TBI.

Epidemiological studies clearly indicate that a significant number of children in the United States have diagnoses that disrupt sustained attention (Faul, et al., 2010; Pastor & Reuben, 2008; Scahill, et al., 2009). Doctors, teachers, and other child specialists often refer children suspected of having attentional problems for psychological or neuropsychological evaluation to help understand the aspects and severity of various attention-related problems. Methods used to quantify sustained attention include subjective surveys and objective assessments. Teachers and parents typically fill out subjective attention surveys. Subjective surveys of attention provide normative estimates of the attention-related behavior of children in categorical domains, such as distractibility, hyperactivity, and inattention (Conners, Sitarenios, Parker & Epstein, 1998a; Brown & Wynn, 1982). Objective measures of sustained attention provide normative estimates of a child's capacity to sustain attention. These evaluations enable clinicians to compare child performance with that of the standardization sample.

Subjective and objective measures of attention can be useful in identifying children with significant sustained attention problems. Information provided by these assessments is important for intervention planning designed to reduce the impact of attentional problems (Smith, Barkley & Shapiro, 2007): These measures do not provide estimates of the functional limitations of a child's sustained attention. While these measures help to identify the types of attentional problems that children are likely to exhibit, the scores that they yield are difficult to translate into natural settings (Riccio, Reynolds, & Lowe, 2001).

The importance of sustained attention in learning and development, combined with the high incidence of childhood disorders that impair sustained attention, highlights the need for new ways of understanding the limitations that problems with sustained attention impose on children in natural settings.

Purpose and Significance of the Proposed Study

The purpose of the present study was to investigate the validity of translating raw scores from the Code Transmission subtest of the TEA-Ch into time-based measures of sustained attention to estimate the overall time-on-task (Code Transmission-Time on Task, CT-TOT) and maximum duration of sustained attention (Code Transmission-Longest Duration, CT-LD) of children ages 6-12. The task and format of the Code Transmission subtest is similar to sustained attention tasks required of children in natural settings, such as the classroom where they have to process spoken language (Manly, et al., 2001). Interpretation of standardized scores on measures of sustained attention entails evaluating performance as being below, within, or above average-normal limits. Time-based measures of sustained attention will enable clinicians to provide performance-based estimates of a child's capacity to sustain attention in an 11-minute window of time. These performance-based estimates of sustained attention will enable psychologists to educate teachers, community providers, and parents about what to expect from children in terms of their time-based capacity to sustain attention to auditory information in natural settings.

Chapter II: Review of the Literature

The present study is a preliminary investigation of the validity of using time-based measures to quantify sustained attention. In essence, the new outcome scores proposed in this project represent potential addendums to an existing sustained attention measure. It is necessary to investigate the literature pertaining to psychometric test construction, including best practices and recommendations for ensuring tests meet adequate standards of validity and reliability.

The first section of the literature review covers psychometric theories relevant to this project and recommended practices in the development or revision of a psychometric assessment. This section provides the framework for the rest of the paper by outlining the steps necessary to establish a new or revised psychometric instrument. The second section of the literature review covers the theoretical models upon which the TEA-Ch subtests were founded to establish the construct validity of the existing TEA-Ch subtests of sustained attention (criterion variables) and the new methods for measuring sustained attention under investigation (outcome variables) in the present study. The third section of the literature review highlights the novelty of the proposed study by critically examining existing measures of sustained attention and the theoretical constructs that they measure. In the fourth section of the literature, I critically examine the test design and psychometric properties of the TEA-Ch in order to establish it as a psychometrically valid and reliable measure of sustained attention for children.

Psychometric Test Development

Test conceptualization starts with the desire to measure some construct that there is no other measure to quantify, or to create a modified version of an existing test to provide additional, relevant information about the construct under investigation (American Educational Research Association [AERA], 1999; Cohen & Swerdlik, 2002). The first step in test development typically involves the creation of a purpose statement, a description of the construct, and a framework for the test that describes the scope of the construct measured by the test (AERA, 1999). The purpose of the time-based measures derived from the Code Transmission subtest of the TEA-Ch is to provide a new way of describing individual capacities to sustain attention to auditory information. The new measures will not replace existing tests but provide additional information about the construct of sustained attention.

The construct measured by the test needs to be clearly defined along with an explanation of how the test provides new information about the construct (AERA, 1999). The objective of the test must be clear and differentiated from existing tests that measure the same construct (AERA, 1999; Cohen & Swerdlik, 2002). It should be assumed that the assessment is providing a valuable service to the individual and those involved in his/her care, development, employment or treatment as a whole (Cohen, & Swerdlik, 2002). By furthering our understanding of individuals, tests should provide for better intervention planning, placement, and overall care.

For this investigation it would not be appropriate to have randomly investigated just any of the existing measures of sustained attention. The format of the TEA-Ch Code Transmission subtest uses a task designed to be similar to real-world sustained attention tasks that children are likely to experience on an everyday basis, especially in the classroom setting. It is on this premise that I investigated the validity of the two new, time-based measures of sustained attention that I derived from the Code Transmission subtest. It is my hope that these new measures will provide new and useful information about the capacities of children to sustain attention to auditory information in natural settings. Neuropsychologists, school psychologists, and other professionals can readily translate the scores from these time-based measures into targeted goals of school-based intervention plans, such as Individualized Education Plans (IEP), and 504 plans. Professionals can also use these scores to measure changes, and improvement over time.

Test reliability. Reliability in testing refers to consistency. It is a measure of how consistently the test measures the given criteria (Cohen, & Swerdlik, 2002). Reliability demands that the test report results in a consistent and generally predictable manner (Cohen & Swerdlik, 2002; AERA, 1999). In classical test theory, the term *reliability* refers to the amount of total variance that is attributable to the true score. The theoretical value that is free of error is the *true score* (AERA, 1999). On any given measure, test developers must assume a certain amount of error to coincide with the true score of the individual (Cohen & Swerdlik, 2002). The difference between an examinee's observed score and the true score or universal score is the measurement error or error variance.

There are four types of reliability: test-retest reliability, alternate forms reliability, split-half reliability, and inter-rater reliability (AERA, 1999). Only test -retest is relevant for the purposes of this study. Test-retest reliability refers to the degree to which a test provides a consistent outcome when administered to the same subject on two or more separate occasions. Test-retest reliability is appropriate when the test is measuring a trait or construct believed to be relatively stable over time. Test developers assess the test-retest reliability of a measure by calculating the correlational coefficient between separate, repeat administrations with the same sample population. It is incumbent upon test developers to investigate the reliability of an instrument as fully as practical considerations permit and report the findings for all scores (AERA, 1999). Manly et al. (2001) provide sufficient evidence of the test-retest reliability of the TEA-Ch subtests, which I present in section four of the literature review.

Test validity. Validity is a unitary construct that provides an indicator of the extent to which all accumulated evidence supports the intended interpretation of test scores for the proposed purpose (AERA, 1999). Validity refers to how well the test is measuring what it claims to measure (Cohen, & Swerdlik, 2002). In test design, authors are most often interested in establishing four different forms of validity: content validity, construct validity, criterion-related validity, and external validity. The four types of validity all contribute to the overall validity of a test and are not mutually exclusive. The indicators of validity have varying degrees of relevance, depending upon the nature and purpose of the test.

Cohen and Swerdlik (2002) define construct as "an informed, scientific ideas developed or hypothesized to describe or explain behavior" (p. 173). Constructs are traits that cannot be directly observed. Test content refers to the items and format of the test used to measure the construct. Content validity is the basic judgment of how well a test samples behavior representative of the larger set of behaviors associated with the construct being evaluated (AERA, 1999; Cohen & Swerdik, 2002). The content validity of an objective measure of a cognitive construct refers to the tasks used to generate the scores for comparison. Tests with good content validity use tasks that are representative of the behaviors associated with the construct under investigation. The extent to which item inter-relationships are consistent with the presumptions of the test design is relevant to validity (AERA, 1999). Important evidence for the validity of a measure can be found in the analysis of the relationship between a test's content validity and construct validity. Sections two, three, and four of the literature review help establish the content validity of the TEA-Ch. In these three sections I review evidence of the relationship between the construct of sustained attention and the tasks used to quantify it.

Construct validity refers to the extent to which inferences can be made about the construct that it was intended to measure (AERA, 1999; Cohen & Swerdlik, 2002). Construct validity is established by first postulating hypotheses about the expected behaviors of those who score high as compared to those who score low on a given measure. Researchers use the initial hypotheses to generate a theory about the nature of the construct the test measures. Tests that are valid measures of the construct will demonstrate that high and low scorers perform as predicted by the theory. Construct validity refers to the extent to which inferences can be made about the construct that it was intended to measure (AERA, 1999; Cohen & Swerdlik, 2002).

Test developers provide evidence of the construct validity of a measure in numerous ways that include providing evidence of changes with age, convergent evidence, discriminant evidence and factor analysis (AERA, 1999; Groth-Marnat, 2009). In later sections and chapters I present data from the research literature and the present study that provides these forms of evidence of the construct validity of the new measures of sustained attention. Sections two, three, and four of the literature review support the construct validity of the TEA-Ch. In section two, I review theoretical and research-based evidence of the TEA-Ch as a valid measure of the various components of attention. In section three I review the research literature on psychometric test elements that researchers have linked to the sustained attention construct, including those that are used in the TEA-Ch. Section four is a review of research on the design and psychometric properties of the TEA-Ch, and provides further evidence of its construct validity.

A criterion is the standard against which a test or score is evaluated (AERA, 1999). Criterion-validity is an evaluation of how well a test infers an individual's performance on another, similar measure. There are two types of criterion validity: concurrent and predictive validity. Concurrent validity refers to measurements taken at approximately the same time, and predictive validity refers to measures taken some time after the initial test. Groth-Marnat (2009) suggests that predictive validity is important to establish for tests designed to assess someone's future attributes or performance; concurrent validity is useful for tests designed to measure current performance (p. 19). In studies examining the concurrent validity of a measure, prior research has established satisfactory validity of the criterion tests. Comparisons determine how well the new test compares with the more established ones. In this type of investigation, the established measures are the "validating criteria" (p.162). I investigated the concurrent validity between the new scores (CT-TOT and CT-LD) and existing, criterion measures of sustained attention in the present study.

While comparisons between a test and similar measures help establish convergent validity, comparison between one test and tests designed to measure different constructs provide evidence of discriminant validity (AERA, 1999; Groth-Marnat, 2009). Evidence of discriminant validity can also be investigated by comparing the performances of different populations of individuals administered the same assessment. I review evidence of the discriminant validity of the TEA-Ch in section four and the Results section of the present study.

External validity refers to the extent to which a test provides a valid measure of the same constructs with individuals in the larger community (AERA, 1999). External validity is important to consider for any test. It helps to understand how well the validity of the test can be generalized to different settings without having to investigate the validity within those contexts. Studies of test validity generalization are often conducted to investigate the extent to which examinee population impacts the validity of a measure. Findings from these investigations enable test users who work with individuals in populations different from the standardization population to make informed decisions about whether or not the measure is adequate for its intended purpose. Two studies are reviewed in Chapter IV that provide evidence for the external validity of the TEA-Ch for use with children ages 6-0 - 15-11 from the United States (Belloni, 2011; Passantino, 2011). I describe the population of child participants for this study in the Methods and Results sections to clarify the external validity of the findings of this investigation.

Psychometric test revisions require developing empirical support and examining relevant literature to support the validity and reliability of the revised version (AERA, 1999). Existing evidence from similar tests can enhance the quality of the validity argument (p.11). The test developer is responsible for providing relevant and compelling evidence and a rationale that supports the intended use of the test. Establishing the validity of the CT-TOT and CT-LD is the primary focus of this research project. The literature review sections provide substantial evidence of the reliability, construct, and content validity of the TEA-Ch sustained attention subtests to establish that they are acceptable criterion measures. In the present study, I investigated the concurrent, criterion validity of two new, time-based measures of sustained auditory attention.

The next section provides evidence of the construct validity of the TEA-Ch by reviewing the literature on theories of sustained attention based on neuroscientific research of the neurological substrates of sustained attention.

The Neuroanatomical Basis of Sustained Attention

Theoretical models of attention used to develop the TEA-Ch are based on neuroscientific research that provides evidence for the neurological attention models posited by Posner and Peterson (1990); Mirsky, Anthony, Duncan, Ahearn, and Kellam (1991); and Mirsky, Pascualva, Duncan, & French, (1999). Neuroscientific research relies on the post-positivistic theory of localization of neurologic functions. The fundamental premise of localization is that cognitive functioning is attributable to neuro-anatomical structures and their associated processes in the brain. By extension, these areas and processes are responsible for carrying out specific cognitive tasks and observable behaviors (Kolb & Whishaw, 2009). Post mortem lesion studies and, in more recent years, neuro-imaging techniques have enabled neuroscientists to make increasingly accurate inferences about the relationships between the brain and behavior. Table 8 in the Appendix provides a brief overview and explanation of prominent neuro-imaging techniques.

Two types of cognitive processes are discussed in the literature to describe sustained attention: top-down, conscious processes that operate by selective choice, and automatic processes that operate in a bottom-up fashion guiding our actions thoughts and behaviors with little or no conscious awareness (Mirsky, et al., 1991; Robertson, et al., 1997). Endogenous, top-down processes are conceptually driven, whereas exogenous, bottom-up processes are reactive to stimuli present in the environment (Robertson, et al., 1997). Top-down cognitive processing involves brain structures in the cerebral cortex that direct attention and allocate processing resources to specific aspects of experience. Bottom-up cognitive processing describes the attentional alerting system that originates in lower central nervous system structures located in the midbrain and brain stem. These regions regulate the level of arousal (or alertness) which then provides mental resources to the upper regions in the brain responsible for sustaining attention (Mirsky et al., 1991; Mirsky et al., 1999; Posner & Peterson, 1990). Both regions coordinate within a central nervous system (CNS) network that comprises the sustained attention network.

Post-mortem lesion studies and lesion studies in animals provide considerable knowledge about the brain regions associated with aspects of attention to the neuroscientific research literature (Mirsky et al., 1991; Mirsky et al., 1999; Posner and Peterson, 1990). Methods of neuro-imaging, such as electroencephalogram (EEG), magnetic resonance imaging (MRI), functional MRI (fMRI), positron emission tomography scans (PET), and computerized tomography scans (CT), have helped further specify neurological regions associated with processes involved in attention (Parasuraman, Warm, & See, 2000). The models of attention reviewed for this study served as the foundational theories for the TEA-Ch (Manly et al., 2001). This section is a review of aspects of both models that pertain to theoretical foundations of sustained attention.

Mirsky et al. (1991, 1999), and Posner and Peterson (1990) based their models of attention on lesion studies and neuro-imaging studies. Both theories hold that attention is not a unitary phenomenon, but rather a coordination of a group of distinct neural processes. Mirsky et al. (1991) posited that attention is a complex set of processes with three distinct functions: focus, sustain, and shift. Mirsky et al. (1999) later revised the model to include five specific functions: focus, execute, sustain and stabilize, shift, and encode (Mirsky et al., 1999). Distinct brain regions specialized for carrying out attention-related behaviors support each of these functions.

Similarly, the attention system posited by Posner and Peterson (1990) is purported to interact with other parts of the brain while maintaining its own neurological identity (Grahn & Manly, 2012). In Posner and Peterson's model, attention is conducted by a network of anatomical regions that comprise three distinct subsystems of attention including: orienting to sensory events (orienting), detecting signals for conscious processing (detection), and maintaining a vigilant or alert state (vigilance). Both models of sustained attention agree that there are limits and thresholds of attentional resources (Mirsky et al., 1999; Posner & Peterson, 1990). In both models, attention has conscious and unconscious processes that place varying demands on the information processing system.

Sustained attention, as it is assessed by objective measures of sustained attention, requires all three components of attention in Posner and Peterson's (1990) model (orienting, detecting, and vigilance) and three of the five components of attention from the model proposed by Mirsky et al. (1991, 1999) (focus, execute, and sustain). The tests under investigation in the present study require examinees to orient to a specific signal, maintain vigilance, and detect specific aspects of the signal stimuli. In order to provide theoretical evidence that supports the designs of the tests under investigation, it is necessary to review research that supports the entirety of Posner and Peterson's (1990) model and much of Mirsky et al.'s (1991; 1999) models of attention. Figure 3 in the Appendix is a visual depiction of the neurological regions and their distinct roles in sustained attention.

Orient/Focus. The role of attention is to modulate processing efforts towards stimuli deemed most important. The 'orient' and 'focus' aspects of both models of attention refer to the process by which the brain gives priority to a specific stimulus in the environment (Mirsky et al.1991; 1999; Posner & Peterson, 1990). In their attentional model, Posner and Peterson (1990) describe the processes involved in orienting the visual system. Attention can be oriented overtly, by directing the eyes towards the target, or covertly, without shifting the posture or eyes to the target. Attention is oriented similarly in the auditory modality. The mental act of orienting towards a stimulus enables more efficient processing of it. Cortical and midbrain structures implicated in visual orienting and auditory sustained attention include the posterior parietal lobe, the lateral pulvinar nucleus of the postereo-lateral thalamus, and the superior colliculus (Posner & Peterson, 1990; Robertson, et al., 1997). Brain injuries of various parts of these regions result in different types of orienting deficits.

Damage to the posterior parietal lobe and superior colliculus causes problems with shifting attention (Posner & Peterson, 1990). Posterior parietal lesions make it difficult to disengage from a target; lesions in the superior colliculus slow attentional shift from one target location to another (Weissman, Roberts, Visshcer, and Woldorff, 2006). The thalamus plays an important role in filtering irrelevant stimulus to enable orienting (Kim, et al., 2012; Posner & Peterson, 1990). According to Posner and

Peterson (1990), individuals with lesions of the thalamus show difficulty in covert orienting on the side opposite the lesion. In Posner and Peterson's model of attention, each of these neuro-anatomical regions plays a distinct role in orienting. The posterior parietal region is involved in disengaging attention from a stimulus, the superior colliculus moves attention towards the target region, and the thalamic region filters irrelevant stimuli to create a contrast between competing stimuli and the target stimulus to facilitate processing and detection.

Detect. The *detect* element of attention is important for processing information presented by sensory processing systems and information presented by mnemonic systems in the brain (Posner & Peterson, 1990). In the models proposed by Posner and Peterson and Mirsky et al., (1991) the anterior cingulate gyrus is involved in target detection and plays an important role in attentional neglect (Mirsky et al., 1991; Posner & Peterson, 1990; Weissman, et al., 2006). The anterior cingulate gyrus interacts directly with the posterior parietal lobe and the dorsolateral prefrontal cortex, brain regions that facilitate sensory processing, which suggests that this region is important to carry out visual and verbal target detection tasks (Duncan & Owen, 2000; Weissman, et al., 2006).

A recent fMRI investigation provides evidence of the importance of the anterior cingulate cortex and prefrontal cortex in target detection and the continuous processing of sensory information. Weissman, et al., (2006) investigated neural activation during moments of attentional lapse, which were defined as slow response times to targets. Weissman et al. used functional MRI (fMRI) to measure the neural activity of multiple subjects, ages 18-35, as they performed a focused global-local visual attention task. As expected, slowed response time was associated with reduced activity in several neural regions that support sustained attention: the right middle gyrus and inferior frontal gyri and the anterior cingulate cortex.

Findings from a study conducted by Shallice, Stuss, Alexander, Picton, and Derkzen (2008) supports the involvement of these regions in sustained attention; the results suggest that the anterior cingulate gyrus is involved in the maintenance of attention, rather than target detection, as suggested by Posner and Peterson (1990). Shallice et al. (2008) divided adult subjects into four groups based on lesion localization: the right lateral frontal cortex (RL), the left lateral frontal cortex (LL), the superior medial frontal gyrus (SM), and the inferior medial frontal gyrus (IM). Shallice et al. compared performance on fast and slow tone-counting tasks between lesion groups and a healthy control group. The fast tone-counting task required alerting and fast processing; the slow counting task required greater sustained attention, due to its relatively lengthy, dull, and low-stimulus demand format. The RL and SM groups showed significant impairment on the fast counting task relative to controls and the other lesion groups. Only the SM group showed significant impairment on the slow counting task, which suggests that this region, which includes the anterior cingulate gyrus, plays a role in the arousal network, which signals mid-brain regions to maintain necessary levels of alertness to sustain attention.

Vigilance. Posner and Peterson (1990) defined vigilance as the alert state necessary to prepare an individual to successfully process high priority targets and focus on processing tasks. Similarly, Mirsky et al.(1999) described the sustain aspect of their model as the ability to stay on task in a vigilant manner for a significant amount of time to enable "not missing targets, responding briskly to them, and inhibiting responses to non-targets."(p. 171). The alert state produces more rapid responding to a target, but the trade-off is more frequent commission errors. Models of the attention system differ in some respects; they all include the reticular formation as playing an important role in vigilance (Parasuraman, et al., 2000).

The tectum, reticular formation, and other regions of the brain stem represent the most primitive brain structures that are necessary for conscious processing and attention (Mirsky et al., 1991). These midbrain portions of the vigilance system are the platform upon which other brain mechanisms involved in sustained attention have been developed (Mirsky et al., 1999). Midbrain structures are necessary for the maintenance of vigilance. The reticular formation produces the readiness to respond, which sustained attention tests measure by reaction time and correct responding to target signals. Rostral midbrain structures, including the mesopontine reticular formation and midline and reticular thalamic nuclei, are responsible for sustaining attention to both visual and verbal stimuli (Mirsky et al., 1999). Evidence from fMRI studies shows that cells in these regions fire more rapidly in visual discrimination tasks requiring sustained attention (Lawrence, Ross, Hoffmann, Garavan, and Elliot, 2003). The midbrain regions work in concert with cortical regions to maintain conscious processing. According to Mirsky et al. (1999), all patients whose symptoms include disruption of sustained attention share some pathological disturbance in the cortico-reticular system.

The right cerebral hemisphere is crucial for the ability to develop and maintain an alert state (Lawrence, et al., 2003; Posner & Peterson, 1990; Shallice, et al., 2008). The neurologic literature indicates that lesions in the right cerebral hemisphere are associated with signal neglect and a slowing of alerting. Damage to the frontal lobes, especially the right side, impairs cortical arousal and alertness to a warning signal (Rueckert & Graffman, 1996). Rueckert and Graffman investigated performance differences on vigilance tasks between individuals with either right or left frontal lobe lesions and controls. Individuals with right frontal lobe lesions performed worse than the other groups, as measured by the number of targets detected and response time on vigilance tasks. PET scan studies of adults performing auditory sustained attention tasks show greater activation of the right frontal lobe with more localized activity in the middle prefrontal gyrus (Parasuraman, et al., 2000). Numerous other brain-imaging studies demonstrate similar patterns of right hemisphere dominance during sustained attention tasks (Lawrence, et al., 2003; Shallice, et al., 2008).

The neuroscience literature on sustained attention provides considerable evidence of distinct cortical regions that are responsible for continuous processing of information (right prefrontal cortex) and target detection (anterior cyngulate gyrus): two mental tasks required in sustained attention. Whereas Posner and Peterson (1990) and Grahn and Manly (2012) implicate the right prefrontal cortex in maintaining sustained attention, contrary evidence from lesion and neuro-imaging studies suggests that this region subsumes response inhibition (Aron, Robins, & Poldrack, 2004). Aron, Robbins, and Poldrack (2004) reviewed the literature on neuro-imaging and lesion studies of the pre-frontal cortex. Previous lesion studies indicate that damage to the right inferior frontal cortex disrupts response inhibition and task set switching. Neuro-imaging studies show that response inhibition activates the right inferior frontal cortex region.

Considerable neuroscientific research comparing neural activity during various auditory and visual sustained attention tasks provide evidence of a sustained attention network that operates in concert with other neurological regions (Grahn & Manly, 2012; Parasuraman, et al., 2000). Grahn and Manly (2012) found convincing evidence of a multiple-demand or global sustained attention workspace, which they report biases attention selection in a task-relevant manner. Grahn and Manly used fMRI to investigate similarities and differences in cortical activity during an auditory counting task and a visual go, no-go paradigm: tasks widely used to measure sustained attention. Eighteen healthy adults, ages 19-29, participated in the study. Subjects completed neutral tasks in each modality that required minimal effort to sustained attention. Grahn and Manly first contrasted neural activity of sustained attention tasks with neutral tasks in each sensory modality to specify neural regions involved in sustained attention. They then contrasted cortical activity during visual and auditory sustained attention tasks to identify areas of common neural activity involved in the various tasks. Several cortical regions showed considerable activity in both task modalities. Cortical regions active during both tasks included the bilateral inferior frontal operculum, the anterior cingulate cortex, and the bilateral premotor cortex. The study supports a multiple demand, or sustained attention network, with specific neurologic regions that subsume diverse sustained attention tasks.

Summary of neuroanatomical evidence. The models proposed by Posner and Peterson (1990) and Mirsky et al. (1991; 1999) are based on convincing evidence from the neuroscience literature that specific regions of the midbrain (reticular formation, superior colliculus, and postereolateral thalamic nucleus) and cerebral cortex (anterior cyngulate gyrus, posterior parietal regions, right anterior frontal lobe) are important for sustaining attention to target signals. Numerous studies conducted since the inception of these models provide further evidence of a sustained attention network; however, evidence of the exact functions of the subcomponents of this network is inconclusive. Current knowledge from the neuroscientific literature suggests that specific neural regions operate in concert to provide the platform for sustaining attention (Grahn & Manly, 2012). Individuals with damage or anatomical variations in any of these specific neurological regions and their interconnections are likely to show varying degrees of inefficiencies within the overall sustained attention network (Grahn & Manly, 2012; Mirsky et al., 1999; Parasuraman, et al., 2000; Posner & Peterson, 1990). Psychometric tests with behavioral tasks that require various forms of sustained attention should theoretically be able to detect these functional correlates of anatomical variations, and quantify differences in sustained attention performance.

Manly, Nimmo-Smith, Watson, Anderson, et al. (2001) modeled the sustained attention tasks of the TEA-Ch after the tasks used to investigate sustained attention in the neuroscientific research literature. A link between tasks used in objective measures of sustained attention, including the TEA-Ch subtests, and the neural correlates of sustained attention reviewed has been clearly established in the neuroscientific research literature (Parasuraman, et al., 2000; Riccio, Reynolds, Lowe, & Moore, 2002).

Objective Measures of Sustained Attention

Objective measures of sustained attention quantify how well individuals can override their natural inclinations to let their attention be guided by the most stimulating or rewarding aspects of their experience (Douglas, 1983). This is why most objective measures of sustained attention were intentionally designed to be dull and boring, so as not to naturally draw the individual's attention to the task (Manly et al., 2001; Mirsky et al., 1999). Objective assessments of sustained attention are based on theories of vigilance that were first investigated by Mackworth (1950) in the 1940's (Parasuraman, et al., 2000).

Test developers modeled the most widely used modern-day objective assessments of sustained attention after the original Continuous Performance Test (CPT) that was developed by Rosvold, Mirsky, Sarason, Bransome, and Beck (Riccio, Reynolds, & Lowe, 2001; Mirsky, et al., 1999). In the study by Rosvold et al. (1956), two different conditions were administered: an X paradigm in which participants pushed a button every time an X was presented and a A-X paradigm, in which participants were to push a button only when presented with an X immediately preceded by an A. Two outcome measures were used to quantify the results: the Absolute Score, which was based on a ratio of correctly identified targets over actual targets (omission errors), and the Relative Score, which was based on the ratio of correct responses over the number of subject responses (commission errors) (Rosvold et al, 1956).

Since Rosvold et al.'s (1956) original CPT, test makers have developed numerous CPT designs for use in clinical practice (Riccio, et al., 2001). Most CPTs used today for clinical and research purposes are computer-administered and last between 6 and 15 minutes (Strauss, et al., 2006). The majority of CPTs continue to use the X and A-X paradigms, but in many instances, test developers replaced the letters with different visual stimuli, such as numbers or pictures. Some developers have modified the format of the task, requiring examinees to identify the target stimuli, and others, such as the Conner's CPT-II, require the examinee to respond to all non-targets and inhibit responding to the target (go, no-go paradigm).

There are currently 13 commercially available objective assessments designed to measure attention; of these 13 measures, 9 were designed for use with child populations (Strauss, et al., 2006). Five of the nine measures of children's attention evaluate sustained attention: the Conner's Continuous Performance Test (CPT-II), the Gordon Diagnostic System (GDS), the Integrated Variables of Attention+ (IVA+Plus), the Children's Paced Auditory Serial Addition Test (CHIPASAT), and the Test of Variables of Attention (T.O.V.A). In addition to these stand-alone measures of sustained attention, five subtests from the Test of Everyday Attention for Children (TEA-Ch) and two subtests from the NEPSY II neuropsychological test battery (Auditory Attention and Response Set) were designed to measure children's sustained auditory attention. Sustained attention measures share similar features, but each one uses a unique combination of administration procedures, task factors, and outcome scores that provide distinct, interpretive data about the quality of the sustained attention of the individual. Table 1 lists the eight different commercially available, objective clinical measures of sustained attention along with test formats.

Table 1
Method of Administration, Age range, and Duration of Clinical Measures of Sustained Attention

Test	Administration	Age Range	Test Duration
CPT-II	Computer	6- 55+	14 minutes
K-CPT	Computer	4-5	7.5 minutes
IVA+Plus	Computer	6-99	13 minutes
T.O.V.A & T.O.V.A (A)	Computer	6-80	22 minutes
GDS	Microprocessor	4-16	6 or 9 minutes
NEPSY-II	Examiner	5-16	N.P.
CHIPASAT	Examiner	8-14.5	N.P.
TEA-Ch Subtests	Examiner	6-15.11	N.P.

Note. N.P. = Not Provided in the test manual.
Table 1 was adapted from Manly et al., 2001; Strauss, Sherman, & Spreen, 2006

The following section reviews the similarities and differences between the various objective measures of sustained attention for children used in clinical settings.

Test administration. There are two primary categories of test administration for objective measures of sustained attention: computerized tests and examiner administered tests (Strauss, et al., 2006). Administration procedures of computerized CPTs are carried out almost completely by the software program. With the exception of the T.O.V.A and GDS, computers present test instructions to examinees.

Computerized administrations have several advantages over examiner-administered tests. First, using the computer reduces the variability in the presentation of stimuli, thereby improving the reliability of the test findings (AERA, 1999). Second, computers offer more accurate response recording and can accurately measure response time to the nearest millisecond (Riccio, et al., 2001; Strauss, et al., 2006). Once the test is administered, outcome scores are automatically calculated by computer software (except for the GDS which uses a combination of computerized and manual scoring), which significantly reduces the likelihood of scoring errors that can result from manual scoring procedures. The software included for computerized CPTs provides numerous types of outcome measures that are not possible to generate from examiner-administered assessments.

The majority of examiner administered measures of sustained attention use similar, basic administration procedures (Strauss, et al., 2006). The examiner provides instructions, and practice trials help ensure proper understanding of each of the tasks. The examiner sits across from the examinee to ensure accurate recording of responses, completion times, and missed targets on the test protocols. An advantage of examiner-administered assessments is that they allow for greater procedural flexibility and create a test dynamic that may result in more consistent examinee performance (Riccio, et al., 2001). Using practice trials and repeat instructions when necessary, allows examiners to screen out children who may have cognitive, language, or sensory problems that would preclude them from effectively engaging in the sustained attention tasks (Manly et al., 2001).

The effect of administration type on the sustained attention performance of children has received little attention in the research literature. Riccio, et al. (2001) suggest that the face-to-face orientation of the examiner and examinee may improve effort and reliability of test results, as examinees are more aware that their efforts are being scrutinized. The current literature on the administration of sustained attention tests clearly indicates that there are distinct differences between computerized and examiner administration methods (Strauss, et al., 2006). Each method of administration offers unique advantages over the other.

Test format. Since the 1940s, neuroscientific and psychological researchers have substantiated the construct of sustained attention in numerous studies (Manly et al., 2001; Parasuraman, et al., 2000; Posner & Peterson, 1991). Since this time the CPT has become the most widely used and accepted measure of sustained attention (Barkley, 2006; Riccio et al., 2001). Numerous studies comparing examinee performance between CPTs have identified substantial performance differences between measures (Borgaro, et al., 2003; Parasuraman, Warm & See, 2000). These findings suggest that there is considerable variance in the type and number of additional mental resources required of these tasks.

It is widely accepted that numerous task factors affect sustained attention performance (Parasuraman, et al., 2000). For example, the X-paradigm used in many CPTs requires merely listening for irregular target signals; the A- paradigm requires greater signal processing and working memory demand. Event rate, the decision criteria required to provide responses, and the sensory modality of target signals are important factors that affect the processing demands of sustained attention tasks and contribute to the relative difficulty of these tasks (Parasuraman, et al., 2000; Ricco, et al., 2001). The formats of sustained attention measures vary primarily along these three dimensions (see Table 2).

Table 2
Test Factors of Clinical Measures of Sustained Attention for Children

Test	Signal Modality	Decision Factor(s)	Event Rate
CPT-II	Visual	Go, No go	1, 2 or 4 s.
K-CPT	Visual	Go, No go	1.5 - 3.0 s.
IVA+Plus	Visual & Auditory	X paradigm	1.5 s.
T.O.V.A & T.O.V.A (A)	Visual or Auditory	X and AX paradigm	2 s.
GDS	Visual or Auditory	X and AX paradigm	Constant
NEPSY-II	Auditory	X paradigm	1 s.
CHIPASAT	Auditory	A+B, B+C, C+D, …	1.2 - 2.4 s.
TEA-Ch Score!	Auditory	Serial Counting	500-5000 ms
TEA-Ch Sky Search DT	Visual & Auditory	Counting & detection	1000 ms
TEA-Ch Score DT	Dual Auditory	Counting & detection	500-5000 ms
TEA-Ch Walk, Don't Walk	Auditory	Go, No go	500-1500 ms
TEA-Ch Code Transmission	Auditory	XX-Pre-X paradigm	2 s.

Table 2 was adapted from Manly et al., 2001; Strauss, Sherman, & Spreen, 2006.Note. Ms= milliseconds. S.= seconds

Decision criteria are test rules that examinees must follow in order to provide correct responses. Decision criteria in sustained (tasks) vary in complexity, from the usual requirement of simple signal detection to more elaborate response requirements involving judgment, response inhibition, decision-making, and working memory (Davies & Parasuraman, 1981, p. 28). As the complexity of the decision criteria increases, so does the demand on the sustained attention system. Higher demands result in a faster onset of the vigilance decrement, a phenomenon explained by resource theories of sustained attention (Parasuraman, et al., 2000; Rosvold et al., 1956). According to resource theories, signals from the arousal system wane over time due to a depletion of neural resources over the length of the detection task (Helton, et al., 2005). Research that has linked a more rapid onset of the vigilance decrement to more cognitively demanding signal detection tasks supports resource theories (Helton & Warm, 2008; Helton et al., 2005).

The simplest decision criteria used on measures of sustained attention is signal detection. Measures that use signal detection tasks require examinees to indicate each time they detect a discrete target signal. Although Mackworth (1950) was the first to measure signal detection errors over time, it was Rosvold et al.'s (1956) who created the seminal term x-paradigm to describe the task they used which required examinees to indicate every time they saw an x stimulus. Since this time, many tests of sustained attention, such as the IVA+Plus, continue to use the x-paradigm. The CPT-II uses a similarly simple variation of the x-paradigm, called the go, no-go paradigm. This format requires examinees to respond to all non-target signals and to refrain from responding to each target signal. Tests that use the simple x-paradigm as decision criteria can be said to be some of the most theoretically pure measures of sustained attention because they minimize the demand for other cognitive processes, such as working memory and response inhibition: factors known to impact sustained attention performance.

Tests that use the A-X paradigm, such as the GDS and the T.O.V.A, require examinees to respond only when target signals are directly preceded by a specific, non-target signal, such as the letter *A*, which was used by Rosvold et al. (1956). The A-X paradigm uses more complex decision criteria than simple, signal detection tasks, by requiring examinees to hold non-target A's briefly in short term memory while processing the next signal. Research evidence supports the contention that the tests that use the A-X paradigm are more difficult than those that use the X paradigm, as evidenced by increased errors of omission and commission (Rosvold et al., 1956).

The TEA-Ch Code Transmission subtest uses similar but slightly more challenging decision criteria that require examinees to hold a random number in working memory while processing the next two consecutive numbers (Manly et al., 2001). The addition of this criteria places greater demand on working memory and response inhibition. Examinees must temporarily store information in working memory until the next letter (or number) is presented to decide whether to respond. Other sustained attention measures use even more complex decision criteria that demand increased working memory, greater response inhibition, and additional processing tasks.

The NEPSY-II Auditory Response Set and the CHIPASAT use perhaps the most complex combination of decision criteria of all tests of sustained attention for children (Strauss, et al., 2006). The NEPSY Auditory Response Set subtest requires examinees to listen to an audio CD with many different words, including four color-words (Korkman, Kirk, & Kemp, 2007). Examinees are instructed to touch the red circle when they hear the word *yellow*, touch the yellow circle when they hear the word *red* and touch the blue circle when they hear the word *blue*; they are asked to keep their hands on the table in between targets. These decision criteria create a high working memory demand and require careful response inhibition, in order to refrain from automatically responding to the color word (Korkman, et al., 2007).

The Children's Paced Auditory Serial Addition Test (ChiPASAT) also uses demanding decision criteria. The ChiPASAT's auditory sustained attention decision criteria (A+B, B+C, C+D...) place a high demand on working memory and information processing, including mental calculation and rapid retrieval of math facts (Strauss, et al., 2006). The CHIPASAT becomes even more difficult as the time interval between targets, or event rate, increases in each of five successive trials, another factor that is widely known to affect sustained attention.

The event rate denotes the speed of presentation of target and non-target signals (Parasuraman, et al., 2000). A substantial number of investigations of vigilance have found an inverse relationship between the quality of sustained attention and the rate of presentation of neutral events (Denney, Rapport, & Chung 2005; Parasuraman, 1985; Warm, 1984). The higher the event rate, the faster the onset of the vigilance decrement as measured by a more rapid increase in commission errors and response times. Most computerized sustained attention measures, including the CPT-II, IVA+Plus, and T.O.V.A vary the event-rate between trials to measure the effects it has on sustained attention performance. Tasks with high event rates tend to elicit more commission errors. Because high event-rate conditions leave little time for the decision criteria, examinees must exert greater response and inhibitory control.

While high event-rate conditions place a greater demand on the sustained attention system and thereby challenge the endurance of the arousal system, low event-rate conditions have the opposite effect. Because of their slow, dull, and non-reinforcing nature, low event rate conditions test one's ability to block out task unrelated thoughts (TUT's) that compete for attention under boring processing conditions (Datta, et al., 2007; Manly et al., 2001). Overall, tests with higher background event rates result in more commission errors and a faster increase in response time differences; tests with lower background event rates typically result in an increase in omission errors due to attentional lapses.

The type of sensory stimuli (visual or auditory) used in various measures of vigilance impacts the level of difficulty of various CPT tasks (Baker, Taylor & Leyva, 1996; Borgaro, et al., 2003). Studies comparing visual and auditory CPTs provide evidence that auditory vigilance tasks are more cognitively demanding than visual tasks (Baker, et al., 1996; Borgaro, et al., 2003; Curtindale, Laurie-Rose, Bennett-Murphy & Hull, 2007). In their study comparing performance differences on auditory and visual vigilance tasks, Baker, et al. (1996) found that graduate students performed significantly poorer on the auditory vigilance task as indicated by higher numbers of omission errors.

Borgaro et al. (2003) found a similar pattern in a study with adolescents. One hundred in-patient psychiatric care adolescents with a range of psychiatric diagnoses other than ADHD completed three separate computer administered auditory and visual CPTs. Significant performance differences were found in the adolescent population between visual and auditory CPTs, with participants scoring significantly lower on the auditory CPT. Aylward, Brager, and Harper (2002) provided similar findings with a large sample of children and adolescents ages 5.5-17.9 (N=634) mostly referred for clinical evaluation of ADHD or possible learning disability. Aylward, et al. compared performance differences on the visual and auditory versions of the Gordon Diagnostic

System. As in previous studies, they found significant performance differences between visual and auditory sustained attention tasks: Children performed much worse on the auditory CPT. The research literature provides clear evidence of significant performance differences on sustained attention by sensory modality. These findings indicate that sensory modality is a clear differentiating factor between measures of attention.

Overall, studies that have compared performances between CPTs clearly indicate that there are significant variations in the cognitive demands of the various test formats (Baker, et al., 1996; Curtindale, et al., 2007; Parasuraman, et al., 2000). These findings suggest that certain CPTs are likely to be better predictors of the type(s) of sustained attention demands required of children in natural settings.

Outcome scores. All objective measures of sustained attention have three behavioral performance indicators to quantify sustained attention: errors of omission, errors of commission, and change in reaction time over time (Riccio, et al., 2001). Errors of omission occur when a child fails to detect a target signal. Omission errors occur during moments when the examinee is no longer processing the test stimuli. Errors of commission occur when an examinee falsely responds to a neutral test stimulus. Both omission and commission errors reveal a failure on the part of the child to react adequately and consistently to target stimuli and are interpreted as evidence for inhibitory and attentional problems (Douglas, 2004).

Commission errors provide evidence of inhibitory problems under low-demand test conditions, but may indicate attentional lapses under high event-rate conditions (Parasuraman, et al., 2000). Omission errors simply indicate attentional lapses as evidenced by a failure to respond to a target signal. Most computerized CPTs also measure the vigilance decrement by the change in response time latency over the duration of the continuous processing task. Response time is considered a more sensitive measure of the quality of sustained attention (Parasuraman, et al., 2000). Theoretically, increased response time reveals waning attentional resources as reflected by a child's slowing response speed.

Outcome scores on examiner-administered assessments indicate accuracy in responding; outcome scores from computerized tests also include measures of response time differences between trials and over time (Strauss, et al., 2006). Examiner-administered assessments provide standardized scores based on the number of correctly identified targets and the number of falsely indicated non-targets. In addition to scores based on response accuracy, computerized tests offer numerous outcome scores to provide a broader picture of a child's sustained attentional problems. Examiners contrast all scores derived from the various tests with normative data to provide an estimate of the child's performances relative to peers of the same age. Some tests, such as the TEA-Ch, allow for comparison of age and gender-matched peers, and several others (including the CPT-II) have comparative norms for clinical populations (such as ADHD) (Strauss, et al., 2006).

Even though research on objective measures of sustained attention clearly indicates that cognitive demand varies considerably between different types of sustained attention tasks, many clinicians use these measures indiscriminately to assess children's sustained attention, with little consideration to how well the results may generalize to natural settings (Riccio et al., 2001; Barkley, 1991). When Mackworth (1950) conducted the first study of sustained attention, he investigated the capacity of military personnel to maintain vigilance to visual and auditory radar signals. The British Royal government commissioned the study to improve the performance and accuracy of radar operators in the British Armed Forces, following World War II. Mackworth designed the vigilance tasks, not only to measure vigilance, but also to closely match the vigilance demands of radar operators. The primary purpose of Mackworth's study was to make recommendations regarding ideal conditions for radar operators to work with the greatest signal detection accuracy. Mackworth's tasks closely modeled those required of a specific population of adults in natural settings. Consequently, his findings had strong ecological validity and were highly applicable outside of the laboratory.

Clinical tests of sustained attention continue to use task paradigms that are similar to those first designed by Mackwork in the 1940s. The presentation of stimulus and processing demands of many of the most commonly used CPTs is significantly different from the sustained attention required of children in natural settings (Barkley, 1991; Riccio, Reynolds, & Lowe, 2001). Computers often present the stimulus and record child responses. On computer-administered CPTs children must press a button or buttons on the computer or mouse in response to either visual or auditory targets, rather than provide an auditory response, as is often the case in natural settings. Instructions for most computerized CPTs suggest that the examiner is present during the administration of the subtests, especially for younger children, but the examiner's presence is largely unobtrusive (Riccio, et al., 2001). In short, the test conditions and processing demands of many computerized CPTs are significantly different from those required of children in natural settings where they are often required to sustain attention to speech and to provide an auditory response in return.

Unlike radar operators, the sustained attention demands placed on children are heterogeneous and vary across social settings. One of the most important social environments where children are required to sustain attention is the classroom setting, where teachers provide instructions and lessons using a combination of auditory instructions and visual information. Not only are children required to sustain attention to auditory instructions and deskwork, but they must also be prepared to provide an auditory response when called upon. Children must focus and sustain their attention to the teacher's voice and process what she/he is saying in order to respond to the lessons in the expected fashion. In this context sustained attention requires not only the ability to focus on the teacher's voice, but also the ability to process what the teacher said. Processing spoken language requires the use of working memory to store sequential words long enough to comprehend the entire message, using semantic and syntactic cues (Just, & Carpenter, 1992; Robertson & Joanisse, 2010).

Objective measures of sustained attention that use an A-X paradigm require examinees to continuously process each target signal and briefly store each one in working memory because correct targets are contingent upon a previous neutral signal (Parasuraman, et al., 2000). The format of A-X CPTs places a working memory load on the sustained attention task that is similar to that required in language processing (Montgomery, Evans, & Gillam, 2009). Several computerized CPTs use signal-detection paradigms that more closely resemble the type of sustained attention demanded of children in natural settings; many of them rely on a computer screen or a headset to present stimuli. The Code Transmission subtest of the TEA-Ch uses an XX-pre-X paradigm, which also requires working memory similar to language processing tasks. A

CD or cassette player presents the auditory stimuli rather than a headset or computer screen: a format that is arguably more like natural settings than computerized tests (Manly et al., 2001). Rather than providing a manual, motoric response, examinees are required to provide an auditory response. Examinees listen to the audio stimulus along with the examiner, rather than through a headset; examinees are likely more aware that the examiner is mindful of their performance at all times (Riccio, et al., 2001).

The factors discussed above differentiate objective measures of sustained attention, making some more similar than others to the sustained attention demands of children in natural settings. Regardless of the format, all objective measures of attention provide only normative estimates of performance. Objective methods of assessment, though helpful in identifying children with attentional problems and diagnosing attention-related disorders in children, offer little information about the limitations that problems with sustained attention impose on a child’s ability to engage effectively in natural settings (Barkley, 1991). Existing methods of measuring sustained attention, though demonstrated to be reasonably valid, reliable, and useful in clinical research, offer little in the way of interpretable data for practicing, clinical psychologists working with children suspected of having problems with sustained auditory attention (Barkley, 1991; 2006). An assessment that estimates how long a child is able to sustain attention, and the amount of overall time that a child can sustain auditory attention may help adults and professionals understand the difficulties children experience in traditional classroom settings that rely primarily on oral presentation of lesson plans and explanations. The TEA-Ch Code Transmission may provide the closest approximation of attentional demands of children in the classroom setting; the standard score provides limited data about the sustained attention capacities of children that is translatable to natural settings. To date, there exist no objective, clinical measures of sustained attention that provide time-based estimates of sustained attention, nor has a study been undertaken to investigate this method of assessing sustained attention in clinical settings.

Psychometric Properties of the TEA-Ch

In 1994, Robertson, Ward, Ridgeway and Nimmo-Smith (1996) created the Test of Everyday Attention (TEA), a multi-dimensional assessment of adult attention. Robertson et al. modeled the subtests of the TEA after everyday tasks to improve the ecological validity of the measure. Several years later Manly, Robertson, Anderson, and Nimmo-Smith (2001) created the Test of Everyday Attention for Children (TEA-Ch) based on the earlier TEA. Manly et al. (2001) designed the TEA-Ch to provide clinicians a more comprehensive assessment of the various domains of attention to improve diagnostic specificity and inform treatment and intervention planning for children. Like the TEA, which used attentional tasks similar to those required in everyday settings, Manly et al. developed the TEA-Ch with ecological validity in mind. Manly et al. developed the TEA-Ch to assess the three primary subcomponents of attention based on neurological theories of attention developed by Posner and Peterson (1990) and Mirsky (1991, 1999).

TEA-Ch validity. In section two, I reviewed the literature that provided the theoretical basis of the construct validity of the TEA-Ch. The following studies link the theoretical constructs of attention with the TEA-Ch subtests and provide further evidence for the construct validity of the TEA-Ch.

Researchers use factor analysis to investigate evidence of a test's convergent and discriminant validity: how well it converges with the factors associated with a theoretical model, and how well it discriminates between the different factors (Bryant & Yarnold, 2009). During test development, exploratory factor analysis helps determine how well the outcome scores of the examinees align with the theoretical model of the latent factors, or construct(s) under investigation (Bryant & Yarnold, 2009; Field, 2009; Mertler & Vannatta, 2002).

Manly et al. (2001) used exploratory factor analysis to link the TEA-Ch subtests to an optimal, theoretical model of attention. A sample of 293 children ages 6 to 16 from Australia comprised the normative population for the TEA-Ch. All participants were administered the TEA-Ch subtests. Manly et al. (2001) first investigated a single factor model of attention and found that this model did not provide an adequate fit to the TEA-Ch subtest data. Next, they investigated a three-factor model based on models proposed by Posner and Peterson (1990) and Mirsky et al. (1991) and entered it as the a-priori model. The three latent factors for the model (selective attention, sustained attention and attentional control) provided a good fit to the TEA-Ch subtests postulated to impose a primary demand on the related attentional function. Five of the 9 subtests on the TEA-Ch were linked to the sustained attention factor: Score!; Score DT; Walk, Don't Walk!, Sky Search DT, and Code Transmission. Manly et al. used three incremental fit measures to evaluate the goodness of fit of the model: the Comparative Fit Index (CFI), the Normed Fit Index (NFI), and the Non-Normed Fit Index (NNFI). The value of each index was above the recommended value of 0.9 indicating that the three factors formed a good fit to the patterns of performance observed in the normative sample (Bryant & Yarnold, 2009).

The findings of the exploratory factor analysis conducted by Manly et al. provided evidence of the link between the TEA-Ch subtests and the attentional constructs in the models of attention developed by Posner and Peterson (1990) and Mirsky et al. (1991; 1999).

Confirmatory factor analysis (CFA) is a statistical method that tests a theory, model, or factor structure previously developed to define or understand a construct (Bryant & Yarnald, 2009; Passantino, 2010). Confirmatory factor analysis (CFA) often follows exploratory factor analysis or other statistical methods (Bryant & Yarnold, 2009). In CFA, researchers use a specified factor model to generate predicted relational values (correlations or covariances) between the latent factors and discreet variables. Researchers are interested in understanding how well the observed, relational values between the discreet variables and latent factors match the relational values predicted by the factor model. The closer the predicted and observed relational values, the better the model fits the data, or the better the goodness of fit (Bryant & Yarnold, 2009, p. 111). Like exploratory factor analysis, CFA provides indicators of how well the various tests load on each latent factor within the model, and provide crucial evidence for the construct validity of the test. In separate studies, Passantino (2011) and Belloni (2011) used confirmatory factor analysis to examine the goodness of fit of Manly et al.'s (2001) three-factor model of attention with children from the United States.

Belloni (2011) used CFA to investigate the TEA-Ch's three-factor model of attention with a sample of children from the United States. Participants matched age and inclusion criteria of the students in the Manly et al.'s (2001) original study. Participants included 158 children (78 males and 80 females) ages 6 to 15-11 months, stratified into the same six age-bands as Manly et al.'s participants. The findings of Belloni's study supported Manly et al.'s three-factor model of attention as a good fit to the TEA-Ch subtest data. Passantino (2011) also used CFA to investigate the fit of several models of attention, including Manly et al.'s (2001) three-factor model, with the 9 TEA-Ch subtests. Participants were children, ages 6.0 - 12.9 from the United States drawn from two previous studies. Manly et al.'s (2001) three-factor model provided a satisfactory fit, as indicated by three out of four statistical measures of goodness of fit. Because Passantino found significant correlational overlap between the control/shift and selective attention factors, she investigated a two-factor model that included sustained attention and a new factor she called *visual control attention*. Passantino found that the two-factor model provided a better fit to the data than the other models, but not significantly.

The findings of both studies support the validity of the TEA-Ch's three factor model of attention (Belloni, 2011; Passantino; 2011). More relevant to this research project, in both studies, Belloni (2011) and Passantino (2011) found that the sustained attention factor provided a good fit to the data from the five TEA-Ch sustained attention subtests, regardless of the model investigated. The results of the investigations by Manly et al. (2001), Belloni (2011), and Passantino (2011) provide further evidence of the construct validity of the four TEA-Ch subtests used as measures of sustained attention in this study.

Evidence of performance differences that coincide with age provides another source of construct validity for tests designed to quantify a construct that is believed to develop and/or decline with age, such as sustained attention (Cohen & Swerdlik, 2002; Groth-Marnat, 2009). Numerous studies indicate that the attention of younger children is much more limited than that of older children: a difference believed to reflect developmental differences in the central nervous system (Brown, 1982; Curtindale, et al., 2007; Gale & Lynn, 1972; McKay, Halperin, Schwartz, & Sharma, 1994). Several different investigations of the relationship between performance on the TEA-Ch subtests and age revealed significant, positive correlations between these factors (Belloni, 2011; Manly et al., 2001; Passantino, 2011). These findings support performance patterns predicted by the research literature that sustained attention should improve with age, and the findings also provide additional evidence of the validity of the TEA-Ch.

TEA-Ch content validity. Content validity is the extent to which test items represent the constructs intended. Manly et al. (2001) designed the tasks for the TEA-Ch subtests to minimize the need for other cognitive skills, such as memory, language, and comprehension. Manly et al. modeled the four TEA-Ch subtests used in this study after well-established, valid methods of measuring sustained attention. The Score! subtest is a children's version of a well-established means of assessing sustained attention in adults (Grahn & Manly, 2012; Manly et al., 2001; Shallice, et al., 2008). Examinees must sum a series of tones with varying inter-stimulus time intervals. The simplicity of the task and the long pauses between some counting signals places a high demand on the sustained attention system. Counting errors represent lapses in attention. The Score DT subtest puts an even greater demand on the sustained attention system than the Score! Subtest. The format requires simultaneous signal counting while listening out for an animal name in a news broadcast. Both tasks on the Score DT require continuous processing of auditory information. Manly et al. (2001) simply described the Code Transmission subtest as a traditional continuous performance test. A considerable amount of evidence from the research literature established CPTs as valid measures of sustained attention (Mirsky et al., 1999; Parasuraman, et al., 2000). The Walk, Don't Walk subtest uses the go, no-go paradigm from other well-established measures of sustained attention (Anderson, Fenwick, Manly, & Robertson, 1998; Grahn & Manly, 2012; Strauss, et al., 2006). The Walk, Don't Walk subtest assesses how well individuals can actively maintain attention, rather than lapsing into an absent-minded, automatic type of responding (Manly et al., 2001). Examinees must sustain their attention and actively match their rate of response with the varying rates of stimulus presentation; automatic responding results in commission errors. Considerable research supports the content validity of the tasks used in each of these TEA-Ch subtests used in this investigation.

TEA-Ch convergent and discriminant validity. Manly et al. (2001) assessed the convergent and discriminant validity of the TEA-Ch by administering three well-established measures of attention to 96 children from the normative sample, along with the TEA-Ch: the Stroop task, Trails Test, and Matching Familiar Figures Test. The Stroop Test and Trails tests are both well-established measures of selective attention and attentional control. The Matching Familiar Figures subtest measures impulsivity. The correlations between the values showed a relatively consistent pattern between performances on established tests that measure the same construct as the TEA-Ch subtests. Surprisingly, the Code Transmission subtest shared a significant positive correlation with each of the criterion tests, which suggests that these tests do not discriminate well between sustained attention and the other attentional constructs. Manly et al. (2001) interpret the significant correlations with the Code Transmission as evidence that each of the tests require sustained attention.

Manly et al. (2001) administered the WISC-III to 160 of the sample population to investigate the discriminant validity of the TEA-Ch subtests. They calculated correlations between TEA-Ch subtest and the Full Scale IQ (FSIQ), Vocabulary subtest score, Similarities, Block Design, and Object assembly standard scores from the WISC-III. Overall, correlations between the measures revealed good discriminant validity. Some correlations between measures reached significance, especially scores where speed of performance is a factor, such as on the Block Design and Object Assembly subtests and the Map Mission and Creature Counting Accuracy subtest scores. The Code Transmission scores showed significant correlations ($p<.05$) with the FSIQ, Similarities and Block Design scores, which suggests an interaction between IQ and sustained attention.

Investigations comparing children diagnosed with various disorders known to be disruptive of attention with healthy controls provide additional evidence of the discriminant validity of the TEA-Ch. Catroppa, Anderson, Morse, Haritou, and Rosenfeld (2007) used the TEA-Ch to compare the attentional abilities of children, 5 years post-TBI with healthy controls. Catroppa et al. grouped children ages 2.0 - 7.9 at age of head injury into mild, moderate, and severe TBI. Participants completed measures of IQ, adaptive functioning, and several TEA-Ch measures of sustained, divided, and selective attention. Catroppa et al compared performances between groups with a control group of healthy age-matched controls. They found significant correlations between the control group and the three TBI groups on the Code Transmission and Score! subtests of the TEA-Ch, with the severe group showing the largest effect size.

Numerous researchers used the TEA-Ch to investigate attentional differences between Children with ADHD and controls (Gardner Sheppar, & Effron, 2008; Heaton, Reader, Preston, Fennell, Puyana, Gill, & Johnson, 2001). Gardner, et al. (2008) found that the TEA-Ch Score! was useful in discriminating between children with ADHD and controls. Repeat measures of children diagnosed with ADHD on and off stimulant medication also revealed significant performance differences on the Score! subtest. Heaton, et al. (2001) compared TEA-Ch performances of 63 children diagnosed with ADHD with 23 age-matched controls. Significant group differences were found among three of the sustained attention measures (Score!, Walk, Don't Walk, and Code Transmission), with children with ADHD performing significantly worse.

Manly et al. (2001) compared TEA-Ch scores of 24 boys diagnosed with ADHD with those of age-matched controls. The six TEA-Ch subtests used included: Sky Search, Score!, Sky Search DT, Score DT, Walk, Don't Walk, and Opposite Worlds. The results showed significant performance among the groups, with the overall performance of the boys diagnosed with ADHD being much worse than the control subjects' scores. It is noteworthy that the sustained attention subtests showed the greatest statistical differences among groups. These studies provide evidence of the TEA-Ch as effective in discriminating between children with diagnoses known to impact attention and healthy controls.

TEA-Ch reliability. To ensure reliable test results, test designers must create standardized administration procedures to minimize variability in the procedures and test conditions that might otherwise have an impact on the outcome of the test itself (AERA, 1999). Test designers must also consider the meaning that attributed to the test and the potential for harm, as well as who will benefit from the test administration. The content of the test should capture the construct under investigation and minimize intervening variables to help ensure reliable and valid test results.

Manly et al. (2001) carefully describe the TEA-Ch administration procedures and precautions in testing in the test manual to ensure valid and reliable test results. The instructions provided in the manual minimize variance, identify foreseeable problems that may invalidate the scores, and help ensure that examinees have a proper understanding of the tasks before test administration. Explicit administration procedures clearly specify the protocol for each TEA-Ch subtest (Baron, 2001). Administration procedures include recommendations for ensuring an appropriate test environment and instructions regarding examinee and examiner placement and proximity. Verbatim instructions provided in the manual help minimize error variance that might otherwise occur from inconsistent testing procedures. The authors allow examiners to repeat instructions to help children understand the tasks when necessary, and practice items for each subtest help identify individual problems that may interfere with test performance.

Manly et al. (2001) caution that children who have apparent difficulty with comprehension of instructions should not be administered the test. They also note that examiners must rule out problems with sensory processing, communication, and motor performance need to ensure valid test results. Manly et al. (2001) caution against administering the test to children below average levels of IQ because the impact of below average IQ on TEA-Ch scores has not been investigated. Other threats to validity reviewed by the TEA-Ch authors are the child's approach to the task, level of motivation, ability to count to 15, problems with receptive language, and slow information processing and/or response speed.

Manly et al. (2001) investigated the test-retest and alternate forms reliability of the TEA-Ch by administering the B version of the TEA-Ch to 55 of the children from the normative sample between 6 and 15 days after the first administration. Reliability coefficients ranged from 0.57 on the Creature Counting subtest to 0.87 on the Same World subtest. Reliability coefficients for measures of sustained attention were all at acceptable levels for psychometric tests: Score! = 0.76, Score DT = 0.71, Walk, Don't Walk, .71, and Code Transmission .78 (Cohen & Swerdlik, 2002). Confidence intervals provided for each subtest help interpret the reliability of each subtest score (Groth-Marnat, 2009; Manly et al., 2001).

The research provides sufficient evidence of the TEA-Ch as a valid and reliable measure of sustained and selective attention and attentional control for children in the United States (Belloni, 2011; Passantino, 2011). Of greater import to this study, there is strong evidence of the validity and reliability of the five TEA-Ch subtests that measure sustained attention. Review of the TEA-Ch test manual provided evidence of the careful design and instructions for each subtest. These also help to minimize error variance and maximize the validity and reliability of each measure.

Conclusion

The purpose of the present study was to investigate the validity of two different time-based measures of sustained attention derived from an existing subtest. In essence, this study investigated a modified version of an existing test of sustained attention.

Investigating a modified version of an existing test requires several important steps. First, the researcher must establish that the new measure will provide information about examinees that is distinct from other measures. Second, careful examination of the validity and reliability of the original test is required to establish the test as a valid and reliable measure of the construct in question. Third, the researcher must establish the validity of the new measures.

There are numerous ways to investigate the validity of a test instrument. Several important indicators of the validity of a test are construct validity, content validity, criterion validity, and, discriminant validity. Each of these indicators provides complementary arguments for the validity of a test instrument. It is incumbent upon the researcher to investigate each form of validity to the greatest extent possible in order to establish the validity of a new or modified test. The reliability of a test refers to the stability of test scores. Test-retest reliability provides an estimate of the consistency of test scores on repeat administrations of the same instrument. Evidence of the various types of validity and test-retest reliability provided in sections 2-4 in the literature review indicate that the TEA-Ch is a valid and reliable test of attention.

In section two of the literature review evidence was provided from the neuroscientific literature of the construct validity of the four TEA-Ch tests of sustained attention used in this investigations. The findings from these studies largely supported the theoretical models of attention developed by Posner and Peterson (1990) and Mirsky et al. (1991; 1999) used in the development of the TEA-Ch. Overall, the neuroscientific literature provided convincing evidence of distinct neural regions that comprise a network that subsumes sustained attention. These findings strongly support sustained attention as a distinct, cognitive construct, quantifiable by tests of sustained attention.

Section three of the literature review investigated the research literature on objective, clinical measures of sustained attention. The earliest investigations of sustained attention (or vigilance) established the CPT as a valid test instrument in the research literature. Since the earliest investigations, numerous CPTs have been designed and tested for clinical assessment. The research literature has established numerous other methods as appropriate for measuring sustained attention. A significant amount of evidence suggests that sustained attention tests differ by administration procedures, test format, and outcome scores. There is sufficient evidence that existing clinical measures of sustained attention quantify distinct aspects of sustained attention. Investigations of performances on various measures demonstrated that numerous factors contribute to the relative difficulty of the tasks used on measures of sustained attention. Outcome scores measure various types of behavioral markers as evidence of waning sustained attention. The behavioral markers of waning sustained attention include omission errors, commission errors, and response speed. No measures of sustained attention currently exist that used time-based outcome scores as performance indicators.

The final section of the literature review established the TEA-Ch as a valid and reliable measure of sustained attention. Investigation of the design and instrumentation of the TEA-Ch provided evidence of the reliability and content validity of the TEA-Ch. A review of several studies that investigated the factor structure of the sustained attention model of the TEA-Ch provided additional evidence of the construct validity. The research literature provided more than sufficient evidence of the reliability and construct, content, criterion, and discriminant validity of the TEA-Ch subtests.

Hypotheses

The following general research questions were investigated in this study to address the following questions: a) Are time-based estimates of sustained attention converted from raw scores of the TEA-Ch Code Transmission subtest valid measures of children's sustained auditory attention? b) Tests designed to measure sustained attention should capture behavioral phenomena related to sustained attention while minimizing other cognitive demands, such as intelligence. The second question addressed by this research project is the extent to which CT-LD and CT-TOT scores measure cognitive phenomena that is distinct from intelligence. c) Sustained attention is widely known to improve with age up through middle childhood. The third question addressed is the extent to which the time-based measures will reflect this developmental pattern and improve with age.

Specific Hypotheses:

1) There will be a significant positive correlation between the outcome variable Code Transmission Time on Task (CT-TOT) and the criterion measures of sustained attention: S-SS, SDT-SS, WDW-SS and CT-SS. The null hypothesis investigated was that there would be no correlation between the CT-TOT and the four criterion measures of sustained attention (H_0: $r = 0$).
2) There will be a significant positive correlation between the outcome variable Code Transmission Longest Duration (CT-LD) and the criterion measures of sustained attention: S-SS, SDT-SS, WDW-SS and CT-SS. The null hypothesis investigated was

that there would be no correlation between the CT-LD and the four criterion measures of sustained attention (H_0: $r = 0$).

3) There will be a non-significant correlation between the outcome variable CT-TOT and IQ as estimated by WISC-IV GAI ($r < 0.2$, $p > 0.05$, as determined by a priori power analysis). The null hypothesis investigated was that there would be a significant correlation between the CT-TOT and the WISC-IV GAI (H_0: $r > 0.2$, $p < 0.05$).

4) There will be a non-significant correlation between the outcome variable CT-LD and IQ as estimated by WISC-IV GAI ($r < 0.2$; $p > 0.05$ as determined by a priori power analysis). The null hypothesis investigated was that there would be a significant correlation between the CT-LD and the WISC-IV GAI (H_0: $r > 0.2$, $p < 0.05$).

5) There will be a significant, positive correlation between CT-TOT and subject age. The null hypothesis was that there would be no correlation (H_0: $r = 0$) between the CT-TOT and subject age.

6) There will be a significant, positive correlation between CT-LD and age. The null hypothesis was that there would be no correlation (H_0: $r = 0$) between the CT-TOT and subject age.

Chapter III: Methodology

Participants

The total sample of participants for this study consisted of 290 school-age children between the ages of 6 and 12 years-11 months. The subjects were children referred to an outpatient, pediatric neuropsychology clinic for neuropsychological evaluation by primary care physicians, and behavioral and school specialists. The clinic is located in a middle to upper income neighborhood in Washington State. Most children were referred to the clinic to evaluate suspected learning disabilities, followed by suspected Attention Deficit Hyperactivity Disorder. Boys comprised 75.9% of the sample population (n=220), and 24.1% (n=70) of the participants were girls.

Studies using CPTs to measure sustained attention in individuals, indicate the most significant improvement in sustained attention occurs between the ages of 6 and 10 and continues to improve gradually until puberty, when sustained attention was found to level off to near adult levels (Gale & Lynn, 1972; McKay, et al., 1994; Klimkeit, 2004; Betts, Mckay, Maruff, & Anderson, 2006). In their original investigation of the TEA-Ch, Manly et al. (2001) found that age-based differences in children's performance on the subtests diminished considerably around age 13. The age range for this study was limited to children between 6 and 12 years, 11 months. Mean age of participants was 9.43 years (SD = 1.99). Table 3 provides the sample participant characteristics.

Table 3

Number and [Percentage of total population] of Subject Gender, and ADHD Diagnosis in the Total Sample and in each Age-band

Characteristic	All subjects (n=290)	Age 6.0-6.11 (n=42)	Age 7.0-8.11 (n=84)	Age 9.0-10.11 (n=82)	Age 11-12.11 (n=82)
Female	70 [24.1%]	17 [40.5%]	14 [16.7%]	12 [14.6%]	27 [32.9%]
Male	220[75.9%]	25[59.5%]	70 [83.3%]	70 [85.4%]	55 [67.1%]
Diagnosed ADHD	235 [81%]	27 [64.3%]	69 [82.1%]	75 [91.5%]	64 [78%]

All children in the sample population met the following criteria

- 6 to 12 years, 11 months old;
- successfully completed TEA-Ch subtests, Score!, Score DT, Walk, Don't Walk, and Code Transmission, of the TEA-Ch;
- attained General Abilities Index (GAI) scores within two standard deviations of the mean (70-130) as measured by the Wechsler Intelligence Scale for Children (4th ed) (WISC-IV);
- absence of hearing impairment, seizure disorder, or other neurological condition that might impact hearing and/or fluid language processing; and
- fluency in English.

Two participants completed alternate measures of IQ. In these two cases the Wechsler Pre-school and Primary Scale of Intelligence (4th ed.) (WPPSI-IV) Full Scale Intelligence Quotient (FSIQ) was used as an estimate of intelligence for one of the 6 year-old participants, and the Kaufman Adult Intelligence Test (KAIT) Composite was used to estimate the intelligence for one of the 12 year-old participants.

Qualified Master's and Bachelor level psychometrists administered testing. I gathered the chart data from a heterogeneous, clinical sample of children, referred for various clinical and psychological concerns. Not all children were administered the same battery of assessments, nor were tests administered in a consistent order.

Data Collection and Procedures

Prior to data collection, I reviewed all available clinical charts to identify qualified candidates. I then entered the names of qualified participants by gender and age into one year age-groups (6,7,8,9,10,11,12) into a Microsoft Excel (2007) database. I coded each participant name for random selection by age group and gender. Charts of female children began with the letter *f* and boys with the letter *b* (ie. charts of 7 year-old female participants begin with the code f7-1 and continue to the total number of n charts f7-n). Using a random number generator, I selected 41-42 charts for each age and gender stratification. Many children in the sample had an ADHD diagnosis. Whenever possible, I stratified the sample by gender to match estimates of ADHD prevalence rates for male and female children in the United States, which is approximately a 6:1 male to female ratio (Barkley, 2006). When possible, the sample of each age stratum included 35 boys and 6 girls, intended to match the estimates of U.S. ADHD prevalence rates whenever the number of male and female charts were sufficient (see Table 3).

I gathered relevant research data from the randomly selected clinical charts of qualified candidates. I photocopied the data, absent identifying information, and placed the data for each participant in individual folders labeled by the codes detailed above, to maintain the privacy of the participants in accordance with the Ethical Guidelines of the American Psychological Association (APA, 2010). I stored the files separately from the clinical charts as a further precaution to maintain subject confidentiality. These charts will be available for seven years after the completion of this project, in accordance with APA research guidelines (APA, 2010). The following data are contained in each of the coded files: code number, age at time of testing (in years and decimals converted from months), WISC-IV FSIQ, GAI, VCI and PRI, Code Transmission subtest standard score (CT-SS), a photocopy of the Code Transmission subtest record form, Score! subtest standard score (S-SS), Walk, Don't Walk subtest standard score (WDW-SS), Score DT subtest standard score (SDT-SS), and presence or absence of ADHD diagnosis (ADHD: 1 = ADHD diagnosis; 2 = no diagnosis). I saved a master code sheet with the names and corresponding code numbers of each clinical chart used in the study on an encrypted thumb drive and stored it in a locked filing cabinet in order to maintain the privacy of participants.

Data entry. I entered all relevant participant data into a customized database software program specifically designed for the present study. I later transferred the data into an IBM SPSS Statistics Student Grad Pack (version 19) spreadsheet for statistical analysis and graph construction. I made a codebook, listing all of the variables, along with the abbreviated variable names, and the method used to code participant names (Pallant, 2010, p. 12). I used separate data entry fields to collect the relevant data for each participant which included: Code; age; gender; ADHD diagnosis; GAI; FSIQ; PRI; WMI; PSI; standard scores of the TEA-Ch subtests, Score!, Score DT, Walk Don't Walk, and Code Transmission.

Foreseeable threats to the reliability of this study include the possibility of scoring errors and mistakes that occurred during data entry. The clinic has a strict policy that all test data be scored and score-checked by qualified psychometrists, which helped to ensure the accuracy of the test data. To ensure that the data entered into the statistical software was accurate, a research assistant, trained by the primary investigator, independently re-scored a representative sample (25%) of the data collected. We crosschecked the original dataset scored by the primary researcher with the re-scored data for errors: there were no data entry errors (Cresswell, 2009). We double-checked all data entries for the raw score values of the Code Transmission subtest.

We used a separate data collection form to record the raw data from the Code Transmission subtest. I describe the data collection process for the raw data in the paragraphs that follow. We entered participant age in years and decimals converted from months at the date of testing. We used a binary code for Gender and ADHD diagnosis, with a 1 signifying male and the presence of ADHD diagnosis, and 2 signifying female and the absence of an ADHD diagnosis. We entered the standard scores from the four TEA-Ch subtests for the independent, predictor variables including: Score! (S-SS), Score DT (SDT-SS), Walk, Don't Walk (WDW-SS), and Code Transmission (CT-SS). Data collection for the dependent variables required a much more complicated process; see below.

First, I created a numbered template with holes to help ensure accurate data collection. I made forty holes in the template to line up with the 40 targets on the Code Transmission record form. When properly aligned over a record form, the template reveals only the 40 targets, making data collection more efficient and accurate. I numbered the holes to correspond with the order of the 40 targets of the Code Transmission tracking form. Using the template, we tallied correct and incorrect responses on record forms numbered 1-40, specifically designed for this task. We used the record forms later to enter the detected and missed targets into the corresponding 40 data fields of the database software.

We used a binary code to simplify data collection and reduce the likelihood of calculation and data entry errors. A 1 signified correctly identified targets and 0 signified incorrect or missed targets. We entered the appropriate code into the corresponding target fields of the database software (numbered 1-40) to signify a missed or identified target. Before data collection using a Casio timer, I recorded the time intervals between Code Transmission version-A targets to the nearest second and then assigned a time value to each of the 40 target fields in the database software program.

A research assistant with a background in software engineering programmed a software-based algorithm into the database to quantify the Code Transmission Time on Task (CT-TOT) and the Code Transmission Longest Duration (CT-LD). To calculate the CT-TOT, the program summed the time intervals between each consecutive pair of correctly identified targets. For example, if an examinee correctly identified targets 4 and 5, then the program added the interval assigned to target 5 to the total time on task. If the examinee missed target 6, then no time interval was added to the total for either 6 or 7, even if target 7 was correctly identified. To calculate the CT-LD scores, the program summed the time intervals between the longest sequence of correctly identified, consecutive targets.

Once we entered all of the data into the data collection fields for each participant, and double-checked for accuracy, selecting the *Show* button transferred the data for each participant into the database. We organized the data for each participant into rows, with each column corresponding to the identification number, independent, and dependent variables collected for the study. All relevant participant data were then transferred into IBM SPSS Student Grad Pack software (version 19) and R 2.14.2 (http://cran.r-project.org) for statistical analysis and graph construction. Statistical analysis is described later in this section

Instrumentation

I used four of the five subtest standard scores from the TEA-Ch that contribute to the sustained attention factor in Manly et al.'s (2001) original design as predictor variables. The Score! standard scores (S-SS); Score DT standard scores (SDT-SS); Walk, Don't Walk! standard scores (WDW-SS); and Code Transmission standard scores (CT-SS) served as criterion measures to evaluate the convergent validity of the time-based methods of measuring sustained attention investigated in this study. TEA-Ch subtest standard scores range from 1-19, with a mean value of 10 and standard deviation of 3. Standard scores are age-corrected and grouped by age-band and gender.
A description of each independent measure of sustained attention used in this study follows:

Score!. The Score! subtest is a 10-item, auditory counting test in which examinees are asked to count the number of scoring tones they hear from an audio-cassette recording (Manly et al., 2001). Inter-stimulus intervals vary from 500 to 5000 milliseconds (ms) between scoring tones. The long pauses between some tones require examinees to hold their count in working memory and resume counting when the next tone sounds. Two practice trials help ensure proper understanding and identify any individual impairment that might preclude performing the task as intended by the authors. Raw scores range from 0-10 and represent the sum of all correctly counted items.

Score DT. Manly et al. (2001) designed the Score DT subtest to increase the sensitivity of the basic Score! subtest by including a distracter. Examinees must count the tones, in the same manner as on the Score! subtest, and at the same time listen for an animal name mentioned in a news broadcast. At the end of each of the 10 trials, examinees are to indicate the number of tones counted and the animal name. Examiners administer two practice trials: one to practice just listening for the animal name, and the other to practice both tasks at once. Before proceeding to the test items examiners may repeat practice trials to ensure proper understanding of the task. Examinees earn a point for each item correctly counted and for each animal identified, for a total possible raw score of 20.

Walk, Don't Walk. The Walk, Don't Walk subtest is a 20-item measure designed to emphasize controlled responding to an auditory stimulus. Examinees use a dry-erase pen and a laminated sheet with 20 vertical paths comprised of 14 numbered, square steps with footprints. Examinees must listen to a series of tones and place a mark on consecutive steps for each tone heard. Examinees are to refrain from marking when the normal tone is followed by a *no-go* tone. The inter-stimulus interval is constant within each trial but reduced from 1500 ms on the first trial to 500 ms on trial 20. To ensure proper understanding, examinees see two demonstrations and have two practice trials before the start of the subtest. Raw scores equal the number of correct stops and range from 0-20.

Code Transmission. On the Code Transmission subtest, the examinee listens to an audio recording of a woman's voice saying one digit between 1 and 9, every two seconds. Every time two consecutive 5s (or 7s on the B-version) occur, the examinee is to say the single digit that directly preceded them. For example, in this series of numbers 3,4,2,1,6,5,5,8 the target would be 6. To ensure proper understanding, examinees are administered two practice trials. Targets occur at randomized intervals ranging from approximately 9 seconds to 26 seconds between targets. The subtest lasts for just under 12 minutes. The examiner sits across from the examinee and places a check mark on each correctly identified target, and an X on targets that were either missed, or misidentified. There are 40 possible targets to detect. Raw scores range from 0-40, and comprise the number of correctly identified targets.

Research Design and Analysis Plan

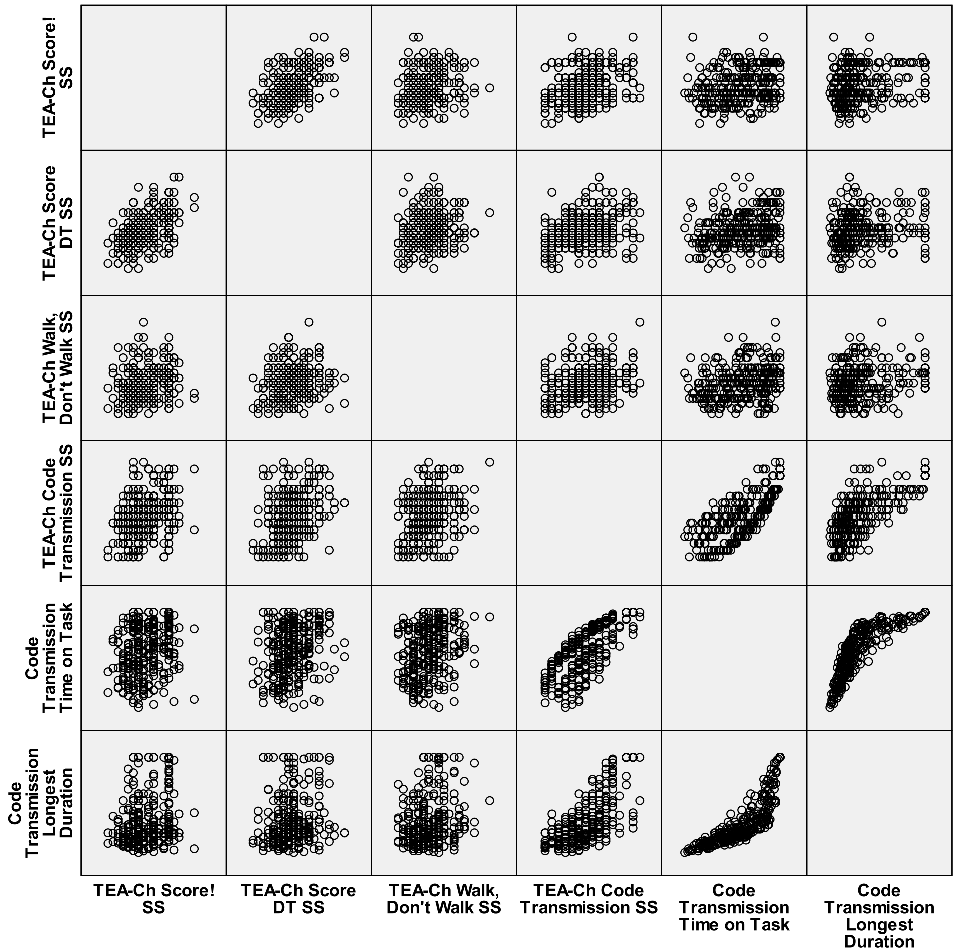
We summed and tabulated subject characteristics using means and standard deviations for continuous characteristics and counts and proportions for categorical ones. This was done for all subjects together, as well as within age-bands (6 years 0 months – 6 years 11 months, 7.0-8.11, 9.0-10.11, 11.0-12.11) (see Table 7, p. 83). The age-bands correspond with those used by Manly et al. (2001) to establish the standard scores for the TEA-Ch.

Preliminary analysis. Using IBM SPSS Statistic Grad pack (Version 19), we created histograms of the distribution of sample scores. Visual inspection of the histograms revealed several distributions that did not appear to meet standards of normality (Field, 2009; Pallant, 2010). The histograms also revealed outliers in three out of the four criterion variables. The Walk, Don't Walk and Score! subtests each had one outlier. The Score DT subtest had two outliers. I re-checked the charts of the participants with outlying scores to rule out data entry errors and found none. Four different children 6-8 years-old attained these scores. Eliminating outlying scores that are more than three standard deviations above the mean is a simple rule of thumb adopted by many statisticians to prevent outliers from significantly altering measures of central tendency and the statistic of interest (Field, 2009; Osborne & Overbay, 2004). There are several methods to deal with outliers. Transforming the entire data set can minimize the impact of large differences among scores. Removing the scores altogether makes sense when the scores are three or more standard deviations from the mean: especially suspected erroneous scores. Another possible method involves truncating the high or low scores so that they fall within three (in some cases two) standard deviations of the mean. Because I determined that each outlying score was correct, and within three standard deviations of the mean for the entire population and each age-band, I chose to keep all outliers without alteration.

We later used scatterplots to investigate the strength and the direction of the relationship between each of the criterion variables and outcome variables. Table 4 presents visual Scatterplots of the correlations between criterion and outcome variables. Visual inspection of the scatterplots revealed seemingly non-linear relationships for several of the correlations (see Table 4). Overall, preliminary analysis of the data did not conclusively support Gaussian assumptions required to run parametric statistics (Pallant, 2010). We elected to use a non-parametric bootstrapped distribution to allow for the calculation of Pearson correlation coefficients, as the best method for this investigation.

Statistical analysis. Researchers base judgments of the concurrent validity of a measure on the validity coefficient (AERA, 1999). The validity coefficient is a correlation coefficient that measures the relationship between test scores and scores on a criterion measure. Researchers typically use the Pearson correlation coefficient to measure the concurrent validity of a test instrument. Because not all distributions appeared to meet standards of normality, we chose to calculate Pearson Correlation coefficient using bootstrapped distributions. The bootstrap is appropriate for use when the normal theory assumptions are felt to be questionable or inadequate (Efron & Tibshirani, 1993; Lunneborg, 1985; Mooney & Duval, 1993). Even though the bootstrap does not assume the form of the sample distribution, it does assume that the sample provides information about the larger population (Lunneborg, 1985). According to Efron & Tibshirani (1993), non-parametric bootstrap provides a crude form of inference that provides accurate answers for large samples, regardless of the underlying population (p. 395).

Table 4
Scatterplots of the Relationships Between Criterion and Outcome Variables



To assess the validity of using Code Transmission (CT), Time on Task (CT-TOT), and CT Longest Duration (CT-LD) as measures of sustained attention for children, we conducted several analyses. We calculated Pearson correlation coefficients to test for an association between the standard scores of the four criterion measures of sustained attention [Code Transmission (CT-SS), Score! (S-SS), Score DT (SDT-SS), and Walk/Don't Walk (WDW-SS)] and the one discriminant measure of intelligence: WISC-IV General Abilities Index (GAI) (H1, H2, H5, & H6). We examined correlations between the two time-based measures (CT-TOT & CT-LD) and a continuous measurement of age (H3 & H4). We calculated and plotted the mean and standard deviations (SD) to establish typical ranges of scores on each measure. Because Manly et al. (2001) standardized the criterion measures of sustained attention according to the aforementioned age-bands, we chose to calculate the means and plot the data within each age-band. Figure 1 (p. 77) and Figure 2 (p. 78) are graphs of the mean scores and standard deviations by age-band.

To calculate confidence intervals for the Pearson correlations using the non-parametric bootstrap, we used SPSS Statistics Grad pack (version 19) (Efron & Tibshirani, 1993; Lunneborg, 1985). The bootstrap allows for statistical inferences based on a distribution of the test statistic of interest (Pearson *r* for the present study) rather than the distribution of scores (Efron & Tibshirani, 1993). The software program creates the distribution of correlations by randomly sampling with replacement from the original data to obtain a new data set consisting of (possibly repeated) observations from the original data. The software calculates the correlation coefficient for this resample. This method is then repeated a large number of times, in this case 10,000, each time calculating the correlation coefficient. This process produces a distribution of Pearson correlation coefficients along with the standard error of the new distribution. We based statistical inferences on the bootstrapped distribution. We set confidence intervals by the 2.5 and 97.5 percentiles of the re-sampled correlations (Efron & Tibshirani, 1993).

We used SPSS (Gradpack 19) to calculate one-tailed bootstrap tests to test for significance of the correlation coefficients (Efron & Tibshirani, 1993). Bootstrap significance tests also make no parametric assumptions on the underlying distribution of the data. Any statistical test of significance examines the behavior of a test statistic under the null hypothesis, in this case that the correlation between variables is zero ($H_0 = 0$), or almost equivalently that the distribution of one measure is independent of the other. If the null hypothesis offered the best explanation of the data, then randomly reassigning the sample of values attained on one measure to another should not affect our estimate of correlation.

To build a sampling distribution of the correlation coefficient under the null hypothesis, we hold the values of one variable constant and pair them with randomly assigned values from the second variable (Efron & Tibshirani, 1993). The computer generates many randomly paired values. The computer then takes a sample, with replacement from the pool of randomly paired values, and calculates a correlation coefficient. The program repeats this process many times, in this case 10,000 times, to build a distribution of correlations under the null hypothesis. This distribution is then used to calculate the p-values (H_0: $r = 0$). The p-value is thus the proportion of sample correlations from randomly paired test values that are larger than our observed correlations. For example, if the samples produced 29 correlations with values greater than the achieved correlation, then the p-value for the correlation would be 0.0029 (29/10,000). If the null hypothesis were in fact true, our true observed correlation should not look much different from the simulated, randomly paired correlations. P-values of less than 0.01 were considered significant (Isaac & Michaels, 1997; Pallant, 2010). The null hypotheses for H_3 and H_4 stated that there would be a perfect, linear correlation between the two time-based measures of sustained attention and GAI (H_0: $r = 1$). We considered p-values greater than 0.05 non-significant.

The task of the researcher is to determine an adequate sample size to ensure that the alpha (α) and power are at acceptable levels so that the results can be interpreted at the desired level of confidence. I used the G*Power 3.1.5 (Faul, Erdfelder, Buchner, & Lang, 2009) software program to run an a-priori power analysis to calculate an adequate sample size for the present study (Pallant, 2010, p. 208). In the present study I investigated correlations between four criterion variables (standard scores from the Code Transmission, Score!, Score DT, and Walk, Don't Walk subtests of the TEA-Ch), age, and two outcome variables (CT - Time on Task, CT- Longest Duration). I selected Correlation: Bivariate normal model as the statistical test. I set the power parameter at 0.80 and the alpha (α) at a conservative level of 0.01 because I ran multiple correlations to investigate the criterion validity of the new measures (Cohen, 1991). The effect size (ES), or difference between the hypothesis (H_1) and the null hypothesis (H_0), determines the degree to which the null hypothesis (H_0) is false (Cohen, 1991). The greater the N in a study, the smaller the ES that is needed to establish an interpretable difference between the H_1 and the H_0. I initially set the ES at Cohen's suggested "small" level of ES = 0.10 and found that the sample size required to interpret such a small effect is 1,163, which is more than the charts I had available for the present study. I changed the effect size to a higher value of ES = 0.2, but below what Cohen (1991) denoted as a medium ES (0.3), and the calculated sample size was reduced to 287. I reviewed 290 charts for the study, anticipating that the Pearson correlations between predictor and outcome variables would be at least $r = 0.2$.

Chapter IV: Results

Analysis of Hypotheses

I present results from the study in this chapter, including analyses of the hypotheses presented, along with descriptive statistics for the sample population.

We calculated means and standard deviations on all measures for the entire sample and for each age band using SPSS Statistic Grad Pack (version 19) (see Table 7, p. 83). The total population mean IQ score (107.5) was in the Average range. Mean subtest scores on all criterion measures ranged from Low Average (Walk, Don't Walk SS = 7.0; Code Transmission= 7.0) to Average (Score SS= 8.5; Score DT= 8.7). Mean IQ scores by age band were within the Average range with some variability. Mean Score DT and Score! standard scores by age band were all in the Average range. The mean scores for the 9.0-10.11 age-band were below average on both the Code Transmission subtest (5.9) and Walk, Don't Walk subtest (6.4). The mean Code Transmission standard score (6.8) was also Below Average for the 7.0 - 8.11 age band. Mean scores on the CT-TOT and CT-LD showed a pattern of performance that improved with age. I discuss this pattern in detail in the Chapter V.

Table 5
Means and [Standard Deviations] of Age, IQ score, and Scores on Measures of Sustained Attention for the Sample Population

Characteristic	All subjects n=290	Age 6.0-6.11 n=42	Age 7.0-8.11 n=84	Age 9.0-10.11 n=82	Age 11-12.11 n=82
Age	9.4 [2.0]	6.5 [0.3]	7.9 [0.6]	9.9 [0.6]	11.9 [0.6]
General Ability Index	107.5[11.5]	110.5[9.9]	109.9[10.9]	107.3[11.3]	103.8[12.2]
Score DT	8.7 [3.3]	9.4 [3.4]	8.8 [3.2]	8.6 [3.4]	8.1 [3.2]
Score SS	8.5 [3.4]	9.3 [3.4]	8.2 [3.0]	8.1 [3.5]	8.8 [3.5]
Walk, Don't Walk SS	7.0 [3.3]	7.2 [2.8]	7.1 [3.1]	6.4 [3.3]	7.6 [3.6]
Code Transmission SS	7.0 [3.3]	8.0 [2.8]	6.8 [3.0]	5.9 [3.5]	7.9 [3.4]
CT-TOT	401 [173]	247 [152]	328 [143]	438 [158]	517 [125]
CT-LD	224 [172]	112 [76.1]	148 [109]	253 [171]	333 [188]

Note: Decimal values for age-bands represent months, ie. 6.11 represents 6 years 11 months.

The first two hypotheses focused on the relationship between the four criterion measures of sustained attention (S-SS, SDT-SS, WDW-SS & CT-SS) and the two time-based measures of sustain attention (CT-TOT & CT-LD). The first hypothesis (H_1) stated that there would be a significant, positive correlation between CT-TOT scores and the four criterion measure scores (S-SS, SDT-SS, WDW-SS, & CT-SS). Hypothesis two (H_2) stated that there would a significant, positive correlation between CT-LD scores and the four criterion measures scores (S-SS, SDT-SS, WDW-SS, & CT-SS). Hypotheses three and four (H_3 & H_4) investigated the relationship between the two new measures of sustained attention (CT-TOT & and CT-LD) and IQ as estimated by the WISC-IV GAI. Hypotheses three and four predicted a small and non-significant correlation between the two sustained attention measure scores and IQ scores. The fifth and sixth hypotheses stated that there would be a significant, positive correlation between age and scores on both outcome measures, CT-LD and CT-TOT scores.

Hypothesis one (H_1). We investigated the relationship between the CT-TOT and the four criterion measures of sustained attention. As illustrated in table 5, we calculated Pearson correlation coefficients for each of the four criterion variables (S-SS, SDT-SS, WDW-SS, & CT-SS) and the outcome variable (CT-TOT). Pearson correlation coefficients revealed significant correlations between all criterion measures and the outcome variable CT-TOT (r = 0.25 - 0.75, P < 0.001) (see Table 5). Because of the significance of the p-values, I rejected the null hypothesis (H_0), which stated that there would be no correlation between CT-TOT and the criterion variables. Thus, the findings in the present study support H_1.

Hypothesis two (H_2). Using Pearson correlation coefficients, we investigated the relationship between each of the criterion variables (S-SS, SDT-SS, WDW-SS, & CT-SS) and the outcome variable CT-LD (see Table 5). Significant correlations were found between all criterion variables and the CT-LD outcome variables (r = 0.16 - 0.71, p<0.003); the correlation between CT-LD and SDT-SS did not achieve the level of significance specified by the a priori power analysis. The findings showed significant results (p ≤ 0.003 between all measures) for all but one criterion variable as determined by the a priori power analysis; I was unable to reject the null hypothesis, in favor of H_2.

Table 6
Summary of Correlations and [95% Bootstrap Confidence Intervals] for Scores on Measures of Sustained Attention and Intelligence

Measure	1	2	3	4	5	6	7
1. General Ability Index	--						
	--						
2. Score SS	0.05	--					
	[-0.06, .016]	--					
3. Score DT SS	0.23***	0.52***	--				
	[0.12, 0.34]	[0.43, 0.60]	--				
4. Walk Don't Walk SS	0.21***	0.22***	0.23***	--			
	[0.10, 0.32]	[0.11, 0.33]	[0.12, 0.34]	--			
5. Code Transmission SS	0.22***	0.34***	0.35***	0.32***	--		
	[0.10, 0.33]	[0.24, 0.44]	[0.24, 0.46]	[0.22, 0.43]	--		
6. CT-TOT	0.09	0.26***	0.25***	0.27***	0.75***	--	
	[-0.17, 0.19]	[0.14, 0.37]	[0.14, 0.36]	[0.17, 0.37]	[0.71, 0.79]	--	
7. CT-LD	0.05	0.23***	0.16**	0.23***	0.71***	0.83***	--
	[-0.52, 0.16]	[0.12, 0.33]	[0.04, 0.28]	[0.13, 0.33]	[0.66, 0.76]	[0.80, 0.85]	--

Note. P-values were calculated from one-sided bootstrap tests. $^{**}p<0.01$, $^{***}p<0.001$

Hypotheses three and four (H_3 & H_4). The correlation between the CT-TOT and General Abilities Index for the total sample did not achieve significance (r =0.087, p= 0.069); I rejected the null hypothesis, which stated that there would be a significant, positive correlation between GAI and CT-TOT scores, as determined by a priori power analysis. The findings of the present study support hypothesis three. The correlation between the CT-LD and General Abilities Index (GAI) for the total sample was also not significant (r = 0.05, p= 0.19) (see Table 5), which supports H_4.

Table 7
Summary of Pearson Correlations [95% Bootstrap Confidence Intervals] between participant age and Code Transmission Time on Task (CT-TOT) and Longest Duration (CT-LD) Scores

Measure	
Code Transmission-Time on Task	Code Transmission - Longest Duration
0.56***	0.49***
[0.479,0.637]	[0.403,0.565]

Note. P-values calculated from one-sided bootstrap test.*** P<0.001

Hypotheses five and six (H5 & H6). To investigate hypotheses five and six, I correlated the relationship between participant age and performance on the two outcome measures across the entire sample population. Age had a significant, positive correlation with both outcome measures (CT-TOT $r = 0.561$, $p < 0.001$; CT-LD $r = 0.487$, $p < 0.001$), which supports H5 and H6 for this study. Figures 1 and 2 in Chapter V provide visual evidence of the significant difference in mean scores by age-band.

Results summary. The findings of the present study support all six hypotheses of the present study. I found significant correlations between both outcome measures (CT-TOT & CT-LD) and the four criterion measures. The findings also revealed significant correlations between participant age and performance on both outcome measures, supporting hypotheses 5 and 6. As predicted, there were non-significant correlations ($p > 0.05$) between the outcome measures and IQ, supporting hypotheses 3 and 4. I present further analysis of the results in Chapter V.

Chapter V: Discussion

This chapter includes a discussion of the results of the study along with an evaluation of the significance of the findings in relation to the six hypotheses investigated in the present study. I then discuss the implications and relevance of the current findings, followed by a discussion of the limitations and directions for future research.

Hypotheses

The findings of the present study supported all six of the hypotheses. Bootstrapped Pearson correlation coefficients reached significance between all four, criterion measures (S-SS, SDT-SS, WDW-SS, & CT-SS) and both time-based outcome measures (CT-TOT & CT-LD). The correlation between age and the two outcome measures also reached significance for both measures. The following section is a discussion of the findings in relation to the two time-based scores of sustained attention (CT-TOT & CT-LD) investigated in the present study.

Validity evidence of the CT-Time On Task. The findings revealed significant, positive correlations between the Code Transmission Time on Task (CT-TOT) and the four criterion measures. Not surprisingly, we found the highest correlation between CT-TOT and Code Transmission SS (CT-SS). We anticipated a high correlation between these measures because I derived the CT-TOT score from the CT-SS subtest. The importance of this correlation for the present study is that it provides an indicator of how much of the same variance is shared between the CT-SS and the CT-TOT in terms of the phenomena each one captures. Manly et al. (2001) already established the Code Transmission as a valid and reliable assessment of sustained attention. Demonstrating that the CT-TOT shares a significant amount of overlap with the CT-SS, provides evidence that the new measure captures much of the same sustained attention construct as the original measure (Salkind, 2010, p. 130).

The coefficient of determination estimates the amount of variance shared between two variables (Pallant, 2010; Salkind, 2010). This estimate is useful for estimating the degree to which changes in one variable coincide with similar changes in another. The coefficient of determination between the CT-TOT and CT-SS for the entire sample was 56%. This indicates that the outcome score CT-TOT and the criterion measure CT-SS shared more than half of the variance, and capture much of the same sustained attention phenomena.

The correlation between CT-TOT and the three other criterion measures were significant at the $p<0.001$ level. The amount of shared variance for each of these measures and CT-TOT ranged from 6.3% (Score DT SS) - 7.3% (Walk, Don't Walk SS) (see Table 3). This means that the CT-TOT accounts for between 6.3 and 7.3% of the shared variance of the criterion measures. By contrast, the amount of shared variance between the Code Transmission subtest and the other criterion measures ranged from 10-12% of the shared variance. The amount of variance shared between the measures was approximately two-thirds as much as that found between the CT-SS and the three other criterion measures. Manly et al. (2001) designed each of the TEA-Ch sustained attention subtests to measure mostly distinct aspects of sustained attention. A significant but not large, positive correlation was anticipated between the CT-TOT and the criterion measures.

The power estimate determined at the outset of this study was set at $r= 0.2$; correlations at or above this value were necessary to indicate a significant relationship between the criterion and outcome variables in this investigation. All of the correlations between the criterion measures and CT-TOT were above the minimum $r = 0.2$ level. The findings support hypotheses one and provide evidence of the criterion validity of the CT-TOT as an estimate of sustained attention.

Figure 1. Code Transmission Time on Task Means and Confidence Intervals by Age Band

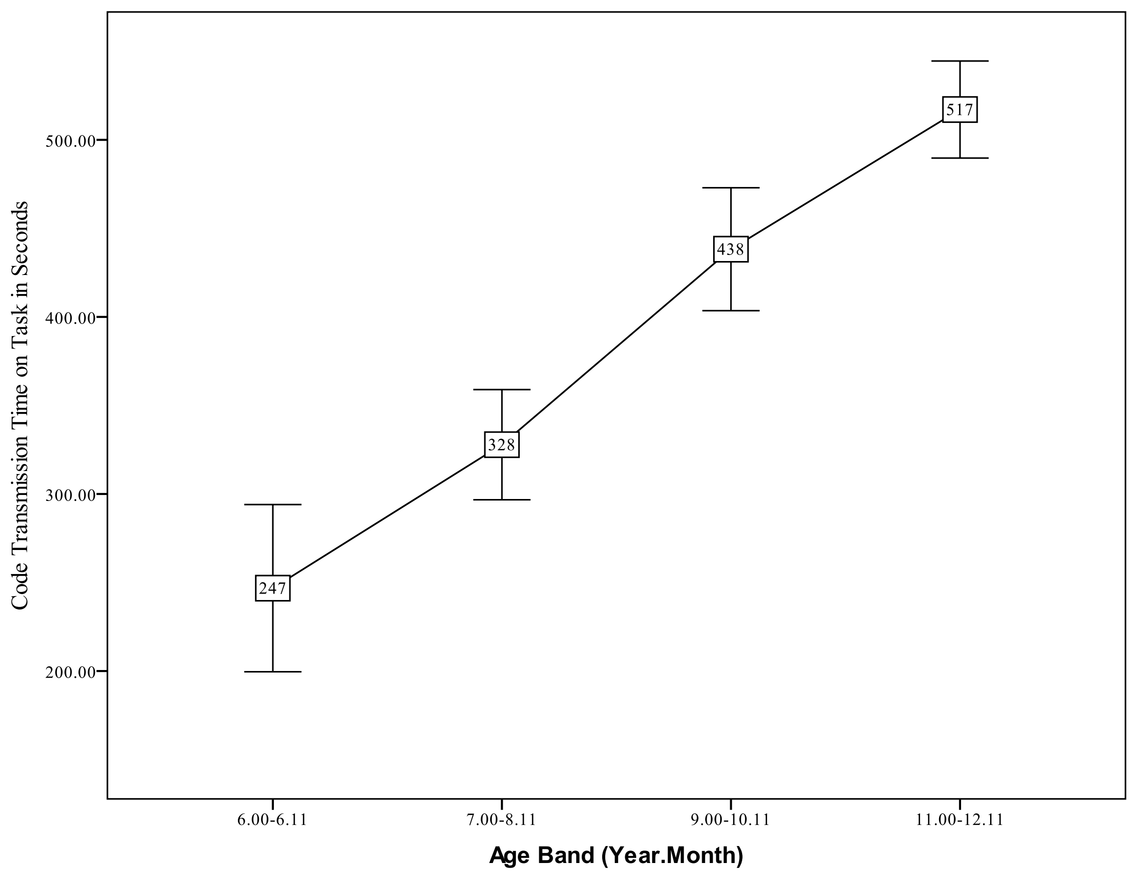


Figure 1. The bars above and below the mean values for each age-band represent 95% Confidence Intervals. Mean values for each age-band are presented in the data labels.

The significant correlation between the CT-TOT and age ($p < 0.001$) provided further evidence of the validity of this measure (H5). The amount of shared variance between age and CT-TOT scores was 31%. This finding is consistent with previous research, which has shown that sustained attention improves with age (Betts, et al., 2006;

Gale & Lynn, 1972). The significant amount of shared variance between age and CT-TOT provides additional support for the validity argument of CT-TOT as a measure of sustained attention. Figure 1 provides a visual representation of the relationship between age and CT-TOT scores. The overlap between the first two age-bands suggests that differences in sustained attention performance are not as pronounced as they are later on in childhood. It is also possible that the overlap in these age-bands occurred because of the much higher proportion of children diagnosed with ADHD in the 7.0-8.11 age-band (82.1%) than the 6.0-6.11 age-band (64.3%).

We measured the relationship between the CT-TOT and the GAI scores from the WISC-IV to investigate the discriminant validity of the CT-TOT. A small, non-significant correlation was found between CT-TOT and GAI scores ($p= 0.069$). The shared variance between GAI and CT-TOT was less than 1%. The small, non-significant relationship between CT-TOT and IQ suggests that CT-TOT measures cognitive phenomena that are, for the most part, distinct from IQ. This finding provides evidence of the discriminant validity of the CT-TOT. Combined with evidence of criterion validity provided above, it makes the validity argument of the CT-TOT even more compelling. Overall, the findings of the present study support the CT-TOT as a valid measure of sustained attention for children ages 6.0 - 12.11 referred for clinical assessment.

Validity evidence of the CT-Longest Duration. The results of the present study did not completely support H_2. Significant, positive correlations were found between Code Transmission Longest Duration (CT-LD) and all four criterion measures ($p<0.01$); the correlation between CT-LD and Score-DT SS did not have the necessary power to indicate significance (r = 0.16), as determined at the outset of the study. The amount of shared variance between these two measures was less than 3%.

Figure 2. Code Transmission Longest Duration Means and Confidence Intervals by Age-Band

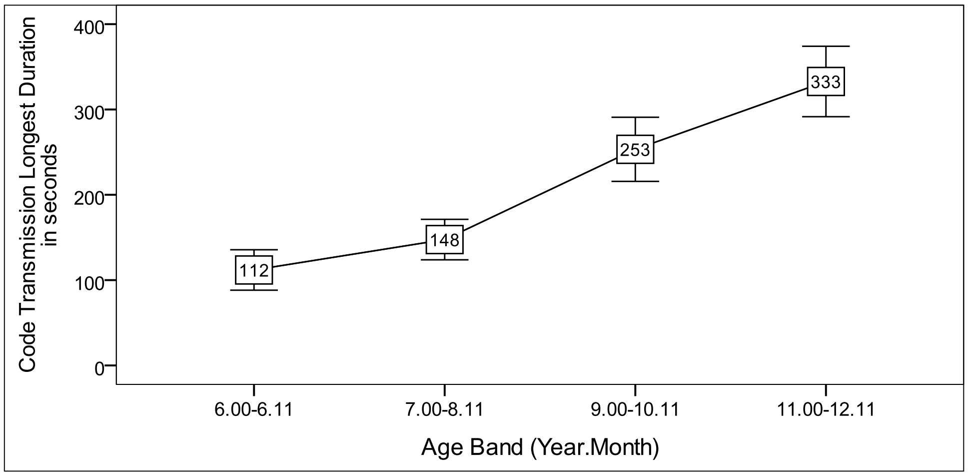


Figure 2. The bars above and below the mean values for each age-band represent 95% confidence intervals. Mean values for each age-band are presented in the data labels.

The amount of shared variance between the CT-LD and CT-SS was 49%, which accounted for under half of the total variance. This finding indicates that the CT-LD subtest captures nearly half of the same phenomena as the CT-SS. Although the correlation between CT-LD and the four criterion measures reached statistical significance, the amount of shared variance between the measures was minimal (3 - 5% across criterion measures). This was less than half as much of the shared variance between the three TEA-Ch criterion scores and CT-SS. As predicted, we found that the CT-LD had a significant correlation with age ($p < 0.001$), with shared variance of 24% and a non-significant relationship with intelligence ($p > 0.05$). Figure 2 provides a visual representation of the relationship between age and CT-LD score.

The findings of the present study supported all three hypotheses related to CT-LD; the strength of the correlations between CT-LD and the criterion measures was not strong enough to provide compelling evidence of its validity.

I developed the CT-LD score to measure the longest duration of sustained attention without an attentional lapse. Theoretically, this measure may have provided information regarding a child's maximum capacity to sustain attention to an auditory stimulus before attention starts to break down. The differences in test formats and the method used to calculate the CT-LD score likely explain why it did not share a higher correlation with the three criterion measures of sustained attention. The three criterion measures (other than the Code Transmission SS) use trials that require sustained attention for much shorter periods (Manly et al., 2001). Although all measures require sustained attention, high scores on the CT-LD required greater sustained attentional endurance than the criterion measures.

We calculated CT-LD scores by summing the longest string of consecutively correct responses on the Code Transmission subtest. As such, it was highly sensitive not only to single errors, but also to the timing of an error. For example, missing one item near the middle of the sequence of targets automatically cut the highest possible score in half; missing a target at the beginning or end of the subtest had less of an effect on the potential, overall score. The instability of this measure likely reduced the correlation of the CT-LD with the four criterion measures.

ADHD and Sustained Attention

Other than age, ADHD appears to have had the greatest impact on performance on the four criterion measures and two outcome measures. The findings presented in the next paragraph suggest that the proportion of children with an ADHD diagnosis in each age band had a negative effect on overall mean performance on the sustained attention measures. This pattern of performance is consistent with the extensive amount of evidence in the research literature that indicates that ADHD has a negative impact on sustained attention (Barkley,2006; Manly et al., 2001). The most striking difference between age-bands on measures of sustained attention was evident for the 9.0-10.11 group, which produced mean scores that were significantly below average on two of the criterion measures: Code Transmission SS and Walk, Don't Walk SS (see Table 7). The only other below average mean value on measures of sustained attention was produced by the 7.0-8.11age-band on the Code Transmission SS. These low scores coincided with the two age bands that had the highest proportion of children diagnosed with ADHD (9.0-10.11 = 91.5%; 7.0-8.11 = 82.1%). The high proportion of children diagnosed with ADHD in the sample population (81%) may also explain why the mean scores on the criterion, sustained attention measures for the entire sample, and all four age-bands were below the mean value for the standardization population (SS = 10) (see Table 7).

Calculating MANOVA is appropriate for investigating how well several outcome measures (dependent variables) predict group membership (independent variable) (Field 2009, p. 586). In the present study I used MANOVA to investigate the performance of participants with and without ADHD diagnoses on the six measures of sustained attention (Field, 2009). Using Wilk's statistic, I found a significant effect of ADHD diagnosis on performance on the six measures of sustained attention (Λ= 0.73, $F(6, 283) = 17.3$, $p<0.001$). The effect of ADHD on test performance was not a primary focus of this investigation so I chose not to conduct ANOVAs to calculate effect sizes for each of the separate measures of sustained attention. The clinicians who work at the clinic where the charts originated used the TEA-Ch subtests to aide in the determination of ADHD diagnoses for most of the participants in the study. The MANOVA likely overestimated the significance of the relationship between ADHD and lower performance on the sustained attention subtests.

Implications of Findings

The present study was a preliminary investigation of the validity of two time-based scores of sustained attention for children. To my knowledge, the present study was the first to investigate time-based methods for measuring sustained attention for children. The results of the study showed a pattern of performance on one of the time-based measures of sustained attention investigated that is similar to that of existing standardized measures of sustained attention. As anticipated, scores on the CT-TOT improved with age and showed minimal correlations with measures of intelligence and significant correlations with existing measures of sustained attention. As such, the new CT-TOT score is the first of its kind to provide a valid estimate of the amount of time that a child is able to sustain his/her attention to an auditory stimulus. This time-based measure offers new information about children's sustained attention that, as of yet, has received little attention in the psychometric literature. The CT-TOT measure helps explain children's sustained attention in a way that is meaningful in natural settings.

Ecological validity refers to the degree to which the results of psychometric tests relate to behaviors of interest as they occur in natural, everyday settings (Barkley, 1991; Marcotte, Scott, Kamat & Heaton, 2010). Test makers design instruments with greater ecological validity to resemble the activities required of individuals in everyday life. This enables examiners to make accurate predictions about functioning in real-world settings. Assessments that emphasize greater ecological validity are often performance-based as well as norms-based. In recent years, neuropsychologists have expressed an increased interest in developing psychometric instruments that emphasize ecological validity (Marcotte, et al., 2010). Manly et al. (2001) designed the TEA-Ch to be an ecologically valid measure of children's attention. The nine subtests use tasks that mimic the attentional demands that children experience in everyday settings, such as school. By extension, the authors intended the TEA-Ch to contribute to the understanding of child attentional behavior in natural settings. Currently, the TEA-Ch scores offer normative data. The two new scores investigated in this study are performance-based, rather than norms-based.

Performance-based measures assess the functional capacity of an individual to perform tasks under optimal conditions (Marcotte, et al., 2010). Raw scores indicate the performance capacity of an individual to carry out specific real-world tasks that are critical to everyday functioning. The focus of performance-based tests is on understanding the capabilities of the individuals. The time-based measures of sustained attention investigated in this study represent a shift towards a more ecologically valid method for measuring sustained attention. Time-based measures in clinical practice will give professionals who use psychological assessments as a regular part of their work the ability to provide clients ecologically valid values that have direct, interpretive meaning in natural settings.

The CT-TOT score estimates the amount of time, out of approximately eleven minutes, that the child spent processing the auditory stimulus of the Code Transmission subtest. Unlike any other clinical measure of sustained attention, the CT-TOT reports scores in seconds, rather than the number of errors or standard scores. The mean scores and standard deviations generated for each age-band provide useful, rough estimates of the normative amount of time that a child referred for neuropsychological evaluation can sustain attention to an auditory stimulus (see Table 7). For example, the mean amount of time that a 6 year-old was able to sustain attention to the Code Transmission subtest was 4 minutes 7 seconds. Average sustained attention values for 6 year-olds ranged from 1 minute 35 seconds, to 6 minutes 39 seconds.

These mean values also provide information that may inform best practices in working with children who have suspected attentional problems. For example, the mean scores indicate that kindergarten and first grade teachers working with diverse populations of children will want to limit auditory instructions to approximately four minutes or less before taking a break or shifting activities. The findings clearly indicate that older children are able to sustain their attention to auditory information for longer periods. Teachers and professionals working with older, clinical populations of children can use the normative time-based estimates to adjust their expectations accordingly.

The performance-based score of the CT-TOT is an estimate of time that the child was able to sustain attention to a non-reinforcing auditory stimulus. Interested parties may also calculate a simple ratio of the amount of time the child sustained attention out of the total time of the task by dividing the CT-TOT score by the total duration of the Code Transmission test (CT-TOT/ Code Transmission total time). The CT-TOT score will help adults who work with children in natural settings (such as teachers) readily understand the implications of a child's auditory sustained attention problems.

The purpose of assessment is to provide a certain level of understanding about an individual (Groth-Marnat, 2009). Measures of sustained attention are intended to aide in the diagnosis of attention-related problems and to inform intervention planning (Barkley, 2006; Manly, et al., 2001). With an understanding of the attentional capacities of children, health and educational professionals can advocate for them in natural settings (such as the classroom) to help ensure that they are receiving the necessary support and accommodations. The CT-TOT provides information about a child's sustained attention capacity, which will enable parents and other care-providers to more accurately identify with the challenges of children under their care.

Limitations of the Study

External validity is an estimate of the extent to which a test provides a valid measure of the same constructs with individuals in the larger community (AERA, 1999). A detailed description and analysis of the sample population follows to inform the reader about the external validity of the findings. The participants in this study comprised a heterogeneous, clinical sample of children ages 6.0 - 12.11 referred for neuropsychological assessment. Most of the participants had a diagnosis of ADHD (81%). I did not provide cultural and ethnic demographic characteristics for the study, but the majority of participants likely came from Caucasian families. The sampled charts came from a clinic located in an affluent community in Washington State; most of the participants came from middle to upper income families (DeNavas-Walt, Proctor, & Smith, 2011). The findings of the study are relevant to clinical populations of children who share similar demographic and diagnostic characteristics of the population sample.

The findings may not be relevant to children who come from minority ethnic and cultural backgrounds or to children not referred for neuropsychological evaluation.

Clinical tests of sustained attention employ sustained attention tasks that have considerable variability (Parasuraman, et al., 2000; Sherman, et al., 2006). The research literature is rife with studies on the impact that test factors have on sustained attention performance (Curtindale, et al., 2007; Parasuraman, et al., 2000). Clinicians using these measures must be aware, at least in a cursory sense, of the impact that these factors may have on a child's sustained attention performance. Ideally, clinicians will also consider whether the tasks used in various sustained attention tests are similar to the sustained attention demands of children in natural settings. Manly et al. (2001) intentionally designed the TEA-Ch Code Transmission subtest to be dull and non-reinforcing so that the stimuli would not capture the attention of examinees (Manly et al., 2001). These studies provide convincing evidence that task factors have a profound impact on sustained attention, as indicated by variability in the onset of the vigilance decrement. The time-based measures investigated in this study provide estimates of a child's sustained attention capacity under similar, non-reinforcing auditory processing conditions.

There are numerous environmental and individual factors known to influence performance on measures of sustained attention (Roca, et al., 2012; Warm, 1984). Some individual factors that affect sustained attention are temperament, hunger, fatigue, mood, and rapport between subject and examiner (Curtindale, et al., 2007; Warm, 1984). Environmental factors include the signal to noise ratios in test settings, the order of test administration, the time of day, and ambient distractions in the environment (Warm, 1984). Because the present study used archival data, I was unable to control for numerous factors that may have caused variability in performance. All tests were administered by qualified psychometrists, and administration procedures and test conditions for all children were consistent with the recommendations provided in the TEA-Ch manual (Manly et al., 2001). Of the potentially intervening factors listed above, the test conditions only controlled for background noise and ambient distractions. I did not control for psychotropic medication, which previous research shows can affect performance on measures of sustained attention (Losier, McGrath, & Klein, 1996). Some children diagnosed with ADHD were on prescribed medication while others were not. The present study examined the relationship between children's scores on different psychometric instruments taken at approximately the same time. It is likely that uncontrolled test factors had less of an impact on the correlations between measures because they were likely to exert a similar influence on all tests. Uncontrolled test factors may have caused variability in child performance for all measures, thereby affecting overall mean scores for the different age-bands. Readers should interpret the mean scores for the different age-bands with this understanding in mind.

I used the Code Transmission subtest raw scores to calculate both of the time-based measures (CT-TOT & CT-LD) and the Code Transmission SS. It is important to consider that the significance of the correlations between these measures in and of themselves do not provide strong evidence of the criterion validity of these new measures. These correlations indicate that the raw scores capture much of the same information as the original Code Transmission subtest score. Most of the unexplained variance between these measures (45%) likely resulted from the method of calculation for the CT-TOT scores. The CT-TOT time-based estimates vary, depending upon the pattern of identified targets on the Code Transmission. For example, two children from the same age-band may both attain a 10 on the CT-SS; the CT-TOT score for each of them may be markedly different. The child who produced the more inconsistent of the two records (missing every other target, for example) will have a much lower CT-TOT score, than a child that correctly identified targets during more consecutive intervals of the test, even though their raw scores may be close enough to produce the same standard score.

The CT-TOT is an additive, performance-based score and not a replacement of the standard score of the Code Transmission subtest. The Code Transmission subtest is a CPT intended to contribute to a larger picture of a child's sustained attention capacity (Manly et al., 2001). The results of this, or any other, single test of attention should never be used to formulate a diagnosis nor be used as the entire basis for intervention planning (Barkley, 2006; Manly et al., 2001).

The methods used to calculate the total scores for the Code Transmission Time on Task (CT-TOT) and Code Transmission Longest Duration (CT-LD) assume that a child does not have an attentional lapse between subtest targets. CT-TOT scores represent conservative time estimates rather than exact measures of the amount of time the child spent processing the auditory stimulus.

Directions for Future Research

It is important to recognize that each of the TEA-Ch sustained attention subtests have unique task characteristics, which precludes them from sharing a large amount of the total variance between measures. Manly et al. (2001) designed the sustained attention subtests of the TEA-Ch to measure different aspects of the same, sustained attention construct (see Table 10). Other investigators found correlations between the TEA-Ch sustained attention measures that reflect these differences (Belloni, 2011; Passantino, 2011). While the findings show statistically significant results between the criterion and outcome measures, this relationship was likely limited by the different types of tasks used in the various measures. Research is needed to investigate the relationship between the CT-TOT and CT-LD scores and well-established CPTs that use more comparable sustained attention paradigms, such as the auditory version of the GDS. These findings may add to the validity argument of using the CT-TOT and CT-LD scores to quantify sustained attention.

Computer administered tests of sustained attention offer quick and reliable methods for calculating outcome scores (Riccio, et al., 2001; Strauss, et al., 2006). CPTs such as Conner's CPT-II that use the go, no-go paradigm capture processing efforts on a moment-by-moment basis. This format lends itself to accurate calculations of time-based estimates of sustained attention. Future research into the feasibility of using computerized CPTs to provide time-based estimates of sustained attention may add to the ecological validity of these measures by making scores more applicable to natural settings. These studies may lend additional support for the use of time-based measures of sustained attention.

This study was a preliminary investigation of the validity of time-based sustained attention scores. The present study design was retroactive and did not control for many demographic and individual variables. Research designed to control for demographic and individual variables would provide important evidence of the applicability of the time-based measures to wider populations of children. Between-groups investigations of performance on the CT-TOT and CT-LD with diagnostic groups of children and clinical controls will help to understand how well these new measures advance treatment of attention-related disorders (Cresswell, 2009).

The overall findings of the present, preliminary study support the use of time-based measures of sustained attention. In the future, researchers interested in time-based measure of sustained attention may want to design a study to help establish normative data for the new measure based on scores attained by a healthy, demographically representative sample of children from the United States. Researchers may also want to investigate the validity of using the method for calculating time-based sustained attention scores with other, existing measures of sustained attention. Researchers might also be interested in correlating scores on these measures with behavioral observations of sustained attention behaviors in classrooms or other social settings to provide greater evidence of their ecological validity. These time-based scores may add to the ecological validity of existing, clinical measures or, at least, provide additional information about children's sustained attention capacity.

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Appendix A

Table 8
Overview of the Neuro-imaging Techniques used to Investigate Functional Neuroanatomy

Neuroimaging Techniques			
Functional Imaging Premise: Neural activity correlates with observable behaviors.		**Anatomical Imaging** Premise: Anatomical variations correlate with observable behaviors.	
Type	**What it measures**	**Type**	**Imaging method**
PET	Variations in regional brain bloodflow	CT	X-rays taken from many perspectives integrated to create a 3-dimensional image.
EEG	Voltage Fluctuations in the brain	MRI	Measures different tissue densities to create a 3-dimensional image.
fMRI	Increases in regional brain bloodflow		

Kolb & Whishaw, 2006

Table 9
Theoretical Interpretations of Behavioral Markers of Sustained Attention

Behavioral Marker	**Theoretical Interpretation**
Response Time	Response time is the elapsed time between a target signal and examinee response. Increasing response times over the course of the sustained attention task indicate a depletion of cognitive resources devoted to the sustained attention task. Rapid responding, in the presence of many commission errors, signifies problems with response inhibition and a highly alert state.
Commissions	Commissions are erroneous detections that occur when the examinee provides responses to non-target signals. These error types signify lapses in attention due to mindless (automatic) responding under high-demand conditions, problems with inhibition during low-demand conditions, or failures to distinguish between target and non-target responses.
Omissions	Omissions are failures of the examinee to respond to a target signal. These error types signify lapses in attention under both demanding and non-demanding task conditions.

Table 9 was adapted from information presented in Helton, & Warm, (2008), Warm (1984), Parasuraman, et al., (2000).

Table 10

Theoretical Explanations for Changes in Behavioral Markers of Sustained Over Time During High and Low Demand Conditions

Behavioral Marker	Theoretical Explanations	
	High Task-Demand	**Low Task-Demand**
Response Time	High processing demands deplete cognitive resources and result in slowed reaction times. A shift in the inter-stimulus signal rate can cause a more conservative response style and lead to increased response times.	Dull non-reinforcing nature of the sustained attention task leads to increased competition from task unrelated thoughts (TUT's) and a subsequent lag in response time.
Commissions	High processing demands deplete cognitive resources and cause a shift to a more automatic response bias and careless responding. Processing demands are too great (or fast-paced) for the examinee to keep up with, resulting in latent responses.	Highly alert and impulsive response style, characterized by problems with response inhibition, result in false detections.
Omissions	High processing demands deplete cognitive resources and result in attentional lapses. Can also occur due to changes towards a more conservative response bias (especially during go, no go tasks).	Dull non-reinforcing nature of the task leads to increased competition from TUT's which results in subsequent lapses in attention.

Table 10 was adapted from information presented in Helton, & Warm, (2008), Warm (1984), Parasuraman, et al., (2000).

Figure 3
Theoretical Model of Neuroanatomical Regions Associated with Sustained Attention

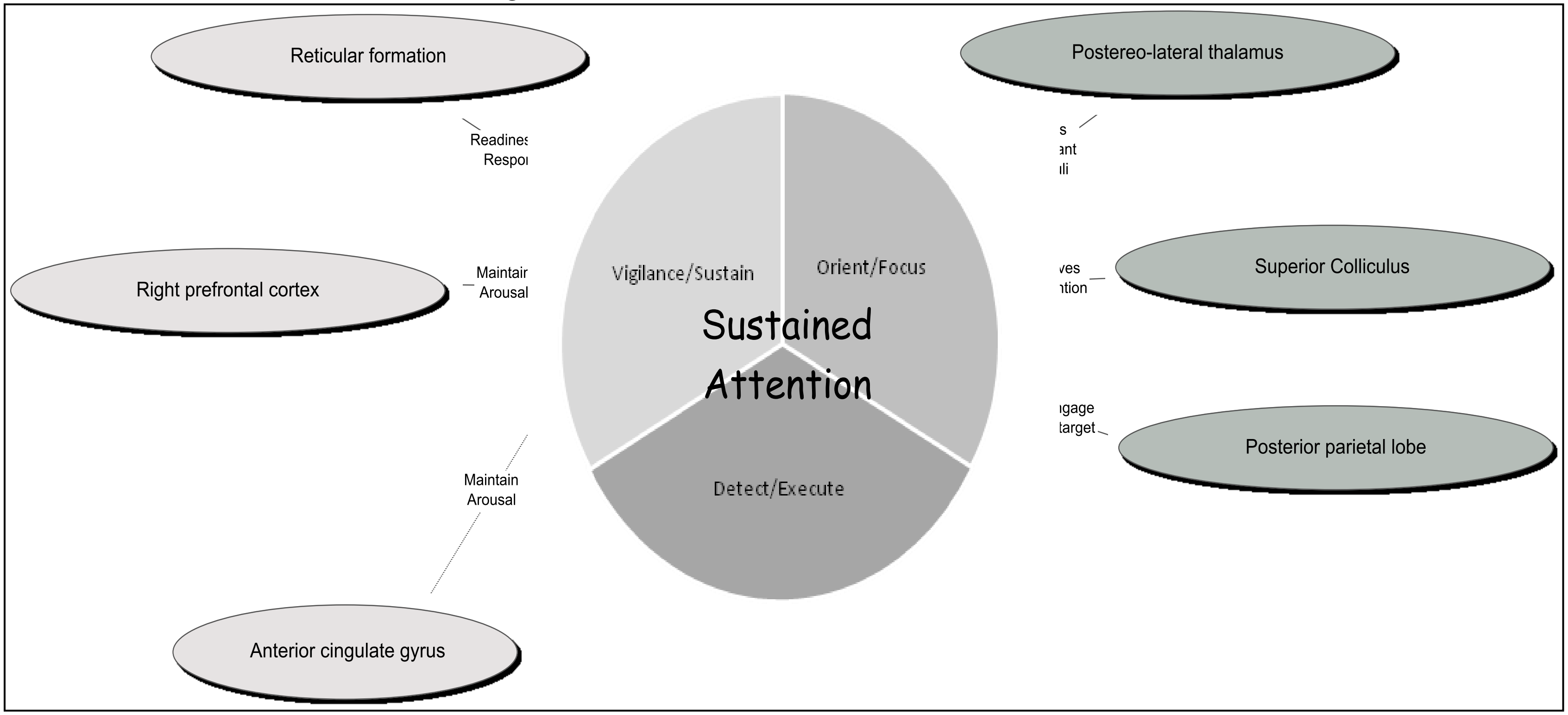

Figure 3 depicts the cognitive functions necessary to sustain attention and the neurologic regions responsible for carrying out these functions. The models of attention posited by Mirsky, Pascualva, Duncan, and French (1999) and Posner and Peterson (1990) were used to design the figure, along with evidence from the neuroscientific literature.

Definition of Terms

Psychometrics - The field of study concerned with the theory and technique of psychological measurement, which includes the measurement of knowledge, abilities, attitudes, personality traits, and educational measurement.

Ecological Validity - The degree to which the results of psychometric tests relate to behaviors of interest as they occur in natural, everyday settings (Marcotte, Scott, Kamat & Heaton, 2010).

Endogenous - Refers to characteristics, traits, behaviors and/or mechanisms that originate within an organism.

Exogenous - Refers to an action, event, or object that originates outside of the system or organism.