

COMPUTERIZED SCREENING IN ADOLESCENTS AND YOUNG ADULTS WITH
ADHD

by

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Abstract

This study examined the sensitivity of a computerized neuropsychological screening battery (ImPACT) to the cognitive effects of ADHD in a sample of 68 young adults with ADHD and 68 healthy students matched for age, education, gender, and history of head injury. Students with ADHD self-reported more cognitive difficulties on the Post-Concussion Scale of ImPACT ($p < .005$, $d = .68$, medium-large effect size), and performed more poorly on the Memory Composite ($p < .005$, $d = .50$, medium effect size). The two groups did not differ significantly on the Processing Speed Composite or the Impulse Control Composite. There was a nonsignificant trend for the individuals with ADHD to display slower reaction times ($p < .076$, $d = .33$, small effect size). This is the second study using ImPACT in ADHD research. The brevity and sensitivity of ImPACT to the cognitive effects of ADHD warrants further research with this population.

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Introduction

Attention deficit hyperactivity disorder (ADHD) is recognized as a serious neurobehavioral disorder that arises in early childhood and is prevalent throughout the lifespan (American Psychiatric Association, 2000; Barkley, 1997; Culbertson & Krull, 1996; Epstein, Johnson, Varia, & Conners, 2001). Neuropsychological problems in children with ADHD have been well documented (e.g., Halperin et al., 1990; Konrad, Gauggel, Manz, & Scholl, 2000; Kupietz, 1990; Loge, Staton, & Beatty, 1990; Seidel & Joschko, 1990; van der Meere & Sergeant, 1988). In the past, the disorder was thought to subside in adolescence (Culbertson & Krull, 1996; Johnson et al., 2001), and as a result the neuropsychological deficits associated with ADHD in adults are less well documented.

Adults with ADHD have been shown to perform significantly more poorly on a variety of cognitive tests measuring attention, memory, reaction time, processing speed, set shifting (i.e., the ability to shift from one cognitive task to another), inhibition, and problem solving (Epstein et al., 2001; Murphy, Barkley, & Bush, 2001; Murphy, 2002b; Seidman, Biederman, Weber, Hatch, & Faraone, 1998; Walker, Shores, Trollor, Lee, & Sachdev, 2000; Woods, Lovejoy, Stutts, Ball, & Fals-Stewart, 2002). However, these studies have been criticized for their lack of consistency in differentiating adults and adolescents with ADHD from controls (Corbett & Stanczak, 1999; Kovner et al., 1998; Murphy, 2002a; Schmitz et al., 2002; Seidman, Biederman, Faraone, Weber, & Ouellette, 1997). As a result, the existing literature examining cognitive functioning in young adults with ADHD is not conclusive, and further research with more refined measures of cognitive functioning is needed.

Woods, Lovejoy, and Ball (2002) suggest that the use of new neuropsychological assessment tools incorporating multiple cognitive constructs that assess a broad array of

attentional and executive functions is needed. Many of these tests measure the frontal-subcortical circuit dysfunction proposed to underlie ADHD (Faraone & Biederman, 1998). Implementing these measures in ADHD research may advance the understanding of the neurocognitive deficits associated with ADHD in adults.

The present thesis builds upon previous research on adults with ADHD by utilizing a new assessment tool called ImPACT (Immediate Post-Concussion Assessment and Cognitive Testing; Lovell et al., 2003; Maroon et al., 2000) in a young adult ADHD sample. ImPACT is a computerized, self-administered, 25-minute neuropsychological test battery composed of seven individual test modules that are used to measure five aspects of cognitive functioning: attention, memory, reaction time, processing speed, and impulse control. The purpose of this study is to examine the sensitivity of this computerized neuropsychological screening battery for distinguishing the cognitive effects of ADHD in young adults from the performance of non-ADHD controls. Specifically, the present study compares young adults with an ADHD diagnosis (as determined by self-report) to non-ADHD controls matched for education, gender, and history of head injury, to determine whether or not there are cognitive differences between the two groups in terms of their memory, reaction time, processing speed, and impulse control. ImPACT also includes a symptom questionnaire. Of additional interest is whether or not there are differences in self-reported cognitive difficulties, such as perceived concentration and memory functioning, between the ADHD sample and the matched non-ADHD controls. If ImPACT proves sensitive to cognitive problems associated with ADHD in young adults, it might be a useful measure in research and clinical practice due to its ease and rapidity of administration. It might also be useful as a primary outcome variable in the evaluation of the efficacy of pharmacological interventions on cognitive symptoms associated with ADHD.

Literature Review

Overview of Attention Deficit Hyperactivity Disorder

Attention Deficit Hyperactivity Disorder (ADHD) is the one of the most common emotional, cognitive, and behavioral disorders diagnosed and treated in youth. ADHD affects approximately 3-5% of school age children with a male: female gender ratio of 3:1 (American Psychiatric Association, 2000; Barkley, 1997; Culbertson & Krull, 1996; Schachar, Mota, Logan, Tannock, & Klim, 2000; Wilens, Biederman, & Spencer, 2002).

The disorder emerged in the early 1900's medical literature, with researchers describing aggressive and defiant children as having poor volitional inhibition and defective moral regulation of behavior (Barkley, 1997). Under the diagnostic term hyperkinetic reaction of childhood, it first appeared in the second edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM; American Psychiatric Association, 1968), referring to excessive activity as the primary symptom (Culbertson & Krull, 1996). In the early 1970's, Douglas (1972; as cited in Schachar et al., 2000) provided a model that proposed attention deficit, rather than excessive activity, was the main feature of the disorder. This model guided future research and led to the term attention deficit disorder, which appeared in the DSM-III (American Psychiatric Association, 1980) reflecting an attention deficit, rather than excessive activity, as the main feature of the disorder.

By the 1980's there was a movement towards distinguishing a hyperactivity component, and the term attention deficit hyperactivity disorder emerged as a separate disorder from ADD. This was adopted in the DSM-III-R (American Psychiatric Association, 1987). In both the DSM-IV and DSM-IV-TR (American Psychiatric Association, 1994, 2000) ADHD is divided

into three primary subtypes: predominantly inattentive type, predominantly hyperactive-impulsive type, and combined type.

ADHD is characterized by age-inappropriate levels of inattention, with or without impulsivity, and overactivity that occurs across settings and causes functional impairment.

ADHD begins in childhood, and 50-70% of childhood cases persist into adulthood (Murphy & Schachar, 2000; Wilens et al., 2002). Although the observable symptoms can change in quality and quantity over time, most individuals with ADHD continue to experience some symptoms as adults (Mercugliano, 1999). Adolescents and adults with ADHD are at a higher risk for academic problems, poor peer and family relations, anxiety and depression, aggression, conduct problems, delinquency, early substance abuse, driving accidents, and unemployment (Barkley, 1997; Gallagher & Blader, 2001; Schmitz et al., 2002). As a result, ADHD is considered a major clinical and public health problem, due to its associated morbidity and disability in individuals across all ages (Wilens et al., 2002).

The majority of researchers and clinicians agree that the primary disturbance of ADHD results via poor control over executive functions, with at least some of these executive functions linked to the frontal and sub-cortical regions of the brain (Faraone & Biederman, 1998; Gallagher & Blader, 2001; Royall et al., 2002). However, evidence to support this view has been somewhat mixed, and it is not yet clear which aspects of cognitive functioning reliably distinguish people with ADHD from those without. According to Barkley (1997), the primary behavioral characteristics of ADHD are age-inappropriate levels of inattention, impulsivity, and hyperactivity. These problems are considered to reflect difficulty with the management and executive control of behavior. Deficits in attention are not considered the result of an inability to attend, but rather a problem in the executive tasks of organising

attention (i.e., sustaining attention on stimuli and shifting attention). Similarly, impulsivity is not defined as a failure to control one's actions. Rather, it is a difficulty with deciding when actions should be taken, and controlling the impact and order of those actions. Lastly, hyperactivity is not seen as a result of overactivity, but as a disturbance in the executive task of controlling the appropriate situational level of arousal and activity (Gallagher & Blader, 2001).

Using neuropsychological testing in children with ADHD, researchers have identified reduced performance in attention, inhibition, and executive functions compared to non-ADHD controls (Benezra & Douglas, 1988; Douglas & Parry, 1983; Pineda et al., 1998; Schachar et al., 2000; Seidel & Joschko, 1990). Despite these findings, the role of neuropsychological testing in children remains controversial. This is due to the inconsistent findings across neuropsychological measures, and concerns regarding inadequate positive and negative predictive power of the cognitive measures. These may be partially attributable to methodological limitations of the studies (Kempton et al., 1999). In addition, childhood ADHD might be characterized by more overt behavioral characteristics (i.e., hyperactivity), rather than cognitive deficits in attention and executive functioning. The behavioral symptoms of ADHD subside as children mature, and signs of excessive gross motor activity are less common in early adolescence (American Psychiatric Association, 2000). Researchers believe that adults are more likely to exhibit cognitive deficits in attention and inhibition than the behavioral deficits that characterize children with ADHD (Barkley, 1997; Woods, Lovejoy, & Ball, 2002). However, the potential cognitive differences between children with ADHD and adults with ADHD have not yet been established, due to the limited research in this area.

Preliminary research suggests that young adults and adults with ADHD have deficits compared to non-ADHD controls on measures of attention, memory, reaction time, processing

speed, inhibition, problem solving, and set shifting (Epstein et al., 2001; Murphy et al., 2001; Murphy, 2002b; Seidman et al., 1998; Walker et al., 2000; Woods, Lovejoy, Stutts et al., 2002). However, similar to the children's literature, these results are not consistent across tests and studies. Moreover, controversy still exists regarding the validity of ADHD as a disorder of adulthood due to the lack of a reliable set of diagnostic criteria, and the few neuropsychological tests that can clearly differentiate the putative cognitive deficits associated with the condition (Johnson et al., 2001).

According to DSM-IV-TR (American Psychiatric Association, 2000), an individual must have had symptoms of ADHD that date back to childhood. For an adult that was not diagnosed with ADHD as a child it is not always possible to obtain this information from multiple raters or sources. As a result, the clinician or researcher must often rely on an individual's self-report of their symptoms. Further, the age-of-onset criterion of the disorder requires that symptoms be apparent prior to the age of seven. An adult's ability to validly self-report past symptoms necessary to retrospectively diagnose the condition has been constantly debated in the literature (Applegate et al., 1997; Barkley & Biederman, 1997; Levin, 1998; Mota & Schachar, 2001). Murphy and Schachar (2000) explain that researchers and clinicians are often forced to rely on an individual's account of current and childhood symptom because it is often impractical or impossible to obtain this information from a former teacher, parent, or current employer.

To advance research on young adults with ADHD it is necessary to determine if they can accurately self-report past and current symptoms. Moreover, according to Woods, Lovejoy, and Ball (2002), new neuropsychological assessment techniques that include a comprehensive

battery approach (e.g., assess multiple constructs at one time) are needed to better characterize the cognitive deficits in adults with ADHD.

Neuropsychological Functioning in Adolescents and Adults with ADHD

Of primary interest to the present study is the role of neuropsychological tests in the identification of adolescents and adults with ADHD. Surprisingly few studies to date have examined whether neuropsychological tests of particular cognitive abilities can consistently differentiate adults with ADHD from those without the disorder. A review of studies designed specifically to examine the neurocognitive functioning of adolescents and adults with ADHD is provided in Table 1. The purpose of the review is to provide the reader with an overview of the current state of this literature in terms of the varied measures, diagnostic criteria, and sample selections. Due to the limited literature available in this area, all studies pertaining to this area were included. Studies were not excluded based on possible methodological weaknesses, including small sample sizes, or the use of tests with limited psychometric properties. These findings are reviewed according to the neuropsychological tests (rather than the study) and the cognitive areas measured.

Most of these studies focus on attention and executive functions because much of the current research is based on the conceptualization of ADHD as a frontal-subcortical disorder (Barkley, 1997; Faraone & Biederman, 1998; Gallagher & Blader, 2001; Johnson et al., 2001; Mercugliano, 1999). The emerging neuroimaging literature suggests the presence of abnormalities in frontal networks as shown by positron emission tomography brain imaging in adults with ADHD (Wilens et al., 2002).

However, empirical support for the precise neural pathways associated with ADHD remains elusive. Hence, the nature of the proposed connection between frontal lobe function

and actual cognitive task performance in ADHD is not yet supported by consistent data, as stated earlier in the review. Given the recency of this area of inquiry, it is not surprising that many researchers are considering many different indices of cognitive performance that (they hope or hypothesize) are loosely linked to the broad construct called “executive functioning.”

Table 1

Summary of Studies Reporting on the Neuropsychological Performance of ADHD Adults

Study	Participants (Sex, age range)	Diagnostic criteria (Medication use, subtypes of ADHD indicated; use of subtypes in analysis)	Design and grouping procedures (Using IQ as a covariate)	Measures	Major Findings
Murphy (2002a)	18 ADHD 18 Controls (Males, aged 27-58 years)	DSM-IV semi- structured interview (Medication: not indicated, subtypes not indicated)	IQ not significant between groups.	SSRT; GSRT	Adults with ADHD performed significantly more poorly than controls on tasks of inhibitory control. However the results were not significant between the two groups on a reaction time test.
Murphy (2002b)	18 ADHD 18 Controls (Males, aged 27-58 years)	DSM-IV semi- structured interview (Medication: not indicated, subtypes not indicated)	IQ not significant between groups.	BVRT; TOH; TMT- A&B	Adults with ADHD performed significantly more poorly than the control group on tests of executive control (i.e., TOH, and TMT- B).
Johnson et al. (2001)	56 ADHD 38 NC (71% males, aged 20-63 years)	DSM-IV Semi- structured interview (Medication: subjects were washed out, subtypes identified but not used in analysis)	Age was used as a covariate, IQ not significant between groups. (IQ was used as a covariate in a secondary analysis).	WMS-R; COWA; Stroop; WCST; TMT-A & TMT-B; RTT	Adults with ADHD showed deficits relative to controls on tasks of memory, selective attention, visuomotor tracking, and reaction time. Using IQ as a covariate showed no significant differences between groups.

Study	Participants	Diagnostic Criteria	Design and grouping criteria	Measures	Major findings
Walker et al. (2000)	30 ADHD 30 Controls 30 Psychiatric (Sex mixed, aged 17-50 years)	DSM-IV criteria (Medication: subjects were not on any, subtypes not identified)	Age was used as a covariate, IQ not significant between groups.	COWA; CPT; Stroop; TMT; WAIS-R subtests	Compared to healthy controls, adults with ADHD scored significantly more poorly on the dependent measures. However, no significant differences on any task were identified between adults with ADHD and those with a psychiatric disorder.
Seidman et al. (1998)	64 ADHD 73 Controls (Sex mixed, aged 19-59 years)	DSM-III criteria, and self-report of childhood symptoms (Medication: subjects were not on any, subtypes not identified)	Age was used as a covariate, IQ not significant between groups.	WAIS-FD; CVLT; Stroop; WCST; CPT; ROCF	Significant differences were found between the adults with ADHD and control subjects on reaction time and verbal learning tasks. The groups did not differ on any traditional measures of executive functioning.
Epstein et al. (2001)	25 ADHD 15 Controls 15 Psychiatric (Sex mixed, aged 18-65 years)	Computer interview-self report of symptoms (Medication: subjects were not on any, subtypes were not identified)	Gender, age, and education were not different between any groups. IQ was not measured.	CPT; PVOT; SST	Adults with ADHD demonstrated significantly poorer performance on measures of response inhibition (e.g., reaction time) as compared to normal controls and individuals with anxiety disorders.
Epstein et al. (1998)	60 ADHD 72 Controls (Sex mixed, mean age 25 & 35 years)	Semi-structured interview (Medication: not reported, subtypes identified and used in analysis)	Age was used as a covariate, IQ was not examined.	CPT	Adults with ADHD performed significantly more poorly on all CPT indices (i.e., omission, commission, and reaction time scores) compared to normal controls. No significant differences between the ADHD subtypes were found. Diagnostic classification results for the CPT were moderate.

Study	Participants	Diagnostic Criteria	Design and grouping procedures	Measures	Major Findings
Murphy et al. (2001)	105 ADHD 65 Controls Sex mixed, aged 17-28 years)	Structured interview, (Medication ceased 24 hours prior to testing, subtypes identified and used in analysis)	Groups did not differ on age or sex. IQ scores were significant on the KBIT. (IQ and gender were used as covariates in a secondary analysis)	CPT; Stroop; WAIS-III Digit Span & Digit Symbol; COWA	After controlling for IQ significant between group differences were found in areas of attention, nonverbal working memory, interference control, and verbal fluency. Women with ADHD scored significantly higher than men on one measure (digit symbol subtest). No significant differences between the ADHD subtypes were found.
Corbett & Stanczak (1999)	27 ADHD 10 Controls (Sex mixed, aged 18-72 years)	Semi-structured interview, (Medication: subjects were asked to refrain on day of testing, subtypes not identified)	No difference between groups on gender and age. IQ was not examined.	Stroop; TOAD	Significant differences between the adults with ADHD and normal controls were found on the dependent measures. The Goldman-Fristoe-Woodcock Test of Auditory Discrimination (TOAD) showed high specificity and predictive power in discriminating adults with ADHD from controls. This test appears to be a measure of distractibility and behavioral disinhibition.
Woods, Lovejoy, Stutts et al. (2002)	26 ADHD 26 NC (Sex mixed, aged 21-55 years)	DSM-IV criteria from normative database, (Medication: Subjects were not on any, subtypes identified)	No group differences between groups on gender, age, or education. (IQ was used in analysis)	COWA; CVLT; Stroop; TMT; WAIS-R FD	Significant group differences between adults with ADHD and normal controls were found using a discrepancy analysis between intelligence and executive function. The diagnostic accuracy was moderate for the individual tests.
Kovner et al. (1998)	19 ADHD 10 Psychiatric (Sex mixed, aged 18-57 years)	Structured interview (Medication: Subjects were not on any, subtypes were identified but not used in the analysis)	No group differences were found on age, education, or intelligence. (IQ was not examined)	WAIS-R; Benton; Boston Naming Test; CPT; SST; WMRT	Adults with ADHD scored significantly lower than a psychiatric group on a measure of simple attention (WAIS-R Digit Span subtest) and the reaction time component of the Shifting Sets Test (SST). Group classification rates between the psychiatric group, and the ADHD group, were adequate.

Study	Participants	Diagnostic criteria	Design and grouping procedures	Measures	Major Findings
Nigg et al. (2002)	22 ADHD 21 Controls (Sex mixed; mean age was 23 and 21 years for the two groups)	Previous diagnoses by psychiatrist and self-report of symptoms. (Medication: Subjects were not on any, subtypes identified but not used in analysis)	The groups were not significantly different on age, gender, or IQ.	Anticascade task; Negative Priming Task	Young adults with ADHD had significantly more difficulty with effortful motor inhibition on a computer task than the control group
Fischer et al. (1990)	100 ADHD 60 Controls (Males, aged 12-20 years)	Structured clinical interview. (Medication discontinued prior to testing, subtypes not identified)	Age was used as a covariate. The groups were not significantly different on IQ.	Stroop Test; WCST; CPT; ROCF	Young adults with ADHD showed no significant differences from healthy controls on any of the dependent measures.
Schmitz et al. (2002)	30 ADHD 60 Controls (Sex mixed, aged 12-16 years)	Structured clinical interview (Medication: some subjects were taking medication, subtypes were identified and used in analysis)	The groups were not significantly different on any demographic variables. (No effect of sex or IQ was found in any measure).	WCST; Stroop; Digit Span.	The authors examined effects of the three subtypes of ADHD. Adolescents with predominantly inattentive and combined subtypes performed more poorly on tasks of attention and psychomotor speed. Adolescents with predominantly hyperactive-impulsive type did not differ from the control group on any of the measures. These findings moderately support the diagnostic distinction among the ADHD subtypes proposed in the DSM-IV.
Seidman et al. (1997)	118 ADHD 99 Controls (Males, aged 9-22 years)	Structured clinical interview (Medication: 80% of ADHD group on medication. No significant differences between medicated and non-medicated groups, subtypes not identified)	The groups were significantly different on age and IQ. (IQ was purposefully not controlled for).	WCST; ROCF; Stroop test; CPT; CVLT	Young adults with ADHD performed significantly more poorly on tasks of visual memory, problem solving, and set shifting. No significant differences were found between the two groups on tasks of attention and reaction time (CPT), or on a verbal list learning task (CVLT).

Study	Participants	Diagnostic Criteria	Design and grouping procedures	Measures	Major Findings
Stearns et al., (2004)	70 ADHD (Sex mixed, mean age= 25 years)	Structured interview, (21.1% taking medication, subtypes not identified)	Sample did not differ on age, sex, or education. IQ scores were not significantly different between sample (i.e., sex, or those on medication).	WAIS-III; WMS-III (Working Memory Indices); Brown ADD Scales	In a group of adults with ADHD no significant relationship was found between working memory and self-reported symptoms. Moreover, no significant effects were found for gender or those taking stimulant medications.

Note: ADHD= Attention Deficit Hyperactivity Disorder group. SSRT = Stop Signal Reaction Time Test; GSRT = Go Signal Reaction Time; BVRT; Benton Test of Visual Recognition; TOH= Tower of Hanoi; Stroop = Stroop Test Color Word Task; WCST= Wisconsin Card Sorting Test; TMT = Trail Making Test; RTT = Reaction Time Test; COWA= Controlled Oral Word Association; WMS-R = Wechsler Memory Scale-Revised; CPT = Continuous Performance Test; WAIS-R = Wechsler Adult Intelligence Scale; WRAT=Wide Range Achievement Test; CVLT = California Verbal Learning Test; ROCF = Rey-Osterrieth Complex Figure; PVOT=Posner Visual Orientating Task; TOAD = Goldman-Fristoe-Woodcock Test of Auditory Discrimination; WMRT = Warrington Recognition Memory Test.

A general profile of poor performance on tests of frontal/executive function is evident in adults with ADHD (Epstein et al., 2001; Johnson et al., 2001; Murphy, 2002a, 2002b; Woods, Lovejoy, & Ball, 2002). However, as shown in the reviewed studies (Table 1) adults with ADHD do not perform consistently more poorly than healthy controls across studies, nor do they consistently perform more poorly on specific measures (Fischer et al., 1990; Kovner et al., 1998; Seidman et al., 1998).

Alexander and Stuss (2000) argue that the lack of discriminant validity (i.e., differentiating ADHD from healthy controls; differentiating clinical subtypes of ADHD; differentiating ADHD from other disorders) on specific measures may be due to the fact that individual neuropsychological tests (e.g., CPT, WCST) assess too many dimensions of executive functioning. As a result, they are not always helpful in discriminating neurocognitive problems associated with ADHD, where primary involvement is thought to reside with frontal subcortical systems. Future research needs to incorporate new assessment techniques to help characterize the cognitive deficits of adults with ADHD (Alexander & Stuss, 2000; Barkley, 1997; Johnson et al., 2001; Schmitz et al., 2002; Seidman et al., 1998). Moreover, implementing a battery approach utilizing multiple neuropsychological tests has been shown to improve the discriminant validity in this population (e.g., Woods, Lovejoy, Stutts et al., 2002).

Numerous methodological limitations are inherent in the ADHD literature. Primarily, the lack of a reliable and valid method for diagnosing ADHD in adults is a major problem. In the reviewed studies, researchers often relied on only one diagnostic indicator (e.g., self-report in a clinical interview) with no cross-validation of symptoms from multiple settings (Epstein et al., 1998; Epstein et al., 2001; Murphy, 2002a, 2002b; Nigg et al., 2002).

Murphy and Schachar (2000) explored the use of self-ratings in the assessment of symptoms of ADHD in adults (ranging from 20 to 50 years of age) in two studies. The first study examined the validity of childhood recollections of ADHD behavior by having the individual with ADHD and a parent or spouse fill out similar rating scales. The second study followed a similar methodology but examined an individual's ability to self-report current symptoms of ADHD. Correlations between the self-reports of over 2100 individuals with ADHD, and their partners or spouses, were calculated. Results from both studies revealed significant similarity between ratings, and the authors concluded that adults with ADHD can provide reliable self-reports of past and present ADHD symptoms (Murphy & Schachar, 2000).

The use of small sample sizes was a weakness in many of the studies reviewed in Table 1. Most studies had no more than 20 participants in the ADHD or control group (e.g., Corbett & Stanczak, 1999; Kovner et al., 1998; Murphy, 2002a, 2002b; Schmitz et al., 2002) resulting in low statistical power and increasing the probability of type II errors. Moreover, many researchers did not provide effect sizes or other indices of diagnostic efficiency (e.g., Fischer et al., 1990; Schmitz et al., 2002; Seidman et al., 1998), leaving specific interpretation of the findings uncertain, and decreasing the clinical utility of the results (Woods, Lovejoy, & Ball, 2002).

The age ranges of the samples were often large, with participants ranging in age from 18-72 years of age (Corbett & Stanczak, 1999; Kovner et al., 1998; Murphy, 2002a, 2002b; Seidman et al., 1998; Walker et al., 2000; Woods, Lovejoy, Stutts et al., 2002). Thus, the potential effects of developmental changes that occur across the lifespan, and potential age-related declines in executive functions, were not controlled for.

Numerous studies have examined the effects of age-related declines on healthy adults using measures of executive and other cognitive functions. The prefrontal cortex (i.e., the primary region examined by tests of executive function) has been found to be the most vulnerable area to aging compared to other areas of the brain, and age-related declines are thought to begin in early adulthood (Salthouse, 2003). However, most of the ADHD research to date is cross sectional, and longitudinal data is needed to examine the precise relationship between aging and its effects on cognitive tests in the ADHD population.

Many of the reviewed studies had stringent inclusion criteria and controlled for factors known to affect cognitive performance (i.e., comorbid disorders such as depression or anxiety, and medication use). However, some studies did not (e.g., Epstein et al., 1998). Although individuals with ADHD often reported higher levels of depression than controls (Seidman et al., 1998; Walker et al., 2000), it is often difficult to distinguish individuals with ADHD from those with a psychiatric disorder (e.g., anxiety disorder) on neuropsychological tests. From the studies reviewed, only three examined psychiatric groups compared to individuals with ADHD (Epstein et al., 2001; Kovner et al., 1998; Walker et al., 2000), and only one study (Kovner et al., 1998) reported differences between individuals with ADHD and a psychiatric sample. Differentiation of ADHD from commonly comorbid disorders (i.e., depression, anxiety, substance abuse) is cited as a weakness of the literature (Woods, Lovejoy, & Ball, 2002). Future research needs to examine the ability of tests to discriminate ADHD from other comorbid conditions.

The use of stimulant medications is generally found to increase the cognitive performance of individuals with ADHD (Schmitz et al., 2002). In the study for this thesis, the use of medication could not be controlled for. However, two studies reviewed examined this

issue (Seidman et al., 1997; Stearns et al., 2004) and found no significant differences on cognitive performance between medicated and unmedicated participants with ADHD, although differences were found in Schmitz et al. (2002).

In the children's ADHD literature, executive function deficits have been examined more thoroughly in males than in females (Carte, Nigg, & Hinshaw, 1996; Nigg, Hinshaw, Carte, & Treuting, 1998). Some researchers suggest that girls with ADHD display greater cognitive impairment, while boys with ADHD display more obvious behavioral impairments (Gaub & Carlson, 1997). However, Halperin et al. (1990) found no cognitive differences between boys and girls with ADHD. In the adult ADHD literature, potential sex differences have received little attention, and some studies include only male participants (Fischer et al., 1990; Murphy, 2002a, 2002b; Seidman et al., 1997). Other studies included both sexes (Kovner et al., 1998; Murphy et al., 2001; Woods, Lovejoy, Stutts et al., 2002), but only analyzed whether the ratio of males to females in the ADHD group differed from the sex ratio in the control group. However, these studies did not examine whether or not there were performance differences on tests according to sex. However, Murphy et al., (2001) explored the potential cognitive differences between males and females with ADHD, and reported that women demonstrated higher scores than men on two measures: attention and working memory. In contrast, other studies (Schmitz et al., 2002; Seidman et al., 1998) found no significant sex differences in young adults with ADHD on multiple measures of cognitive functioning.

A long-standing debate in the literature is whether or not to separate adults with ADHD by DSM-IV-TR subtypes. Some researchers maintain that executive function deficits do not appear to be a function of ADHD subtype (Woods, Lovejoy, & Ball, 2002). Due to small sample sizes, the majority of reviewed studies did not partition their ADHD sample by subtype

(Epstein et al., 2001; Kovner et al., 1998; Nigg et al., 2002; Walker et al., 2000). Only three studies have identified subtypes of ADHD and included them in their analyses (Epstein et al., 1998; Murphy et al., 2001; Schmitz et al., 2002), and only one study of the three found cognitive differences across the three DSM-IV-TR subtypes (Schmitz et al., 2002). Specifically, Schmitz et al. (2002) found that adolescents with predominantly inattentive and combined type performed more poorly on tasks of attention and psychomotor speed. Adolescents with the predominantly hyperactive-impulsive subtype did not differ from the control group on any measures. These findings appear to support the diagnostic distinction among the ADHD subtypes proposed in the DSM-IV that individuals with the hyperactive-impulsive subtype experience attentional deficits to a lesser degree than the other subtypes, and show the greatest decline in ADHD symptoms with age (Epstein et al., 1998; Schmitz et al., 2002). However, these results are very preliminary and run counter to the bulk of the literature to date. The present study did not partition the ADHD sample by ADHD subtype because this information was not available.

Accounting for the different results across studies is difficult due to methodological differences (i.e., sample sizes, age ranges, and inclusion criteria). Further, the disparity may relate to the differences in the measures and the constructs examined. However, these findings mirror results in the pediatric literature that, thus far, have not consistently identified different cognitive profiles among the ADHD subtypes (Barkley, Grodzinsky, & DuPaul, 1992; Carlson, Lahey, & Neeper, 1986; Trommer, Hoeppner, Lorber, & Armstrong, 1988). Future research with larger numbers of participants and more stringent inclusion criteria is needed to determine whether or not there are cognitive differences on tests of executive functions among the ADHD subtypes. The total number of tests across studies that have reported significant and non-

significant group differences between adults with ADHD, non-ADHD controls, and psychiatric groups is reported in Table 2.

Table 2

Number of Studies Reporting Significant differences between Adults with ADHD, non-ADHD controls, and patients with psychiatric disorders, on commonly administered neuropsychological tests

Measure	Non-ADHD Controls		Psychiatric Group	
	Yes	No	Yes	No
Attention/Executive Function Tests				
Continuous Performance Test (CPT)	7	3	0	2
Wisconsin Card Sorting Test (WCST)	1	4	0	1
Stroop Test	6	3	0	1
Trail Making Test- A (TMT-A)	2	2	0	1
Trail Making Test- B (TMT-B)	3	1	0	1
Language Skill Tests				
Word Fluency: COWAT	3	1	0	1
Learning/Memory Tests				
California-Verbal Learning Test (CVLT)	2	2	0	0
Rey Complex Figure Test (RCFT)	1	2	0	0
WMS-R Logical Memory	2	0	0	1
WMS-R Visual Reproduction	1	0	0	1
Intelligence Tests				
WAIS-R Full Scale IQ*	2	5	0	0
WISC-III & WAIS-R Digit Span	3	0	0	0
WISC-III & WAIS FD/Digit Symbol	3	1	0	1

Note: Yes = significant differences between adults with ADHD and comparison group/psychiatric group; No = No significant differences between adults with ADHD and comparison/psychiatric group; ADHD = Attention Deficit Hyperactivity Disorder group. WMS-R = Wechsler Memory Scale-Revised; WAIS-R = Wechsler Adult Intelligence Scale-Revised; WISC-III = Wechsler Intelligence Scale for Children- Third edition; COWAT = Controlled Oral Word Association Test.

Summary of Results for Specific Neuropsychological Tests

As can be seen in Table 2, the results from the studies are highly variable. However, most studies (although not all) have demonstrated significant differences between young adults with ADHD and healthy controls. The individual tests and subsequent results presented in Table 2 are discussed in detail below.

Tests of Attention/Executive Functions. Barkley (1997) defines executive functions as a variety of higher-order cognitive skills that assist with the self-regulation of behavior. However, others have proposed different definitions, and a precise standardized operational definition has yet to be agreed upon in the literature. The term executive functions seems to incorporate planning or any goal-directed action, including persistence toward achieving a goal, inhibition (i.e., one's ability to resist a response or behavior), problem solving and strategy development, including monitoring, flexibility, and self-awareness across time (Barkley, 2000). These activities are underpinned by many lower order cognitive operations, with working memory being one of the most important processes (Spree & Strauss, 1998). It is important to note that impairment of executive functions such as planning, flexibility, and judgment can be present with any major change in intellectual functioning (Lezak, 1995). Following this approach, many researchers' working definition of executive functions includes the following components: working memory, response inhibition, planning, cognitive flexibility, and concept formation (Royall et al., 2002). The cognitive tasks that measure these executive functions are typically components of large neuropsychological batteries, made up of many different tests, which include tests of frontal or executive functioning, and tests of other cognitive abilities (e.g., language and memory).

The Continuous Performance Test (CPT) is the most commonly used test for assessing attention deficits in ADHD (Woods, Lovejoy, & Ball, 2002). The CPT is a computerized test of attention, impulsivity, and vigilance. It involves discriminating between visually presented target and non-target stimuli (Spree & Strauss, 1998). The task requires an individual to rapidly press a computer space bar or click a mouse button to letters presented in sequence in the center of the screen. In the standard condition, the examinee is required to press the space bar (mouse click) for every letter presented except the letter "X." The test takes 14 minutes to complete. The omission errors (number of targets the person did not respond to), commission errors (number of times the person responded to a non-target "X"), incidental reaction time (mean response time), and variability of reaction time (consistency of response time) are calculated (McGee, Clark, & Symons, 2000). Low to moderate correlations are reported between the CPT and other measures of attention. However, the precise cognitive processes assessed by the CPT are unclear. The general consensus (Halperin, Sharma, Greenblatt, & Schwartz, 1991; as cited in Spree & Strauss, 1998) is that omission errors reflect difficulties with sustained attention, while commission errors reflect problems with impulsivity, attention, and memory.

The CPT normative data is most representative of males (75.4% in sample) between 6 and 30 years of age (only one-fifth of the sample was over eighteen years of age). The usefulness of the CPT as a measure that can distinguish children with ADHD from controls has been demonstrated consistently in the literature (Barkley, DuPaul, & McMurray, 1990; Halperin et al., 1990; Halperin et al., 1991). However, the measure has not been demonstrated to discriminate children with ADHD from other clinical groups (Barkley et al., 1990).

A more mixed pattern of results using the CPT is found in the adult ADHD literature. Kovner et al. (1998) found no differences on CPT performance between adults with ADHD and a psychiatric control group. Further, the CPT did not discriminate between adults with ADHD and controls in terms of hit reaction time (Murphy et al., 2001). In contrast, two other studies comparing adults with ADHD to healthy controls found that the ADHD group made significantly more errors of commission and omission than the control group (Epstein et al., 1998; Walker et al., 2000). Still, the majority of studies have found significant differences between groups on the CPT (see Table 2).

The Wisconsin Card Sorting Test (WCST) assesses conceptualization and measures an individual's ability to problem-solve and/or shift cognitive strategies (Johnson et al., 2001). The task requires the examinee to sort a set of cards based upon three different criteria (i.e., color, form, and number). No instructions on the sorting criteria are given to the examinee. The examinee is instructed to match their cards, one at a time, with one of four "key cards." They are then only given feedback on a correct or incorrect placement, and are required to use that feedback to guide their future card placements to optimize correct responses. After correctly matching a card according to a matching stimulus (i.e., color) for 10 consecutive trials, the matching feature changes without warning (e.g., color to form), and the examinee must again discern the correct sorting criteria by the examiner's feedback (Lezak, 1995). This occurs six times (i.e., color, form, number, color, form, number), or until all 128 cards are administered.

Successful performance on the WCST requires that an individual determine the correct response for each set, maintain it, and then shift set (e.g., color to form) according to feedback (Romine et al., 2004). The problem-solving component involves the examinee considering a variety of hypotheses and maintaining or rejecting them according to the feedback they receive.

Performance is scored by *categories completed* (the number of correct matches completed in each category), *trials to complete first category* (the number of cards it takes to complete the first matching task), number of *failures to maintain set* (the number of times the examinee makes an incorrect category response more than four times in a row), and *percent preservative errors* (which reflects the amount of preservative errors as a percentage of overall test performance).

Normative data for the test are available for individuals 6 to 89 years of age (Spreen & Strauss, 1998). Age has the strongest demonstrated relationship to WCST performance. Performance increases are reported from ages 5 to 19 years; performance stability is noted for individuals aged 20-50 years; and declines in some aspects of performance are reported in individuals aged 60 years and above (Heaton, Chelune, Talley, Kay, & Curtis, 1993; as cited in Spreen & Strauss, 1998). The test's sensitivity and specificity as a measure of executive functioning has been demonstrated in numerous studies (Lezak, 1995).

Similar to the CPT, statistically significant differences on the WCST between children with ADHD and controls frequently are reported (Barkley et al., 1992; Schmitz et al., 2002). However, there has been little success using the WCST to discriminate children with ADHD from other clinical populations (Snow, 1998). With regard to the reviewed literature, only the studies that included adolescents and young adults with ADHD found significant differences compared to healthy controls (Schmitz et al., 2002; Seidman et al., 1997). Two other studies using older participants (aged 19-63) found no significant differences on the WCST compared to healthy controls (Johnson et al., 2001; Seidman et al., 1998). Moreover, similar to the difficulty discriminating children with ADHD from other clinical populations, Fischer et al. (1990) found no significant differences on the WCST between a group of adults with ADHD

and psychiatric controls. Taken together (see Table 2), the majority of studies fail to differentiate between adults with ADHD and controls using the WCST, especially in adulthood.

The Stroop Test is a classic test of reading fluency, visual attention, mental flexibility, and inhibitory control requiring participants to read lists of words and colors (Johnson et al., 2001). The first part of the task requires the examinee to read color names printed in black ink (e.g., red, green). The second part of the test requires the individual to name the colors that colored Xs, are printed in. In the last part of the task the individual is presented with color names that are now printed in different colored ink (e.g., the word “red” printed in blue ink), and they are required to disregard the word, and name the ink color. This requires the individual to inhibit the over-learned, automatic response of reading the stimulus word in order to respond to the more novel task of naming the color of the ink. For each part of the test, both the time to complete the test and the number of errors are recorded and scored. Having to inhibit the over-learned (prepotent) word reading response results in significantly slower performance than word reading or color naming alone. This decrement in performance has been labeled the Stroop “interference effect” (Spreeen & Strauss, 1998).

The construct validity of the Stroop test has been examined in adolescents with and without ADHD. MacLeod and Prior (1996) found significant correlations between Stroop interference and the Paced Auditory Serial Addition Task (a task requiring speeded processing, mental arithmetic, and the ability to divide attention), but not between the Stroop and a test purported to measure intelligence (Slossan Test of Intelligence). However, normative data for the Stroop test suggests that both age and intellectual levels are strong predictors of performance. Individuals aged 25-35 years of age have shown higher levels of performance on the first part of the task (reading the color names in black ink), and lower levels of performance

on the interference part of the task (naming the ink color). However, older participants, aged 70-80 years of age are relatively slow on the first part of the task, but relatively faster on the interference part of the task (Klein, Ponds, Houx, & Jolles, 1997, as cited in Spreen & Strauss, 1998).

The Stroop Test has been frequently used to differentiate between children with ADHD and healthy controls (Barkley et al., 1992; Loge et al., 1990; Pineda et al., 1998) and has been effective in discriminating ADHD and non ADHD individuals in the majority of studies conducted (see Table 2). However, similar to the previous reviewed tests of executive functioning (e.g., CPT, WCST), only the studies that included adolescents and young adults with ADHD found significant differences compared to healthy controls (Murphy et al., 2001; Schmitz et al., 2002; Seidman et al., 1997). Two other studies using older participants, up to sixty-three years of age, found no significant differences on the Stroop test compared to healthy controls (Johnson et al., 2001; Seidman et al., 1998).

The Trail Making Test (TMT) is a test of speed of visual scanning/attention, visuomotor speed, sequencing, and mental flexibility. The TMT has two parts. Part A requires the participant to draw lines in numerical sequence (1-25) connecting 25 circled numbers placed randomly on a page. Part B also requires the examinee to draw lines in a similar fashion, but with the addition of having to alternate between connecting numbers (i.e., 1-13) and letters (i.e., A-L) (i.e., connecting 1-A-2-B-3-C and so on). Part B is a more complex task than Part A because it requires divided attention, set shifting, and maintaining two different streams of information in working memory. Moreover, besides switching between numbers and letters in Part B, the actual distances between the circles are larger (Spreen & Strauss, 1998). Both Parts A and B are timed, and feedback is given to the examinee if an incorrect move is made (e.g.,

connecting out of sequence) and the participant is required to continue with the correct connection. The score reflects the time to completion in seconds (Johnson et al., 2001).

Normative data for the Trail Making test demonstrates that both parts of the test (A & B) are sensitive to age, education, and intelligence (Salthouse & Fristoe, 1995). However, Part B is more sensitive to age-related declines and differences in intelligence, which likely reflects the differing cognitive demands between the two tasks. The reported correlation between Part A and B is only .49 (less than 25% of the variance in performance), suggesting they are underpinned by substantially different cognitive functions (Heilbrunner, Henry, Buck, Adams, & Fogle, 1991; as cited in Spreen & Strauss, 1998).

Similar to the children's ADHD literature, studies comparing the performance of adults with ADHD to clinical or non-ADHD control samples show inconsistent results (Barkley et al., 1992). Specifically, two studies in the review demonstrated that adults with ADHD performed significantly more poorly than healthy controls on both Part A and Part B of the TMT (Murphy, 2002a; Woods, Lovejoy, Stutts et al., 2002). In contrast, Walker et al. (2000) found no difference on Parts A or B when they compared adults with ADHD to either healthy controls or a psychiatric group. Finally, Johnson et al. (2001) administered the TMT to adults with ADHD and non-ADHD controls and found that the ADHD group performed significantly more poorly on Part B, but not on Part A. The authors suggest the reason for this discrepancy was that Part B is a more complex task with far greater cognitive demands, and is therefore more sensitive to differences between adults with ADHD and healthy controls.

Language Skill Tests. Measures of verbal fluency require an individual to generate words associated with a certain letter (phonemic verbal fluency - e.g., g= golf, gift, great) or a certain category (semantic verbal fluency - e.g., animals = dog, horse, cat) in a fixed amount of

time (typically 60 seconds). Verbal fluency tests have shown mixed results in distinguishing children with ADHD from non-ADHD controls (e.g., Barkley et al., 1992). The results with adults have been mixed, too (see Table 2).

The Controlled Oral Word Association Test (COWAT) was the only test used to measure verbal fluency in the adult ADHD literature reviewed. Of the studies reviewed, three demonstrated significant differences in COWAT performance between adults with ADHD and non-ADHD controls (Murphy et al., 2001; Walker et al., 2000; Woods, Lovejoy, Stutts et al., 2002), and one study found no differences (Johnson et al., 2001). Significant differences in performance between adults with ADHD and non-ADHD controls on the COWAT are likely due to the identified deficits in the functioning of frontal systems in ADHD that are tapped by the COWAT's demands on sustained attention to stimuli, organization, and retrieval of verbal information (Woods, Lovejoy, & Ball, 2002). Similar to the poor discriminatory power of other tests of executive function in differentiating ADHD performance from the performance of psychiatric groups (e.g., WCST, Stroop test), Walker et al. (2000) reported that performance on the COWAT did not distinguish adults with ADHD from psychiatric controls. Thus, as suggested in Table 2, results of studies examining differences between ADHD and non ADHD individuals using the COWAT have yielded rather equivocal results, with some studies showing significant difference and some not.

Learning and Memory Tasks. Verbal list learning difficulties are commonly identified in adults with ADHD. As a result, list learning tests are the most widely used measures in studies of learning and memory in the ADHD population (Seidman et al., 1997; Seidman et al., 1998; Woods, Lovejoy, Stutts et al., 2002). The California Verbal Learning Tests (CVLT, CVLT-II, CVLT-C) are the most popular memory tests used with this population. The CVLT is

constructed to provide an assessment of the strategies and processes involved in learning and remembering verbal material. The 16 items included in the CVLT (e.g., items from a shopping list) are presented five times to the examinee. A distractor list is then administered once, after which short delay free and cued recall, long-delay free and cued recall, and recognition memory trials are administered (Woods, Lovejoy, Stutts et al., 2002).

Both Seidman et al. (1998) and Woods, Lovejoy, Stutts et al. (2002) reported that adults with ADHD performed significantly more poorly than non-ADHD controls on aspects of the CVLT, including the total words learned after five learning trials and in their use of semantic clustering. However, although they learned fewer words initially, they retained the same percentage of the total words they learned after a long delay. One possible interpretation for the above findings is that adults with ADHD lack the ability to discern and/or use the inherent semantic structure of the groups of words in the list (e.g., tools, articles of clothing) to aid in the organization of material to be learned (Woods, Lovejoy, & Ball, 2002). As a result, adults with ADHD appear to have deficits in the encoding of verbal information, but not with the storage or retrieval of the material. This profile of impairment is evident in the children's literature as well. The poor use of efficient semantic clustering learning strategies is proposed to reflect the frontal-subcortical impairment believed to underpin the deficits of individuals with ADHD (Woods, Lovejoy, & Ball, 2002).

This pattern of performance does not seem to be reflected in tests of visual learning and memory (Kovner et al., 1998; Murphy, 2002a). Only one of the reviewed studies, using the Visual Reproduction subtest of the WMS-R, found that adults with ADHD performed more poorly than a control group (Johnson et al., 2001). In contrast, other studies using different tests of visual memory (e.g., Benton Test, Rey-Osterrieth Complex Figure Test) did not find any

differences between adults with ADHD and non-ADHD controls (Kovner et al., 1998; Murphy, 2002a; Seidman et al., 1998). This may reflect the fact that visual tests, unlike the verbal list learning paradigm, do not appear to have an obvious advantageous learning strategy.

Tests of Intelligence. As illustrated in Table 2, tests of intelligence (IQ) have not been successful in discriminating between adults with ADHD and non-ADHD controls (Seidman et al., 1998; Walker et al., 2000). However, most of the studies used only estimates of intelligence based on either oral reading tests (e.g., Shipley test) or short-forms of intelligence tests (e.g., Kovner et al., 1998; Walker et al., 2000), thus reducing the possibility of finding differences. However, Murphy and colleagues (2001) found that, after controlling for IQ, differences found on tests of executive functioning between young adults with ADHD and non-ADHD controls did not retain their significance. Similarly, Woods et al. (2002) applied an alternative method of neuropsychological test interpretation by using an intra-individual discrepancy analysis. They examined the differences between adults with ADHD and non-ADHD controls in terms of their intellectual functioning and performance on a battery of six tests measuring executive functioning. Significant discrepancies between the adults with ADHD and non-ADHD controls were found between their IQ estimates and multiple tests of executive functioning.

The Freedom from Distractibility Index (i.e., Arithmetic and Digit Span subtests) from the WAIS-R and the WAIS-III has been used successfully to distinguish between adults with ADHD and non-ADHD controls (e.g., Kovner et al., 1998; Woods, Lovejoy, Stutts et al., 2002). Moreover, the Digit Symbol Subtest from the WAIS-R and the WAIS-III has also shown success in identifying differences in adult ADHD research (e.g., Murphy et al., 2001; Walker et al., 2000). However these findings are not consistent (e.g., Seidman et al., 1998).

The use of intellectual measures for identifying individuals with ADHD is a contentious issue (Woods, Lovejoy, & Ball, 2002). Many researchers question the utility of studies reporting significant differences on measures of intelligence due to the fact that many measures of IQ are composed of tasks that are sensitive to attentional deficits and executive functions. As a result, these findings could potentially be explained by impairments in attention, and or frontal/executive functions, rather than differences in IQ (Woods, Lovejoy, & Ball, 2002).

Summary

In summary, research has produced variable results in terms of the utility of neuropsychological measures for differentiating individuals with ADHD from non-ADHD controls. A detailed review of the literature indicates that the most success to date has been found in discriminating *children* with ADHD from healthy controls. Studies of adolescents and young adults are somewhat weaker, with the most variable findings reported in the adult ADHD literature. Even greater difficulty has been encountered when neuropsychological tests are used to discriminate persons with ADHD from other clinical populations such as psychiatric patients. This is likely a result of the overlapping deficits in attention and executive dysfunction, as is seen, for example, in schizophrenia, and the fact that the poorly defined construct of executive functioning reflects a number of higher-order cognitive abilities which are predicated on more basic cognitive functions such as attention and memory abilities. Further, the fact that the neuropsychological literature continues to reflect poor general agreement as to what abilities constitute the executive functions compounds the difficulty faced by researchers. Existing tests of executive functioning are often confounded to some degree by the need to assess the executive functions in association with tasks that utilize other non-executive cognitive abilities (for example, set shifting on the Trails B task is assessed via visual

scanning and graphomotor ability). Further, many of the tests used by researchers lack good psychometric data (Lezak, 1995). This is perhaps one of the most serious weaknesses in the rapidly growing field of clinical neuropsychology, and is also attributed to the lack of consensus on the definition of executive functions.

The literature also reflects a number of additional significant methodological limitations. Specifically, poor research design, small sample sizes (no more than 20 participants), poor control for medications, poor gender control, poor age control, lack of IQ control, and very limited investigation of the impact of the subtypes of ADHD on neuropsychological performance.

One trend that clearly emerges from the overall literature is that neuropsychological batteries composed of tests of a number of different cognitive abilities, with executive functioning components, appear to be more successful at discriminating the cognitive effects of ADHD from the performance of non-ADHD controls and of other clinical populations. However, battery approaches tend to be time consuming, expensive and burdensome, and as a result the cost-benefit ratio for large-scale screening and diagnosis of ADHD tends to be poor. Research in this area is ongoing, but there appears to be a clear need for a rapid, objective, and cost effective screening approach that can reliably identify the cognitive profile associated with ADHD from non-ADHD controls and other clinical populations.

Rationale for the Current Study

Due to the multiple cognitive deficits associated with ADHD, there is a need for tests that cover a broad array of attentional and executive functions. As many authors have identified, neuropsychological assessment in the adult ADHD population will be most useful when multiple cognitive constructs are assessed (Alexander & Stuss, 2000; Barkley, 1997;

Johnson et al., 2001; Schmitz et al., 2002; Seidman et al., 1998). Most neuropsychological tests require specialized training to administer and score, and can be very time consuming to administer. Computerized testing has a number of advantages over traditional pencil and paper tests, including greater reliability due to decreased variability in administration, and more precise response recording. Moreover, the administration of standardized examiner-administered neuropsychological tests requires a substantial amount of training. Disadvantages of computerized testing include the absence of behavioral observations (i.e., qualitative information) during the test process, and the poorly understood and investigated influence of using a computer interface and administration method on performance characteristics.

ImPACT, the test used for this study, is a 20-25 minute computerized battery that is sensitive to subtle cognitive problems, such as those associated with concussions in sports (Lovell et al., 2003; Lovell, Collins, Iverson, Johnston, & Bradley, 2004). If ImPACT could also be demonstrated to be sensitive to the problems associated with ADHD, it might be useful in clinical practice and research, and especially in clinical trials involving medications. Given its brevity, minimal practice effects, and multiple alternate forms, it also has the potential to be very useful in longitudinal ADHD research.

This thesis will contribute to the literature by examining whether ImPACT is sensitive to cognitive problems in young adults with ADHD. This study does not overcome all of the noted methodological limitations associated with previous research. However, it does have an adequate sample size for the statistical analyses, samples across one age group, and compares young adults with ADHD with non-ADHD controls matched on several relevant demographic variables (i.e., age, gender, education). As such, it takes significant steps towards overcoming some of the methodological limitations that exist in the extant ADHD literature.

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)

ImPACT (Maroon et al., 2000) was developed to address the need for rapid screening of the large number of athletes pre-season and after experiencing concussions. This battery was designed to address the limitations associated with traditional neuropsychological testing in sports (e.g., administration time, expense, practice effects). Prior to 1998 there were few neuropsychological test batteries developed specifically for use with athletes.

ImPACT is composed of a demographic questionnaire, injury evaluation form, symptom inventory, and a neuropsychological test battery (Collins et al., 2002; Lovell et al., 2003). The neuropsychological test battery consists of seven individual test modules (word discrimination, symbol memory, color click, symbol matching, color word match, sequential digit tracking, and visual attention span) that measure aspects of cognitive functioning including attention, memory, reaction time, processing speed, and impulse control. Composite scores for the test modules are computed by standardized formulas derived from the results of seven cognitive tasks (Collins et al., 2003). The seven modules can be administered as a complete test battery, or can be administered individually (Maroon et al., 2000). Various indices of performance are derived from these seven tasks, and can be combined to yield four composite scores, reflecting the individual's reaction time, memory, processing speed, and impulse control. The tasks involved in each module, and the indices included in each composite, are described in greater detail in the methods section.

The ImPACT battery includes a Post-Concussion Scale that is frequently used in both amateur and professional sports (Collins et al., 2003; Collins et al., 2002; Iverson, Gaetz, Lovell, & Collins, 2004a, 2004b). The Post-Concussion Scale asks each participant to report on 22 symptoms (e.g., headaches, dizziness, problems with sleep, irritability, sadness, feeling

slowed down, difficulties concentrating, poor memory, visual problems) using a 7-point Likert scale (i.e., 0-6). The present study examined whether young adults with ADHD endorse more symptoms with greater severity in total than a group of matched non-ADHD controls.

Symptoms included on the questionnaire that are known to be associated with ADHD (e.g., difficulty concentrating) are of particular interest to the present study.

ImPACT was designed as a rapid screening tool to permit the evaluation of a large numbers of athletes in a limited time. As such, the ImPACT test battery is brief (approximately 20 to 25 minutes for baseline evaluations) and does not evaluate all cognitive functions (e.g., it does not include tests of intelligence, achievement, or language). ImPACT was initially constructed to evaluate the areas of cognitive functioning most likely to be affected after cerebral concussions. When an individual experiences a concussion, cognitive functioning is disrupted. Immediately following the concussion, individuals are found to have difficulties in the areas of orientation, attention, executive functioning, information processing, mental set shifting, concentration, and memory (Delaney, Lacroix, Gagne, & Antoniou, 2001; Erlanger, Kutner, Barth, & Barnes, 1999). Although ImPACT was not specifically designed to screen for cognitive functioning in ADHD, it evaluates areas of cognitive functioning with tests that have been demonstrated to discriminate between individuals with ADHD and non-ADHD controls (e.g., verbal list learning, response inhibition, sustained attention; Johnson et al., 2001; Walker et al., 2000; Woods, Lovejoy, Stutts et al., 2002).

ImPACT is automatically computer scored. The test stimuli are randomized from one testing session to another. This allows for the test battery to be used repeatedly over short intervals, while controlling for practice effects (Iverson, Lovell, Collins, & Norwig, 2002;

Maroon et al., 2000). Most examiners can administer the battery after a few hours of instruction and review of materials, and little supervision of the test-taker is required (Maroon et al., 2000).

ImPACT has been used in several studies of concussion in amateur athletes, and has been shown to be sensitive to the immediate effects of concussion, and to reliably identify rapid improvement in functioning (Collins et al., 2003; Collins et al., 2002; Iverson et al., 2004a, 2004b; Lovell et al., 2003; Lovell et al., 2004). Several aspects of the reliability (e.g., test-retest reliability) and validity of ImPACT have been investigated (Iverson, Lovell, & Collins, 2002; Iverson, Lovell, Collins et al., 2002; Iverson, Lovell, Podell, & Collins, 2003).

Iverson, Lovell, Podell, and Collins (2003) summarized the reliability and validity data for version 1.0 of ImPACT. The reliability studies have addressed test-retest reliability and the determination of reliable change. It is not possible to assess internal consistency on the individual subtests or the composite scores because individual subtest responses cannot be downloaded from the program, and the composite scores are composed of a small number of subtest scores (thus, they are not amenable to reliability analyses).

The test-retest reliability and estimates of reliable change have been presented for version 1 and version 2 of ImPACT (Collins et al., 2003; Iverson, Lovell, & Collins, 2002, 2003). Reliable Change methodology uses statistical formulae to identify whether change in an individual's performance on a measure with repeated testing is the result of a "true" change in their performance, or remains within the confidence interval associated with the instrument's measurement error. In contrast, test-retest reliability provides an index of the consistency with which a measure evaluates a given function on repeat testing (i.e., how well results from testing at time 1 relate to testing at time 2; Hageman & Arrindell, 1993; Heaton et al., 2001; Jacobson & Truax, 1991; Temkin, Heaton, Grant, & Dikmen, 1999).

Test-retest reliability and reliable change estimates were derived from 49 amateur athletes tested over three occasions. The second administration of the test was given an average of 14 days (Range = 7-21 days) after baseline testing. The correlation coefficients from Time 1 to Time 2 ranged from .54 - .76 for the composite scores. The third administration was given approximately 4.5 days (Range = 2-7 days) after the second testing, and the correlation coefficients from Time 2 to Time 3 ranged from .48 - .68 for the composite scores.

Iverson, Lovell, and Collins (2005) conducted a study on the construct validity of ImPACT. They compared ImPACT (version 2.0) to a traditional neuropsychological measure, the Symbol Digit Modalities Test (SDMT). The SDMT is a test of visual scanning, visuomotor ability, attention, and speed of processing. It has similar task demands as the Trail Making Test Part A, and the Digit Symbol (Coding) Test (Spreen & Strauss, 1998). The authors hypothesized that the Processing Speed and Reaction Time Composites of ImPACT would correlate most highly with the Symbol Digit Modalities Test. Results from the analyses suggested that the SDMT, Reaction Time Composite, and Processing Speed Composite from ImPACT were measuring similar constructs, demonstrating some preliminary convergent validity (Iverson et al., 2005). Because the Processing Speed and Reaction Time Composites from Version 1.0 of ImPACT are identical to that of Version 2.0, the results of this research are relevant to the current study. The ongoing validation of a new test is a lengthy and time-consuming process (Lezak, 1995). Future validity research on ImPACT needs to examine its convergent and discriminant validity with other tests (Iverson et al., 2005).

The validity of ImPACT as a battery that measures sports-related concussion has been examined (e.g., Iverson, Lovell, & Collins, 2002). Amateur athletes (N= 120) who had completed pre-season testing were re-evaluated within three days of having a concussion.

Divergent validity was studied through an intercorrelation matrix of the composite scores at preseason and post injury. At preseason the only statistically significant correlation was between the Reaction Time and Processing Speed ($r = .35$). At post injury, there were significant, but small, correlations between Memory and Reaction Time ($r = -.27$), Memory and Processing Speed ($r = .35$), and Reaction Time and Processing Speed ($r = .32$). These results suggest that the composite scores do not share a great amount of variance, and are therefore capturing predominately different aspects of cognitive functioning.

To date, the psychometric data available for ImPACT is quite limited. Much additional research is needed. The battery appears to have adequate test-retest reliability, solid estimates of reliable change, and it is sensitive to the acute effects of concussions in high school and university students. In young people with ADHD, there is a substantial overlap in terms of the identified areas of compromised cognitive functioning evaluated by ImPACT; thus, there might be potential utility of the ImPACT battery in the ADHD population.

ImPACT measures several areas of cognitive functioning that adults with ADHD appear to show deficits (e.g., attention, memory, reaction time, and processing speed; Epstein et al., 2001; Kovner et al., 1998; Murphy et al., 2001; Murphy, 2002b; Seidman et al., 1998; Walker et al., 2000; Woods, Lovejoy, Stutts et al., 2002). The sensitivity of this computerized battery to the subtle effects of concussion suggests that the battery may also be useful for identifying cognitive problems associated with ADHD. One study has been conducted with adolescents with ADHD. Iverson and Strangway (2004) examined ImPACT version 2.0 performance in a sample of 38 adolescents with ADHD and 38 non-ADHD students matched for age, education, gender, and history of head injury. The average age of the students was 15.5 years (Range = 13-19) and their average education was 9.1 years (all were in grades 8-12). The

majority of the participants were boys (92%). All participants were derived from the ImPACT normative sample. The students with suspected ADHD were not diagnosed through structured interviewing or testing; a psychologist did not evaluate them. Each individual in the ADHD group was identified from their self-reported responses on the demographic questionnaire, which asked them to identify (yes/no) whether or not they had ever been diagnosed with attention deficit hyperactivity disorder (ADHD) or attention deficit disorder (ADD). Results from the study revealed significant differences between the control and ADHD groups in terms of their performance on the visual memory, processing speed, and impulse control composite scores. The groups did not differ significantly in terms of their verbal memory or reaction time composites.

The results are similar to those found by Seidman and colleagues (1997) who used a comparable sample, and investigated the cognitive task performance of a group of young ADHD males (aged 9 to 22) and non-ADHD controls using standard neuropsychological tests. The individuals with ADHD performed significantly more poorly on a task of visual memory, and on tasks of concentration/executive functioning primarily involving components of impulse control (Stroop test), and problem solving, set shifting, and cognitive flexibility (WCST). No differences were found between the two groups on a verbal list learning task (CVLT) or a reaction time task (CPT). Schmitz et al. (2002) reported similar findings when they compared a group of adolescents with ADHD to non-ADHD controls on measures of neuropsychological performance. These, and a number of additional studies, suggest that neuropsychological impairments identified in children with ADHD continue into adulthood (e.g., Halperin et al., 1990; Konrad et al., 2000; Kupietz, 1990; Loge et al., 1990; Seidel & Joschko, 1990; van der Meere & Sergeant, 1988).

Hypotheses

The purpose of the study was to examine the potential utility of ImPACT for distinguishing ADHD and non-ADHD individuals in a sample of young adults. The participants were matched on education, gender, and history of head injury. The study investigated whether the ADHD and matched controls displayed cognitive differences in terms of their concentration, memory, reaction time, processing speed, and impulse control as measured by ImPACT. Of additional interest was whether self-reported cognitive difficulties, as reported on ImPACT's Post-Concussion Scale, distinguished between ADHD and non-ADHD participants. The specific hypotheses for this study are listed below:

1) Young adults with ADHD will perform significantly more poorly on the memory composite than matched non-ADHD controls.

Adults with ADHD appear to have deficits in the encoding and retrieval of verbal information, primarily related to executive aspects of efficient memory strategy and verbal organization skills (e.g., semantic versus phonemic chunking of information). Moreover, verbal memory deficits are one of the most common difficulties identified in adults with ADHD (e.g., Seidman et al., 1997; Seidman et al., 1998; Woods, Lovejoy, Stutts et al., 2002). Some researchers have reported deficits on visual memory tests, too (Johnson et al., 2001).

2) The reaction time score for the young adults with ADHD will not be significantly different than the normative comparison group.

Reaction time tests have received little attention in the adult ADHD literature. However, Johnson et al. (2001) found that adults with ADHD performed more slowly than non-ADHD controls on a reaction time task (3RT) as the task became more complex. Only one other study (Murphy, 2002a) used a measure of simple reaction time (GSRT) and found that the test did not

discriminate adults with ADHD from controls. The most commonly used test to assess reaction time in the adult ADHD literature is the Continuous Performance Test (CPT). However, the CPT is not an explicit test of reaction time. Rather, reaction time is measured "incidentally" (i.e., the participant is not asked to solely respond to a stimulus as quickly as they can - because they are also required to monitor for "X's" to which they do not respond; Epstein et al., 1998; Epstein et al., 2001). For the purposes of the CPT, variability in reaction time over the duration of the task is used to identify inconsistent attentional patterns, or attention/arousal that diminishes over time. Further, the majority of the studies using the CPT to evaluate reaction time have not demonstrated significant differences between adults with ADHD and controls (Fischer et al., 1990; Murphy et al., 2001; Seidman et al., 1997). Iverson and Strangway (2004) reported no differences between young people with ADHD and controls on version 2.0 of ImPACT. Because the literature does not appear to support reaction time differences between non-ADHD controls and individuals with ADHD, there is no empirical reason to expect that they would differ in terms of reaction time on ImPACT. Hence it is expected that they will follow the pattern of previous literature and perform similarly.

3) The processing speed composite will be significantly slower for young adults with ADHD compared to non-ADHD controls.

Tests of psychomotor speed have shown limited utility in discriminating between adults with ADHD and non-ADHD controls (Seidman et al., 1998; Walker et al., 2000). However, because results from Iverson and Strangway (2004) using ImPACT version 2.0 demonstrated differences on the processing speed composite score between adolescents with ADHD and non-ADHD controls, there is some reason to believe that the ImPACT processing speed composite will discriminate between young adults with ADHD and non-ADHD controls.

4) Young adults with ADHD will score significantly more poorly than the control group on the impulse control composite.

Two traditional neuropsychological tests (CPT and Stroop Test) have been typically used to measure impulse/inhibitory control, and have been frequently used to differentiate between children with ADHD and non-ADHD controls (Barkley et al., 1992; Loge et al., 1990; Pineda et al., 1998). The CPT has generally been successful at distinguishing adults with ADHD from Non-ADHD controls by measuring impulse control through errors of commission (i.e., responding to a target stimuli when withholding of response is required; Epstein et al., 1998; Murphy et al., 2001; Walker et al., 2000).

The Stroop task measures inhibition by requiring the participant to suppress their prepotent (overlearned) reading response. The most numerous significant results differentiating participants with ADHD from controls with Stroop-type tests are reported in studies that include only adolescents and young adults with ADHD (Schmitz et al., 2002; Seidman et al., 1997). Similarly, using version 2.0 of ImPACT, Iverson and Strangway (2004) found significant differences between adolescents with ADHD and non-ADHD controls. These findings provide some empirical basis to believe that the ImPACT Impulse Control composite score will differentiate between the ADHD and control group.

5) Young adults with ADHD will report significantly more symptoms on the Post-Concussion Scale than controls.

Adults with ADHD self-report more psychiatric symptoms than Non-ADHD controls (e.g., feeling down, feeling irritable, feeling depressed; Woods, Lovejoy, & Ball, 2002), and other symptoms tapped by the Post-Concussion Scale overlap with common symptoms of ADHD (e.g., trouble concentrating and trouble with memory). As such, the Post-Concussion

Scale is likely to reflect elevated scores in ADHD because it is expected that they will endorse many of the symptoms with more frequency than Non-ADHD controls.

Methodology

Participants

From an initial database of 2,389 subjects, 84 were identified as having self-reported ADHD. Of these subjects, 68 had complete data (e.g., 9 were missing data on education). The normative database for ImPACT ($N = 1,746$) was then used to select a matched group of 68 non-ADHD controls. Participants were matched precisely on education, gender, and number of previous concussions. Each group had 88% males and 12% females. The average number of completed years of education was 12.3 ($SD = 2.0$) for the ADHD group and 12.3 ($SD = 2.0$) for the control group. The average number of previous concussions was .68 ($SD = 1.3$) for the ADHD group and .62 ($SD = 1.2$) for the control group. The breakdown of self-reported educational problems in the ADHD group was as follows: repeated a grade = 7.4%, reading problem = 22.1%, spelling problem = 25.0%, math problem = 17.6%, and recipient of special education services = 16.2%. The control subjects, by selection criteria, did not have any self-reported educational problems.

For the total sample, 39% percent were in high school and 61% were in university. The breakdown of participants by highest grade completed was as follows: Grade 9 = 13.2%, Grade 10 = 18.4%, Grade 11 = 13.2 %, Grade 12 = 22.1%, 1st year university = 20.6%, 2nd year = 8.1%, 3rd year = 13.2%, and 4th year = 4.4%.

Procedure

All participants completed Version 1.0 of ImPACT as part of a larger collection of normative data for ImPACT. The testing was done in group settings (e.g., computer labs in schools). Each administration of ImPACT took approximately 20-25 minutes. The students with self-reported ADHD were not diagnosed through structured interviewing or testing; and a psychologist did not evaluate them. This is a sample of convenience, derived from a normative database. The students were identified as having ADHD by their self-reports in the demographic questionnaire. Specifically, the students were asked whether or not they had ever had a diagnosis of attention deficit hyperactivity disorder (ADHD) or attention deficit disorder (ADD).

Measures

The following section provides a detailed description of ImPACT. This program contains a demographic questionnaire, current symptoms questionnaire, and a neuropsychological screening battery.

The first section of ImPACT is the Subject Profile and Health Questionnaire. It requires the participant to input basic demographic and descriptive information including their name, date of birth, age, sex, grade level, and first language. It also requires the individual to report their height, weight, handedness, sport, and whether or not they have ever had a concussion. In addition, the questionnaire requires the test-taker to report whether or not they have received any speech therapy, attended special learning classes, repeated one or more years of school, or been diagnosed with ADHD.

Section two of ImPACT pertains to "Current Symptoms and Conditions", or what is referred to as the Post-Concussion Scale. The Post-Concussion Scale asks each participant to

report on 22 concussion-related symptoms on a 7-point Likert scale (i.e., 0-6) identifying the degree of difficulty, if any, they are having with each symptom (e.g., problems with sleep, irritability, sadness, feeling slowed down, difficulties concentrating, poor memory, visual problems). The Post-Concussion Scale is reprinted in Table 3.

Table 3

Post-Concussion Scale

Symptom	Minor		Moderate		Severe	
Headache	1	2	3	4	5	6
Nausea	1	2	3	4	5	6
Vomiting	1	2	3	4	5	6
Balance Problems	1	2	3	4	5	6
Dizziness	1	2	3	4	5	6
Fatigue	1	2	3	4	5	6
Trouble Falling Asleep	1	2	3	4	5	6
Sleeping More Than Usual	1	2	3	4	5	6
Sleeping Less Than Usual	1	2	3	4	5	6
Drowsiness	1	2	3	4	5	6
Sensitivity to Light	1	2	3	4	5	6
Sensitivity to Noise	1	2	3	4	5	6
Irritability	1	2	3	4	5	6
Sadness	1	2	3	4	5	6
Nervousness	1	2	3	4	5	6
Feeling More Emotional	1	2	3	4	5	6
Numbness or Tingling	1	2	3	4	5	6
Feeling Slowed Down	1	2	3	4	5	6
Feeling Mentally "Foggy"	1	2	3	4	5	6
Difficulty Concentrating	1	2	3	4	5	6
Difficulty Remembering	1	2	3	4	5	6
Visual Problems	1	2	3	4	5	6

Note: Participants checked a box if they were "not experiencing the symptom."

The sum of all responses on the Post-Concussion Scale was used to create a total post-concussion score (range = 22-132), with higher scores indicating a larger proportion of symptoms present during the test administration. For each item, scores ranged from 0-6 with

higher scores indicating more severe difficulties. The internal consistency of the entire scale as estimated with Cronbach's alpha was .92 ($M=8.54$, $SD=15.14$) for the total sample, .93 ($M=11.47$, $SD=16.09$) for the ADHD group, and .90 ($M=5.60$, $SD=8.79$) for the Control group.

Section three of ImPACT is composed of a battery of seven neuropsychological tests, referred to as modules. Each module contributes scores that produce four different composites (i.e., memory, processing speed, reaction time, and impulse control) that were used to assess specific aspects of cognitive functioning as described below. The breakdown of the scores that comprise each composite is provided in detail, after the descriptions of all modules.

It is not possible to conduct internal consistency reliability analyses on the individual tests or the composite scores. This is because individual test responses cannot be downloaded from the program, and the composite scores are composed of a small number of subtest scores (from the modules) and thus are not amenable to reliability analyses.

Module 1 Word Discrimination. The first module evaluates attentional processes and verbal recognition memory by requiring the participant to discriminate between correct and incorrect words after two acquisition trials. Twelve target words are presented for 750 milliseconds each on the computer screen. The word list is presented twice in the same order at the same rate to facilitate learning. Immediately after the second presentation the participant is given a 24-word list that is composed of the twelve target words previously presented, and twelve non-target words. The target words are matched to the non-target words semantically (e.g., if "knife" represents a target word, "fork" represents a non-target word). The participant responds to the words by mouse-clicking the "yes" and "no" buttons on the screen to specify whether the word presented was on the previously learned list. Subsequently, in a delayed condition that follows administration of all other test modules (approximately 20 minutes), this

task is re-administered using the same procedures as described above. There is no time limit for the immediate and delayed recognition portions during this module. For both the immediate and delayed assessment, the sum of correct and incorrect responses is computed. This module contributes to the *memory composite* (a total percent correct score is derived) with higher scores reflecting greater word learning and memory.

The presentation of a word list in a visual format is similar to the Consortium to Establish a Registry for Alzheimer's Disease battery (CERAD; Morris et al., 1989). This task is also conceptually similar to verbal list learning tasks, such as the California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987; Delis, Kramer, Kaplan, & Ober, 2000) and the Rey Auditory Verbal Learning Test (RAVLT; Rey, 1964).

Module II Symbol Memory & Module III Color Click (distractor task). Symbol Memory measures visual working memory and visual processing speed. The Color Click module serves as a distracter task, and is also a measure of focused attention, response inhibition, and reaction time. Prior to beginning the visual memory task (Symbol Memory), the participant is allowed to practice the distracter task (Color Click). Color Click is a choice reaction time test during which the participant is asked to click the left mouse button if a red circle is presented and the right mouse button if a blue square is presented. Once the participant has completed the practice task, the Symbol Memory task begins. For each of the trials of the memory task, a screen is displayed for 1.5 seconds that has a computer generated random assortment of X's and O's. Three of the X's or O's are illuminated in yellow on the screen. The participant is asked to remember the location of the illuminated objects. Immediately after the presentation of the three X's or O's the distracter task re-appears on the screen and distracter items (i.e., red circle or blue square) are presented for 30 seconds. Following the distracter task, the memory

screen (X's and O's) re-appears and the participant is asked to click to identify the location of the previously illuminated 3 objects. The participant completes 4 trials involving presentation of the X's and O's, followed by the distracter task, followed by recall of the location of the X's and O's. Scores are provided for the *memory composite* (correct identification of the X's and O's), *reaction time composite* (reaction time for the distracter task), *impulse control composite* (number of errors on the distracter task).

The Symbol Memory component of this module is conceptually similar to the Spatial Location subtest from the Kaplan Baycrest Neurocognitive Assessment (KBNA; Leach, Kaplan, Rewilak, Richards, & Proulx, 2000). The task requires visual attention and visual-spatial working memory. The Color-Click task (distracter task) in this module is similar to the Connors' Continuous Performance Test (CPT; Connors, 2002), requiring speeded responding, impulse control, and sustained visual attention and vigilance.

Module IV Symbol Match. The Symbol Match module evaluates visual processing speed, learning, and memory. Initially, the participant is presented with a screen that displays nine symbols (e.g., triangle, square, and arrow). Directly under each symbol is a number button from 1 to 9. Below this grid, a symbol is presented. The participant is required to click the matching number as quickly as possible, and to remember the symbol/number pairings. Correct performance is reinforced through the illumination of a correctly clicked number in green. Incorrect performance illuminates the number button in red. Following the completion of 27 trials, the symbols disappear from the top grid. The symbols again appear below the grid and the participant is asked to recall the correct symbol/number pairing by clicking the appropriate number button. This module provides an average *processing speed* score and a score for the *memory* condition.

The first part of this module resembles the Digit Symbol task from the Wechsler Adult Intelligence Scale, Third Edition (WAIS-III; Wechsler, 1997), and the Symbol Digit Modalities Test (Smith, 1972). Both of these tasks are underpinned by visual processing speed, visual scanning, and learning. The second part of the module resembles the incidental learning portion of the Digit Symbol task on the WAIS-III (Wechsler, 1997).

Module V Color-Word Match. The Color-Word Match represents a choice reaction time task, and also measures impulse control and response inhibition. The first part of this test, a practice task, presents the participant with three squares of different colors (i.e., red, blue and green). The examinee is asked to click on either the red, blue, or green square as the word for that color appears on the screen. This process ensures that the participant can perform the basic task of matching a word to a color (e.g., match the word red, to the red square) ruling out colorblindness and grossly impaired reading ability. The actual test requires the examinee to click on the word (e.g., *green*) inside the box when it is a correct match between color and word (e.g., green word in a green ink). This is referred to as a congruent match. The examinee is required to inhibit or not respond when the word presented does not match the ink color. This is referred to as an incongruent match (e.g., the word green printed in red ink). A new stimulus (i.e., colored word in a box) is presented for two seconds with a one-second delay between the stimuli. In addition to providing a *reaction time score*, this task also contributes to the *impulse control composite* providing both omission (failing to click on a congruent match) and commission error (clicking on an incongruent match) scores.

This test measures impulse control and incidental reaction time. It relies on the examinee inhibiting an automatic word reading response in favor of a more novel response (i.e., identifying the ink color). It is very similar to the traditional Stroop test (Golden, 1978).

Module VI Sequential Digit Tracking/Trigram Memory. The Sequential Digit Tracking module measures working memory and visual-motor response speed. First, the participant is allowed to practice the distractor task, which consists of 25 numbered buttons (5 x 5 grid). The participant is instructed to click as quickly as possible on the numbered buttons in backward order starting with "25." Once the participant has completed this initial practice task, he/she is presented with three consonant letters that are displayed on the screen and instructed to remember them. Immediately following display of the three letters, the numbered grid reappears and the participant is instructed to click the numbered buttons in backward order as quickly as possible. After a period of 18 seconds, the numbered grid disappears and the participant is asked to recall the three letters by typing them from the keyboard. Both the number placement on the grid and letters displayed are randomized for each trial. Five trials of this task are presented for each administration of the test. This module yields a *memory score* (total number of correctly identified letters) and a *processing speed score* (average number of correctly clicked numbers per trial from the distractor test).

The three-letter task is similar to the Brown-Peterson short-term memory paradigm (Brown, 1958; Peterson & Peterson, 1959); it is also called the Auditory Consonant Trigrams Test (Mitrushina, Boone, Razani, & D'Elia, 2005). The speeded distractor task is conceptually similar to the Trail Making Test-A (TMT-A; Reitan & Wolfson, 1993), which is a visual motor task involving scanning and graphomotor speed.

Module VII Visual Attention Span. The Visual Attention Span module evaluates visual attention span under two conditions: forward span and backward span. During the forward span task, the examinee is presented with a 3 x 3 grid of square buttons. The buttons are highlighted in random order. The examinee is required to remember the order and mouse click on the

correct sequence. Following a sample item, four trial sequences are presented. Each sequence involves more grid items to be repeated, with the final trial including nine squares. The backward span task is identical to the forward span condition, except that the participant is required to click on the presented sequence in backward order. The task begins with a sequence of two highlighted squares within the grid, and progresses until the participant reaches a maximum of eight squares to remember. Both the forward and backward component are discontinued once the participant fails two trials in a row at any level. Two scores from this module are calculated, which contribute to the *memory* and *processing speed* composites. This task is modeled on, and essentially identical in nature to, the WMS-III Spatial Span task.

ImPACT Composite Scores. Performance across tasks on ImPACT yielded four overall composite scores for each participant: Memory Composite, Reaction Time Composite, Processing Speed Composite, and Impulse Control Composite. The breakdown of the module scores that contribute to each composite is provided below:

1. The Memory Composite is comprised of the average of the following scores: (a) Word Discrimination total percent correct, (b) Symbol Match-Total correct hidden symbols, (c) Sequential Digit Tracking total percent of total letters correct, (d) Visual Attention Span- Total percent of numbers correct (forwards and backwards), and (e) Symbol Memory total percent of X's and O's correct.
2. The Reaction Time Composite is comprised of the average of the following scores: (a) Symbol Memory X's and O's-Average correct RT (interference), (b) Symbol Match-Average correct RT/3 and, (c) Color Click-Average. correct RT.

3. The Processing Speed Composite is comprised of the average of following scores: (a) Symbol Memory-total correct (interference)/4, (b) Sequential Digit Tracking Three-letters-Average counted correctly*3, and (c) Visual Attention Span.
4. The Impulse Control Composite is comprised of the average of the following scores: (a) Symbol Memory-total incorrect- (interference), and (b) Color Match total commissions.

Analyses

The dependent variables were first examined for skewness and kurtosis, and transformations were performed on any variables that violated the assumptions of normality. Bivariate correlations (Pearson) among the composite variables of ImPACT were calculated to establish the degree of association among the dependent variables.

In order to evaluate whether the matched groups (ADHD and non-ADHD) differed across the six dependent variables evaluated in this study, dependent t-tests were conducted for each of the variables (i.e., Post-Concussion Scale, Memory Composite, Reaction Time Composite, Impulse Control, and Processing Speed Composites). The dependent t-test is the most appropriate (i.e., robust) calculation to test the null hypotheses in a matched groups design. Statistically, the dependent t-test is almost identical to the independent t-test, except that it takes into account the degree of correlation between the two groups. Large correlations between the two groups on the dependent measures reduces the size of the error variance, making the t-test more powerful.

Effect sizes for each comparison are reported using the original (untransformed) means and standard deviations for the ADHD and control group.

In addition, analyses are conducted to determine whether self-reported academic problems or participation in special education was related to performance on ImPACT (i.e., participants

taking special classes for reading). Lastly, for exploratory purposes, the three symptoms from the Post-Concussion Scale dealing with cognitive difficulties (feeling mentally foggy, poor concentration, and poor memory) were combined to examine whether or not the ADHD subjects endorse significantly greater cognitive difficulties than the control group.

Results

The descriptive statistics for the composite scores are presented in Table 4. Several variables violated assumptions of normality, and showed significant skewness and kurtosis including the Post-Concussion Scale, Memory Composite, and Impulse Control Composite. Variables were deemed to exhibit significant skewness and/or kurtosis if the z-scores associated with these indices were outside the range of ± 3 . Variables with a significant Kolmogorov-Smirnov statistic ($p < .05$) were considered to violate assumptions of normality. To correct for these violations of normality, these variables were transformed using the square root method as an alternative to the logarithmic transformation because some of the data points were 0, and therefore undefined in a logarithmic transformation. Instead of adding a constant of 1 to these variables, the more conservative square root method of transformation was applied.

Square root transformation of the variables did not alter the significance of any of the relationships among the data on the dependent t-tests. As a result, the means and standard deviations of the untransformed data were used for all analyses. This is preferable, because the square root transformation of the variables alters their natural distribution, generally by artificially compressing high data points in a non-systematic way (e.g., a participant score might greatly exceed their matched control's score, resulting in the scores being altered in a

non-systematic way). Furthermore the t-test is relatively robust to violations of assumptions, especially when sample sizes are above twenty (Tabachnick & Fidell, 2001).

Table 4

Descriptive statistics for the ImPACT composite scores

	Mean	Standard Deviation	Interquartile Range	Skewness	Kurtosis	KS
Symptoms	8.54	13.25	0.0 - 10.00	2.26	4.89	.00
Memory	86.24	10.84	79.53 - 95.49	-1.07	1.41	.00
Reaction Time	.58	.07	.53 - .62	.62	.37	.20*
Processing Speed	34.23	7.02	29.71 - 38.80	.09	.29	.20*
Impulse Control	10.34	8.04	5.0 - 13.0	1.92	5.15	.00

Note: KS = Kolmogorov-Smirnov test of normality; * = Significant violations of normality.

In assessing for univariate outliers in the data, the standardized values revealed that several cases were potential outliers ($z > \pm 3$). These cases were further assessed by an examination of the histograms, stem and leaf plots, box plots, and the raw data itself. All potential outliers appeared to be connected to their respective distributions, and were therefore retained as legitimate values.

Intercorrelations among the dependent variables are presented in Table 5. Correlations greater than 0.9 violate assumptions related to multicollinearity and singularity. However, the bivariate correlations among the dependent measures in the present sample were small to medium. Accordingly, each of the six dependent measures was considered separately in subsequent analyses.

Table 5

Pearson's correlation coefficients among the ImPACT composite scores

	<u>Symptoms</u>	<u>Memory</u>	<u>Reaction time</u>	<u>Impulse Control</u>	<u>Processing Speed</u>
Symptoms					
Memory	-.24**				
Reaction time	-.07	-.35**			
Impulse control	.15*	-.16*	-.08		
Processing Speed	-.15*	.30**	-.50**	-.03	

*Correlation is significant at the 0.01 level (1-tailed).

**Correlation is significant at the 0.05 level (1-tailed).

Dependent t-tests were conducted to evaluate differences between the adults with ADHD and the matched control group across all five dependent variables (Post-Concussion Scale, Memory Composite, Processing Speed Composite, Impulse Control Composite, Reaction Time Composite). For exploration purposes, independent t-tests were also run, but not reported¹. Results of these analyses indicated that the individuals with ADHD and the control group differed significantly on the Post-Concussion Scale ($t(1, 33) = -2.46, p < .05$), and the Memory Composite ($t(1, 33) = 2.88, p < .05$). The groups did not differ significantly on the Processing Speed Composite ($t(1, 33) = .727, p > .05$) or the Impulse Control Composite ($t(1, 33) = -.866, p > .05$). Differences between ADHD and Control groups approached significance for the Reaction Time Composite ($t(1, 33) = -.178, p > .07$). As reported in Table 6, the effect sizes for the significant differences were medium. An examination of the means for these analyses (see Table 6) indicated that young adults with ADHD report more symptoms (Post-Concussion Scale) and demonstrate a poorer ability across memory tasks. There was a

¹ The same pattern of results were obtained when Independent t-tests were used rather than dependent t-tests.

nonsignificant trend for the individuals with ADHD to display slower reaction time than controls.

Table 6

Descriptive statistics, significance tests, and effect sizes (Cohen's d)

	ADHD		Non-ADHD Controls		p	d
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>		
Symptoms	11.47	16.09	5.60	8.87	.010	.68
Memory	83.59	10.73	88.88	10.34	.004	.50
Reaction Time	.58	.06	.56	.06	.076	.33
Processing Speed	33.79	7.37	34.65	6.67	.479	.12
Impulse Control	10.86	8.05	9.80	8.05	.445	.13

Given that a significant number of individuals in the ADHD group reported academic difficulties, additional analyses were conducted to determine whether self-reports academic problems or participation in special education systematically affected performance on ImPACT. Due to small sample sizes for specific educational problems, participants with ADHD were sorted into binary groups: those with one or more academic problems (i.e., reading, spelling, math, repeated grade, learning assistance, or special education) versus those with no self-reported academic problems. There were 31 participants with academic problems and 37 without problems. The two groups did not differ on total symptoms, The Memory Composite, Processing Speed Composite, or the Impulse Control Composite. ADHD subjects with academic problems had slower reaction times, however [$t(66) = -.26, p < .012, d = .64$].

For exploratory purposes, the three specific symptoms from the Post-Concussion Scale dealing with cognitive difficulties (feeling mentally foggy, poor concentration, and poor memory) were summed to create a single score (See Table 7). The ADHD subjects endorsed significantly greater cognitive problems ($M = 2.51$, $SD = 3.84$) than the control subjects [$M = .88$, $SD = 2.0$; $t(67) = -2.98$, $p < .005$, $d = .56$].

Frequency distributions for the three scores that were significantly different between the ADHD group and the controls were examined and cutoff scores were selected. These cutoff scores represented the approximate 10th percentile for the control group. That is, 90% or more of the control group scored better than the cutoff. Specifically, the cutoff score for the Post-Concussion Scale was > 15 points, the cognitive symptom total score was > 3 points, and the Memory Composite was $< 76.9\%$ correct. These three cutoff scores were then examined, in combination, to determine if they could reasonably separate the two groups. These results are presented in Table 7. Notice that 82% of the control subjects did not have a single unusual score, compared to 56% of the ADHD sample. Applying a decision rule of one or more unusual scores would result in a correct classification rate of 44.1% of the ADHD subjects and 82.4% of the controls. Applying a decision rule of two or more unusual scores would result in a correct classification rate of 23.5% for the ADHD group and 92.6% for the controls.

Table 7

Percent of subjects with unusual scores

Number of Unusual Scores	ADHD Group		Control Group	
	Percent	Cumulative Percent	Percent	Cumulative Percent
0	55.9	55.9	82.4	82.4
1	20.6	76.5	10.3	92.6
2	16.2	92.6	5.9	98.5
3	7.4	100.0	1.5	100.0

Note: "Unusual" scores occur in less than 10% of the control group for each of the three variables.

Discussion

Increasingly there is recognition that many symptoms of ADHD persist into adulthood (Epstein et al., 2001; Murphy, 2002a). However, because it is a diagnosis made based on childhood history, retrospective diagnosis in adulthood has proven challenging. No “gold-standard” test exists that has been shown to reliably differentiate adults with ADHD from those without ADHD. Recently, research has examined the utility of neuropsychological tests for identifying differences between persons with and without ADHD (Johnson et al., 2001; Murphy, 2002b; Nigg et al., 2002). The findings have tended to be mixed: The most consistent results have emerged from the childhood literature (e.g., Barkley et al., 1992; Snow, 1998); somewhat more variable results with adolescents (e.g., Schmitz et al., 2002; Seidman et al., 1997); and highly variable results with the adult ADHD population (e.g., Murphy et al., 2001; Seidman et al., 1998).

Further complicating this literature is the fact that the construct “executive functioning” remains poorly operationalized in most of the neuropsychological literature, and executive functions such as planning, organizational skills, judgment, and inhibitory control are difficult to separate from other cognitive functions that underpin them. There is little consistency in the neuropsychological tests used, although most fall under the general category of tests of executive functioning.

Use of a battery of neuropsychological tests rather than individual measures increases the ability of neuropsychological tests to discriminate persons with ADHD from those without ADHD (e.g., Woods, Lovejoy, Stutts et al., 2002). However, administration of a test battery is both time consuming and expensive, and as a result generally not a viable or cost effective way of screening large numbers of individuals. Research continues to investigate

neuropsychological measures with a continued focus on ways to rapidly differentiate persons with ADHD from those without it.

ImPACT version 1.0 is a brief, computer administered and scored, neuropsychological battery initially constructed for rapid evaluation of post-concussive cognitive problems and symptoms in athletes. Recently, ImPACT Version 2.0 demonstrated some promise in a preliminary study examining its utility in differentiating adolescents with ADHD from non-ADHD controls (Iverson & Strangway, 2004). ImPACT is brief and easily administered. As a result, it represents a cost-effective solution for screening large numbers of adults for ADHD.

The present study examined the utility of ImPACT Version 1.0 for differentiating young adults with ADHD from matched non-ADHD controls on four composite scores and the Post-Concussion Scale. There were significant differences between adults with ADHD and non-ADHD controls on two of the five variables considered, the Post-Concussion Scale and the Memory Composite, with a nonsignificant trend toward slower reaction times in the ADHD group. No significant differences were found on the Impulse Control Composite, or the Processing Speed Composite. Each of these is discussed below in light of relevant research.

As predicted, young adults with ADHD were found to perform significantly more poorly on the ImPACT Memory Composite score than matched non-ADHD controls. The Memory Composite produced by ImPACT version 1.0 is composed of five subtest scores measuring different aspects of memory (e.g., verbal learning, visual learning, incidental learning, and working memory). Tasks of verbal learning and memory have been investigated in the adult ADHD literature, and have yielded the most consistent results in differentiating adults with ADHD from non-ADHD controls (e.g., Seidman et al., 1998; Woods, Lovejoy, Stutts et al., 2002). Adults with ADHD appear to have deficits in the encoding and retrieval of

verbal information, primarily related to executive aspects of efficient memory strategy and verbal organization skills (e.g., semantic versus phonemic chunking of information) (Woods, Lovejoy, & Ball, 2002). Research on differentiating adults with ADHD has not demonstrated consistent results using visual memory tasks (e.g., Murphy, 2002a). Because individual memory subtests that comprise the Memory Composite, were not readily available, it was not possible to determine which aspects of memory function contributed to the ability of the Memory Composite to reliably distinguish participants with ADHD from the matched controls.

As predicted, the reaction time score for the young adults with ADHD was not significantly different than the normative comparison group. This prediction was based on previous findings that tests of simple reaction time and incidental reaction time (e.g., extracted from the CPT) have not proven useful in differentiating adults with ADHD from controls (Murphy, 2002a). Despite the fact that the literature does not appear to support reaction time differences between non-ADHD controls and individuals with ADHD, a trend toward a significant effect was observed in the present study, with young adults with ADHD tending to show slower reaction times than their matched controls. Moreover, when the ADHD group was divided into those with versus without self-reported academic problems, those with academic problems had significantly slower reaction times. Similarly, Johnson et al. (2001) found that adults with ADHD performed more slowly than non-ADHD controls on a reaction time task (3RT), as the task became more complex.

Results from Iverson and Strangway (2004) using ImPACT version 2.0 revealed differences on the ImPACT Processing Speed composite score between adolescents with ADHD and non-ADHD controls. Accordingly, it was expected that, in the present study of young adults, the ImPACT processing speed composite might also discriminate between young

adults with ADHD and non-ADHD controls. However, the results did not reveal slower processing speed in the ADHD group. One possibility for the failure of this study to discriminate adults with ADHD from controls on the basis of processing speed is that, similar to many of the investigations of processing speed in the literature, only the child and adolescent groups differed significantly from non-ADHD controls, while young and middle aged adults with ADHD did not (Seidman et al., 1998; Walker et al., 2000). Adults with ADHD may have found ways to compensate or adapt to their cognitive deficits with age. This does not necessarily mean that there are “real” cognitive improvements, but rather that the neuropsychological tests are unable to capture these subtle deficits in adults.

Unexpectedly, the ImPACT Impulse Control composite did not differentiate the adults with ADHD from the matched controls. However, Iverson and Strangway (2004) using ImPACT version 2.0 reported significant differences between adolescents with ADHD and controls. Two traditional neuropsychological tests, the CPT and Stroop test, have typically been used to measure impulse/inhibitory control in the ADHD literature. ImPACT contains tests almost identical to the Stroop and CPT (Color Word Match & Color Click, respectively). Both of these tests have a large inhibitory control component, and have been frequently and successfully used to differentiate between children with ADHD and non-ADHD controls. Within the adult population, the CPT has also been generally successful at distinguishing adults with ADHD from controls on the basis of number of commission errors (i.e., responding to a target stimuli when withholding of a response is required) – an index of inhibitory control (Epstein et al., 1998; Murphy et al., 2001). In comparison, the Stroop task has primarily been successful only with the adolescent population (Schmitz et al., 2002; Seidman et al., 1997). It is possible that a similar pattern of results was found on the ImPACT Impulse Control composite,

which is composed of an average of the two scores (i.e., commission errors on Color Word Match & total incorrect/interference on Color Click). It is possible that good differentiation between groups on one of the scores was diluted to the point of non-significance by a non-discriminating result on the other score. As mentioned in the context of the Memory Composite, the extraction and examination of the individual test scores was not readily available for this study. More importantly, the test instructions and practice items for one or more of the tasks that comprise the Impulse Control Composite were revised and clarified for Version 2.0 of ImPACT. This might have increased the usefulness of this composite in the previous study.

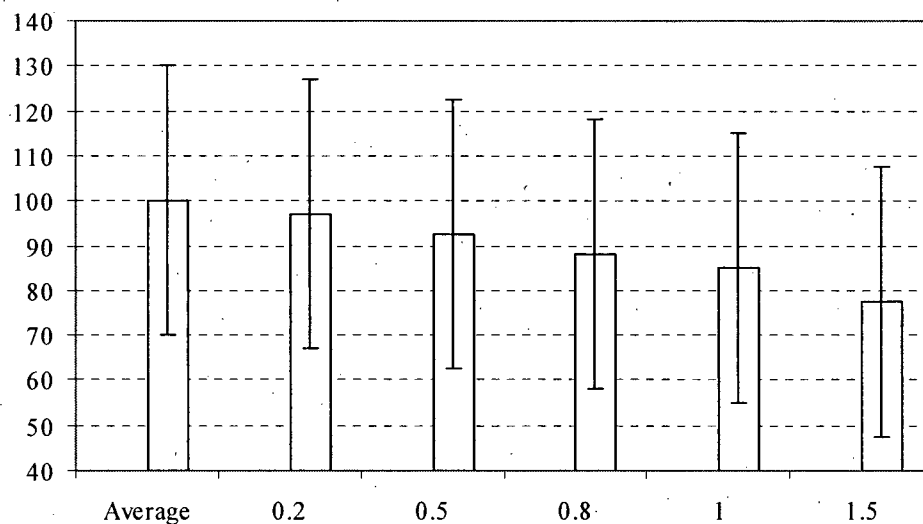
Finally, as predicted, young adults with ADHD in the present sample reported significantly more symptoms on the Post-Concussion Scale than matched controls. They also reported greater difficulty with the cognitive symptoms on that scale. This finding is consistent with the literature that adults with ADHD report more psychiatric symptoms than healthy controls (e.g., feeling down, feeling irritable, feeling depressed) (Woods, Lovejoy, & Ball, 2002). Moreover, the scale includes items that specifically relate to ADHD symptomatology (e.g., trouble concentrating).

Throughout this thesis, I have discussed the “differentiation” of people with ADHD from non-ADHD control subjects. It is important to emphasize that this means statistical differentiation, not practical differentiation. Indeed, as emphasized throughout this thesis, the practical differentiation of people with ADHD based on neuropsychological tests has been difficult and elusive. Finding a statistically significant difference between two groups on a test does not, of course, mean that the test can differentiate individuals on a case-by-case basis. This is illustrated in Figure 1.

Using IQ scores as the metric of interest, average scores are 100 with a standard deviation of 15. Therefore, the vast majority of subjects would score within two SDs from the mean (30 points). Differences between a clinical group and a “normal” group are illustrated using effect sizes ranging from .2 (small) to 1.5 (large). As seen in this figure, even a “large” effect size of .8 results in tremendous overlap between a clinical group and a “normal” distribution. This, of course, makes it very difficult to accurately differentiate individuals within groups based on a test score.

Figure 1.

Overlapping distributions based on effect sizes (using the IQ metric).



Note: This figure illustrates the theoretical overlap between clinical groups that differ from “normal” by certain magnitudes of effect sizes.

Conclusions

The pattern of results produced by this investigation of ImPACT is consistent with the adult ADHD literature in that the ImPACT test battery did not consistently demonstrate differences across all neuropsychological tests between individuals with ADHD compared to controls (e.g., Corbett & Stanczak, 1999; Kovner et al., 1998; Walker et al., 2000). Adults with ADHD performed significantly more poorly than controls on the Memory Composite, and

showed a nonsignificant trend towards slower reaction times on the Reaction Time Composite, but did not differ on the Processing Speed or Impulse Control Composites. The nature of these results is similar to the reviewed literature that has found the most promising results on memory tasks (e.g., Seidman et al., 1998; Woods, Lovejoy, Stutts et al., 2002). The lack of consistent results across the ImPACT composites likely results from a number of factors.

The biggest factor appears to be problems with the test itself. Iverson and Strangway (2004) reported much stronger findings using version 2.0 of the test, especially for the Impulse Control Composite (the effect size was large, $d = .93$). Improvements to the administration instructions and practice items from version 1.0 to version 2.0 might account for the different results. Another major factor relating to the lesser differences between groups in this study was the nature of the sample. Most of the subjects were in university, whereas in Iverson and Strangway (2004) all were in high school. It stands to reason that those people with ADHD who go to university have less pronounced cognitive difficulty, as a group, than those who do not.

Another factor is that as adults with ADHD age, they find strategies to compensate for potential attentional deficits, and therefore some tests become less able to discriminate their performance as they get older and adapt better. This does not suggest that attention deficits necessarily disappear with age, but rather that they become more difficult to identify with cognitive measures.

Further, the disorder is variable by nature, and adults with ADHD do not manifest cognitive deficits equally under all conditions. One of the noted hallmarks of ADHD is poorer performance as extraneous distractions increase (Woods, Lovejoy, & Ball, 2002). Completing a test battery under quiet and controlled conditions is likely not a good algorithm for functional

performance under “real world” conditions. Thus, it is not reasonable to assume that these deficits can always be reliably identified in the testing environment. Further, ADHD is associated with day-to-day variability in performance so one testing session during one period of time may also not capture the full nature of their deficits.

Limitations

There were a number of limitations to the current study. First, the self-report method of identifying the ADHD group introduces retrospective bias and although the literature appears to support self-report by individuals with ADHD, the bias associated with self-report could not be determined. Using a single diagnostic indicator such as a self-report with no cross-validation of history or symptoms from multiple settings or informants is not ideal. However, given the lack of a gold standard method for diagnosing ADHD, this study, like many others (Epstein et al., 1998; Epstein et al., 2001; Murphy, 2002a, 2002b; Nigg et al., 2002) relied by necessity on self-reported ADHD symptoms for group classification. In the present study, this problem was slightly mitigated because of the young age of the sample. It is reasonable to suppose that young adults aged 15-22 would have been diagnosed more recently than those in other studies where participants were up to 89 years of age. Further, some of the older participants might not have been diagnosed at all in childhood, because the diagnosis might not have been identified or have become well-known to clinicians, given its recent inclusion in the DSM. In contrast, there is a strong likelihood that the present sample of young adults would have received a diagnosis of ADHD within the past 10 years (i.e., in the 1990's). Further, this sample received no obvious gain from participating in this study, and they had no reason to mislead the researcher.

Because this was a sample of convenience, derived from a normative database, the individuals with ADHD were not classified or separated according to DSM-IV-TR subtypes. The majority of previous studies have not differentiated their samples on this basis, and research to date has not consistently identified different cognitive profiles among the ADHD subtypes (e.g., Epstein et al., 2001; Kovner et al., 1998; Nigg et al., 2002; Walker et al., 2000). However, further investigation of the subtypes in terms of identifying whether their ImPACT performance profiles differed might be interesting.

A contentious issue is whether or not to control for intelligence. In the present study, this variable could not be analyzed because it was not collected in the normative database. Further, many researchers have suggested that controlling for intelligence might remove meaningful variance associated with ADHD (Seidman et al., 1997). Seidman et al. (1997) contend that using intelligence as a covariate constitutes "overcontrol," thereby limiting the possibility of finding significant differences between adults with ADHD and controls. In the studies reviewed, the majority that controlled for intelligence found no differences on neuropsychological tests between adults with ADHD and controls (Kovner et al., 1998; Walker et al., 2000).

A final limitation of the present study relates to the participants' use of medication. In most of the reviewed studies, adults with ADHD were either not taking medication, were taken off stimulant medications prior to testing, or the studies implemented statistical procedures to control for the possible cognitive effects of medication (e.g., Corbett & Stanczak, 1999; Epstein et al., 2001; Seidman et al., 1998). In the present study, the effects of medication (stimulant or other) could not be examined because specific medication information was not collected in the normative database. However, researchers exploring the use of stimulant medications on

cognitive performance have found conflicting results. Schmitz et al. (2002) found that unmedicated participants with ADHD performed more poorly than those on stimulant medications. In contrast, Seidman et al. (1997) found no performance differences on cognitive measures between unmedicated and medicated participants with ADHD. Future research investigating whether the profiles of individuals with ADHD differ according to whether they are using stimulant medications would be valuable.

Future Directions

ImPACT is a new test. Developing a new test takes time, money, and most importantly feedback from both clinicians and researchers. Via such feedback the test has undergone revisions resulting in ImPACT version 2.0. Future researchers using this test should examine the individual subtests, not just the composite scores. Moreover, the ease of administration including time, cost-efficiency, and limited examiner training requirements, suggests that a large number of individuals with ADHD or other disorders could be tested rapidly. With larger samples some of the current methodological limitations of the reviewed literature could be addressed with ease. Future research could examine the differential neuropsychological performance of individuals within constrained age ranges in order to identify if there are primary cognitive differences between the age groups. Longitudinal studies are needed with repeated evaluation over time to improve on the cross-sectional literature that currently dominates the research in this area. One of the advantages of ImPACT is its automatic randomization of stimuli to allow for repeated testing with minimal practice effects.

Larger sample sizes also allow for research relating to cognitive differences between ADHD subtypes. The battery approach appears to improve the ability of cognitive tests to discriminate the performance of adults with ADHD from non-ADHD controls. Continued

investigation of the battery approach to ADHD differential diagnosis appears to be the most likely route to creating a reliable diagnostic method for the deficits associated with ADHD throughout the lifespan.

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