ATTENTIONAL IMPAIRMENT AND PROCESSING SPEED IN CHILDREN DIAGNOSED WITH ATTENTION DEFICIT HYPERACTIVITY DISORDER

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ABSTRACT

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The behavioral and cognitive symptomology that children with ADHD typically show can have a widespread impact on their overall functioning in everyday life. Children with ADHD may show poor short term memory, poor organizational skills, difficulty with goal directed behavior, difficulty regulating emotions, and difficulty shifting from one task to another. Children with ADHD have shown a higher risk for learning problems, substance abuse, psychopathology, and difficulty with social situations. Children with ADHD are at a significantly increased risk for school failure, and are more likely to repeat at least one school grade, and are at-risk for dropping out of school in adolescence.

The present study compared children diagnosed with ADHD Primarily Inattentive Type to children diagnosed with ADHD Combined Type and to children without a diagnosis of ADHD. Additionally, this study examined the Attentional Impairment Index for use in the diagnosis of ADHD in children and the differentiation of its subtype. Furthermore, the impact of processing speed and working memory as predictors of

ADHD subtype was studied. Participants in the current study were approximately 283 children between the ages of 7 and 19 years of age. Separate MANOVAs were conducted to see if there were differences between Processing Speed and Working Memory Index scores, and scores from a battery of neuropsychological assessments. Results indicated that neither index score was a significant predictor of ADHD subtype in children. However, it was found that children without ADHD performed better on the neuropsychological assessments than did the children with ADHD. Finally, an ANOVA was conducted to see if there were differences between the Attentional Impairment Index score among diagnostic groups. No statistically significant differences were found. The results provides evidence that the neuropsychological profile of children diagnosed with ADHD differs from that of children without a diagnosis of ADHD, and that the profiles of children diagnosed with ADHD-I differ from that of children diagnosed with ADHD-C. The current study demonstrated that the battery of assessment instruments used has the potential to differentiate between ADHD subtypes in an objective way, as opposed to the rather subjective method of diagnosis currently in use.

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CHAPTER I

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is characterized by symptoms such as inattention, distractibility, impulsivity, and hyperactivity (Simon, 2006). It can be classified into one of three subtypes: Predominately Inattentive Type, Predominately Hyperactive Type, or Combined Type. Although the exact cause of ADHD is unknown, it is often thought to be a manifestation of deficits in one or more of the child's executive functions. Executive functions impairments may include poor short term memory, poor organizational or planning skills, difficulty with goal directed behavior and self-monitoring of behavior, difficulty regulating emotions, and difficulty shifting from one task to another.

Characteristics of ADHD

According to the DSM-IV-TR (APA, 2000), children with ADHD may present with a low frustration tolerance, frequent outbursts of temper, bossiness, stubbornness, insistence that demands be met, lability of mood, demoralization, dysphoria, peer rejection, and low self-esteem. Children with ADHD commonly have lowered academic achievement that is often devalued by the individual, creating conflict between the children and school authorities. Delays in social skills and strained parent-child relationships are also common in children with ADHD. The DSM-IV-TR cites the prevalence rate of ADHD at 3-7% of school children. (APA, 2000)

According to the DSM-IV-TR, a child can be diagnosed with Attention Deficit Hyperactivity Disorder if he or she meets the following criteria: Either six or more maladaptive symptoms of inattention, or six or more maladaptive symptoms of hyperactivity and/or impulsivity. These symptoms must not be consistent with what one would expect for the child's developmental level and continue for six months or more. Symptoms of inattention include: (a) failing to pay close attention to details and/or making careless errors in schoolwork, work or other activities; (b) difficulty remaining attentive in play activities or work tasks; (c) often appears as though not listening when directly spoken to; (d) frequently leaves tasks unfinished or doesn't follow through on instructions, but not out of willful disobedience; (e) difficulty organizing work or play activities; (f) has an aversion to, or is unwilling to participate in tasks that require mental effort for a prolonged time, such as schoolwork and homework; (g) frequently misplaces required objects such as toys, school supplies and homework; (h) easily distracted by outside movement and noise; and (i) is generally forgetful in everyday activities. Symptoms of hyperactivity include (a) excessive movement of the hands and feet or moving around when seated; (b) leaves his or her seat in the classroom or other situations at inappropriate times; (c) runs or climbs excessively in inappropriate situations, or feels restless; (d) has difficulty participating in quiet activities; (e) seems to be constantly in motion; and (f) excessive talking. Symptoms of impulsivity include: (a) answering questions before they have been completely asked; (b) difficulty with waiting for his or her turn; and (c) frequently interrupts or intrudes on others such as during a conversation.

In order for the diagnosis to be made, some of the impairing symptoms must have been present prior to age 7, and some of the symptoms must be present in at least two different settings, such as at home and at school. The symptoms must cause clear and significant impairment to the child's social, academic or occupational performance. The symptoms must also not occur solely within another psychiatric disorder, or be explained better by another disorder. If a child shows six or more inattentive symptoms for more than six months or more, but less than six hyperactive-impulsive symptoms, the diagnosis given will be Attention Deficit Hyperactivity Disorder, Predominately Inattentive. If a child shows six or more hyperactive-impulsive symptoms for more than six months or more, but less than six inattentive symptoms, the diagnosis given will be Attention Deficit Hyperactivity Disorder, Predominately Hyperactive-Impulsive. If a child shows six or more inattentive symptoms and six or more hyperactive-impulsive symptoms for six months or more, a diagnosis of Attention Deficit Hyperactivity Disorder, Combined Type will be given. (APA, 2000)

ADHD is thought to be more common in males than in females, with ratios between 2:1 and 9:1, depending on subtype (APA, 2000). This disorder is found across various cultures, though more prevalent in Western cultures due to diagnostic practices (APA, 2000).

Subtyping of ADHD

ADHD can be parceled out into three distinct subtypes, which include Predominately Inattentive Type, Predominately Hyperactive-Impulsive Type, or

Combined Type. ADHD Predominately Inattentive Type (ADHD-I) is the most frequently diagnosed subtype of ADHD, followed by Combined Type (ADHD-C), with significantly fewer cases of Hyperactive-Impulsive Type (ADHD-HI). Though ADHD-I is the most commonly diagnosed subtype, ADHD-C is more prevalent among those who seek pharmacological treatment, perhaps because ADHD-C is correlated more highly with pervasive impairment across domains and are frequently diagnosed at a younger age (Carlson, Shin, & Booth, 1999). ADHD-C is more often seen comorbidly with externalizing disorders such as Oppositional Defiant Disorder and Conduct Disorder (Carlson et al., 1999).

Barkley (1997) proposed that ADHD-I is attributable to a deficit in selective or focused attention, whereas ADHD-C is attributable to a deficit in inhibition and sustained attention. Additionally, some have suggested that ADHD-C is characterized by social performance deficits and aggressive behavior, whereas ADHD-I is characterized by both social performance and knowledge deficits (Carlson et al., 1999). Children with ADHD-HI are thought to be significantly less impaired than those with ADHD-I or ADHD-C in academic and social performance, though children with ADHD-HI do exhibit more impaired externalizing behaviors than controls but to a lesser degree than do those with ADHD-C (Carlson et al., 1999). Neuropsychologically, children with ADHD-I and ADHD-C show worse performance on instruments such as the Wisconsin Card Sort Test, Stroop Test and the Digit Span test, while children with ADHD-HI showed no neuropsychological impairment (Schmitz et al., 2002).

Comorbidity with Other Disorders

Children with ADHD have lower intellectual development as measured by standard IQ instruments than do children in the general population; though the difference is on average only 7 to 15 points (Barkley, 1998). Conduct Disorder, Oppositional Defiant Disorder, and Tourette's syndrome have a very high co-morbidity rate with ADHD (APA, 2000). Learning disabilities are seen in higher proportions of ADHD children than in children without ADHD, though research is unclear as to whether the ADHD or the learning disability came first and caused the symptoms of the other disorder (Barkley, 1998; Fergusson & Horwood, 1992; McGee & Share, 1988). Working memory deficits are also common in children with ADHD (Barkley, 1998). Children with ADHD frequently show an increased likelihood of accidental injury, up to 57% greater than children in the general population (Barkley, 1998).

Incidence Rates

The United States has seen ADHD prevalence rates near 3-5% for school-aged children and adolescents in recent years (Burd, Klug, Coumbe, & Kerbeshian, 2003). This rate is nearly double that seen in European nations. Other studies applying only the DSM-IV criteria to school children have seen prevalence rates between 11-16% (Rowland, Lesesne, & Abramowitz, 2002). Between the ages of 3 and 17, the number of boys diagnosed with ADHD exceeds the number of girls diagnosed by three to four times. Incidence rates are higher for urban children than for rural children. No difference has been seen between the incidence rates for Caucasian and African American children.

However, Caucasian parents are more likely to seek medication as a treatment for their children with ADHD (Rowland et al., 2002). Annually, the estimated cost of caring for a child's ADHD is nearly $479. With the current United States child population near 85 million, approximately 3.3 million children diagnosed and treated for ADHD each year, for an annual health care cost of $2.15 billion. In 2003 (Pastor & Reuben), the Centers for Disease Control (CDC) examined data from the National Survey of Children's Health (NSCH). This survey questions families about both the physical and emotional wellbeing of non-institutionalized children less than 17 years of age in the United States. Results revealed that approximately 7.8% of children in the United States between the ages of 4 and 17 had or have a diagnosis of ADHD. This percentage is equivalent to between 4,234,000 and 4,602,000 children. Males were 2.5 times more likely to respond yes to statements asking if they have ever had a diagnosis of ADHD. As age increased, so did the prevalence of ADHD. Children from a non-Hispanic heritage, those who spoke primarily English, and those with insurance were diagnosed with ADHD more frequently. Additionally, males living below the poverty line were significantly more likely to have received an ADHD diagnosis than children in families with higher income levels. Study results indicated that approximately 56.3% of the children with an ADHD diagnosis were medicated for the condition. Medication was more common among children in the 9 to 12 year-old range. There was no significant difference among the percentage of females and males medicated for ADHD (Visser & Lesesne, 2005).

Risk Factors and Long-term Effects

Research has shown that children who are born with birth weights between 1500 and 2500 grams are at an increased risk for a later diagnosis of ADHD, though more studies are needed before the risk is more clearly defined (Rowland et al., 2002). Other studies have shown that an early exposure to lead may increase a child's risk of developing ADHD, even if the lead exposure does not reach the lead poisoning level (Needleman et al., 1979).

Children with ADHD have shown a higher risk for learning problems, substance abuse, psychopathology, and difficulty with social situations. Those with early signs of aggression along with ADHD are at an increased risk for school failure, criminal behaviors, and severe psychopathology such as personality disorders. Furthermore, adolescents with ADHD are more likely to engage in unhealthy behaviors such as smoking, having unprotected sexual relationships with multiple partners, as well as alcohol and substance abuse. Teenagers with ADHD have been found to receive 50% more moving traffic violations than teens without a diagnosis of ADHD (Rowland et al., 2002).

Up to 70% of adults who were diagnosed with ADHD in childhood continue to show symptoms as adults (Reid, 2007). These adults often struggle with tasks in the workplace, have difficulty tolerating boredom, have difficulty taking orders from supervisors, and frequently move from job to job with little or no success (Reid, 2007).

Adults with ADHD also frequently have poor handwriting skills, are disorganized at home and at work, and struggle with feelings of inferiority and depression (Lamb, 2006)

ADHD in the Schools

Children with ADHD are at a significantly increased risk for school failure (McKinley & Stormont, 2008). Such children are likely to perform more poorly in academic subjects and have lower scores on standardized tests of math and reading subject areas. Students with ADHD are more likely to repeat at least one school grade, and are at-risk for dropping out of school in adolescence. Children with ADHD can qualify for modifications and accommodations in the school setting through Section 504 of the Rehabilitation Act or the Individuals with Disabilities Education Improvement Act of 2004 (McKinley & Stormont, 2008). School psychologists are often called upon to assess children showing symptoms of ADHD to determine educational need for special education services, accommodations and modifications. Demaray, Schaefer, and DeLong (2003) examined the training and assessment practices for ADHD by school psychologists and found that on average, school psychologists receive approximately 17 referrals for ADHD assessment yearly. ADHD is a diagnosis that the practicing school psychologist will encounter frequently, whether it is for assessment, consultation or intervention.

Purpose Statement

The present study compared children diagnosed with ADHD Predominately Inattentive Type to children diagnosed with ADHD Combined Type and to children referred for evaluation but who did not meet diagnostic criteria for a diagnosis of ADHD on several neuropsychological measures of attentional abilities, as well as processing speed. In addition, this study examined the utility of a revised version of the Attentional Impairment Index (AI) for use in the diagnosis of ADHD in children and the differentiation of its subtype. Furthermore, the impact of processing speed and working memory as predictors of ADHD subtype was studied. Various neuropsychological instruments were utilized to examine the neuropsychological implications of ADHD in children.

Assumptions and Limitations

As this study examined archival data, it was assumed that the children were accurately diagnosed as having or not having ADHD, and that the subtype with which they were diagnosed was correct. Furthermore, it was assumed that the diagnosis was made after a comprehensive evaluation by a licensed professional. Participants were selected from archival data collected at the ADD Treatment and Research Center in Dallas, Texas. Selection of participants was made by limiting participation to children between the ages of 7 and 19 years of age and to those who had been administered the instruments that comprise the Attentional Impairment Index and the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV) or the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III) Processing Speed and Working Memory Indices. All children and adolescents in the sample were referred for testing for either attention concerns, learning difficulties or emotional concerns. It is likely that the children who were not given a diagnosis of ADHD were exhibiting sub-clinical symptoms of the disorder, or had another psychiatric or learning problem that might confound the results of the present study.

Because the data is archival, there was no control over the demographics of the participants. There was no way to ensure that the demographics of the sample population approximated the demographics of the total population. The majority of this data set's participants were middle class Caucasian children. Though the evaluations were completed by one or more examiners, all evaluations were completed at the ADD Treatment and Research Center using a standard protocol and assessment procedures.

CHAPTER II

REVIEW OF LITERATURE

History of ADHD

Attention-Deficit Disorder (ADD) first appeared in the Diagnostic and Statistical Manual, Third Edition (DSM-III), published in 1980 (Barkley, 1998). Prior to this time, hyperactive or impulsive children were thought to suffer from minimal brain damage syndrome or Hyperkinetic Reaction of Childhood Disorder in the DSM-II (Barkley, 1998). With the advent of ADD also came subtyping of the disorder based on the presence or absence of hyperactivity. In 1989, the DSM-III became the DMS-III-R and ADD was replaced with Attention Deficit Hyperactivity Disorder (ADHD), which could be differentiated by level of severity: mild, moderate or severe based on the level of impairment in the home and school environments (Barkley, 1998). In 1994, the DSM-III-R was replaced with the DSM-IV, which again included ADHD, but with the revision once again added sub-typing, differentiating between ADHD Combined Type, ADHD Predominately Inattentive Type, and ADHD Predominately Hyperactive-Impulsive Type (Barkley, 1998). This three type model of ADHD is the current diagnostic model of ADHD found in the DSM-IV-TR (American Psychiatric Association: APA, 2000).

ADHD is believed to have a genetic component, and though no specific gene has been identified at this time, genes that control monoaminergic neuromodulation have been found (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006). Additionally, differences in neuroanatomy, neurotransmitter levels and function of specific brain regions have been found. In ADHD, deficient levels of the neurotransmitters dopamine and norephinephrine are thought to lead to executive dysfunction (Hesse, Ballaschke, Barthel, & Sabri, in press; Pliszka, 2005).

Attention

Attention has long been an ill-defined, vague construct with no clear definition. Though various models of attention have been proposed, attention is often considered to be comprised of four basic components: selective attention, divided attention, sustained attention, and shifting attention. Selective attention is focusing on relevant information while simultaneously ignoring extraneous information. Divided attention is the act of attending to two or more stimuli concurrently. Sustained attention is prolonged focus on a stimulus. Shifting attention is moving ones focus from one object or stimulus to another. Children with ADHD may have deficiencies in one or more components of attention, or they may have widespread attentional difficulties that span all the components (Barkley, 1998).

In a study of children with and without ADHD, researchers attempted to examine the efficiency of executive processes including inhibition, shifting attention and sustained attention (Cepeda, Cepeda, & Kramer, 2000). Participants were asked to complete a single task repeatedly during the first trial for a set duration of time. In the second trial, participants were asked to switch between two tasks rapidly and accurately. Children with ADHD who were not medicated showed significantly poorer performance on the trial requiring shifting attention. However, children with ADHD who were medicated at the time of the study performed as well as children without a diagnosis of ADHD. Children on medication also performed better than those not taking medication at inhibiting incorrect responses.

Neuroanatomy of ADHD

ADHD has long been thought of as a neurological disorder, evidenced by its origination as minimal brain damage or organic brain dysfunction. Primary regions of the brain implicated in ADHD include the brainstem, amygdala, hippocampus, temporal lobe, frontal lobe, basal ganglia, limbic system, cerebellum, and motor cortex (Barkley, 1998; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003; Tucker & Williamson, 1984). Recent studies have identified 18 genes involved in ADHD, some of which have known associations with structural differences within the prefrontal cortex (Curatolo, Paloscia, D'Agati, Moavero, & Pasini, in press).

Recent imaging studies conducted by Rothenberger and Banaschewski (2007) have shown smaller than normal frontal lobes and cerebellar regions in the brains of children with ADHD as compared to normal controls, and to a lesser degree, smaller temporal and parietal lobes. ADHD symptomology is thought to be attributed to deficient information processing in these smaller than normal brain regions. Additionally, these researchers have encountered lower than expected levels of dopamine in children with ADHD, theoretically lessening the effectiveness of rewards in response to desired behaviors, either intrinsically or extrinsically applied (Rothenberger & Banaschewski, 2007).

In a similar study, Prince (2008) also found individuals with ADHD to have low levels of dopamine as well as norepinephrine. He further stated that the efficacy of stimulant medication in the treatment of ADHD further confirms his findings of deficient neurotransmitter levels in ADHD individuals.

Neurophysiologic studies of the brain have pointed towards at least four mechanisms that comprise what we call attention (Wagner, 2000). Attending to the spatial location of an object is accomplished with the help of the parietal cortex. Deciphering the object and determining which of its features are important is accomplished with the help of the visual and posterior temporal cortices. The inferior temporal region is responsible for the selection of, or attention to, a specific object among all of the available objects one might encounter. Additionally, selecting a response and dividing attention among two or more objects simultaneously is accomplished by the frontal lobes, specifically the anterior cingulate cortex. The reticular activating system plays an important role in ADHD, as it modulates arousal. The two most prevalent neurotransmitters found in the reticular activating system, dopamine and norephinephrine, are the neurotransmitters most affected by stimulant medications used in the treatment of ADHD.

Also important to the study of the ADHD brain and symptomology is the visual-motor pathway (Wager, 2000). This area of the brain plays an important role in selective attention, or the ability to pay attention to a particular stimulus while at the same time ignoring extraneous stimuli. Children with ADHD who have deficits in the visual-motor pathway are often described as not seeing or not being aware of visual stimuli. The parietal-temporal-frontal pathway is another critical brain region that influences children with ADHD. This pathway is responsible for identifying important information, processing and sorting through it, and selecting an appropriate behavioral response. Deficits in the parietal-temporal-frontal pathway can manifest as difficulty with selective attention or deficient processing of information. The dorsolateral pre-frontal cortex is believed to be a critical structure to the executive functions and attention processing, as well as working memory capacity (Kane & Engle, 2002).

Anatomic differences in the brains of children with ADHD have also been reported (Hill et al., 2003; Kieling, Goncalves, Tannock, & Castellanos, 2008). One study examined the brain volumes of children with and without an ADHD diagnosis using MRI scans (Hill et al.). Overall brain volume was found to be significantly less in children with ADHD than in children without a diagnosis, especially in the right superior prefrontal region. In addition, smaller corpus callosum and cerebellum sizes were seen in children with ADHD than in control group children.

The basal ganglia, which impacts the sequencing and inhibition of motor movements, has been reported to be approximately the same size in both hemispheres, whereas in children without ADHD, the basal ganglia in the right hemisphere is often slightly larger than in the left hemisphere (Wager, 2000). In a study by Castellanos et al. (2006) the caudate nucleus was found to be symmetrical in children with ADHD, contrary to the asymmetry typically seen in children without ADHD. The study also showed a reduction in the size of the globus pallidus on the right side for children with ADHD. These changes are correlated with symptoms of impulsivity, impaired fine motor control, and an increased desire for sensory stimulation. The corpus callosum was shown to be smaller in the posterior portions of children with ADHD, which correlates with deficient selective attention abilities (Semrud-Clikeman et al., 1994).

Researchers have been seeking the implication of anatomical differences in the brains of children with ADHD as compared to children without the diagnosis since the late 1950's. In 1957, Laufer, Denhoff and Solomons conducted an electroencephalogram (EEG) study of 50 children from a psychiatric hospital for emotional disturbed children examining children who displayed behaviors characteristic of hyperkinetic impulse disorder, the term for ADHD at the time. Laufer and his colleagues found that the EEGs of the children with symptoms of hyperkinetic impulse disorder could be altered by using amphetamines, and concluded that the symptoms of hyperkinetic impulse disorder were due to damage in the diencephalon, possibly sustained during the prenatal period, during birth, or during early childhood. In a similar study (Knobel, Wolman, & Mason, 1959) of 40 children with behavioral difficulties, the EEG response was again examined as a way to differentiate between those children with hyperkinesis and those without. Researchers concluded that the syndrome characterized by hyperactive behavior could be attributed to poor filtering by the thalamus of stimuli entering into the brain, which lead to what they termed cortical over-functioning.

By the 1970's, researchers had begun to examine the implication of the hyperactivity syndrome on sustained attention and impulsivity (Barkley, 2002). Satterfield and Dawson (1971) tested the electrodermal skin conductance of 24 children with hyperkinesis and 12 without, and found that children with the hyperkinetic syndrome had lower skin conductance levels, fewer nonspecific electrodermal responses and smaller specific electrodermal responses. Additionally, it was found that administering amphetamines to the children with the hyperkinetic syndrome raised the skin conductance levels and increased the electrodermal responses to levels near that of the children without hyperkinesis. Satterfield and Dawson concluded that the symptoms of the hyperkinetic syndrome could be attributed to a decrease in the activity of the reticular activating system, as it is the reticular activating system that regulates electrodermal activity. Dykman, Ackerman, Clements, and Peters (1971) viewed ADHD as a type of specific learning disability with the primary symptoms being defective attentional abilities. They attributed the learning disability to a developmental lag or neurological immaturity, which was correlated with a deficit in the forebrain inhibitory system and an underactive diencephalon.

The study of attention difficulties in the 1980s and 1990s shifted towards an examination of motivation, reaction to rewards, self-control of behavior, and information processing (Barkley, 2002). Gorenstein and Newman (1980) examined the connection between humans with attentional difficulties and studies that examined the behavior of animals with lesions to specific brain regions. It was suggested that these animal studies could produce research theories to examine the disinhibitory psychopathology in humans. Gorenstein and Newman theorized from the animal studies that symptoms of behavioral disinhibition in children and adolescents may be due to dysfunction of the medial septum. After comparing those with hyperkinesis to those with frontal lobe injuries and discovering similarities, Mattes (1980) theorized that the hyperkinetic behavior was due to frontal lobe dysfunction. In 1984, Lou, Henriksen, and Bruhn conducted a study of the regional cerebral blood flow in 13 children diagnosed with dysphasia and Attention Deficit Disorder (ADD). All 11 of the children diagnosed with ADD showed hypoperfusion in the frontal lobes, and 7 also showed hypoperfusion in the caudate nuclei, leading to the conclusion that ADD symptoms were caused by this hypoperfusion in the frontal lobes and/or caudate nuclei. Hunt, Minderra, and Cohen (1985) studied the effects of the medication clonidine when taken by ten children between the ages of 8 and 13 years diagnosed with ADD with hyperactivity for eight weeks, followed by a placebo medication for four weeks. Due to the favorable response and symptom reduction in these children, Hunt et al. concluded that the dysfunction in the locus coerulens leading to fluctuation in the levels of norepinephrine being released may be implicated in the cause of the ADD symptoms.

In a study of the neuropsychological performance of children with ADD as compared to children without the diagnosis, Chelune, Ferguson, Koon, and Dickey (1986) found a pattern of weaknesses among the children with ADD on instruments measuring frontal lobe inhibitory control. These deficits were noted to lessen with age, reinforcing the developmental lag hypothesis of researchers past. Chelune et al. also concluded that ADD was at least in part caused by frontal lobe dysfunction. Voeller and Heilman (1988) set the stage for future neuropsychological research of ADHD with a study examining children with and without attentional difficulties, using a letter cancellation task. They concluded that the performance of the children with ADD resembled adults with right hemisphere dysfunction, which implicated dysfunction in the right frontal lobes as a possible cause for ADD symptomology. In 1989, Schaughency and Hynd conducted a study in which they hypothesized that there were neuropsychological structure and biochemical systems responsible for the symptoms of hyperactivity and inattention in children diagnosed with ADD. Results from the study suggested that for children diagnosed with ADD with hyperactivity, the right frontal lobe appeared to function differently than in non-ADD controls. Results also suggested that for children diagnosed with ADD without hyperactivity, the right parietal lobe seemed to function differently than in non-ADD controls. For all children diagnosed with ADD, whether with hyperactivity or without, levels of dopamine and norepinephrine appeared to be deficient as compared to children without the ADD diagnosis.

Hynd, Semrud-Clikeman, Lorys, Novey, and Eliopulos (1990) utilized magnetic resonance imaging (MRI) scans to examine the anatomical differences in brain structure in ten children diagnosed with ADD with hyperactivity, ten children diagnosed with dyslexia, and ten children without any diagnosis. Hynd et al. noted that the children with dyslexia and the children with ADD showed significantly smaller right anterior width measurements than did children without a diagnosis. The hypothesis is also presented that right frontal lobe dysfunction may be a cause of the symptoms of inattention and hyperactivity in children with ADD.

In a review of studies of adults and children with ADHD and related conditions, Heilman, Voeller, and Nadeau (1991) compared children with ADHD to adults with Dysexecutive Syndrome, a disorder characterized by difficulty with initiation, self-monitoring behavior, and responding to environmental cues by changing behaviors. In this comparison, Heilman et al. suggested that because children with ADHD show similar symptoms as adults with Dysexecutive Syndrome, these children likely have the same right frontal-striatal dysfunction as adults with Dysexecutive Syndrome. Furthermore, symptoms of restlessness and hyperactivity are attributed to a possible impairment in the dopamine system.

A recent meta-analysis of 16 neuroimaging studies conducted with participants with ADHD and participants without a diagnosis revealed significant patterns of frontal lobe hypoactivity in participants with ADHD (Dickstein, Bannon, Castellanos, & Milham, 2006). This hypoactivity had neural implications in the anterior cingulate, dorsolateral prefrontal area, inferior prefrontal cortices, basal ganglia, thalamus and parietal cortex, indicating that the executive dysfunction typically seen in children with ADHD is not localized in one portion of the brain, but rather widespread, though the most significant impairment most likely originates from the frontal region of the brain.

A study of 120 children examined electroencephalogram readings of children between the ages of 8 and 12 years with ADHD- Combined Type, ADHD-Inattentive, or no diagnosis (Clarke, Barry, McCarthy, & Selikowitz, 2001). Children with ADHD were significantly different than control group children, as were the subtypes of ADHD. Children with ADHD- Combined Type showed higher levels of theta waves than children with ADHD- Inattentive Type, which showed higher levels of theta waves than control group children. Results from this study point towards a developmental divergence in central nervous system functioning.

Though no causal link exists, it has been noted that ADHD is characterized by frontal-striatal abnormalities and that children and adults with the disorder are also often characterized by deficits in inhibitory control, regulation of attention, difficulties with sensory-motor skills, and problems with executive functioning which includes working memory and processing speed (Hale et al., in press; Sonuga-Barke, Sergeant, Nigg, & Willcutt, 2008). A meta-analysis of 83 studies examining executive functions in 3,734 children with ADHD and 2,969 children without a diagnosis found that overall, children with ADHD show significant impairment on measures of executive function, with the most impairment in the areas of response inhibition, vigilance, working memory, and planning (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005).

In an attempt to further clarify the types of neurocognitive impairment seen in children with different ADHD subtypes, 50 boys with ADHD and 44 boys without an ADHD diagnosis were given a psychological and neuropsychological battery of tests (Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007). The battery of test instruments used assessed executive functioning in the areas of inhibition, divided attention, phonological working memory, visual object working memory, and variability of reaction times. Results indicated that children with ADHD had a general impairment in executive function and attention, and that inhibition served as a predictor for working memory performance.

A group of researchers in South Africa proposed a vastly different explanation for the deficits typically seen in children and adolescents with ADHD, especially on tasks requiring continual responses to rapid, externally presented stimuli (Russell et al., 2006). They hypothesized that astrocyte function insufficiency leading to an insufficient production of lactate is the primary cause for the deficient skills and development of ADHD. Furthermore, they believe that deficient adenosine triphosphate (ATP) production leads to overall delayed neuronal firing, and an insufficient lactate supply leads to reduced myelination of axons during critical developmental periods. The researchers concluded by stating that such a hypothesis could provide implications into interventions designed for ADHD students, in that breaking complex tasks into smaller, more manageable chunks and allowing self-paced work would alleviate the problem of delayed neuronal firing and decreased myelination and call for less neuronal energy.

ADHD and Processing Speed

Processing speed has also been implicated in the deficits and symptoms often seen in children with ADHD (Calhoun & Mayes, 2005; Kaufman, 1994;Mayes & Calhoun, 2007a; Mayes & Calhoun, 2007b; Rucklidge, 2006; Sergeant, 1988 Shanahan et al., 2006;). Although processing speed is a term that appears frequently in research and in evaluation materials, there is not a universally accepted definition for processing speed. Some view it as the quickness with which one performs a cognitive task over a sustained period of time (Mather & Wendling, 2005). McGrew and Flanagan (1998) define processing speed as the ability to automatically perform cognitive tasks while simultaneously maintaining focus and concentration. A detailed operational definition can be found in an article by Shanahan et al. (2006). These researchers defined processing speed as the "underlying cognitive efficiency at understanding and acting upon external stimuli, which includes integrating low level perceptual, higher level cognitive and output speed." Processing speed is an integral component of intelligence measured on the Wechsler intelligence batteries. The Processing Speed Index (PSI) on the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Psychological Corporation, 2003) has been investigated for its utility in distinguishing between ADHD subtypes, and found to be helpful (Calhoun & Mayes, 2005; Mayes & Calhoun, 2007b).

Processing speed, as measured by the Wechsler intelligence batteries, is influenced by clinical factors, personality characteristics, behavior, and neurological variables (Kaufman, 1994). Additionally, processing speed is sensitive to low motivation, reflectivity, compulsivity, and fine motor deficits. The Processing Speed Index of the WISC-III includes two measures of processing speed: one measuring mental speed and one measuring motor speed.

Children with ADHD are frequently observed to show slower processing speed than do other children without ADHD, regardless of gender (Rucklidge, 2006; Sergeant, 1988). Rucklidge examined the processing speed abilities of 114 adolescents with and without ADHD using the Processing Speed Index from the WISC-III and WAIS-III. Both males and females with ADHD performed significantly worse on all measures of processing speed than did the control participants without a diagnosis of ADHD.

Calhoun and Mayes (2005) examined processing speed in children with a variety of clinical disorders, also using the WISC-III Processing Speed Index. Results suggested that children with ADHD- Predominately Inattentive type showed a greater weakness in processing speed than did children with ADHD- Predominately Hyperactive/Impulsive type or combined type. Children with a learning disability (LD), autism, spina bifida, depression, and bipolar disorder also showed processing speed deficits. Furthermore, children with all types of ADHD were more likely to have a comorbid LD, suggesting that LD and processing deficits are neurologically interrelated. Calhoun and Mayes conclude by indicating that the Processing Speed Index may assist in distinguishing between ADHD subtypes.

In a follow-up study, Mayes and Calhoun (2007a) conducted a study which included 886 children with ADHD ($n = 724$), depression and/or anxiety ($n = 25$), oppositional defiant disorder ($n = 19$), and autism ($n = 118$). Participants were given the Wechsler Intelligence Scale for Children, Third Edition (WISC-III) or WISC-IV, and the Wechsler Individual Achievement Test (WIAT), WIAT-II, or Wide Range Achievement Test- Third Edition (WRAT-3), depending on when they were examined, as well as portions of the Gordon Diagnostic System and the Developmental Test of Visual-Motor Integration. Results showed that control group children performed better on measures of processing speed than did children with ADHD or autism. Those with ADHD and autism did not differ on processing speed performance. Those who had processing speed deficits also tended to show deficits in attention and graphomotor ability. Processing speed deficits were also highly correlated with learning disabilities. Those with deficits in all three areas of processing speed, attention and graphomotor ability showed the greatest IQ-achievement discrepancies in all academic areas. The cluster of weaknesses in processing speed, attention, graphomotor ability and learning served as a way to differentiate between those with ADHD or high-functioning autism and those with other clinical disorders or control children. Mayes and Calhoun suggest that the WISC-IV Working Memory and Processing Speed Indices combined with the WIAT-II could be used to develop a neuropsychological profile typical of children with ADHD.

In a second concurrent study, Mayes and Calhoun (2007b) stated that the Processing Speed Index (PSI) of the WISC-IV, when used in conjunction with the Working Memory Index (WMI), may be helpful for identifying children who have or are at risk for ADHD. Those children whose lowest index is either PSI or WMI should be given a comprehensive evaluation specific to ADHD. Those children whose lowest scores were not either WMI or PSI are unlikely to have ADHD, according to the results of the current study.

Contrary to what many researchers believe about the neuropsychological profile of children with ADHD, Chhabilda, Pennington and Willcutt (2001) did not find widespread neuropsychological impairment across all ADHD children that was able to differentiate between subtypes. In their study, the neuropsychological profiles of 82 children without ADHD, 67 children with ADHD- Predominately Inattentive Type (ADHD-I), 17 children with ADHD- Predominately Hyperactive Type (ADHD-H), and 33 children with ADHD- Combined Type (ADHD-C) were compared. It was expected that children with ADHD-I and ADHD-C would have deficits in the area of sustained attention and processing speed, while children with ADHD-H would have impaired ability to inhibit behaviors and responses. However, researchers found that children with ADHD-H did not have any clear areas of impairment, while those with any attentional difficulty, whether classified as ADHD-I or ADHD-C had areas of neuropsychological impairment, but no clear profile existed for either subtype.

The Trail Making Test has also been used to measure processing speed in children with and without a diagnosis of ADHD (Shanahan et al., 2006). As part of the Colorado Learning Disabilities Research Center twin study, 395 children and adolescents between the ages of 8 and 18 years were categorized into three groups: participants with ADHD, those with ADHD and a reading disorder, and those with no diagnosis. Participants were given the WISC-R, Peabody Individual Achievement Test, the Rapid Automatic Naming test, the Colorado Perceptual Speed test, and the Identical Pictures task during the first evaluation session. During the second evaluation session, participants were given a neuropsychological battery of tests comprised of the Stroop Test, the Trailmaking Test, the Gordon Diagnostic System and a Stop Task. Results from the study indicated a general processing speed deficit among both children with reading disability and with ADHD. Researchers further indicated that processing speed seems to be a shared cognitive risk factor that contributes to the frequent comorbidity of reading disorder and ADHD.

Also using the Trail Making Tests, Oades and Christiansen (2008) examined cognitive-switching processes in 57 Caucasian children between the ages of 5 and 18 years with ADHD as compared to 44 of their siblings without ADHD and 71 unrelated Caucasian control group participants of the same age. Children with ADHD required more time to complete the Trail Making Test when factoring out psychomotor processing, measured by subtracting the time to complete Trails A from the time to complete Trails B. Additionally, performance was correlated with severity of symptoms as measured by the Conners Rating Scales.

Reitan and Wolfson (2004b) conducted a study of children between 9 and 13 years of age who had either been diagnosed with brain damage or disease, were referred for limited academic progress, or were participants in the control group. These children were given the Trail Making Test Part B in order to screen for neuropsychological impairment. Children with brain damage or disease needed more than three times as long to complete the task as compared to control children, while those making limited academic progress needed more than twice as long as control children. These results indicate that the Trail Making Test Part B is a valid measure of non-specific neuropsychological impairment, which could be used as a preliminary screening instrument for children of concern.

A study of 43 boys ages 6 to 12 with ADHD and without sought to examine the utility of several neuropsychological measures used together to differentiate between children with ADHD and those without (Perugini, Harvy, Lovejoy, Sandstrom, & Webb, 2000). Participants were given the Kaufman Hand Movements Scale from the KABC, the Stroop Color-Word Test, the Controlled Oral Word Association Test, the Trail Making Test, the Arithmetic and Digit Span subtests which comprise the Freedom from Distractibility composite of the WISC-III, and the Conners Continuous Performance Test. The Continuous Performance Test offered the best predictor of ADHD, followed by Digit Span and Trails B, though not to a significant degree. Using neuropsychological tests together as a battery approach seemed to enhance the predictive power more than when individual tests are used alone or in small groups.

A study of 203 children between the ages of 7.6 and 11 with ADHD- Inattentive Type or Reading Disorder examined the speed of processing among these children (Weiler, Bernstein, Bellinger, & Waber, 2000). Results indicated that children with learning problems of any kind show slower processing speed, while those with ADHD-Inattentive Type are especially sensitive to processing speed difficulties.

Mayes, Calhoun, Chase, Mink, and Stagg (in press) conducted a study to address the utility of the WISC-III Freedom from Distractibility (FFD), Processing Speed (PSI) and Working Memory (WM) Indices and the Gordon Diagnostic System in differentiating between subtypes of ADHD coexisting with anxiety, depression and opposition-defiant disorder (ODD). Five hundred and eighty-seven children with ADHD-Combined Type (with no comorbid condition, or with comorbid anxiety, depression or ODD) or ADHD- Inattentive Type (with no comorbid condition or with comorbid anxiety or depression) were assessed. Attention, as measured by the WISC-III FFD/WMI indices and the Gordon Diagnostic System were low across all groups, and not significantly different. Children with ADHD- Combined Type had the greatest level of impulsivity as measured by the Gordon Diagnostic System. Children with ADHD- Inattentive Type had the slowest processing speed as measured by the WISC-III PSI. Comorbidity with other disorders did not have an effect on performance. Researchers were able to differentiate between ADHD subtypes with 72% accuracy using this battery of assessment instruments.

ADHD and Working Memory

The literature surrounding the relationship between ADHD and working memory has been mixed in its findings. A recent study (Sandrini, Rossini, & Miniussi, 2008) used repetitive transcranial magnetic stimulation to examine the role of the dorsolateral prefrontal cortex in working memory. Findings supported the role of the dorsolateral prefrontal cortex in implementing top-down attentional control, and further provided evidence for the theory that working memory controls selective attention in the normal (non-ADHD) brain.

A meta-analysis of 83 studies found working memory, specifically spatial working memory, to offer the strongest evidence for ADHD in a study participant when distinguished from simple storage of information (Castellanos et al., 2006). On the other hand, a study of 51 individuals with ADHD predominately Inattentive, ADHD Combined Type or no ADHD showed little evidence for differences in working memory between ADHD subtypes (Schweitzer, Hanford, & Medoff, 2006). However, significant working memory deficits were present among both ADHD subtype groups. Another study of 72 children who were at risk for developing ADHD, ADHD and ODD, or who were normal controls was conducted for the purpose of examining how three different types of inhibitory control and two types of working memory might serve as longitudinal predictors of ADHD and/or ODD (Brocki, Nyberg, Thorell, & Bohlin, 2007). Initial differences in working memory abilities and in the two year follow up data did not contribute to identifying which children were at risk for either ADHD or ODD.

In 2004, Karatekin published a study investigating the working memory abilities of children with and without ADHD. Participants included 25 children with a mean age of 11 years who had a diagnosis of ADHD, and 27 children with a mean age of 11 years who had no diagnosis of ADHD. All participants were asked to complete a verbal working memory task and a spatial working memory task as well as a dual task to measure simultaneous processing. Contrary to hypothesized results, children with ADHD did not perform significantly differently on the different working memory tasks. Children with ADHD were able to use rehearsal strategies as well as children without ADHD. However, children with ADHD did have overall lower accuracy scores than those children without ADHD. Karatekin attributed these findings to the impulsivity with which the children with ADHD responded, often citing they had mistakenly pressed the wrong button in answering, or that they had not paid sufficient attention to the encoding portion of the working memory tasks. Additionally, children with ADHD showed significant impairment on the dual tasks requiring divided attention between two tasks. This is consistent with the theory that children with ADHD have a deficit in the central executive component of working memory.

Contrary to the previous studies, one involving 288 adolescents and adults showed that working memory was weaker in participants diagnosed with ADHD than in normal controls (Engelhardt, Nigg, Carr, & Ferreira, 2008). Those with ADHD were less skilled at protecting working memory from the effects of interference. However, it must be noted that the deficits in working memory represented an inability to use controlled attention during interference trials rather than a limitation of the memory capacity. A similar study of 35 young boys with either ADHD Combined Type or without ADHD examined the impact of ADHD on working memory (Randall, Bohlin, Kerns, & Brocki, 2008). Results from this study also showed verbal and visuospatial working memory deficits, particularly concerning response inhibition.

A study of 80 boys with and without ADHD was conducted to examine the hypothesis that working memory is impaired in children with ADHD (Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004). Participants completed a choice reaction time test and a visual spatial working memory test. Children with ADHD showed lower working memory scores on all measures as compared with children without ADHD. Results from this study showed that tests of visual spatial working memory are sensitive measures of cognitive deficit in children with ADHD, which supports the hypothesis that working memory deficits are central areas of weakness in ADHD.

In 2006, Palladino published a study that examined the working memory ability of 128 third grade children with ADHD, ADHD and a reading disability, or no diagnosis. Participants were given the Working Memory Span with Categorization test, and a lexical decision task. Children with ADHD and a reading disability remembered the fewest words from the verbal working memory task, but retained more of the irrelevant information. Palladino hypothesized that this finding was due to the impaired inhibitory control of children with ADHD, and is exacerbated by the reading disability.

In order to examine Barkley's proposal that behavioral inhibition is the central deficit in ADHD which causes deficits in both working memory and sense of time, a study was conducted in which 42 children between the ages of 6 and 13 years with either ADHD- Combined Type or no ADHD diagnosis were given time reproduction tasks, working memory tasks, behavioral inhibition tasks and attention tasks (Kerns, McInerney, & Wilde, 2001). Children with ADHD showed more errors on the time reproduction tasks, more total errors on working memory tasks, though not to a statistically significant degree, significantly more omission errors on tasks of behavioral inhibition, and poorer performance on measures of attention. Study findings suggest that in children with ADHD, deficits in time reproduction are more closely related to behavioral inhibition than to working memory, though working memory is a necessary component to time reproduction.

A study of 51 adults with ADHD Combined Type, ADHD Inattentive Type or normal control group participants with no ADHD diagnosis were given tests of working memory in an attempt to discern the diagnostic utility of working memory at predicting subtype (Schweitzer et al., 2006). Although no clear significant differences were found between ADHD subtype groups, overall, working memory performance was significantly less in participants with ADHD than without, especially when the task required significant processing speed. Males with ADHD Inattentive Type were performed most poorly on working memory tasks when the processing speed demands were high.

Forty-four adolescents with ADHD and 34 adolescents without ADHD were given measures of IQ, working memory and decision making to examine the hypothesis that decision making in risky situation is impaired in those with ADHD and is related to IQ and working memory ability (Toplak, Jain, & Tannock, 2005). Adolescents with ADHD performed more poorly on measures of IQ and working memory, and made poorer choices on the decision making task. However, performance on the decision making task was not significantly correlated with either IQ or working memory. These findings support the current model of dual pathways of motivation and executive processes of ADHD.

Providing further evidence for the neuropsychological deficits of ADHD, a study of 143 children with ADHD, ADHD and comorbid language or reading learning disorders, or with no diagnosis were given measures of verbal storage and working memory, and spatial storage and working memory (Martinussen & Tannock, 2006). Results of the study showed that inattentive symptoms but not hyperactivity/impulsivity symptoms of children with ADHD were good predictors of both verbal and spatial storage and working memory.

Another study examining Barkely's model of ADHD which includes deficits in behavioral inhibition, motivation and working memory was conducted using 152 children between the ages of 7 and 12 (Stevens, Quittner, Zuckerman, & Moore, 2002).

Participants were administered a stop-signal measuring simultaneous storage and processing of information, the Kaufman Brief Intelligence Test and the Conners Parent and Teacher Rating Scales. Children with ADHD showed deficits in inhibition, working memory and short term memory as compared to children without ADHD, consistent with Barkley's model of ADHD.

Neuropsychological Assessment

The use of neuropsychological instruments in diagnosing ADHD is common practice, and is even believed to be effective in differentiating between subtype with an estimated accuracy of 80% (Lockwood, Marcotte, & Stern, 2001). Instruments used frequently in the assessment of ADHD include the WISC-II/IV, Rapid Automatized Naming (RAN), Stroop Color and Word Test, Tower of London (TOL), Wisconsin Card Sorting Test (WCST), Warned Simple Reaction Time Test (WSRT), Conners' Rating Scales-Revised, the Stop Task, Trail Making Test, and various continuous performance tests (Fuggetta, 2006; Greve, Williams, Haas, Littell, & Reinoso, 1996; Healey & Rucklidge, 2006; Kaufmann & Nuerk, 2006; Rucklidge & Tannock, 2002; Solanto et al., 2007; Young, Bramham, Tyson & Morris, 2006). For the purposes of this study, the focus will be limited to the Stroop Color and Word Test, Wisconsin Card Sorting Test, and the Trail Making Test.

In a study designed to reveal the role of attention in performance on the Wisconsin Card Sorting Test, Greve et al. (1996) administered the WCST to 31 children between the ages of 8 and 12 years. Fourteen of the children were diagnosed with

ADHD, while the remaining 17 served as normal controls. Results showed main effects for Failure to Maintain Set, showing that this score is sensitive to attentional processes.

Romine et al. (2004) sought to study the sensitivity and specificity of the Wisconsin Card Sorting Test when used to identify executive functioning deficits in children with ADHD and other developmental disorders. Meta-analysis of data revealed that children with ADHD consistently performed significantly poorer on the WCST Percent Correct, Number of Categories, Total Errors, and Perseverative Errors. However, because children with other developmental disorders performed poorly as well, though the WCST does reveal if there is executive dysfunction, it is insufficient alone to diagnose ADHD.

A study designed to compare performance on several neuropsychological instruments known to measure pre-frontal functioning included 47 children in elementary school (Gorenstein, Mammato, & Sandy, 1989). Participants were given several instruments including the WCST, the Matching Memory Test, Trail Making Test, Stroop Color-Word Test, and the Necker Cube task. Children with ADHD performed in the range of impaired pre-frontal function on WCST Perseveration errors, sequential errors on the Matching Memory Test, and reversals on the Necker Cube task. Children with ADHD also performed more poorly on the Trail Making Test, the Stroop Color-Word test and on a sequential memory task, indicating pre-frontal functioning deficits.

Solanto et al. (2007) conducted a study which included 80 children between the ages of 7 and 12 years. Participants were then separated into three groups: children with a diagnosis of ADHD combined type, children with a diagnosis of ADHD Predominately Inattentive type, and those with no attention, learning, emotional or behavior problems. Participants were given the Stroop Color and Word Test to measure interference, the Conners' Continuous Performance Test to measure sustained attention, the Wisconsin Card Sorting Test to measure ability to form, maintain and shift cognitive set, and various other neuropsychological measures of attention and executive functioning. Children with ADHD combined type performed significantly more poorly on the Stroop interference measure, and in the number of categories completed on the Wisconsin Card Sorting Test.

In an attempt to differentiate the neuropsychological profiles of children with ADHD- Combined Type as opposed to ADHD- Inattentive Type, 105 children between the ages of 7 and 12 years were given the Stop Task, Tower of London, Stroop Color-Word Test, and the Trail Making Test (Nigg, Blaskey, Huang-Pollock, & Rappley, 2002). Children with either subtype of ADHD showed deficits in total output speed. However, only boys showed a clear neuropsychological distinction between subtypes in the area of motor inhibition, which was more deficient in children with ADHD- Combined Type.

Young et al. (2006) found that adults with ADHD gave more incorrect responses on all three of the conditions of the Stroop Color and Word Test than did adults without ADHD. Additionally, adults with ADHD had overall slower completion times for all portions of the Stroop Color and Word test. These findings indicate that individuals with ADHD have more difficulty with accuracy and speed in processing both simple and complex verbal information.

A meta-analysis of studies using the Stroop Color-Word Test to examine frontal lobe function impairment in children with ADHD and other developmental disorders revealed that overall, children with ADHD consistently demonstrated poorer performance on all aspects of the Stroop Color-Word Test as compared to children without a clinical diagnosis, but was not accurate at differentiating between children with ADHD and children with other neurodevelopmental disorders (Homack & Riccio, 2004). While the Stroop Color-Word test is beneficial for finding frontal lobe impairment, it is not sufficient to diagnose ADHD independent of other measures.

Rucklidge and Tannock (2002) examined 108 adolescents between the ages of 13 and 16. Participants either had a Reading Disorder (RD) diagnosis, ADHD (ADHD) diagnosis, comorbid RD/ADHD, or no diagnosis. Study participants were administered a number of instruments, including the WISC-III and Stroop Color and Word Test. This study found the color/word naming task of the Stroop Color and Word Test to be one of the best predictors of the predominately hyperactive/impulsive subtype of ADHD, and the Processing Speed Index to be one of the best predictors of predominately inattentive subtype of ADHD. No gender differences were observed within the ADHD groups, indicating that females are just as impaired in processing speed and inhibition as males, contrary to popular opinion.

In a study that examined the two parts of the Trail Making Test, forty college students were given variations of Part A and Part B to determine why participants expressed more difficulty with Part B of the test (Gaudino, Geisler, & Squires, 1995).

The researchers concluded that Part B primarily measured the participants' ability to create, modify and execute a cognitive plan, a more complex mental task than Part A required. This makes the Trail Making Test, specifically Part B a useful diagnostic instrument for assessing the planning abilities of a child suspected of having ADHD. Barkley, Grodzinsky and DuPaul (1992) found the Trail Making Test to be useful for differentiating ADHD children from non-ADHD children. However, Barkley and Grodzinsky (1994) reported a false negative ADHD classification rate of 80-82%, with an overall accuracy rate of 54%, and caution against using the Trail Making Test as a diagnostic tool for diagnosing ADHD in children.

In an attempt to differentiate between ADHD subtypes using a standardized battery of cognitive tests, a group of researchers gave the computerized IntegNeuro battery to 72 adolescents with ADHD- Combined Type, 58 adolescents with ADHD- Inattentive Type, and 130 adolescents without ADHD (Clarke et al., 2007). The IntegNeuro measures skills in the areas of sensory-motor, attention, executive function, language and memory. Results indicated that adolescents with ADHD- Combined Type were more likely to show increased errors on response-inhibition tasks and selective attention tasks, indicating that the IntegNeuro battery was able to differentiate subtypes of ADHD in adolescents.

Models of Attention

There are many models of attention exist in the study of attention and ADHD. Three of the most prominent are Barkley's executive dysfunction model, Mirsky's model of attention, and Cohen's model of attention. No one model is accepted as the authoritative model of attention, though some aspects within each model do overlap.

Barkley's executive dysfunction model (Barkley, 1997) is a hybrid model showing the relationship of executive functions and four functions of behavioral inhibition and motor control. Behavioral inhibition is defined as stopping the initial response to an event, interrupting an ongoing response pattern, and exhibiting interference control when faced with competing attentional demands. Behavioral inhibition sets the stage for the four executive functions (nonverbal working memory, verbal working memory, self-regulation of affect, motivation and arousal, and reconstitution) and protects from the interference of these executive functions. Self-regulation is the key component to Barkley's model of executive dysfunction. The combined purpose of the four executive functions is to internalize behavior to foresee change and future events. Nonverbal working memory is the capacity to mentally maintain information that enables self-regulation of behavior. That is, being able to mentally represent the behavior, the response and the consequences of such a response. Verbal working memory represents the ability to privately speak to oneself to describe and reflect on a situation, engage in self-questioning and problem solving, instruct oneself about rule-governed behaviors, generate meta-rules, and engage in moral reasoning. Self-regulation of affect, motivation and arousal is the ability to change or delay an emotional response, take an objective or social perspective of an event, and the regulation of motivation and arousal levels in response to events or circumstances.

Finally, reconstitution is the analysis and synthesis of behavior, verbal and behavioral fluency, creativity in defining rules, and creativity and diversity of behavior in a goal-directed manner. Reconstitution can be either verbal or nonverbal. Behavioral inhibition paired with the four executive functions leads to motor control and behavioral responding. Children and adults who show behavioral inhibition and good executive functioning skills display self-discipline, willpower, drive, and purposeful goal-directed behavior. ADHD children have fundamental deficits in behavioral inhibition and/or one or more of the executive functions that leads to deficits in motor and behavioral control.

Cohen's (1993) model of attention includes four components thought to comprise attention: sensory selection, response selection, capacity/focus, and sustained attention. Sensory selection is the discrimination between what is necessary and what is simply background noise. In order to engage in sensory selection, one must simultaneously filter cognitive stimuli, enhance salient sensory input, and automatically shift to allow attention to go to a new stimulus. The inferior parietal lobes are thought to be elemental in sensory selection, and the frontal cortex is thought to be primarily responsible for the shifting within sensory selection (Lockwood et al., 2001). Response selection is the active selection and/or inhibition of responses (Cohen, 1993). This process involves initiation of a response, generation of possible responses, inhibition of inappropriate responses, and active switching between responses. The prefrontal cortex, especially the orbital frontal region, is influential in response initiation and inhibition. The third component of Cohen's model of attention, capacity/focus, refers to the actual attentional capacity and ability to focus on a specific stimulus. Capacity/focus includes such elements as arousal, motivation, and effort, and is influenced by factors such as processing speed, and working memory. The frontal cortex, limbic systems and parietal lobes play an important role in capacity/focus. The final component, sustained attention, references the maintenance of attention over time, and is influenced by fatigue and vigilance. Motivation and reinforcement also play an important role in sustained attention. Sustained attention is thought to be controlled primarily through the right frontal cortex, as well as the right parietal lobe and locus ceruleus to a lesser degree.

Perhaps the most widely recognized model of attention, Mirsky's model of attention (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991) incorporates four aspects of attention he identified as encode or select, focus or execute, sustain, and shift. Encode or select is the ability to store and mentally manipulate information in one's mind. Focus or execute is the ability to focus on a stimulus and act quickly. Sustaining attention is maintaining focus for a length of time on a stimulus. Shifting ones attention is being able to shift attention from one stimulus to another, which signifies cognitive flexibility.

Attentional Impairment Index

Based on the Mirsky model of attention and similar to the Halstead Impairment Index (Reitan & Wolfson, 1985), the Attentional Impairment Index (AI) was developed in 1997 by Taylor and Miller as a diagnostic index that integrates scores from several neuropsychological instruments into a cumulative total impairment score that can be used to measure the degree of attentional processing deficits.

The Attentional Impairment Index was intended to be an experimental measure of both the presence of and severity of attention problems without consideration as to the type of attention each instrument measures. In the original study to develop the AI, 470 self-referred adults seeking diagnosis for possible ADHD were given the Trail Making Test, the Stroop Color and Word Test, the Wisconsin Card Sort Test, the Vocabulary and Block Design subtests from the Wechsler Adult Intelligence Scale- Revised, and the Minnesota Multiphasic Personality Inventory, Second Edition (MMPI-2), in addition to completing the Adult Behavior Checklist and/or Checklist for Differential Diagnosis of Attention Problems (CDDAP: Taylor, 1999). Scores from each of these measures were converted to points for poor performance, which were added together to devise the AI. The greater the score, the more severe the attentional deficits are likely to be. The original formula used to create the Attentional Impairment Index is as follows: "= (6 minus the number of WCST categories completed) + (number of failures to maintain the response set on the WCST) + a measure derived from the Stroop Interference score + a measure derived from the time required to complete the Trail Making Test- Part B" (Taylor & Miller, 1997, p. 80).

The study concluded with stating the Attentional Impairment Index was useful for differentiating between adults who met DSM-IV criteria for ADHD and those who did not, as well as for differentiating between those adults with ADHD- Predominately Inattentive and those with ADHD- Predominately Hyperactive/Impulsive Type.

In a study designed to examine the sensitivity of the Attentional Impairment Index (AI) in detecting attention difficulty in children with having one or more psychiatric diagnoses, Hill (1998) found that children with no psychiatric diagnoses scored better overall on the than did children with a diagnosis of ADHD or a diagnosis of ADHD and another comorbid psychiatric disorder. Children who participated in the study were between the ages of 7 and 16 years of age, and had a previous diagnosis of ADHD, depressive disorder or anxiety disorder. Participants were given four neuropsychological tasks, including the Stroop Color-Word Test, Wisconsin Card Sorting Test and the Trailmaking Test, Parts A and B. Attentional impairment was also found to be negatively correlated with age, with impairment becoming less severe as children age, regardless of what diagnosis the child is given.

Purpose of the Present Study

This study compared children diagnosed with ADHD Predominately Inattentive Type to children diagnosed with ADHD Combined Type and to children referred for evaluation, but not determined to meet diagnostic criteria for ADHD, on several neuropsychological measures of attentional abilities, as well as processing speed. In addition, this study examined the utility of a revised version of the Attentional Impairment Index for use in the diagnosis of ADHD in children and the differentiation of its subtype.

Hypotheses

1) It was hypothesized that the Processing Speed Index scores from the WISC-IV or WAIS-III would be significantly different in children diagnosed with ADHD as compared to those who did not meet diagnostic criteria for a diagnosis of ADHD. Participants diagnosed with ADHD-I were expected to have Processing Speed Index scores lower than those with ADHD-C. Furthermore, participants diagnosed with ADHD-I and ADHD-C were expected to have Processing Speed Index scores significantly lower than participants with no ADHD diagnosis.
2) It was hypothesized that the Working Memory Index scores from the WISC-IV or WAIS-III would be significantly different in children diagnosed with ADHD as compared to those who did not meet diagnostic criteria for a diagnosis of ADHD, though to a lesser degree than would the Processing Speed Index. Participants diagnosed with ADHD-I were expected to have Working Memory Index scores lower than those with ADHD-C. Furthermore, participants diagnosed with ADHD-I and ADHD-C were expected to have Working Memory Index scores significantly lower than participants who did not meet diagnostic criteria for a diagnosis of ADHD.
3) It was hypothesized that Stroop Color-Word Test, Trails A and B, and the Wisconsin Card Sort test scores would all be significantly lower in

participants diagnosed with either ADHD-I or ADHD-C than in participants who did not meet diagnostic criteria for a diagnosis of ADHD.

4) It was hypothesized that the Attentional Impairment Index would be significantly different in children diagnosed with ADHD as compared to those who did not meet diagnostic criteria for a diagnosis of ADHD, and that children with ADHD-I will show more overall attentional impairment as evidenced by a higher Attentional Impairment Index total score than will children with ADHD-C or those who did not meet diagnostic criteria for a diagnosis of ADHD.

CHAPTER III

METHODS

Participants

Participants in the current study were 283 children between the ages of 7 and 19 years of age. The participants were selected from an archival data sample of more than 300 participants collected by the ADD Treatment and Research Center in Dallas, Texas, based on age and diagnosis. Participants were excluded if WISC-IV or WAIS-III, Stroop Color-Word Test, Trail Making, and WCST scores were not available. Because the data was archival, there was no control over the ethnicity, gender, socioeconomic class or parent education levels. Participants were placed into one of three groups: those diagnosed with Attention Deficit Hyperactivity Disorder, Predominately Inattentive Type (ADHD-I), those diagnosed with Attention Deficit Hyperactivity Disorder, Combined Type (ADHD-C), and those who were referred for evaluation but who did not meet diagnostic criteria for Attention Deficit Hyperactivity Disorder (no ADHD diagnosis).

Materials

Materials used during the evaluation of participating children included a desk, two chairs, stopwatch, pencil, and the assessment instruments. Assessment Instruments consisted of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV;

Psychological Corporation, 2003) or Wechsler Adult Intelligence Scale (WAIS-III, Psychological Corporation, 1997), the Stroop Color-Word Test (Golden, 1978), the Trail Making Test (Reitan & Wolfson, 1985) and the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993).

Assessment Tools

The WISC-IV is a standardized, norm-referenced intelligence battery for children between the ages of 6-16:11 years (Maller & Thompson, 2005). The WISC-IV is individually administered, and typically requires 1 to 3 hours to complete, depending on the age and skill level of the child. This instrument was developed using a normative sample of 2,200 children with an ethnic diversity matching March 2000 U.S. Census data (Niolon, 2005). Test-retest reliability was established by testing a group of 243 children two times within a one month period, and was found to be between .76 and .80.

The WAIS-III is a standardized, norm-referenced intelligence battery for adults between the ages of 16-89 years. The WAIS-III is individually administered, and typically requires 1 to 2 hours to complete, depending on the age and skill level of the individual. This instrument was developed using a normative sample of 2,450 adults, with stratification of the normative sample matched to the US Census population with regards to ethnicity, age, gender, educational level and geographic region (Zhu & Weiss, 2005).

Standard administration of both the WISC-IV and WAIS-III produces four index scores: Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing

Speed; as well as a Full Scale Intelligence Quotient. The Verbal Comprehension Index is comprised of Similarities, Vocabulary, Comprehension, Information and Word Reasoning. This index measures a person's acquired knowledge and ability to communicate such knowledge verbally. The Perceptual Reasoning Index consists of Block Design, Picture Concepts, Matrix Reasoning, and Picture Completion. This index measures visual perception, organization, problem solving, and reasoning using non-verbal stimuli.

The Working Memory Index is comprised of Digit Span, Letter-Number Sequencing and Arithmetic. This index required the participant to temporarily hold verbally presented information in the memory while simultaneously manipulating it. Digit Span involved presenting an increasingly long string of numbers aloud and asking the participant to repeat the numbers as they were presented in the first trial, and in reverse order in the second trial. On the Letter-Number Sequencing task, participants were presented with an increasingly long string of letters and numbers in random order, and asked to repeat the numbers first in numerical order, followed by the letters in alphabetical order. The Arithmetic subtest required participants to solve word problems within a specified amount of time without using paper and pencil.

The Processing Speed Index is made up of Coding, Symbol Search and Cancellation. Coding required participants to fill in a grid of symbols using the code legend found at the top of the page. Each symbol corresponds to a number from 1 to 9. Participants were given 2 minutes to complete the task. The Symbol Search task required participants under the age of 8 to quickly scan a row of three symbols to see if one target symbol was contained in the row, and required participants between 8 and 16 years of age to scan a row of five symbols to see if one symbol from a pair of target symbols was found within the row. Participants were given 2 minutes to complete the task. In the first trial of the Cancellation subtest, participants were presented with an array of multicolored animal and non-animal symbols arranged in a random fashion. Participants were given 45 seconds to mark as many animal symbols as possible. After the first trial was complete, the participant was presented with the same task with the symbols arranged in straight rows and again given 45 seconds to mark as many animals as possible.

The WISC-IV or WAIS-III, depending on the age of the participant, was used to determine the Processing Speed Index and Working Memory Index of each participant, and to explore the Processing Speed Index and Working Memory Index subtest scores among children with ADHD Predominately Inattentive Type, ADHD Combined Type, and those without an ADHD diagnosis.

The overall internal-consistency reliability coefficients for the Wechsler scales were found to be in the .90s (Zhu & Weiss, 2005). Numerous studies have provided evidence as to the validity of the WISC-IV. Correlations between the Wechsler scales and other scales of intelligence fall between .79 and .91. Finally, the technical manual of the WISC-IV provides evidence for favorable predictive validity in that correlations between Full Scale IQ and academic achievement generally fell between .65 and .75 (Wechsler, 2003).

The Stroop Color-Word Test is a neuropsychological test of attention and inhibition for children and adults aged 5 years and older (Roybal & Soares, 2007). Participants were first shown a list of color words printed in black and white, and asked to read as much of the list as quickly and accurately as possible in 45 seconds. Next, the participant was shown a list of semantically irrelevant stimuli (XXX) printed in red, blue, or green, and was asked to again name as many colors from the list as quickly and accurately as possible in 45 seconds. Finally, the participant was shown a list of color words printed in a discrepant color, and was once again asked to name as many of the colors from the list as quickly and as accurately as possible in 45 seconds, while disregarding the words that are printed. The Stroop Color-Word Test was used in the current version of the Attentional Impairment Index as an indicator of the child's inhibition skills. Test-retest reliability for the Stroop Color-Word Test was established by administering the instrument to 30 participants at intervals ranging from one minute to ten days. Test-retest coefficients were found to be within .73 and .86 (Golden, 1978).

The Trail Making Test from the Halstead-Reitan Neuropsychological Test Battery consists of two parts, A and B, in which the participant connects either numbered circles in order, or 25 numbered or alphabetic circles in alternating order between number and letter. The Trail-Making Test is a measure of motor-speed, visual scanning ability, visual-motor integration, cognitive flexibility and the ability to integrate alphabetic and numeric systems mentally (Dean & Meier, 1985). Scores obtained from the Trail Making Test include time in seconds for Trails A and Trails B, and number of errors made on each.

The Trail Making Test was used in the current version of the Attentional Impairment Index as an indicator of the child's visual-motor integration and cognitive flexibility. The Trail Making Test was standardized and validated as part of the Halstead-Reitan Neuropsychological Test Battery using over 8,000 patients with brain lesions and without. The Halstead-Reitan battery is perhaps the most widely researched neuropsychological battery used in the United States. The Trail Making Test has shown over and over its validity as a general measure of brain functioning. (Reitan & Wolfson, 2004). Because repeated administration to the same participant is common, establishing reliability for the Trail Making Test is difficult. However, when the variability of performance on multiple administrations to the same participant is reduced, interrater reliability is high (Fals-Stewart, 1992). The normative data from Spreen and Gaddes (1969) was utilized for children between 8 and 15 years of age, and normative data from Elias, Robbins, Walter, and Schultz (1993) was utilized for adolescents older than 15 years of age.

The Wisconsin Card Sorting Test is one of the most frequently used measures of frontal lobe dysfunction in adults and children (Grant & Berg, 1948). Designed as a measure of abstract reasoning and ability to shift problem solving strategies in response to feedback, the Wisconsin Card Sorting Test is a valuable indicator of cognitive flexibility and focused attention (Clark, 2001). Children with ADHD frequently perform poorly on the Wisconsin Card Sorting Test (Roman, 2001). The examiner presents the participant with a series of cards with a varying number of differently colored shapes and asks him or her to categorize the cards based on a rule that only the examiner knows. The participant is given immediate feedback as to whether the categorization is correct or wrong. The rule changes at set intervals that only the examiner knows. Although eleven scores are obtained from this instrument, only categories completed and failure to maintain the response set will be utilized in the analysis of the Attentional Impairment Index in the current study, as these scores were used in the original Attentional Impairment Index study (Taylor & Miller, 1997). The Wisconsin Card Sort Test was originally standardized on a normative sample of 899 mostly Caucasian participants between the ages of 6.5 and 89 years. Inter-rater reliability was found to be between .88 and .93, while intra-rater reliability was found to be between .91 and .96. Numerous validity studies were reported in the manual providing evidence for the use of the Wisconsin Card Sort Test in assessing the executive functions of children and adults with a wide variety of neurological and psychological conditions including ADHD. (Elaine, 2001)

Hypotheses

1) It was hypothesized that the Processing Speed Index scores from the WISC-IV or WAIS-III would be significantly different in children diagnosed with ADHD as compared to those without a diagnosis of ADHD. Participants diagnosed with ADHD-I were expected to have Processing Speed Index scores lower than those with ADHD-C. Furthermore, participants diagnosed

with ADHD-I and ADHD-C were expected to have Processing Speed Index scores significantly lower than participants with no ADHD diagnosis.

2) It was hypothesized that the Working Memory Index scores from the WISC-IV or WAIS-III would be significantly different in children diagnosed with ADHD as compared to those without a diagnosis of ADHD, though to a lesser degree than would the Processing Speed Index. Participants diagnosed with ADHD-I were expected to have Working Memory Index scores lower than those with ADHD-C. Furthermore, participants diagnosed with ADHD-I and ADHD-C were expected to have Working Memory Index scores significantly lower than participants with no ADHD diagnosis.
3) It was hypothesized that Stroop Color-Word Test, Trails A and B, and the Wisconsin Card Sort test scores would all be significantly lower in participants diagnosed with either ADHD-I or ADHD-C than in participants with no ADHD diagnosis.

The objective of the current study was to revise the Attentional Impairment Index (Taylor & Miller, 1997) for use as a diagnostic index of ADHD symptomology in children. The Attentional Impairment Index used in the current study included processing speed as an indicator of ADHD symptoms in children. The formula for deriving the Attentional Impairment Index quotient was changed to the following in order to include processing speed:

AI = (6 minus the number of WCST categories completed) + number of failures to maintain the response set on the WCST + (the Stroop Expected Color Word score minus the actual Stroop Color Word score; then calculated as a difference of 0-4 = 0, a difference of 5-9 = 1, and a difference of 10 or more = 2) + (the difference between the age-normative time to complete the Trail Making Test- Part B minus the time the participant actually took to complete the Trail Making Test- Part B; calculated as within one standard deviation of the normative mean = 0, between one and two standard deviations = 1, and three or more standard deviations from the normative mean = 2) + (10 minus the standard scores for the WISC-IV Processing Speed Index subtests, or zero if negative).

4) It was hypothesized that the Attentional Impairment Index would be significantly different in children diagnosed with ADHD as compared to those without a diagnosis of ADHD, and that children with ADHD-I will show more overall attentional impairment as evidenced by a higher Attentional Impairment Index total score than will children with ADHD-C or no ADHD diagnosis.

CHAPTER IV

RESULTS

Descriptive Statistics

Included below are the results of statistical analyses for the current investigation. The participants in this study included 283 individuals (176 males and 107 females), of which 107 had a diagnosis of ADHD-Predominately Inattentive Type, 106 had a diagnosis of ADHD-Combined Type, and 70 who were referred for evaluation for attention difficulties, learning disabilities (LD), or social-emotional concerns, but were not given a diagnosis of ADHD, and served as the control group. The gender of participants in each group is presented in Table 1. The diagnostic information for the control group participants is presented in Table 2.

Table 1

Gender Distribution for Group Participants

Type	Gender		Total
	Male	Female	
ADHD Inattentive	66	41	107
ADHD Combined	76	30	106
No ADHD	34	36	70
Total	176	107	283

Table 2

Diagnostic Information for Control Group Participants

Diagnosis	Number
Sub-clinical symptoms of ADHD	14
Depression	6
Anxiety	4
Mixed Anxiety and Depression	6
LD Reading	4
LD Written Expression	3
LD Mathematics	1
LD Reading and Written Expression	6
LD Written Expression and Math	1
LD Math and Mixed Anxiety and Depression	1
LD Written Expression and Sub-clinical ADHD	1
LD Written Expression and Obsessive-Compulsive Disorder	1
LD Written Expression and Mixed Anxiety and Depression	1
LD Written Expression and Depression	1
LD Written Expression and Adjustment Disorder	1
LD Written Expression and Oral Expression, and Anxiety	1

Diagnostic Information for Control Group Participants (continued)

Diagnosis	Number
Diabetic (low blood sugar causing inattention)	1
Encopresis	1
No diagnosis	16
Total	*70*

Examination of Hypotheses

Hypothesis One

The first analysis was performed to test the null hypothesis that the Processing Speed Index from the WISC-IV or WAIS-III would serve as a significant predictor of ADHD in children and adolescents. It was further hypothesized that participants diagnosed with ADHD-I would have Processing Speed Index scores lower than those with ADHD-C, and that participants diagnosed with ADHD-I and ADHD-C would have Processing Speed Index scores significantly lower than participants with no ADHD diagnosis. The means and standard deviations for each group on each Processing Speed Index score can be seen in Table 3. A multivariate analysis of variance (MANOVA) was conducted to see if there were differences between Processing Speed Index scores among diagnostic groups. An alpha of .05 was selected as the level of significance. No significant differences were found, Wilk's $\Lambda = .97$, $F(4, 264) = 2.169$, $p = .071$,

$eta^2 = .016$, indicating that the Processing Speed Index is not a significant indicator of ADHD subtype in children.

Table 3

Processing Speed Means and Standard Deviations for ADHD Group

	Type	Mean	Standard Deviation	N
Coding	ADHD-I	8.41	2.43	101
	ADHD-C	8.96	2.72	103
	No ADHD	9.42	2.67	65
Symbol Search	ADHD-I	9.20	2.28	101
	ADHD-C	9.92	2.50	103
	No ADHD	9.80	2.69	65

Hypothesis Two

It was hypothesized that the Working Memory Index from the WISC-IV or WAIS-III would serve as a predictor of ADHD in children and adolescents, though to a lesser degree than would the Processing Speed Index. Participants diagnosed with ADHD-I were expected to have Working Memory Index scores lower than those with ADHD-C, and those participants diagnosed with ADHD-I and ADHD-C were expected to have Working Memory Index scores significantly lower than participants with no ADHD diagnosis. The means and standard deviations for each group on each Working Memory Index score can be seen in Table 4. A multivariate analysis of variance

(MANOVA) was conducted to see if there were differences between Working Memory Index scores among diagnostic groups. An alpha of .05 was selected as the level of significance. No significant differences were found, Wilk's $\Lambda = .975$, $F(4, 49) = 1.71$, $p = .146$, $\text{eta}^2 = .013$, indicating that the Working Memory Index is not a significant indicator of ADHD subtype in children.

Table 4

Working Memory Means and Standard Deviations for ADHD Group

	Type	Mean	Standard Deviation	N
Digit Span	ADHD-I	9.49	2.79	103
	ADHD-C	9.13	2.45	103
	No ADHD	9.11	2.54	65
Letter Number Sequencing	ADHD-I	10.14	2.62	102
	ADHD-C	9.99	2.19	103
	No ADHD	10.67	2.30	66

Hypothesis Three

It was hypothesized that Stroop Color-Word Test, Trails B, and the Wisconsin Card Sort test scores would all be significantly lower in participants diagnosed with either ADHD-I or ADHD-C than in participants with no ADHD diagnosis. The means and standard deviations for each group can be seen in Table 5.

A multivariate analysis of variance (MANOVA) was conducted to see if there were differences between the Stroop Color-Word Test, Trails B, and the Wisconsin Card Sort test scores among diagnostic groups. An alpha of .05 was selected as the level of significance. A significant difference was found, Wilk's $\Lambda = .813$, $F(10, 272) = 2.349$, $p < .05$, $eta^2 = .099$. The null hypothesis was rejected. The means for each group were significantly different for Fail to Maintain errors on the Wisconsin Card Sort Test, $F(2, 91) = 4.708$, $p < .05$, $eta^2 = .096$.

Hypothesis Four

It was hypothesized that the Attentional Impairment Index would be a significant predictor of ADHD subtype in children, and that children with ADHD-I would show more overall attentional impairment as evidenced by a higher Attentional Impairment Index total score than will children with ADHD-C or no ADHD diagnosis. A one way analysis of variance (ANOVA) was conducted to see if there were differences between the Attentional Impairment Index score among diagnostic groups. An alpha of .05 was selected as the level of significance. There was no significant difference found among diagnostic groups, $F(2, 89) = 1.287$, $p = .281$. The means and standard deviations of the Attentional Impairment Index for each group can be seen in Table 6.

Table 5

Stroop Color-Word Test, Trails B, and the Wisconsin Card Sort Test Means and Standard Deviations for ADHD Group

	Type	Mean Categories	Standard Deviation	N
WCST Categories	ADHD-I	5.39	1.04	54
	ADHD-C	4.70	1.92	20
	No ADHD	5.39	1.24	18
	Type	Mean No. of Fail to Maintain	Standard Deviation	N
WCST Fail to Maintain	ADHD-I	1.70	1.38	54
	ADHD-C	1.65	1.87	20
	No ADHD	0.56	0.71	18
	Type	Mean Words Read	Standard Deviation	N
Stroop Interference	ADHD-I	30.44	8.50	54
	ADHD-C	28.65	7.86	20
	No ADHD	35.17	9.17	18
	Type	Mean Completion Time	Standard Deviation	N
Trails B Time	ADHD-I	41.86	23.92	52
	ADHD-C	42.63	23.99	20
	No ADHD	40.17	21.51	18

Table 6

Means and Standard Deviations for AI Index, with ADHD Subtypes

	Type	Mean	Standard Deviation	N
AI Index Score	ADHD-I	5.98	4.23	54
	ADHD-C	7.35	5.65	20
	No ADHD	4.94	4.73	18

An ANOVA was also conducted to see if there were differences between the Attentional Impairment Index score when comparing all of those participants with a diagnosis of ADHD (including both ADHD-I and ADHD-C) and those participants without a diagnosis of ADHD. An alpha of .05 was selected as the level of significance. There was no significant difference found among diagnostic groups, $F(2, 89) = 1.313$, $p = .255$. The means and standard deviations of the Attentional Impairment Index for each group can be seen in Table 7.

Table 7

Means and Standard Deviations for AI Index, without Subtypes

	Type	Mean	Standard Deviation	N
AI Index Score	ADHD	6.35	4.66	74
	No ADHD	4.94	4.73	18

An ANOVA was also conducted to see if there were differences between the Attentional Impairment Index score when comparing only those participants with a diagnosis of ADHD-I to those with a diagnosis of ADHD-C. An alpha of .05 was selected as the level of significance. There was no significant difference found among diagnostic groups, $F(2, 89) = 1.265$, $p = .264$. The means and standard deviations of the Attentional Impairment Index for each group can be seen in Table 8.

Table 8

Means and Standard Deviations for AI Index, ADHD Groups

	Type	Mean	Standard Deviation	N
AI Index Score	ADHD-I	5.98	4.23	54
	ADHD-C	7.35	5.65	20

CHAPTER V

DISCUSSION

The behavioral and cognitive symptomology that children with Attention Deficit Hyperactivity Disorder (ADHD) typically show can have a widespread impact on their overall functioning in everyday life. Children with ADHD often show the need for special education services in order to succeed in the school environment, and often have difficulty in the home environment as well. Is has been estimated that ADHD affects between 4,234,000 and 4,602,000 children in the United States (Visser & Lesesne, 2005).

Purpose of the Study

The purpose of this study was to compare children diagnosed with ADHD Predominately Inattentive Type to children diagnosed with ADHD Combined Type and to children without a diagnosis of ADHD on several neuropsychological measures of attentional abilities as well as processing speed. In addition, this study examined the utility of a revised version of the Attentional Impairment Index (AI) for use in the diagnosis of ADHD in children and the differentiation of its subtype. Furthermore, the impact of processing speed and working memory as indicators of ADHD subtype was studied. Various neuropsychological instruments were utilized to examine the neuropsychological implications of ADHD in children.

Study participants were selected from an archival data sample collected by the ADD Treatment and Research Center in Dallas, Texas, based on age and diagnosis. Assessment Instruments consisted of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Psychological Corporation, 2003) or Wechsler Adult Intelligence Scale (WAIS-III, Psychological Corporation, 1997), the Stroop Color-Word Test (Golden, 1978), the Trail Making Test (Reitan & Wolfson, 1985), and the Wisconsin Card Sorting Test (WCST; Heaton, Chelune, Talley, Kay, & Curtiss, 1993).

Review and Discussion of Study Findings

The current study examined three hypotheses which looked at differences among processing speed, working memory, and neuropsychological assessment scores in children diagnosed with either ADHD-I, ADHD-C or those children with no ADHD diagnosis. Additionally, the study examined a fourth hypothesis that a revised version of the Attentional Impairment Index (AI) would serve as a significant predictor of ADHD subtype in children. No significant differences were found between the processing speed index or working memory index scores of children with ADHD-I, ADHD-C or children with no ADHD diagnosis. However, this study found a significant difference between children without a diagnosis of ADHD and children with either a diagnosis of ADHD-I or ADHD-C, in that children without a diagnosis of ADHD performed better on the Stroop Color-Word Test, Trails A and B, and the Wisconsin Card Sort test than did the children with ADHD. Finally, the Attentional Impairment Index did not serve as a significant predictor of ADHD subtype in children.

Processing Speed

The lack of statistically significant differences between the processing speed index scores found in this study contradicts previous research (Calhoun & Mayes, 2005; Rucklidge, 2006; Sergeant, 1988) which showed that children with ADHD have significantly slower processing speeds than do children without ADHD. Examination of the means and standard deviations for the subtest scores that comprise the Processing Speed Index show that the mean score for children with ADHD-I is lower than the mean score for ADHD-C, and that the mean score for children with no ADHD is higher than both groups of children with ADHD.

Working Memory

The lack of statistically significant differences between the working memory index scores found in this study contradicts some previous research (Castellanos et al., 2006; Engelhardt et al., 2008; Randall et al., 2008) which showed that children with ADHD have significantly poorer working memory abilities than do children without ADHD. However, the findings of the present study are in line with other research (Brocki et al., 2007; Karatekin, 2004; Schweitzer et al., 2006) which found no difference between the working memory abilities of children with ADHD and without.

Neuropsychological Assessment

A significant difference was found between the Stroop Color-Word Test interference score, Trails B, and the Wisconsin Card Sort test performance of children with either ADHD-I or ADHD-C and children without a diagnosis of ADHD. These findings indicate that neuropsychological assessment of children suspected of having ADHD may be able to distinguish between children with ADHD and those without ADHD when using an instrument battery comprised of the Stroop Color-Word Test, Trails A and B, and the Wisconsin Card Sort test.

Research supports the use of the Stroop Color-Word Test, Trails A and B, and the Wisconsin Card Sort test to differentiate between children with and without ADHD (Barkley et al., 1992; Gaudino et al., 1995; Gorenstein et al., 1989; Greve et al., 1996; Nigg et al., 2002; Romine et al., 2004; Rucklidge & Tannock, 2002; Solanto et al., 2007; Young et al., 2006;). While previous studies have examined the use of the instruments either independently or with other instruments not used in the present study, this study examined the instruments together as a neuropsychological battery. This exact combination of tests is not found in the current literature, except as part of the Attentional Impairment Index (Taylor & Miller, 1997), which is not a diagnostic instrument, but rather a measure of ADHD's impact on attention.

Attentional Impairment Index

The lack of statistically significant differences between the Attentional Impairment Index scores found in this study contradicts previous research which suggests that the Attentional Impairment Index is useful for differentiating between adults who met DSM-IV criteria for ADHD and those who did not (Taylor & Miller, 1997), though their study was examining the Attentional Impairment Index of adults, not children as in the current study. One previous study (Hill, 1998) has examined the Attentional

Impairment Index in children, but studied the Attentional Impairment Index of children with other psychiatric diagnoses and ADHD, and did not specifically look at the differences between those children diagnosed with ADHD as compared to children with no diagnosis.

Limitations

The present study is limited due to the lack of random selection of participants and lack of random assignment for the diagnostic groups. The sample was obtained from archival data collected by the ADHD Treatment and Research Center in Dallas, Texas. Random sampling is ideal, as it affords the opportunity for all members of a given population to be selected, thus enabling the study sample to accurately represent the true population. Because the current study did not utilize random sampling, the results may not be generalizable outside of the study sample to the larger ADHD population.

Additionally, because all participants for the current study were evaluated at the ADHD Treatment and Research Center, it is likely that even the control group of participants without an ADHD diagnosis may have shown mild attentional difficulties or other difficulties that lead to the initial referral for evaluation. Given that every participant was seeking evaluation for either attention, learning or mental health reasons, the study findings may not truly represent what they would have been if a control group of non-referred participants had been utilized.

Another potential limitation is the method by which attentional abilities were measured with the battery of neuropsychological instruments that were chosen. The

Wisconsin Card Sorting Test is routinely administered at the ADHD Treatment and Research Center only to clients ages 8 and up, despite the normative sample which included children as young as 6.5 years old. Because of this, the Attentional Impairment Index was only able to be applied to children ages 8 or older. The findings may have been different if children between 6.5 and 8 were included, as attentional abilities were found to be negatively correlated with age, with attentional impairment becoming less severe with age, regardless of psychiatric diagnosis, including ADHD (Hill, 1998).

Recommendations for Further Research

More research is needed in the area of differentiating subtypes of ADHD using standardized evaluation instruments. The majority of ADHD diagnoses are made quite subjectively, based solely on parent interviews by physicians and psychiatrists using a checklist of symptoms. What one parent may perceive as significantly impacting a child's functioning may be interpreted differently by another parent, and may lead to differing diagnoses of the same behavior. The American Academy of Pediatrics recommends that a child suspected of having ADHD should undergo a thorough evaluation which should include a comprehensive medical and family history, medical examination, neurological examination, parent, child and teacher interviews, observations of the child, standardized screening tools for ADHD, and a psychological examination which should include intellectual, achievement and social-emotional assessment (American Academy of Pediatrics, 2001). Until a battery of assessments is found that reliably and consistently differentiates between those children who warrant a diagnosis of ADHD and those who do not, as well as differentiates between subtypes of ADHD, the diagnostic process will continue to be driven by subjective reports of caregivers combined with symptom endorsement on standardized ADHD rating scales.

Future studies should aim to include a sample of children diagnosed with ADHD Predominately Hyperactive/Impulsive Type. Though less common, it still accounts for a substantial portion of all ADHD diagnoses. The current study excluded the

Predominately Hyperactive/Impulsive subtype due to the relatively few cases available in the archival data sample. A future study that included all three subtypes of ADHD would be more generalizeable to the true population.

In addition, future research that took into account the affects of gender on the diagnosis and differentiation of ADHD subtype would be beneficial. While ADHD is more commonly diagnosed in males (APA, 2000), females are impacted by the manifestations of ADHD with just as severe consequences. The neuropsychological profiles of males may vary from that of females, and may even suggest the need for a different evaluation protocol in males versus females. A study that examined the affects of gender on the diagnosis and subtype of ADHD could lead to a better understanding of the cognitive and behavioral sequelae unique to each gender.

Conclusions

The results of the current study add to the current knowledge base by providing evidence that the neuropsychological profile of children diagnosed with ADHD differs from that of children without a diagnosis of ADHD, and that the profiles of children diagnosed with ADHD-I differs from that of children diagnosed with ADHD-C. The current study demonstrated that the battery of assessment instruments used has the potential to differentiate between ADHD subtypes in an objective way, as opposed to the rather subjective method of diagnosis currently in use. Additional research is needed to provide the statistical significance needed to confirm the utility of such a battery for diagnostic purposes. Overall, the current study provides evidence that the objective diagnosis of ADHD using standardized neuropsychological instruments is possible, and that differentiation of ADHD subtype based on neuropsychological profile shows promise for the future.

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APPENDIX A

Institutional Review Board Approval

TWU
TEXAS WOMAN'S UNIVERSITY
DENTON DALLAS HOUSTON

Institutional Review Board
Office of Research and Sponsored Programs
P.O. Box 425619, Denton, TX 76204-5619
940-898-3378 Fax 940-898-3416
e-mail: IRB@twu.edu

March 10, 2009

Ms. Crystal Beadle

Dear Ms. Beadle:

Re: *Attentional Impairment and Processing Speed in Children Diagnosed with Attention Deficit Hyperactivity Disorder*

The above referenced study has been reviewed by the TWU Institutional Review Board (IRB) and was determined to be exempt from further review.

If applicable, agency approval letters must be submitted to the IRB upon receipt PRIOR to any data collection at that agency. Because a signed consent form is not required for exempt studies, the filing of signatures of participants with the TWU IRB is not necessary.

Another review by the IRB is required if your project changes in any way, and the IRB must be notified immediately regarding any adverse events. If you have any questions, feel free to call the TWU Institutional Review Board.

Sincerely,

Dr. David Nichols, Chair
Institutional Review Board - Denton

cc. Dr. Dan Miller, Department of Psychology & Philosophy
Graduate School