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Working Memory, Processing Speed, and Academic Achievement in Adults with ADHD

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Abstract

In Barkley's (1997a, 1997b) model of attention-deficit/hyperactivity disorder (ADHD), he proposes that working memory deficits resulting from ADHD may cause impairments in reading comprehension. ADHD has been associated with poorer processing speed and working memory as well as academic underachievement in some studies. However, more research is needed examining the relationship between ADHD, working memory, processing speed, and academic achievement in adults to help elucidate the neuropsychological correlates of ADHD and their potential impact on academic functioning. The aim of the current study is to examine the relationship between ADHD, verbal working memory performance, processing speed, and academic achievement in adults as well as to investigate the academic achievement performance of potential subtypes of adult ADHD characterized by working memory deficits or processing speed deficits. Adult participants with and without ADHD were administered measures of verbal working memory and processing speed from the Wechsler Adult Intelligence Scale-Third Edition, as well as academic achievement measures from the Woodcock-Johnson Third Edition Tests of Achievement. The performance of adults with ADHD and controls were compared on measures of verbal working memory, processing speed, and academic achievement. Processing speed was also investigated as a potential mediator of ADHD status and academic achievement scores. Additionally, the academic achievement scores of ADHD adults with processing speed or verbal working memory deficits were compared to ADHD adults without those specific neuropsychological deficits as well as controls with and without those specific neuropsychological deficits. ADHD was associated with poorer performance on processing speed and academic fluency measures. However, ADHD and control groups did not differ in

their performance on verbal working memory composites or untimed measures of academic achievement. Processing speed was found to mediate the relationship between ADHD and academic fluency, and processing speed and working memory deficits were associated with poorer academic achievement performance in adults with ADHD and controls. These results are consistent with a view of ADHD as a heterogeneous condition with poorer processing speed being present in at least a subgroup of adults with ADHD and accounting in part for the relationship between ADHD and academic fluency.

Introduction

Attention-deficit/hyperactivity disorder (ADHD) is characterized by inattentive and/or hyperactive impulsive behaviors, which cause significant impairment in daily functioning (American Psychiatric Association, 2013). ADHD has traditionally been considered a childhood neurodevelopmental disorder; however, symptoms have been found to persist into adulthood (Barkley, Fischer, Smallish, & Fletcher, 2002). In a study by Kessler et al. (2010), approximately 46% of individuals, who self-reported having ADHD as a child, met criteria for ADHD in adulthood. Adults meeting criteria for ADHD were more likely to report having inattentive symptoms as opposed to hyperactive-impulsive symptoms as children and adults (Kessler et al., 2010). In the general population, the prevalence rate of ADHD in adults is estimated to be between 3-5% (Barkley, Murphy, & Fischer, 2008; Kessler et al., 2006).

The existence of adult ADHD is controversial. The diagnostic criteria are still debated, and more research investigating the neuropsychological profile of adult ADHD is needed. The *Diagnostic and Statistical Manual of Mental Disorders-IV-TR* (DSM-IV-TR; American Psychiatric Association, 2000) diagnostic criteria for ADHD have been commonly used to diagnose ADHD in adults. These criteria require that at least six out of nine inattentive symptoms and/or six out of nine hyperactive-impulsive symptoms be present over the past six months and cause significant impairment. Inattentive symptoms include the following: does not seem to listen when spoken to, often makes careless mistakes, has difficulty organizing tasks, frequently loses things, is often forgetful, is easily distracted, often fails to finish tasks, has difficulties with sustained attention, and avoids tasks requiring mental effort (American Psychiatric Association, 2000). Hyperactive-impulsive symptoms include frequently fidgeting, leaving his or her seat inappropriately, running and climbing inappropriately, being restless, difficulties playing quietly, talking excessively, interrupting others, difficulties waiting his or her turn, and blurting out answers before questions are completed (American Psychiatric Association, 2000). The *DSM-IV-TR* criteria also require that symptoms be present in more than one setting and before the age of seven (American Psychiatric Association, 2000). The *DSM-IV-TR* diagnostic criteria for ADHD were originally developed to aid clinicians in the diagnosis of children, and they have been criticized for lacking sensitivity in adults (Barkley, 1997a; Barkley, 1997b). The *Diagnostic and Statistical Manual-Fifth Edition* was published with revised ADHD diagnostic criteria that only require the presence of five inattention and/or five hyperactive-impulsive symptoms to diagnose ADHD in individuals over 16 years of age (American Psychiatric Association, 2013). The inattentive and hyperactive-impulsive symptoms of ADHD in the *DSM-IV-TR* and *DSM-V* are generally the same. The *DSM-V* requires the onset of ADHD symptoms before the age of twelve instead of seven. Obviously, this change in criteria will only increase the prevalence of ADHD diagnoses.

Research on adult ADHD has increased over the past decade (Alderson, Kasper, Hudec, & Patros, 2013; Hervey, Epstein, & Curry, 2004). The neuropsychological correlates of ADHD have been investigated extensively in children and are more recently being examined in adults with the disorder (Alderson et al., 2013; Hervey et al., 2004). Hervey et al. (2004) conducted a meta-analysis of 33 studies that examined the neuropsychological profile of adults with ADHD. Overall, adults with ADHD exhibited deficits in multiple cognitive domains, with more severe impairments noted on verbal tasks compared to visual tasks and on more complex tasks compared to simple tasks (Hervey et al., 2004).

Barkley (1997a, 1997b) has hypothesized that executive dysfunction is a key aspect of ADHD, and he has suggested that future criteria for ADHD should place a greater emphasis on executive dysfunction. Kessler et al.'s (2010) research supports the prominence of executive functioning deficits in adults with ADHD. Kessler et al.'s (2010) factor analysis of self-reported adult ADHD symptoms yielded three factors: (1) executive dysfunction, (2) inattentive-hyperactive symptoms, and (3) impulsive symptoms. Three symptoms which loaded on the executive dysfunction factor (i.e., "difficulty prioritizing work," "cannot complete tasks on time," and "makes careless mistakes") along with one inattentive-hyperactive symptom (i.e. "difficulty sustaining attention") were most helpful in identifying individuals who endorsed some childhood *DSM-IV-TR* ADHD symptoms and full *DSM-IV-TR* ADHD symptom criteria in adulthood. Additionally, two executive dysfunction symptoms (i.e. "difficulty prioritizing work," "trouble planning ahead") and two inattentive-hyperactive symptoms (i.e. "difficulty sustaining attention," "cannot work unless under a deadline") were the most effective items in identifying individuals who met full *DSM-IV-TR* ADHD criteria in both childhood and adulthood. Notably, the symptoms of executive dysfunction noted above were more specific to ADHD than the inattentive-hyperactive symptoms, as they were not predictive of other psychological disorders after controlling for the total number of ADHD symptoms endorsed. This study suggests further investigation of executive dysfunction in the diagnosis of ADHD is warranted.

In the *DSM-IV-TR* and *DSM-V*, several types of ADHD have been described (American Psychiatric Association, 2000; American Psychiatric Association, 2013). These include a combined presentation with both inattentive and hyperactive/impulsive symptoms, a predominantly inattentive presentation, and a predominantly hyperactive/impulsive presentation. Barkley (1997a, 1997b) argues that the predominantly inattentive presentation is qualitatively distinct from the other two types of ADHD and may be a different disorder characterized by impairments in processing speed. For ADHD combined presentation and ADHD predominantly hyperactive/impulsive type, Barkley (1997a, 1997b) has proposed a model of ADHD with response or behavioral inhibition as the primary impairment. According to Barkley (1997a, 1997b), behavioral or response inhibition includes preventing any response associated with immediate reinforcement, discontinuing the current response, and the blocking of external stimuli from hindering self-directed behaviors. Barkley (1997a, 1997b) suggested that a deficit in behavioral or response inhibition prevents proper executive functioning in individuals with ADHD.

Executive functioning is described by Barkley as the "mainly private (cognitive) self-directed actions that contribute to self-regulation" (Barkley, 1997b, p. 68). Behavioral inhibition and executive functioning are likely frequently employed in activities involving competing immediate rewards and delayed rewards, problem solving, and delays in time (Barkley, 1997a, 1997b). Barkley (1997a, 1997b) has identified four domains of executive functioning which he believes are negatively impacted by impairments in behavioral inhibition. These four executive functions include self-regulation of affect/motivation/arousal, internalization of speech, working memory, and reconstitution (Barkley, 1997a, 1997b). Self-regulation of affect, motivation, and arousal refers to one's ability to self-regulate emotional responses and create "motivational and arousal states that support the execution of goal-directed actions and persistence toward the goal" (Barkley, 1997b, p. 74). Internalization of speech allows individuals to create and follow rules as well as describe, question, and reflect (Barkley, 1997a, 1997b). Working memory is the ability to hold information in mind for manipulation and/or later use (Barkley, 1997a, 1997b). In Barkley's (1997a, 1997b) model, working memory allows for hindsight, foresight, and the ability to perceive time, organize information in time, and imitate complicated responses. Reconstitution includes the ability to analyze (break down into smaller parts) and synthesize (put together in a different way) messages and behavioral responses (Barkley, 1997a, 1997b).

Barkley (1997a, 1997b) proposed that deficits in the executive functions result in a reduced ability to monitor and perform motor responses and goal-directed behavior. Behavioral inhibition also directly influences the motor control system in Barkley's model (1997a, 1997b). Barkley (1997a; 1997b) made many hypotheses regarding the outcomes of these executive functioning deficits in individuals with ADHD. One of these hypotheses is that nonverbal and verbal working memory deficits can result in impaired reading comprehension (Barkley, 1997a). Research has provided some support for the links hypothesized by Barkley (1997a; 1997b) between ADHD, working memory, and reading comprehension.

ADHD and Executive Functioning

Barkley's (1997a, 1997b) model suggests that there is a relationship between executive dysfunction and ADHD, and the empirical literature has generally supported that postulate (Biederman et al., 2004; Biederman et al., 2006; Hervey et al., 2004; Nigg et al., 2005a; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Willcutt, Doyle, Nigg, Faraone, & Pennington (2005) conducted a meta-analysis of studies investigating the association between ADHD and executive functioning in children and adolescents. Overall, Willcutt et al.'s (2005) study yielded small to medium effect sizes (d = .43-.69) of ADHD on various measures of executive functioning performance. Adult ADHD has also generally been associated with executive functioning deficits; however, some studies have not found significant results (Biederman et al., 2006; Gropper & Tannock, 2009; Hervey et al., 2004; Nigg et al., 2005a; Rohlf et al., 2012). Nigg et al. (2005a) propose several reasons for these discrepant findings including small sample sizes and limited power in some studies, insufficient reliability of scores, failure to parse out various components of executive functioning, and the inclusion of individuals with comorbid psychopathology and ADHD. Additionally, it has been suggested that executive functioning deficits or other neuropsychological deficits may only be present in particular subgroups of individuals with ADHD with substantial overlap in neuropsychological performance between ADHD and control groups (Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005b). Nigg et al. (2005a) reported that adults with ADHD had significantly different empirically-derived executive functioning composite scores compared to controls, even after controlling for IQ and comorbid psychopathology. ADHD inattentive-disorganized symptoms were significantly related to executive functioning deficits, while ADHD hyperactive-impulsive symptoms were not (Nigg et al., 2005a). Nigg et al.'s (2005a) executive functioning composite score did not sufficiently assess the working memory component of executive functioning, and as such, the role of working memory deficits contributing to executive dysfunction could not be ascertained.

Several meta-analyses have investigated the performance of adults with ADHD and controls on executive functioning tasks and other neuropsychological measures (Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005; Hervey et al., 2004; Schoechlin & Engel, 2005) with one meta-analysis exclusively examining the working memory performance of controls and adults with ADHD (Alderson et al., 2013) (See Table 1). Schoechlin and Engel (2005) conducted a meta-analysis with 24 studies that compared the neuropsychological functioning of ADHD and control groups. Effect sizes in the various neuropsychological domains examined ranged from small to medium. Overall adults with ADHD performed significantly worse than controls in all neuropsychological domains examined except executive functions and figural memory. The executive functions domain included a measure of set shifting and hypothesis testing (i.e. Wisconsin Card Sorting Test) as well as a measure of planning (i.e., Tower of Hanoi). Hervey et al.'s (2004) meta-analysis yielded medium effect sizes of ADHD on a timed verbal fluency test (i.e., Controlled Oral Word Association Test) and a timed executive functioning measure requiring visual scanning, set shifting, and psychomotor speed (i.e., Trail Making Test B), while the effect size of ADHD on an untimed executive functioning measure (i.e., Wisconsin Card Sorting Test) was minimal.

Table 1. Results of four meta-analyses investigating the relationship between ADHD and neuropsychological functioning, including executive functioning and working memory, in adults.

Study	Population	Domain or Measure	Effect Size
Alderson et al., 2013	Adults (at least 18 years old)	Phonological working memory Visual-spatial working memory	Hedge's *g* = .55 Hedge's *g* = .49
Schoechlin & Engel, 2005	Individuals aged 16 years and older Mean age = 31 years	Verbal intelligence Executive functions Visual/Verbal Fluency Visual/figural problems solving Abstract problem solving/WM Simple attention Sustained attention Focused attention Verbal memory Figural memory	Cohen's *d* = .27 Cohen's *d* = .21 Cohen's *d* = .52 Cohen's *d* = .26 Cohen's *d* = .51 Cohen's *d* = .38 Cohen's *d* = .52 Cohen's *d* = .55 Cohen's *d* = .56 Cohen's *d* = .18

(Table 1 continued)

Study	Population	Domain or Measure	Effect Size
Boonstra et al., 2005	Adults	Verbal Fluency	Cohen's *d* = .62
		Digit Span Forward	Cohen's *d* = .29
		Digit Span Backward	Cohen's *d* = .44
		Word Reading (Stroop)	Cohen's *d* = .60
		Color Naming (Stroop)	Cohen's *d* = .62
		Stroop Color Word (Inhibition)	Cohen's *d* = .89
		Stroop Interference	Cohen's *d* = .13
		Trail Making Test A	Cohen's *d* = .46
		Trail Making Test B	Cohen's *d* = .65
		CPT attentiveness	Cohen's *d* = .55
		CPT commissions (Inhibition)	Cohen's *d* = .64
		CPT risk taking	Cohen's *d* = .22[a]
		CPT response speed	Cohen's *d* = .03[a]
		CPT response consistency	Cohen's *d* = .57
		CPT omissions (attention)	Cohen's *d* = .50
Hervey et al., 2004	Adults (at least 18 years old)	Executive Functioning Domain	
		Trail Making Test – Part B	Cohen's *d* = .68
		WCST – categories completed	Cohen's *d* = .02[a]
		WCST perseverative errors	Cohen's *d* = .12
		COWAT	Cohen's *d* = .60
		Processing Speed and Motor Speed	
		CCPT RT	Cohen's *d* = .04
		CPT Vigilance RT	Cohen's *d* = .21
		CPT Distraction RT	Cohen's *d* = .36
		Trail Making Test Part A	Cohen's *d* = .53
		Word Reading (Stroop)	Cohen's *d* = .23
		Color Naming (Stroop)	Cohen's *d* = .30
		WAIS-R measures	
		Estimated Full Scale IQ	Cohen's *d* = .39
		Vocabulary subtest	Cohen's *d* = .29
		Arithmetic subtest	Cohen's *d* = .50
		Digit Span subtest	Cohen's *d* = .31
		Block Design subtest	Cohen's *d* = .35
		Digit Symbol subtest	Cohen's *d* = .62

Note. CCPT = Conners' Continuous Performance Test; CPT = Continuous Performance Test; COWAT = Controlled Oral Word Association Test; RT = reaction time; WAIS-R = Wechsler Adult Intelligence Scale – Revised; WCST = Wisconsin Card Sorting Test; WM = Working Memory

[a]ADHD individuals exhibited better performance than controls.

Two meta-analyses (Boonstra et al., 2005; Hervey et al., 2004) compared the performance of controls and adults with ADHD on working memory measures from the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III; Wechsler, 1997a) and Wechsler Memory Scale-Third Edition (WMS-III; Wechsler, 1997b). In Hervey et al.'s (2004) meta-analysis, the relationship between ADHD and Digit Span subtest performance yielded a Cohen's *d* effect size of 0.31. The Cohen's *d* effect size of ADHD on the WAIS-III Arithmetic subtest, a measure of verbal working memory and math skills, was 0.50. Boonstra et al. (2005) also conducted a meta-analysis and found controls exhibited better performance on the WAIS-III Digit Span forward and backwards tasks compared to individuals with ADHD (Cohen's *d* effect sizes of 0.29 and 0.44, respectively).

Researchers have also investigated the relationship between ADHD and the WAIS-III Working Memory Index (Stearns, Dunham, McIntosh, & Dean, 2004; Wechsler, 1997a). On the WAIS-III, a higher percentage of individuals with ADHD (30%) than controls (13%) were found to have Working Memory Index scores one standard deviation or more below their WAIS-III Verbal Comprehension scores (Wechsler, 1997a). A study by Stearns, Dunham, McIntosh, and Dean (2004) that included 70 adults with ADHD revealed self-reported ADHD symptoms were not significantly associated with WAIS-III Working Memory Index performance. In their study, medicated and unmediated adults with ADHD did not have significantly different WAIS-III Working Memory Index scores.

Alderson et al. (2013) conducted a meta-analysis including 38 studies which examined the working memory performance of adults with ADHD compared to controls. Phonological working memory and visual-spatial working memory were evaluated separately. Hedge's *g* effect sizes for group membership (ADHD versus controls) on phonological working memory performance ranged from -.39 to 2.34. The ADHD group performed more poorly than controls with a mean medium effect size of 0.55. The gender distribution of the samples and age were not significantly associated with effect size. For phonological working memory tasks, fewer trials were associated with smaller effect sizes, leading Alderson et al. (2013) to question whether tasks such as the Wechsler Adult Intelligence Scale Digit Span have sufficient trials to capture deficits in working memory related to ADHD. Hedge's *g* effect sizes for group membership (ADHD versus controls) on visual-spatial working memory performance ranged from -.21 to 1.12, with a mean small effect size of 0.49. Consistent with Hervey et al. (2004), there was a larger working memory effect size between the groups on verbal/phonological tasks than on visual-spatial tasks.

Overall, research supports an association between ADHD and performance on executive functioning and working memory measures in children as well as adults (Alderson et al., 2013; Biederman et al., 2004, 2006; Boonstra et al., 2005; Hervey et al., 2004; Nigg et al., 2005a; Rohlf et al., 2012; Willcutt et al., 2005). Adults with ADHD have performed more poorly than controls on several measures of executive functioning and working memory, including the WAIS-III Digit Span and Arithmetic subtests. Effect sizes of ADHD on various executive functioning and working memory measures generally ranged from small to medium with only performance on the Stroop Color Word task, a measure of inhibition, yielding a large effect size (Boonstra et al. 2005). In the working memory domain specifically, larger effect sizes were found for phonological memory tasks than visual-spatial memory tasks. Studies generally revealed small to medium effect sizes of ADHD on traditionally administered working memory tasks (Alderson et al., 2013; Hervey et al., 2004).

ADHD and Processing Speed

Boonstra et al.'s (2005) meta-analysis comparing the neuropsychological functioning of controls and ADHD adults yielded comparable effect sizes for executive functioning (Cohen's *d* = 0.40) and non-executive functioning measures (Cohen's *d* = 0.43), suggesting deficits associated with ADHD are likely not specific to the executive functioning domain. In addition to executive functioning, ADHD has also been associated with slowed cognitive processing speed, assessed using a variety of timed measures including Stoop Color and Word, Trail Marking Test A, and the WAIS-III Digit Symbol subtest (Boonstra et al., 2005; Shanahan et al., 2006). Trail Making Test A (Reitan, 1955) is a measure of visual-spatial scanning and psychomotor speed. Two meta-analyses found that control groups outperformed ADHD groups on the Trail Making Test A yielding Cohen's *d* effect sizes of 0.53 and 0.46 (Hervey et al., 2004; Boonstra et al., 2005). The Stroop Word and Stroop Color tasks require individuals to read color names and name colors as quickly as possible. Meta-analyses revealed that adults with ADHD performed more poorly on the Stroop Word and Color tasks than controls with mean Cohen's *d* effect sizes of 0.60 and 0.23 for the Stroop Word condition and 0.62 and 0.30 for the Stroop Color condition. ADHD adults also performed more poorly than controls on the WAIS-R Digit Symbol subtest, a measure of processing speed, yielding a Cohen's *d* effect size of 0.62 (Hervey et al., 2004). While adults with ADHD performed more poorly than controls on the aforementioned processing speed tasks, no significant differences in performance were found between controls and ADHD adults on a task of reaction time with limited cognitive processing required (i.e., Conners' Continuous Performance Test Reaction Time measure) (Boonstra et al., 2005; Hervey et al., 2004). Overall, examining processing speed performance between ADHD and control groups yielded small to medium effect sizes, with adults with ADHD having poorer performance on tasks that require more complex cognitive demands than simple reaction time measures.

Effects of ADHD Medication on Neuropsychological Functioning

Stimulant medications, including amphetamine and methylphenidate, have been used to treat ADHD in children and adults. Researchers have investigated the effect of these ADHD medications on neuropsychological functioning, and although these medications appear to have a positive effect on sustained attention, they have not been shown to consistently improve neuropsychological functioning or academic achievement (Advokat, 2010; Aron, Dowson, Sahakian, & Robbins, 2003; Barkley & Cunningham, 1978; Barrilleaux & Advokat, 2009; Turner, Blackwell, Dowson, McLean, & Sahakian, 2005). Aron et al. (2003) found medication was associated with significantly faster stop signal reaction times but no differences in performance on a measure of discrimination and no-signal reaction times. In a study by Riordan et al. (1999), adults with ADHD exhibited significant improvements in auditory working memory and processing speed after receiving a trial of methylphenidate, while there was no significant change in processing speed or auditory working memory scores of a control group. On the Paced Auditory Serial Addition Task (PASAT), a measure of executive functioning including working memory, adults with ADHD were significantly more accurate when taking methylphenidate and had comparable performance to control individuals, while the ADHD group's scores without medication were significantly poorer than controls (Schweitzer et al., 2004). Overall, stimulant medications have been associated with improved performance in sustained attention, as well as on some auditory working memory and processing speed tasks; however, robust, consistent improvements in neuropsychological or executive functioning have not been demonstrated (Advokat, 2010).

ADHD and Academic Achievement

Researchers have documented a link between ADHD and academic underachievement in reading, mathematics, and writing skills (Barry, Lyman, & Klinger, 2002; Frazier, Youngstrom, Glutting, & Watkins, 2007; Frick et al., 1991; Loe & Feldman, 2007; Norwalk, Norvilitis, & MacLean, 2009; Rabiner, Coie, & The Conduct Problems Prevention Group, 2000). Frazier, Youngstrom, Glutting, & Watkins (2007) examined mostly studies with children but also a few with adults and found a medium effect size (d = .71) for the relationship between ADHD and academic achievement. Larger effect sizes were observed at younger ages and in the content domain of reading (Frazier et al., 2007). In children, ADHD has been associated with academic underachievement in reading, writing, and mathematics skills. Children with inattention problems in the first grade were at an increased risk of exhibiting reading underachievement in fifth grade, compared to those without such problems (Barry et al., 2002; Rabiner et al., 2000).

Moreover, adolescents and adults with ADHD have demonstrated poorer academic performance on a variety of outcome measures including lower graduation rates, lower high school GPAs, lower ACT scores, and a decreased likelihood of attending college (Frazier et al., 2007; Loe & Feldman, 2007; Norwalk et al., 2009). Additionally, ADHD in college students was associated with poorer self-reported performance on assignments (Cohen's d = 0.686), lower college GPAs, and an increased likelihood of being on probation in college and withdrawing from college classes (Advokat, Lane, & Luo, 2011; Heiligenstein, Guenther, Levy, Savino, & Fulwiler, 1999; Weyandt et al., 2013). In a study by

Lewandowski, Lovett, Codding, and Gordon (2008), a higher percentage of adults with ADHD than controls reported having difficulty completing timed tests (ADHD: 64.9%, controls: 28.6%), requiring more time to complete assignments than peers (ADHD: 78.4%, controls: 30.0%) and having difficulties on timed standardized tests (ADHD: 67.7%; controls: 45.4%). Regarding performance on standardized measures, self-referred adults who received ADHD diagnoses were found to perform more poorly than clinical and community controls on the Wide Range Achievement Test-Third Edition (WRAT-III) Spelling and Math subtests and the Nelson-Denny reading comprehension measure but not the WRAT-III Reading subtest (Barkley, Murphy, & Fischer, 2008).

Overall, ADHD has been associated with poorer academic achievement in children, adults, and college students. Medium effect sizes of ADHD on academic achievement have been noted in the literature. Academic achievement measures have included grade point averages, educational attainment, and standardized test scores in spelling, reading, and math. Deficits in fundamental cognitive processes such as executive functioning have been hypothesized as potential explanations for the lower performance of individuals with ADHD in academic achievement given the relationship between cognitive processes and academic achievement described below.

Executive Functioning/Working Memory and Academic Achievement

Executive dysfunction in children, adolescents, and adults with and without ADHD has been associated with academic difficulties, even after controlling for learning disabilities and IQ (Biederman et al., 2004; Biederman et al., 2006). Children and adolescents with ADHD and executive dysfunction were found to perform more poorly on academic achievement measures (e.g., Wide Range Achievement Test Math and Reading subtests) than three comparison groups (individuals with ADHD without executive dysfunction, individuals without ADHD with executive dysfunction, and controls) (Biederman et al., 2004). Individuals without ADHD or executive dysfunction obtained significantly higher academic achievement scores than the three other groups. Even after statistically accounting for IQ differences, children and adolescents with ADHD and executive dysfunction obtained lower scores on the Wide Range Achievement Test-Revised (WRAT-R) subtests than children and adolescents with ADHD without executive dysfunction (Biederman et al., 2004). Adults with ADHD and executive dysfunction performed more poorly on the Wide Range Achievement Test-Third Edition (WRAT-III) Reading and Math subtests than control adults and adults with ADHD but no executive dysfunction (Biederman et al., 2006). Among adults with ADHD, those with executive dysfunction performed more poorly in math and reading compared to those without executive dysfunction. Differences in math between the two groups were still significant after controlling for IQ, but the differences in reading between the groups were no longer significant after controlling for IQ (Biederman et. al., 2006). Additionally, repeating a grade was more common in the group of adults who had ADHD with executive dysfunction compared to the group with ADHD without executive dysfunction (Biederman et al., 2006).

In Barkley's (1997a) model of ADHD, he proposes that deficits in working memory negatively affect reading comprehension performance among individuals with ADHD. Consistent with Barkley's (1997a) model, other researchers have found a relationship between working memory deficits and poorer academic achievement scores (Alloway & Alloway, 2010; Biederman et al., 2006; Macaruso & Shankweiler, 2010; Rohde & Thompson, 2007; Swanson & Kim, 2007). In a sample of children and adults with and without learning disabilities, working memory performance was significantly positively correlated with WRAT-R scores in Reading, Math, and Spelling, as well as Peabody Individual Achievement Test-Revised (PIAT-R) scores in Math, Reading Recognition, and Reading Comprehension (Swanson, 1994). In participants without learning disabilities, significant positive correlations remained between working memory performance and the WRAT Math, PIAT-R Math, and PIAT-R Reading Comprehension scores, even after controlling for intelligence using the Peabody Picture Vocabulary Test-Revised (Swanson, 1994). In the participants with learning disabilities, working memory performance remained significantly correlated with WRAT-R Math and Spelling scores and PIAT-R Math, Reading Recognition, and Reading Comprehension scores even after controlling for intelligence (Swanson, 1994). In Macaruso and Shankweiler's (2010) study, Digit Span performance was significantly related to reading comprehension, decoding, listening comprehension, and oral vocabulary in community college students. Digit span performance and Spoonerism (i.e., a task requiring the manipulation of sounds in words) performance were the best predictors in determining whether community college students had been classified as less skilled or average readers. In a study by Rohde and Thompson (2007), the Operation Span task, a working memory task, did not make any significant independent contributions in predicting WRAT-III scores, GPA, or Scholastic Achievement Test scores among undergraduate college students beyond the variance accounted for by measures of general cognitive functioning, processing speed, and spatial ability.

Overall, poorer executive functioning including verbal working memory performance appears to be associated with lower academic performance in children and adults. These findings provide support for Barkley's (1997) model which posits that deficits in working memory performance negatively impact reading comprehension performance. However, Rohde and Thompson's (2007) study suggests that other cognitive processes including processing speed may also be impacting academic achievement performance.

Processing Speed and Academic Achievement

The relationship between processing speed and academic performance has been investigated mostly in children although there are a few studies with adults. Reading, math, and written language scores are associated with processing speed in children. In a study by Plaza and Cohen (2005), children were administered processing speed tasks in different modalities: auditory-verbal modality with a phoneme elision task; visual-verbal modality with digit naming, letter naming, and color naming tasks; visual-visual modality with a visual-matching task, and visual modality with a visual attention task. Poor readers performed significantly worse on the phoneme elision, digit naming, letter naming, color naming; and visual-matching tasks but not the visual attention task. A written language composite score was significantly correlated with digit naming (r = .57), letter naming (r = .64), color naming (r =.49), visual attention (r = .32), phoneme elision (r = .80), and Coding (r = .35) (Plaza & Cohen, 2005). Catts, Gilispie, Leonard, Kail, & Miller (2002) also found that normal-IQ poor readers performed significantly worse than good readers on motor, lexical, grammatical, and phonological processing speed tasks. In a study by Christopher et al. (2012), processing speed was found to significantly predict word reading even after controlling for IQ in children aged eight to sixteen when ADHD individuals were included and when they were not. Reading comprehension was also predicted by processing speed (Christopher et al., 2012). Additionally, Fuchs et al. (2006) found processing speed was a significant predictor of arithmetic performance in third-grade students. Similarly, processing speed was significantly associated with mathematical ability among children with mean ages of seven and ten (Berg, 2008; Bull & Johnston, 1997). When controlling for reading ability, processing speed was found to be a better predictor of math ability than short-term memory (Bull & Johnston, 1997).

Few studies have investigated the relationship between processing speed and academic performance in adults. In a study by Rhode and Thompson (2007), processing speed was a significant predictor of SAT math scores as well as SAT combined verbal and math scores in college students. Additionally, college students with dyslexia performed significantly worse than controls on a measure of processing speed (i.e. WAIS-R Digit Symbol, Cohen's d = .89) although the groups had comparable scores on the WAIS-R Vocabulary subtest and a measure of non-verbal ability (Hatcher, Snowling, & Griffiths, 2002).

Research in children has generally demonstrated that slowed processing speed is related to poorer performance in reading, math, and written language. Studies in adults also suggest there is a positive relationship between processing speed and academic achievement. It is still unclear, however, if slowed processing speed accounts for the relationship between ADHD and academic achievement.

Potential Mediators of ADHD and Academic Achievement

Researchers have begun investigating potential mechanisms through which ADHD is related to poorer academic performance. Conduct problems have been examined as a potential underlying variable (Frick et al., 1991; Rapport, Scanlan, & Denney, 1999). While conduct disorder is often comorbid with ADHD, conduct problems do not appear to account for the relationship between academic underachievement and ADHD in children (Frick et al., 1991; Rapport et al., 1999). Consequently, relieving behavioral problems is unlikely to result in a remediation of academic difficulties in individuals with ADHD (Daley & Birchwood, 2010; Frick et al., 1991).

Semantic language and verbal working memory have also been examined as potential mediators between ADHD and academic achievement. In children with a mean age of 10 years, Gremillion and Martel (2012) found that semantic language as measured by Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) Vocabulary scores fully mediated the relationship between ADHD symptoms and reading comprehension, as well as partially mediated the association between ADHD symptoms and math reasoning. Additionally, verbal working memory performance as measured by the Digit Span backward subtest of the WISC-IV partially mediated the relationship between ADHD symptoms and math reasoning; however, verbal working memory did not mediate the relationship between ADHD symptoms and reading comprehension. When data from younger (age 6-9) and older children (age 10-12) were analyzed separately, findings were unchanged except for verbal working memory fully mediating the relationship between ADHD symptoms and reading achievement in younger children. As children age, the role of verbal working memory in reading comprehension may possibly become less important. When models with multiple mediators were examined, semantic language and verbal working memory fully mediated the relationship between ADHD and reading achievement and partially mediated the association between ADHD and math achievement. Results of mediation analyses did not change when ADHD inattentive and hyperactive-impulsive symptoms were analyzed separately.

Research examining working memory as a mediator between ADHD and academic performance has focused primarily on children and adolescent populations (Daley &

Birchwood, 2010; Gremillion & Martel, 2012; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). Rogers, Hwang, Toplak, Weiss, & Tannock (2011) investigated whether working memory deficits mediated the association between inattention symptoms and academic achievement in adolescents referred for ADHD evaluations. Auditory verbal working memory performance on the WISC-IV Digit Span and Letter-Number Sequencing subtests was found to mediate the relationship between teacher-rated inattention symptoms and academic achievement in reading and mathematics based on Woodcock-Johnson Third Edition Tests of Achievement (WJ-III) scores (Rogers et al., 2011). Auditory working memory performance accounted for approximately 35-40% of the variance in academic achievement scores.

One pilot study has examined the relationship between ADHD, working memory, and academic achievement in adults (Gropper & Tannock, 2009). In Gropper and Tannock's (2009) study, college students with ADHD were found to have completed fewer years of education than controls; however, the college GPAs of the ADHD and control groups did not differ significantly. College students with ADHD performed more poorly than controls on the WAIS-III Digit Span subtest, Paced Auditory Serial Addition Test, and the Cambridge Neuropsychological Testing Automated Battery (CANTAB) Spatial Span Backward subtest but not the Letter Number Sequencing subtest or the CANTAB Spatial Span Forward subtest. A significant correlation was found between GPA and auditory working memory but not GPA and visual-spatial working memory. Limitations of Gropper and Tannock's (2009) study included a small sample size (N = 46) and the absence of academic achievement measures investigating specific content domains.

Jacobson et al. (2011) examined the influence of processing speed on reading fluency among children with ADHD. ADHD was associated with slower processing speed on the Wechsler Intelligence Scale for Children – Integrated Processing Speed Index. ADHD was also associated with significantly poorer performance on two reading fluency measures. A processing speed measure controlling for motor output significantly predicted the two reading fluency measures on which children with ADHD performed more poorly.

Rationale for Present Study

ADHD has been associated with poorer verbal working memory and processing speed in children and adults. ADHD has also been correlated with poorer academic performance across the life span. Semantic language and verbal working memory have been identified as mediators between ADHD and academic achievement in children; however, it is unclear whether working memory or some other neurocognitive variable like processing speed account for the relationship between ADHD and academic performance in adults. The presence of working memory or processing speed deficits may increase the likelihood that an adult with ADHD will have academic difficulties; however, more research is needed (Daley & Birchwood, 2010). Identifying whether working memory or processing speed performance accounts for the association between ADHD and academic achievement scores could have implications for the identification and/or development of intervention strategies for adults with ADHD (Daley & Birchwood, 2010). Thus, the present study sought to examine the relationship between ADHD, verbal working memory, processing speed, and academic achievement in adults.

Research Questions and Hypotheses

Research Question 1

Do adults with ADHD exhibit poorer verbal working memory performance than adults without ADHD?

Hypothesis 1

It was hypothesized that adults with ADHD would have significantly poorer verbal working memory scores than adults without ADHD.

Research Question 2

Do adults with ADHD exhibit poorer academic achievement scores in reading, math, and written language than adults without ADHD?

Hypothesis 2

It was hypothesized that adults with ADHD would have significantly poorer academic achievement scores than adults without ADHD.

Research Question 3

What is the relationship between verbal working memory performance and academic achievement scores in adults self-referred for psychoeducational evaluations?

Hypothesis 3

It was hypothesized that verbal working memory performance would be significantly positively correlated with academic achievement scores.

Research Question 4

Does verbal working memory performance mediate the relationship between ADHD and academic achievement scores in adults? (See Figure 1)

Hypothesis 4

It was hypothesized that verbal working memory performance would mediate the relationship between ADHD and academic achievement scores.

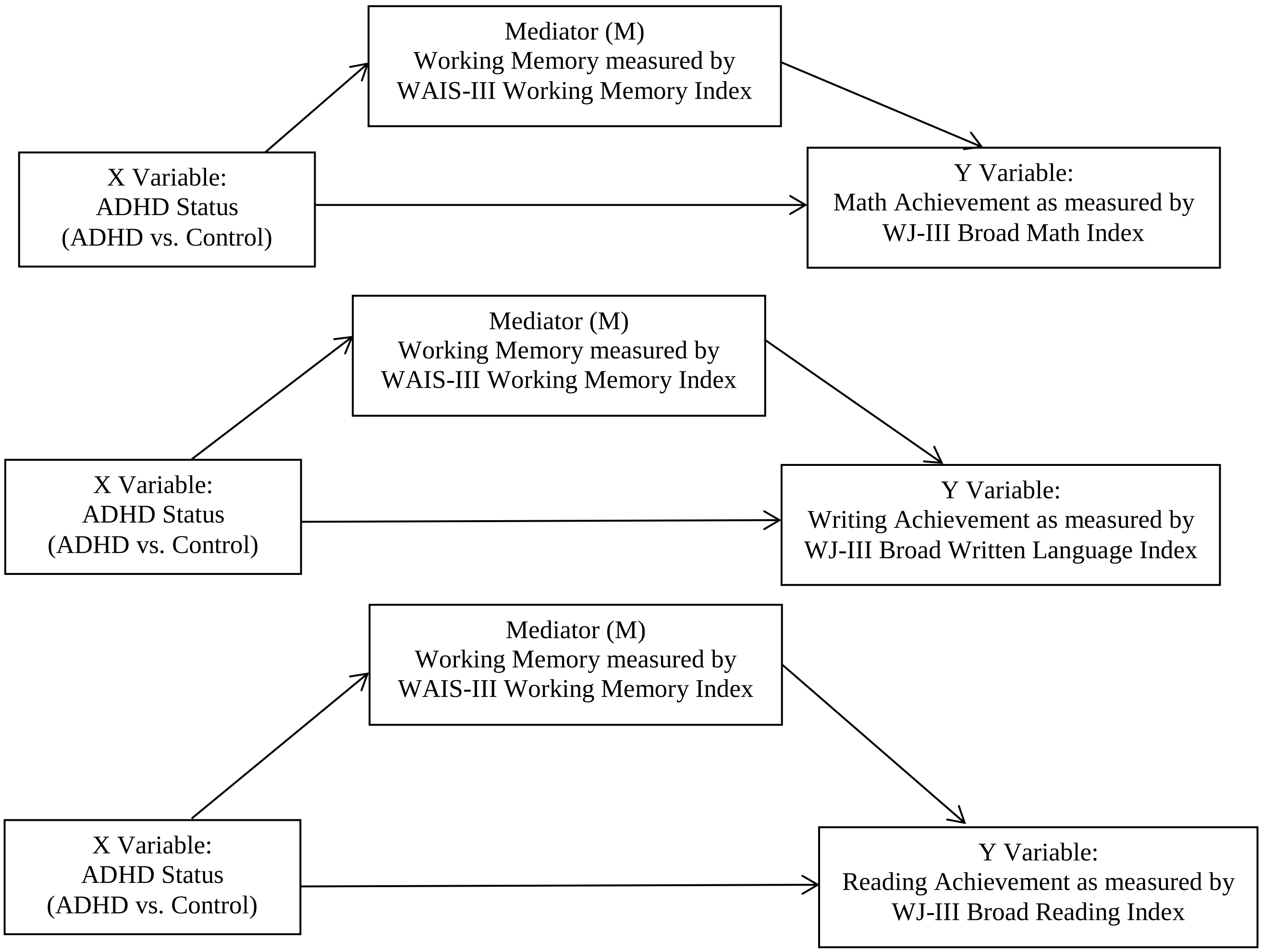

Figure 1. Examining working memory as a mediator between ADHD and academic achievement scores.

Research Question 5

Does academic achievement performance differ based on working memory performance and the presence or absence of an ADHD diagnosis?

Hypothesis 5

It was hypothesized that adults with ADHD and verbal working memory deficits would perform more poorly on academic achievement measures than adults with ADHD without verbal working memory deficits.

Research Question 6

Does academic achievement performance differ based on processing speed performance and the presence or absence of an ADHD diagnosis?

Hypothesis 6

It was hypothesized that adults with ADHD and processing speed deficits would perform more poorly on academic achievement measures than individuals with ADHD without processing speed deficits.

Research Question 7a

Do adults with ADHD exhibit poorer processing speed performance than adults without ADHD?

Hypothesis 7a

It was hypothesized that adults with ADHD would have significantly lower scores on the WAIS-III Processing Speed Index than adults without ADHD.

Research Question 7b

What is the association between processing speed performance and academic achievement scores in adults?

Hypothesis 7b

It was hypothesized that WAIS-III Processing Speed Index scores would be significantly positively correlated with WJ-III academic achievement scores.

Research Question 7c

Does processing speed performance mediate the relationship between ADHD and academic fluency in adults? (See Figure 2)

Hypothesis 7c

It was hypothesized that processing speed performance, as measured by the WAIS-III Processing Speed Index, would mediate the relationship between ADHD and academic fluency, as measured by WJ-III Reading Fluency, Math Fluency, and Writing Fluency scores.

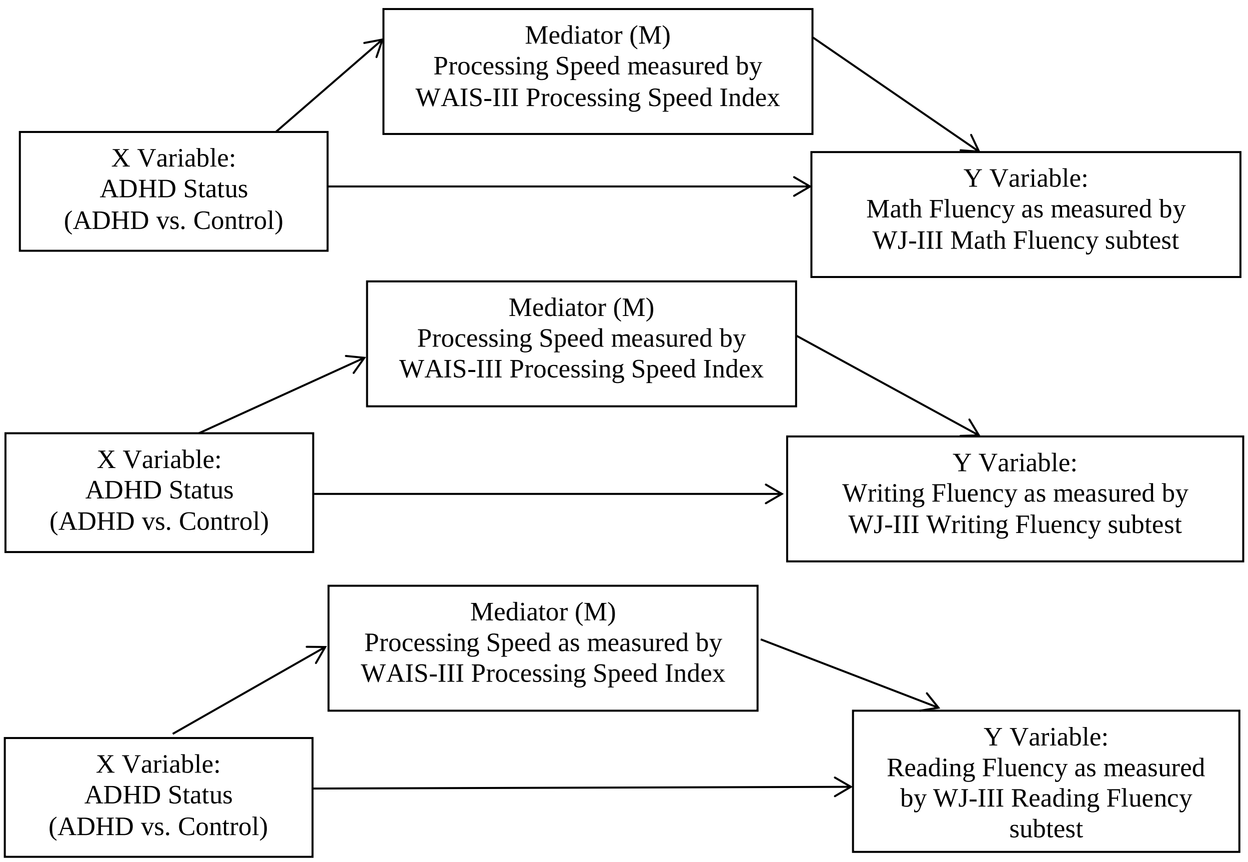

Figure 2. Examining processing speed as a mediator between ADHD and academic fluency.

Methods

Participants and Procedures

Participants included individuals who received psychoeducational evaluations at the Louisiana State University Psychological Services Center (LSU PSC) from 2000 to 2012. Participants were evaluated by trained clinical psychology doctoral students, who were supervised by a licensed clinical neuropsychologist. Participants signed an informed consent form and gave specific permission for their data to be used for archival research. This study was also approved by the LSU Institutional Review Board (See Appendix). After informed consent was obtained, participants were administered a standard psychoeducational battery that included measures of intellectual functioning, memory, attention and concentration, academic achievement, and psychopathology. Participants were administered the Wechsler Adult Intelligence Scales-Third Edition (WAIS-III; Wechsler, 1997a) and the Woodcock-Johnson Third Edition Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001) as part of the standard assessment of intellectual functioning and academic achievement, respectively. Additionally, the psychoeducational battery included several embedded validity indices, namely, the Reliable Digit Span (Greiffenstein, Baker, & Gola, 1994), Rarely Missed Index (Killgore & DellaPietra, 2000), Vocabulary minus Digit Span, and the Mittenberg Index (Mittenberg, Theroux-Fichera, Zielinski, & Heilbronner, 1995). The psychoeducational evaluations conducted at the LSU PSC typically lasted six to eight hours and were generally completed in one day. Participants were not taking stimulant medications on the day of testing. After the evaluation was completed, participants received *DSM-IV-TR* diagnoses via consensus of a clinical team under the direction of a licensed clinical neuropsychologist.

Individuals were excluded from this study if they were under the age of 18 or over the age of 35 at the time they were evaluated, failed two or more of the available validity indices calculated from the standard psychoeducational battery, had a known neurological disorder, or were diagnosed with learning disabilities or psychopathology other than ADHD or an Adjustment Disorder. Individuals were also excluded from Research Questions 1 through 4 and 7 if they had WAIS-III FSIQ scores below 76 to rule out individuals that may have an intellectual disability. Failure of validity indices was defined as a score of less than seven on the Reliable Digit Span (Greiffenstein et al., 1994), a score greater than 0.6 on the Mittenberg Index (Mittenberg et al., 1995), a Vocabulary minus Digit Span scaled score greater than five (Mittenberg et al., 1995), or a Rarely Missed Items Index score less than 136 (Killgore & DellaPietra, 2000). *DSM-IV-TR* diagnostic criteria for an Adjustment Disorder include behavioral or emotional symptoms experienced after a stressor that cause significant impairment in excess of what would be expected (American Psychiatric Association, 2000). The type of adjustment disorder depends on the symptoms experienced. Diagnoses include Adjustment Disorder with Depressed Mood, Adjustment Disorder with Mixed Anxiety and Depressed Mood, Adjustment Disorder with Disturbance of Conduct, Adjustment Disorder with Mixed Disturbance of Emotions and Conduct, and Adjustment Disorder Unspecified. Individuals diagnosed with anxiety, mood, and psychotic disorders, as well as learning disorders were excluded from all analyses because symptoms of those disorders may negatively impact verbal working memory, processing speed, and academic achievement. The inclusion of adults with adjustment disorders increases the external validity of the study by adding variability to a control group that would otherwise consist of individuals referred for psychoeducational evaluations who received no diagnoses. The symptoms experienced by those with adjustment disorders are likely to be less severe and have less of an impact on verbal working memory and processing speed than the symptoms experienced by adults with anxiety, mood, and/or psychotic disorders.

Participant Characteristics for Research Question 1 (Will adults with ADHD exhibit poorer verbal working memory performance than adults without ADHD?)

Participants with WAIS-III scores were categorized into two groups based on their diagnoses: ADHD group (n = 187) and control group (n = 222). The ADHD group included adults with an ADHD diagnosis only or ADHD and an adjustment disorder diagnosis. The control group included adults with no diagnosis or an adjustment disorder diagnosis only. Independent samples t tests revealed the groups differed significantly in age, $t(407) = 2.12$, $p = 0.035$, and education, $t(407) = 2.20$, $p = 0.028$. The control group ($M = 21.92$, $SD = 3.84$) was significantly older than the ADHD group ($M = 21.17$, $SD = 3.19$), and the control group ($M = 14.00$, $SD = 1.93$) had significantly more years of education than the ADHD group ($M = 13.60$, $SD = 1.60$). Additionally, chi-square tests revealed the ADHD and control groups differed significantly in gender, $\chi^2(1, N = 409) = 5.98$, $p = .014$, and race/ethnicity, $\chi^2(4, N = 409) = 11.17$, $p = .025$. The control group had a higher percentage of males than females, while the ADHD group had a higher percentage of females than males. There were more Hispanic participants in the ADHD group than the control group (See Table 2).

Table 2. Participant characteristics for Research Question 1.

	ADHD group (n = 187)	Control group (n = 222)	Significance
	% (n)	% (n)	
Gender			
Males	46% (86)	58% (129)	$p = .014$
Females	54% (101)	42% (93)	

(Table 2 continued)

	ADHD group (n = 187)	Control group (n = 222)	Significance
	% (n)	% (n)	
Ethnicity/race			
Caucasian	84.5% (158)	87.8% (195)	*p* = .025
African-American	6.4% (12)	8.1% (18)	
Asian	2.1% (4)	1.8% (4)	
Hispanic	5.9% (11)	0.5% (1)	
Other	1.1% (2)	1.8% (4)	
	Mean (SD)	Mean (SD)	
Age in years	21.17 (3.19)	21.92 (3.84)	*p* = .035
Years of education	13.60 (1.60)	14.00 (1.93)	*p* = .028

Participant Characteristics for Research Question 2 (Do adults with ADHD exhibit poorer academic achievement scores in reading, math, and written language than adults without ADHD?

Participants with scores on WJ-III subtests were divided into two groups based on their diagnoses: ADHD group (n = 144) and control group (n = 161). Independent samples t tests revealed the groups differed significantly in education, *t*(303) = 2.41, *p* = .017, and age, *t*(299) = 2.05, *p* = .042. The control group (*M* = 14.02, *SD* = 1.74) had significantly more years of education than the ADHD group (*M* = 13.56, *SD* = 1.60). The control group (*M* = 21.81, *SD* = 3.86) was also significantly older than the ADHD group (*M* = 21.00, *SD* = 3.07). Additionally, ADHD and control groups differed significantly in gender, $\chi^2(1, N = 305) = 5.46$, *p* = .020. The control group had a higher percentage of males than females, while the ADHD group had a higher percentage of females than males. The groups did not differ significantly in race/ethnicity, $\chi^2(4, N = 305) = 8.18$, *p* = .085 (See Table 3 for participant characteristics).

Table 3. Participant characteristics for Research Question 2.

	ADHD group (n = 144)	Control group (n = 161)	Significance
	%(n)	%(n)	
Gender			
Males	43.75% (63)	57.14% (92)	*p* = .020
Females	56.25% (81)	42.86% (69)	
Ethnicity/race			
Caucasian	84.03% (121)	88.82% (143)	*p* = .085
African-American	6.94% (10)	8.70% (14)	
Asian	2.08% (3)	1.24% (2)	
Hispanic	6.25% (9)	0.62% (1)	
Other	0.69% (1)	0.62% (1)	
	Mean (SD)	Mean (SD)	
Age in years	21.00 (3.07)	21.81 (3.86)	*p* = .042
Years of education	13.56 (1.60)	14.02 (1.74)	*p* = .017

Participant Characteristics for Research Questions 3 and 4 (What is the relationship between verbal working memory performance and academic achievement scores in adults self-referred for psychoeducational evaluations? Does verbal working memory performance mediate the relationship between ADHD and academic achievement scores in adults?)

Participants (*N* = 300) with WAIS-III WMI and WJ-III scores were included in analyses investigating the relationship between verbal working memory performance and academic achievement scores. Participants' mean age was 21.44 years (*SD* = 3.55). The sample was composed of 151 males and 149 females. The mean years of education of the participants was 13.80 (*SD* = 1.69). The sample included 143 individuals diagnosed with ADHD and 157 controls. Regarding race/ethnicity, the majority of the sample was identified as Caucasian (n = 261), with 22 individuals identified as African-American, five as Asian, 10 as Hispanic, and two individuals were of another race/ethnicity.

Participant Characteristics for Research Question 5 (Does academic achievement performance differ based on verbal working memory performance and the presence or absence of an ADHD diagnosis?)

Participants administered the WAIS-III WMI and WJ-III were divided into four groups: ADHD group without working memory deficit (n = 137), ADHD group with working memory deficit (n = 8), control group without working memory deficit (n = 150), and control group with working memory deficit (n = 10). Working memory deficit was defined as a standard score $\leq$ 85 on the WAIS-III Working Memory Index. Groups differed significantly in ethnicity, $\chi^2(12, N = 305) = 54.19$, $p < .001$; gender, $\chi^2(3, N = 305) = 8.72$, $p = .033$; and years of education, $F(3, 301) = 3.29$, $p = .021$; but not age, $F(3, 301) = 1.27$, $p = .287$. The WAIS-III Full Scale IQ scores of the groups were also significantly different, $F(3, 301) = 21.34$, $p < .001$ (See Table 4 for participant characteristics).

Table 4. Participant characteristics for Research Question 5 when working memory deficit is defined as standard score of $\leq$ 85 on the Working Memory Index.

	ADHD group without WM deficit (n = 137)	ADHD group with WM deficit (n = 8)	Control group without WM deficit (n = 150)	Control group with WM deficit (n = 10)	*p* value
	% (n)	% (n)	% (n)	% (n)	
Gender					.033
Males	43.8 (60)	37.5 (3)	56.67 (85)	80 (8)	
Females	52.2 (77)	62.5 (5)	43.33 (65)	20 (2)	
Ethnicity/race					
Caucasian	86.13 (118)	62.5 (5)	91.33 (137)	40 (4)	< .001
African –American	5.84 (8)	12.5 (1)	6.00 (9)	50 (5)	
Asian	2.19 (3)	0 (0)	1.33 (2)	0 (0)	
Hispanic	5.11 (7)	25 (2)	0.67 (1)	0 (0)	
Other or Unknown	0.73 (1)	0 (0)	0.67 (1)	10 (1)	

(Table 4 continued)

	ADHD group without WM deficit (n = 137)	ADHD group with WM deficit (n = 8)	Control group without WM deficit (n = 150)	Control group with WM deficit (n = 10)	*p* value
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Years of education	13.58 (1.59)[a]	13.00 (1.77)[ab]	14.01 (1.77)[b]	12.80 (1.55)[a]	.021
Age	21.01 (3.11)	20.88 (2.03)	21.78 (3.86)	21.90 (3.93)	.287
WAIS-III FSIQ	107.99 (12.01)[a]	87.75 (11.39)[b]	105.86 (11.40)[a]	82.50 (9.96)[b]	< .001

Note. Means sharing the same superscript are not significantly different from each other at $\alpha = .05$ using the LSD procedure. WM = working memory.

Researchers have questioned the construct validity of the WAIS-III Working Memory Index including the Arithmetic subtest (Shelton, Elliott, Hill, Calamia, & Gouvier, 2009; Stearns et al., 2004). Therefore, another set of analyses were conducted with working memory deficits based on a working memory composite score that did not include the Arithmetic subtest. The working memory composite was calculated by summing participants' scaled scores on the Digit Span and Letter-Number Sequencing subtests. A working memory deficit was defined as a score equal to or less than one standard deviation below the mean ($\leq$ 14) on the working memory composite. Participants were divided into four groups: ADHD group without working memory deficit (n = 135), ADHD group with working memory deficit (n = 10), control group without working memory deficit (n = 149), and control group with working memory deficit (n = 11). Groups differed significantly in ethnicity, $\chi^2(12, N = 305) = 29.28$, $p = .004$; gender, $\chi^2(3, N = 305) = 11.58$, $p = .009$; and years of education, $F(3, 301) = 3.74$, $p = .012$. The groups did not differ significantly in age, $F(3, 301) = 2.29$, $p = .079$. The WAIS-III Full Scale IQ scores of the groups were significantly different, $F(3, 301) = 18.02$, $p < .001$ (See Table 5 for participant characteristics).

Table 5. Participant characteristics for Research Question 5 when working memory deficit is defined as a score of ≤ 14 on working memory composite.

	ADHD group without WM deficit (n = 135)	ADHD group with WM deficit (n = 10)	Control group without WM deficit (n = 149)	Control group with WM deficit (n = 11)	*p* value
	% (n)	% (n)	% (n)	% (n)	
Gender					
Males	45.19 (61)	20 (2)	56.38 (84)	81.82 (9)	.009
Females	54.81 (74)	80 (8)	43.62 (65)	18.18 (2)	
Ethnicity/race					
Caucasian	85.93 (116)	70 (7)	89.93 (134)	63.64 (7)	.004
African-American	5.93 (8)	10 (1)	7.38 (11)	27.27 (3)	
Asian	2.22 (3)	0 (0)	1.34 (2)	0 (0)	
Hispanic	5.19 (7)	20 (2)	0.67 (1)	0 (0)	
Other or Unknown	0.74 (1)	0 (0)	0.67 (1)	9.09 (1)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Years of education	13.61 (1.60)[ab]	12.60 (1.35)[a]	14.01 (1.76)[b]	13.00 (1.90)[ab]	.012
Age	21.09 (3.10)	19.90 (2.18)	21.89 (3.95)	20.36 (1.63)	.079
WAIS-III FSIQ	107.99 (12.01)[a]	87.75 (11.39)[b]	105.86 (11.40)[a]	82.50 (9.96)[b]	< .001

Note. Means sharing the same superscript are not significantly different from each other at $\alpha = .05$ using the LSD procedure. WM = working memory.

Participant Characteristics for Research Question 6 (Does academic achievement performance differ based on processing speed performance and the presence or absence of an ADHD diagnosis?)

Participants administered the WAIS-III PSI and WJ-III were divided into four groups: ADHD group without processing speed deficit (n = 113), ADHD group with processing speed deficit (n = 32), control group without processing speed deficit (n = 148) and control group with processing speed deficit (n = 11). Processing speed deficit was defined as a standard score $\leq$ 85 on the WAIS-III PSI. Groups differed significantly in ethnicity, $\chi^2(15, N = 304) = 25.88$, $p = .039$; gender, $\chi^2(3, N = 304) = 9.15$, $p = .027$; years of education, $F(3, 300) = 3.75$, $p = .011$; and WAIS-III FSIQ scores, $F(3, 300) = 14.34$, $p < .001$. Groups did not differ significantly in age, $F(3, 300) = 1.27$, $p = .286$. (See Table 6 for participant characteristics).

Table 6. Participant characteristics for Research Question 6.

	ADHD group without PS deficit (n = 113)	ADHD group with PS deficit (n = 32)	Control group without PS deficit (n = 148)	Control group with PS deficit (n = 11)	*p* value
	% (n)	% (n)	% (n)	% (n)	
Gender					
Males	44.25 (50)	40.6 (13)	56.08 (83)	81.82 (9)	.027
Females	55.75 (63)	59.3 (19)	43.92 (65)	18.18 (2)	
Ethnicity/race					
Caucasian	87.61 (99)	75 (24)	88.51 (131)	81.82 (9)	
African-American	2.65 (3)	18.75 (6)	8.11 (12)	18.18 (2)	.039
Asian	2.65 (3)	0 (0)	1.35 (2)	0 (0)	
Hispanic	7.08 (8)	3.125 (1)	0.68 (1)	0 (0)	
Other or Unknown	0 (0)	3.125 (1)	1.35 (2)	0 (0)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Years of education	13.57 (1.66)[a]	13.47 (1.37)[ab]	14.03 (1.73)[b]	12.64 (2.11)[a]	.011
Age	21.06 (3.25)	20.81 (2.29)	21.76 (3.84)	22.00 (4.31)	.286
WAIS-III FSIQ	109.18 (11.93)[a]	98.72 (12.62)[b]	105.52 (11.89)[c]	88.45 (12.42)[d]	< .001

Note. Means sharing the same superscript are not significantly different from each other at $\alpha = .05$ using the LSD procedure. PS = processing speed.

Participant Characteristics for Research Questions 7a, 7b, and 7c (Do adults with ADHD exhibit poorer processing speed performance than adults without ADHD? What is the association between processing speed performance and academic achievement scores in adults? Does processing speed performance mediate the relationship between ADHD and academic fluency in adults?)

Participants with WAIS-III PSI and WJ-III scores were divided into two groups: ADHD group (n = 144) and control group (n = 156). The ADHD group included adults with an ADHD diagnosis only or ADHD and an adjustment disorder diagnosis. The control group included adults with no diagnosis or an adjustment disorder diagnosis only. The control group and ADHD group did not differ significantly in age, $t(291) = 1.93$, $p = 0.055$; WAIS-III FSIQ scores, $t(298) = -1.54$, $p = .124$; or race/ethnicity, $\chi^2(4, N = 300) = 7.97$, $p = .093$. The groups did differ significantly in years of education, $t(298) = 2.19$, $p = 0.029$, and gender, $\chi^2(1, N = 300) = 5.30$, $p = .021$ (See Table 7 for participant characteristics).

Table 7. Participant Characteristics for Research Question 7.

	ADHD group (n = 144)	Control group (n = 156)	Significance
	%(n)	%(n)	
Gender			
Males	43.75% (63)	57.05% (89)	$p = .021$
Females	56.25% (81)	42.95% (67)	
Ethnicity/race			
Caucasian	84.72% (122)	89.10% (139)	$p = .093$
African-American	6.25% (9)	8.33% (13)	
Asian	2.08% (3)	1.28% (2)	
Hispanic	6.25% (9)	0.64% (1)	
Other	0.69% (1)	0.64% (1)	
	Mean (SD)	Mean (SD)	
Age	21.01 (3.07)	21.78 (3.88)	$p = .055$
Years of education	13.56 (1.60)	13.98 (1.75)	$p = .029$
WAIS-III FSIQ	107.13 (12.45)	104.96 (11.94)	$p = .124$

Measures

Wechsler Adult Intelligence Scale-Third Edition

The Wechsler Adult Intelligence Scale-Third Edition (WAIS-III; Wechsler, 1997a) assesses intellectual functioning of individuals 16 to 89 years of age. The WAIS-III has a total of fourteen subtests, including Object Assembly, an optional subtest. The subtest scores can be combined to yield the following composite scores: Full Scale IQ, Verbal IQ, and Performance IQ. The Full Scale IQ composite score has an internal consistency reliability of .97 to .98 among adults 18-35 years of age and is calculated based on performance on the following subtests: Vocabulary, Similarities, Arithmetic, Digit Span, Information, Comprehension, Picture Completion, Digit Symbol-Coding, Block Design, Matrix Reasoning, and Picture Arrangement (See Table 8 for descriptions of WAIS-III subtests). The Verbal IQ score includes performance on the Vocabulary, Similarities, Arithmetic, Digit Span, Information, and Comprehension subtests, while the Performance IQ scores is calculated based on performance on the Picture Completion, Digit Symbol-Coding, Block Design, Matrix Reasoning, and Picture Arrangement. For individuals 18-35 years old, the Verbal IQ and Performance IQ scores have internal consistency reliability estimates of .97 and .93-.95, respectively (Wechsler, 1997a).

Table 8. Descriptions of WAIS-III subtests and their reliability estimates.

WAIS-III subtest	Description of subtest	Reliability estimates for 18-35 year olds	Type of Reliability
Vocabulary subtest	Examinees orally state the meaning of words	.92-.94	Internal consistency
Similarities subtest	Examinees orally describe how two objects or concepts are alike	.82-.88	Internal consistency

(Table 8 continued)

WAIS-III subtest	Description of subtest	Reliability estimates for 18-35 year olds	Type of Reliability
Arithmetic subtest	Examinees orally answer math word problems that are read aloud	.87 - .90	Internal consistency
Digit Span subtest	Examinees repeat strings of digits in the same order or the reverse order	.90 - .92	Test-retest reliability
Information subtest	Examinees orally answer general knowledge questions read aloud	.89 - .93	Internal consistency
Comprehension subtest	Examinees orally answer questions regarding social concerns	.82 - .86	Internal consistency
Letter-Number Sequencing subtest	Examinees order and repeat strings of numbers and letters	.77 - .88	Internal consistency
Picture Completion subtest	Examinees identify the missing part of a picture	.76 - .86	Internal consistency
Digit Symbol-Coding subtest	Examinees write matching symbols in empty boxes below lines of numbers	.81 - .84	Internal consistency
Block Design subtest	Examinees assemble blocks to match two-dimensional pictures	.88 - .90	Internal consistency
Matrix Reasoning subtest	Examinees choose the answer choice that best completes the pattern	.88 - .91	Internal consistency
Picture Arrangement subtest	Examinees place cards with illustrations in the most logical order	.66 - .79	Internal consistency
Symbol Search subtest	Examinees indicate whether two target shapes are in another group of shapes	.74 - .82	Internal consistency
Object Assembly subtest	Examinees put puzzle pieces together to form various objects	.70 - .75	Internal consistency

The WAIS-III subtest scores can be combined to yield four index scores, namely, Verbal Comprehension (includes Vocabulary, Similarities, and Information), Perceptual Organization (includes Picture Completion, Block Design, and Matrix Reasoning), Working Memory Index (WMI), and Processing Speed index (PSI). For the WAIS-III, standard composite and index scores have a mean of 100 and a standard deviation of 15. Raw subtest scores can be converted into age-corrected scaled scores that have a mean of 10 and a standard deviation of 3.

The Working Memory Index (WMI) assesses verbal working memory and includes the Digit Span, Arithmetic, and Letter-Numbering Sequencing subtests. For adults aged 18-35, the WMI has an estimated internal consistency reliability of .93-.95 (Wechsler, 1997a). The WAIS-III WMI is highly correlated with the Wechsler Memory Scale-III Working Memory Index (r = .82) and accounted for 43% of the variance in a composite score composed of working memory measures used by cognitive psychologists (Hill et al., 2010; Wechsler, 1997a). The Digit Span subtest of the WAIS-III includes two tasks: Digit Span Forward and Digit Span Backward. For the Digit Span Forward portion of the subtest, the examiner reads a string of numbers, and the examinee is asked to repeat the numbers back in the exact same order. For the Digit Span Backward portion of the subtest, the examiner again reads a string of digits to the examinee, but this time the examinee is asked to repeat the digits in the reverse order. For example, if the examiner reads "5-8-2," the examinee would receive credit for responding "2-8-5." In the Letter-Number Sequencing subtest of the WAIS–III, examinees are read a list of numbers and letters and are asked to state the numbers first in ascending order followed by the letters in alphabetical order. The Arithmetic subtest of the WAIS-III involves the examiner reading an oral arithmetic word problem. The examinee is instructed to solve the word problems without using paper or pencil. There are various time limits for the arithmetic problems.

Processing Speed Index (PSI) scores have internal consistency reliability estimates of .86-.89 for adults aged 18-35 and are based on examinees' performances on the Digit

Symbol-Coding and Symbol Search subtests (Wechsler, 1997a). For the Digit Symbol-Coding task, examinees are presented with a key that includes symbols paired with numbers. They are then presented with a list of numbers with empty boxes below and are asked to draw the matching symbols in the empty boxes as quickly as they can. For the Symbol Search task, examinees are asked to indicate whether either of two target shapes is in the line of shapes next to them by marking a line through a "yes" or "no" box.

Woodcock-Johnson Third Edition Tests of Achievement

The Woodcock-Johnson Third Edition Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001) is a broad measure of academic skills. Math, reading, and written language achievement are assessed with a variety of tasks that measure different aspects of those domains. The Broad Math composite score is derived from the examinee's performance on the Math Fluency, Calculations, and Applied Problems subtests. The internal consistency reliability of the Broad Math score in adults is excellent, ranging from 0.94 to 0.97 (Mather & Woodcock, 2001; McGrew & Woodcock, 2001). The Math Fluency subtest involves examinees writing their responses to as many simple written arithmetic problems (i.e., addition, subtraction, multiplication) as they can during a three-minute time period. For the Calculations subtest, examinees are asked to solve written math problems. Problems involve algebra, geometry, and other math skills. There is no time limit. For the Applied Problems subtest, examinees are read a word problem aloud by the examiner and are asked to solve the problem using paper and pencil if needed. Examinees respond to the word problems orally.

The Letter-Word Identification, Reading Fluency, and Passage Comprehension subtests comprise the Broad Reading composite score. The internal consistency reliability of the Broad Reading composite score ranged from 0.92 to 0.97 in adults (Mather & Woodcock, 2001; McGrew & Woodcock, 2001). For the Letter-Word Identification subtest, examinees identify letters and/or read printed words aloud. The Reading Fluency subtest is timed, and examinees are instructed to read sentences silently and then indicate if they are true or false by circling a "Y" (yes) or "N" (no). For the Passage Comprehension subtest, the examinee is asked to silently read a passage and fill in the missing word.

The Broad Written Language composite score is calculated based on performance on the Spelling, Writing Fluency, and Writing Samples subtests. The Broad Written Language composite score also has excellent internal consistency (0.91-0.97) in adults (Mather & Woodcock, 2001; McGrew & Woodcock, 2001). For the Spelling subtest, the examiner reads a word to the examinee, reads a sentence with the word, and then reads the word again. The examinee is asked to write the word spelled correctly on an answer sheet. For the Writing Fluency subtest, examinees are given items which consist of several words paired with a picture. They are instructed to write short sentences using the words to describe the pictures as quickly as they can. The subtest has a seven-minute time limit. For Writing Samples, the examinee is instructed to write words or sentences to complete various written passages or follow special instructions (e.g., to describe a picture and/or use a certain word in a sentence). Raw scores from WJ-III subtests can be converted to age-corrected standard scores with a mean of 100 and a standard deviation of 15. Composite scores also have a mean of 100 and a standard deviation of 15.

The validity of the WJ-III composite scores has been examined by correlating those scores with composite scores from the Kaufman Test of Educational Achievement (KTEA; Kaufman & Kaufman, 1985) and the Wechsler Individual Achievement Test (WIAT;

Wechsler, 1992), as well as other academic achievement measures (Mather & Woodcock, 2001). The WJ-III Broad Reading score was correlated with both the WIAT Reading Composite ($r = 0.67$) and the KTEA Reading Composite ($r = 0.76$) (Mather & Woodcock, 2001; McGrew & Woodcock, 2001). Correlations of the WJ-III Broad Math composite with the WIAT Math Composite and KTEA Math Composite were 0.70 and 0.66, respectively (Mather & Woodcock, 2001; McGrew & Woodcock, 2001). The WJ-III Broad Written Language composite was also correlated with the WIAT Written Composite ($r = .47$) and KTEA Spelling subtests ($r = 0.67$) (Mather & Woodcock, 2001; McGrew & Woodcock, 2001). Although the WJ-III has been extensively researched in comparison to other measures of academic achievement (Mather & Woodcock, 2001), research linking scores on the WJ-III to measures of academic achievement in the classroom, such as GPA, appear to be lacking.

Effort Measures

Several embedded validity measures from the WAIS-III and WMS-III have demonstrated utility in distinguishing feigned impairment from genuine deficits. These measures include the Reliable Digit Span, Mittenberg Index, Vocabulary minus Digit Span, and Rarely Missed Items Index. The Reliable Digit Span (Greiffenstein et al., 1994) is the sum of the longest number of digits repeated correctly over two trials for the forward digit span and backwards digit span tasks. A Reliable Digit Span cutoff score of seven has demonstrated sensitivity rates ranging from 50-95% in correctly identifying individuals feigning impairment and specificity rates ranging from 73-93.5% in identifying individuals with genuine deficits as non-malingerers (Greiffenstein et al., 1994; Larrabee, 2003; Mathias, Greve, Bianchini, Houston, & Crouch., 2002; Meyers & Volbrecht, 1998). The Mittenberg

Index is a formula based on WAIS-III subtest scores that discriminate function analyses revealed differentiated individuals feigning deficits from individuals with genuine impairments (Mittenberg et al., 1995). The Vocabulary minus Digit Span (Mittenberg et al., 1995) validity index is calculated by subtracting the Digit Span scaled score from the Vocabulary scaled score; scores greater than five are suggestive of poor effort. The Rarely Missed Items Index (Killgore & DellaPietra, 2000) developed using discriminate function analyses is based on individuals' answers to six items on the Wechsler Memory Scale–III Logical Memory Recognition subtest. A cutoff score of 136 in Killgore and DellaPietra's (2000) original study yielded sensitively and specificity rates of 97% and 100%, respectively, in identifying analog malingerers from individuals with genuine impairment.

Results

Research Question 1 – (Do adults with ADHD exhibit poorer verbal working memory performance than adults without ADHD?)

A one-way ANCOVA with group membership (ADHD group versus control group) as the independent variable; education, gender, and ethnicity/race as covariates; and the WAIS-III Working Memory Index as the dependent variable was not significant, $F(1, 401) = 1.70$, $p = .196$, partial $\eta^2 = .004$ (See Table 9).

Table 9. Mean scores and standard deviations for Research Question 1.

	ADHD group (n = 187)	Control group (n = 222)	Significance
	Mean (SD)	Mean (SD)	
WAIS-III WMI	103.79 (12.62)	103.07 (12.08)	$p = .697$
Working Memory Composite	20.94 (4.71)	21.18 (4.39)	$p = .789$
Letter-Number Sequencing	10.60 (2.51)	10.91 (2.32)	$p = .545$
Digit Span	10.34 (2.78)	10.27 (2.61)	$p = .321$
Arithmetic	11.10 (2.47)	10.62 (2.38)	$p = .008$

Note. WAIS-III WMI = Wechsler Adult Intelligence Scale-Third Edition Working Memory Index.

It was proposed that consistent with previous literature, the relationship between ADHD and working memory would be explored with and without controlling for IQ, as measured by the WAIS-III Vocabulary subtest. Notably, the WAIS-III Full Scale IQ scores of the ADHD group ($M = 106.91$, $SD = 13.06$) and control group ($M = 105.33$, $SD = 12.10$) did not differ significantly, $t(407) = -1.27$, $p = .205$; however, the WAIS-III Vocabulary subtest scores of the ADHD and control groups differed significantly, $t(407) = -2.66$, $p = .008$. The ADHD group ($M = 12.08$, $SD = 2.53$) had higher Vocabulary subtest scores than the control group ($M = 11.42$, $SD = 2.46$). Also, on the WAIS-III Verbal IQ index, the ADHD group

(M = 108.13, SD = 13.02) had significantly higher scores than the control group (M = 105.10, SD = 13.83), $t(407) = -2.27$, $p = .024$. Results of a one-way ANCOVA with group membership (ADHD group versus control group) as the independent variable; WAIS-III Vocabulary subtest scores, education, gender, and ethnicity/race as covariates; and the WAIS-III Working Memory Index as the dependent variable was also not significant, $F(1, 400) = .10$, $p = .755$, partial $\eta^2 = .000$.

Due to the questionable construct validity of the Arithmetic subtest as a measure of working memory (Shelton et al., 2009; Stearns et al., 2004), another one-way ANCOVA was conducted with the same covariates (education, gender, race/ethnicity) and independent variable (ADHD status) but with a working memory composite score without arithmetic (i.e., the sum of the WAIS-III Digit Span and WAIS-III Letter-Number Sequencing scaled scores) as the dependent variable. Working memory composite scores of the ADHD group (M = 20.94, SD = 4.71) and control group (M = 21.18, SD = 4.39) did not differ significantly, $F(1, 401) = 0.01$, $p = .926$, partial $\eta^2 = .000$. When WAIS-III Vocabulary subtest performance was added as a covariate, the results remained non-significant, $F(1, 400) = 1.84$, $p = .175$, partial $\eta^2 = .005$.

A one-way MANCOVA was conducted to investigate the effect of ADHD status (ADHD versus controls) on WAIS-III working memory subtest performance (i.e., Digit Span subtest, Letter-Number Sequencing subtest, and the Arithmetic subtest). Covariates again included education, ethnicity/race, and gender. Group membership had a significant effect on working memory subtest performance, Wilks' Lambda = .975, $F(3, 399) = 3.45$, $p = .017$, partial $\eta^2 = .025$. Follow-up ANCOVAs revealed the ADHD and control groups did not have significantly different scores on the Letter-Number Sequencing subtest, $F(1, 401) = .58$,

p = .449, partial η^2 = .001, or the Digit Span subtest, $F(1, 401)$ = .69, p = .406, partial η^2 = .002. However, the ADHD group obtained significantly higher scores than the control group on the Arithmetic subtest, $F(1, 401)$ = 6.37, p = .012, partial η^2 = .016. When the WAIS-III Vocabulary subtest was added as a covariate, the MANCOVA examining the effect of ADHD status on working memory subtest scores was no longer significant, Wilks' Lambda = .982, $F(3, 398)$ = 2.41, p = .067, partial η^2 = .018.

Research Question 2 (Do adults with ADHD exhibit poorer academic achievement scores in reading, math, and written language than adults without ADHD?)

Controlling for education and gender, a one-way MANCOVA with group membership (ADHD versus control) included as the independent variable and WJ-III composite scores (i.e., Broad Reading, Broad Math, and Broad Written Language) as the dependent variables was significant, Wilks' Lambda = .972, $F(3, 299)$ = 2.88, p = .036, partial η^2 = .028. Follow-up ANCOVAs revealed the effect of group membership on Broad Reading, $F(1, 301)$ = 4.04, p = .045, partial η^2 = .013, was significant, but the effect of group membership on Broad Math, $F(1, 301)$ = .12, p = .730, partial η^2 = .000, and Broad Written Language, $F(1, 301)$ = 1.29, p = .258, partial η^2 = .004, was not significant. The control group (M = 101.00, SD = 12.02) had significantly higher Broad Reading scores than the ADHD group (M = 98.13, SD = 11.31) (See Table 10).

Additionally, with education and gender included as covariates, a one-way MANCOVA was performed to investigate the effect of group membership (ADHD versus controls) on individual WJ-III subtest scores. The MANCOVA was significant, Wilks' Lambda = .918, $F(9, 293)$ = 2.90, p = .003, partial η^2 = .082. Follow-up ANCOVAs revealed that the ADHD group obtained significantly lower mean scores than the control group on the

Reading Fluency subtest, $F(1, 301) = 7.60$, $p = .006$, partial $\eta^2 = .025$; Math Fluency subtest, $F(1, 301) = 8.64$, $p = .004$, partial $\eta^2 = .028$; and Writing Fluency subtest, $F(1, 301) = 4.86$, $p = .028$, partial $\eta^2 = .016$. The performance of ADHD and control groups did not differ significantly on the following WJ-III subtests: Letter-Word Identification, Passage Comprehension, Applied Problems, Calculations, Spelling, and Writing Samples (See Table 10).

Table 10. Means and standard deviations for Research Question 2.

WJ-III Measure	ADHD group (n = 144)	Control group (n = 161)	Significance
	Mean (SD)	Mean (SD)	
WJ-III Broad Reading	98.13 (11.31)	101.00 (12.02)	$p = .045$
WJ-III Reading Fluency	95.10 (13.23)	99.72 (14.29)	$p = .006$
WJ-III Letter-Word Identification	99.26 (9.74)	99.04 (9.41)	$p = .937$
WJ-III Passage Comprehension	103.21 (10.11)	103.01 (11.11)	$p = .822$
WJ-III Broad Math	98.65 (11.43)	99.06 (11.86)	$p = .730$
WJ-III Math Fluency	92.00 (12.57)	96.96 (12.90)	$p = .004$
WJ-III Calculations	101.62 (13.34)	101.10 (13.54)	$p = .340$
WJ-III Applied Problems	99.37 (9.88)	99.17 (10.52)	$p = .128$
WJ-III Broad Written Language	98.65 (11.43)	99.06 (11.86)	$p = .258$
WJ-III Writing Fluency	103.19 (11.90)	106.61 (12.60)	$p = .028$
WJ-III Spelling	101.49 (9.94)	101.79 (10.92)	$p = .707$
WJ-III Writing Samples	104.40 (14.35)	104.84 (13.79)	$p = .771$

Research Questions 3 and 4 (What is the relationship between verbal working memory performance and academic achievement scores in adults self-referred for psychoeducational evaluations? Does verbal working memory performance mediate the relationship between ADHD and academic achievement in adults?)

The WAIS-III Working Memory Index, the calculated working memory composite (sum of the Digit Span and Letter Number Sequencing subtest scaled scores), and the WAIS-III working memory subtests (i.e., Digit Span, Letter Number Sequencing, and Arithmetic) were all significantly ($p < 0.001$) positively correlated with WJ-III Broad Reading, WJ-III Broad Math, and WJ-III Broad Written Language as well as each of the following WJ-III subtests: Letter-Word Identification, Passage Comprehension, Reading Fluency, Applied Problems, Calculations, Math Fluency, Spelling, Writing Samples, and Writing Fluency (See Table 11 for bivariate correlations between working memory measures and academic achievement scores).

Table 11. Bivariate correlations between working memory and academic achievement measures.

	Working Memory Measures				
Academic Achievement Measure	WAIS-III Working Memory Index	Working Memory composite without arithmetic	WAIS-III Digit Span subtest	WAIS-III Letter Number Sequencing subtest	WAIS-III Arithmetic subtest
Broad Reading	.524*	.498*	.413*	.479*	.400*
Letter-Word Identification	.515*	.484*	.420*	.446*	.422*
Passage Comprehension	.460*	.382*	.367*	.313*	.461*
Reading Fluency	.403*	.398*	.310*	.405*	.281*
Broad Math	.606*	.476*	.411*	.442*	.656*
Applied Problems	.586*	.431*	.387*	.383*	.675*

(Table 11 continued)

Academic Achievement Measure	Working Memory Measures				
	WAIS-III Working Memory Index	Working Memory composite without arithmetic	WAIS-III Digit Span subtest	WAIS-III Letter Number Sequencing subtest	WAIS-III Arithmetic subtest
Calculations	.493*	.377*	.301*	.375*	.561*
Math Fluency	.337*	.304*	.281*	.261*	.297*
Broad Written Language	.584*	.514*	.446*	.473*	.524*
Spelling	.502*	.456*	.397*	.418*	.438*
Writing Samples	.388*	.332*	.288*	.307*	.375*
Writing Fluency	.426*	.359*	.306*	.337*	.405*

*$p < .001$.

It was originally proposed that verbal working memory would be investigated as a mediator between ADHD and academic achievement. However, this study did not find a significant relationship between ADHD and verbal working memory.

Research Question 5: (Does academic achievement performance differ based on verbal working memory performance and the presence or absence of an ADHD diagnosis?)

A two-way MANOVA evaluating the effect of ADHD status (ADHD versus control) and working memory performance (WAIS-III WMI > 85 versus WAIS-III WMI $\leq$ 85) on academic achievement composite scores (i.e. Broad Reading, Broad Math, and Broad Written Language) yielded a significant main effect of working memory performance, Wilks' Lambda = .840, $F(3, 299) = 18.96$, $p < .001$, partial $\eta^2 = .160$. Follow-up ANOVAs revealed the main effect of working memory performance was significant for Broad Reading, $F(1, 301) = 36.74$, $p < .001$, partial $\eta^2 = .109$; Broad Math, $F(1, 301) = 34.89$, $p < .001$, partial $\eta^2 = .104$; and Broad Written Language, $F(1, 301) = 52.88$, $p < .001$, partial $\eta^2 = .149$.

Broad Reading, Broad Math, and Broad Written Language scores were poorer for individuals with a working memory deficit compared to those without a working memory deficit. The main effect of ADHD status was non-significant, Wilks' Lambda = .980, $F(3, 299) = 2.00$, $p = .113$, partial $\eta^2 = .020$. However, there was a significant interaction of ADHD status and working memory performance, Wilks' Lambda = .968, $F(3, 299) = 3.28$, $p = .021$, partial $\eta^2 = .032$. Follow-up ANOVAs yielded significant interactions for Broad Reading, $F(1, 301) = 3.94$, $p = .048$, partial $\eta^2 = .013$, and Broad Written Language, $F(1, 301) = 7.94$, $p = .005$, partial $\eta^2 = .026$, indicating that the presence of a working memory deficit had a greater negative effect on the Broad Reading and Broad Written Language scores of controls compared to adults with ADHD.

A second two-way MANOVA examined the effect of ADHD status (ADHD versus control) and working memory performance (WAIS-III WMI > 85 versus WAIS-III WMI $\leq$ 85) on academic achievement composite scores that did not include fluency measures (i.e. Reading Composite = average of the Letter-Word Identification and Passage Comprehension subtest standard scores; Math Composite = average of the Applied Problems and Calculations subtest standard scores; Writing Composite = average of the Spelling and Writing Samples subtest standard scores). There was a significant main effect of working memory performance, Wilks' Lambda = .812, $F(3, 299) = 23.12$, $p < .001$, partial $\eta^2 = .188$. The main effect of ADHD status was non-significant, Wilks' Lambda = .988, $F(3, 299) = 1.25$, $p = .292$, partial $\eta^2 = .012$, and the interaction effect was non-significant, Wilks' Lambda = .988, $F(3, 299) = 1.17$, $p = .32$, partial $\eta^2 = .012$. Follow-up ANOVAs revealed the main effect of working memory performance was significant for Reading Composite, $F(1, 301) = 68.68$, $p < .001$, partial $\eta^2 = .186$; Math Composite, $F(1, 301) = 30.14$, $p < .001$, partial η^2 = .091; and Writing Composite $F(1, 301) = 38.10$, $p < .001$, partial η^2 = .112. Working memory deficits were associated with poorer performance on all academic achievement composites.

As hypothesized, pairwise comparisons using Bonferroni correction revealed that the ADHD group with working memory deficits obtained significantly poorer scores than the ADHD group without working memory deficits on Broad Reading, Broad Math, Broad Written Language, Reading Composite, Math Composite, and Writing Composite measures. The ADHD group with working memory deficits and the control group with working memory deficits did not have significantly different scores on any of the academic achievement measures included in analyses (See Table 12).

Table 12. Mean scores for Research Question 5 when working memory deficit is defined as standard score of ≤ 85 on Working Memory Index.

Academic Achievement Measure	ADHD group without WM deficit (n = 137)	ADHD group with WM deficit (n = 8)	Control group without WM deficit (n = 150)	Control group with WM deficit (n = 10)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Broad Reading	98.71 (10.76)[a]	87.75 (14.60)[b]	101.42 (10.95)[a]	79.80 (11.91)[b]
Broad Math	99.27 (11.17)[a]	84.88 (11.67)[b]	99.41 (11.47)[a]	81.20 (9.77)[b]
Broad Written Language	104.24 (10.97)[a]	92.13 (9.03)[b]	105.84 (11.26)[a]	78.40 (12.78)[b]
Reading Composite	101.98 (8.38)[a]	88.63 (7.25)[b]	101.62 (7.95)[a]	81.15 (13.55)[b]
Math Composite	101.02 (10.69)[a]	88.94 (10.03)[b]	99.93 (10.92)[a]	83.20 (8.75)[b]
Writing Composite	103.37 (10.71)[a]	91.88 (7.49)[b]	103.80 (10.08)[a]	84.10 (10.85)[b]

Note. Means sharing the same superscript are not significantly different from each other at α = .05 using Bonferroni correction. WM = working memory.

Another set of analyses were conducted with working memory deficit defined as a score $\leq$ 14 on the working memory composite. A two-way MANOVA evaluating the effect of ADHD status (ADHD versus control) and working memory performance (working memory deficit versus no working memory deficit) on academic achievement composite scores (i.e. Broad Reading, Broad Math, and Broad Written Language) yielded a significant main effect of working memory performance, Wilks' Lambda = .862, $F(3, 299) = 15.99$, $p < .001$, partial $\eta^2 = .138$. The main effect of ADHD status was non-significant, Wilks' Lambda = .994, $F(3, 299) = .562$, $p = .640$, partial $\eta^2 = .006$, and the interaction effect was non-significant, Wilks' Lambda = .990, $F(3, 299) = 1.03$, $p = .378$, partial $\eta^2 = .010$. Follow-up ANOVAs revealed the main effect of working memory performance was significant for Broad Reading, $F(1, 301) = 36.32$, $p < .001$, partial $\eta^2 = .108$; Broad Math, $F(1, 301) = 20.81$, $p < .001$, partial $\eta^2 = .065$; and Broad Written Language, $F(1, 301) = 44.31$, $p < .001$, partial $\eta^2 = .128$. Individuals with working memory deficits had significantly poorer Broad Reading, Broad Math, and Broad Written Language scores than individuals without working memory deficits (See Table 13).

A second two-way MANOVA was performed evaluating the effect of ADHD status (ADHD versus control) and working memory performance (working memory deficit versus no working memory deficit) on academic achievement composite scores that did not include fluency measures (i.e. Reading Composite, Math Composite, and Writing Composite). There was a significant main effect of working memory performance, Wilks' Lambda = .854, $F(3, 299) = 16.99$, $p < .001$, partial $\eta^2 = .146$. There was a non-significant effect of ADHD status, Wilks' Lambda = .989, $F(3, 299) = 1.12$, $p = .341$, partial $\eta^2 = .011$, and a non-significant interaction, Wilks' Lambda = .992, $F(3, 299) = .89$, $p = .466$, partial $\eta^2 = .008$.

Follow-up ANOVAs revealed a significant main effect of working memory performance for Math Composite, $F(1, 301) = 18.07$, $p < .001$, partial $\eta^2 = .057$; Writing Composite, $F(1, 301) = 36.89$, $p < .001$, partial $\eta^2 = .109$; and Reading Composite $F(1, 301) = 47.28$, $p < .001$, partial $\eta^2 = .136$. The presence of a working memory deficit was associated with poorer Math Composite, Writing Composite, and Reading Composite scores.

The ADHD group with working memory deficits obtained significantly poorer scores than the ADHD group without working memory deficits on the Broad Reading, Broad Written Language, Reading Composite, and Writing Composite measures but not the Broad Math and Math Composite. The ADHD and control groups with working memory deficits did not have significantly different scores on any of the academic achievement measures included in analyses (See Table 13).

Table 13. Mean scores for Research Question 5 when working memory deficit is defined as a score of ≤ 14 on Working Memory composite.

Academic Achievement Measure	ADHD group without WM deficit (n = 135)	ADHD group with WM deficit (n = 10)	Control group without WM deficit (n = 149)	Control group with WM deficit (n = 11)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Broad Reading	98.86 (10.75)[a]	87.90 (13.09)[b]	101.39 (11.31)[a]	82.18 (9.11)[b]
Broad Math	99.09 (11.55)[ab]	90.20 (9.89)[ac]	99.30 (11.78)[b]	84.36 (8.62)[c]
Broad Written Language	104.47 (10.88)[a]	91.40 (7.95)[b]	105.59 (11.90)[a]	84.27 (13.43)[b]
Reading Composite	102.00 (8.54)[a]	91.05 (6.59)[b]	101.44 (8.52)[a]	85.45 (12.73)[b]
Math Composite	100.86 (11.00)[a]	93.50 (8.39)[ab]	99.83 (11.20)[a]	86.14 (7.78)[b]
Writing Composite	103.48 (10.74)[a]	92.75 (7.11)[b]	103.79 (10.28)[a]	85.95 (9.69)[b]

Note. Means sharing the same superscript are not significantly different from each other at $\alpha = .05$ using Bonferroni correction. WM = working memory.

Research Question 6: (Does academic achievement performance differ based on processing speed performance and the presence or absence of an ADHD diagnosis?)

A two-way MANOVA evaluating the effect of ADHD status (ADHD versus control) and processing speed performance (processing speed deficit versus no processing speed deficit) on academic achievement composite scores (i.e. Broad Reading, Broad Math, and Broad Written Language) yielded a significant main effect of processing speed performance, Wilks' Lambda = .902, $F(3, 298) = 10.85$, $p < .001$, partial $\eta^2 = .098$, and a significant main effect of ADHD status, Wilks' Lambda = .969, $F(3, 298) = 3.19$, $p = .024$, partial $\eta^2 = .031$. The interaction effect was not significant, Wilks' Lambda = .976, $F(3, 298) = 2.45$, $p = .064$, partial $\eta^2 = .024$. Follow-up ANOVAs revealed a significant main effect of processing speed performance on Broad Reading, $F(1, 300) = 28.66$, $p < .001$, partial $\eta^2 = .087$; Broad Math, $F(1, 300) = 23.66$, $p < .001$, partial $\eta^2 = .073$; and Broad Written Language scores, $F(1, 300) = 19.93$, $p < .001$ partial $\eta^2 = .062$. Individuals without processing speed deficits obtained significantly better Broad Reading, Broad Math, and Broad Written Language scores than individuals with processing speed deficits. Follow-up ANOVAs also revealed a significant main effect of ADHD status on Broad Math scores, $F(1, 300) = 5.43$, $p = .020$, partial $\eta^2 = .018$, with individuals with ADHD obtaining significantly higher scores than controls.

A second two-way MANOVA examined the effect of ADHD status (ADHD versus control) and processing speed performance (processing speed deficit versus no processing speed deficit) on reading, writing, and math composite scores that did not include fluency measures. There was a significant main effect of processing speed performance, Wilks' Lambda = .935, $F(3, 298) = 6.89$, $p < .001$, partial $\eta^2 = .065$, and a significant main effect of

ADHD status, Wilks' Lambda = .973, $F(3, 298) = 2.74$, $p = .044$, partial $\eta^2 = .027$. There was no significant interaction effect, Wilks' Lambda = .985, $F(3, 298) = 1.54$, $p = .204$, partial $\eta^2 = .015$. Follow-up ANOVAs yielded a significant main effect of processing speed performance on the Math Composite, $F(1, 300) = 17.54$, $p < .001$, partial $\eta^2 = .055$; Writing Composite, $F(1, 300) = 15.31$, $p < .001$, partial $\eta^2 = .049$; and Reading Composite, $F(1, 300) = 10.58$, $p = .001$, partial $\eta^2 = .034$. Adults with processing speed deficits performed significantly more poorly than adults without processing speed deficits on all three academic achievement composite scores. Follow-up ANOVAs also revealed a significant main effect of ADHD status on the Math Composite, $F(1, 300) = 8.13$, $p = .005$, partial $\eta^2 = .026$, with adults with ADHD obtaining significantly higher Math Composite scores than controls.

A third two-way MANOVA was performed evaluating the effect of ADHD status (ADHD versus control) and processing speed performance (processing speed deficit versus no processing speed deficit) on academic achievement fluency scores (i.e. Reading Fluency, Math Fluency, and Writing Fluency). The MANOVA yielded a significant main effect of processing speed performance, Wilks' Lambda = .883, $F(2, 297) = 13.12$, $p < .001$, partial $\eta^2 = .117$. There was no significant main effect of ADHD status, Wilks' Lambda = .998, $F(3, 297) = 2.43$, $p = .866$, partial $\eta^2 = .002$. The interaction effect was also non-significant, Wilks' Lambda = .987, $F(3, 297) = 1.35$, $p = .258$, partial $\eta 2 = .013$. Follow-up ANOVAs revealed a significant main effect of processing speed performance on the Math Fluency, $F(1, 299) = 25.42$, $p < .001$, partial $\eta^2 = .078$; Writing Fluency, $F(1, 299) = 15.60$, $p < .001$, partial $\eta^2 = .05$; and Reading Fluency subtests, $F(1, 299) = 33.16$, $p < .001$, partial $\eta^2 = .10$. Adults with processing speed deficits performed significantly more poorly than adults without processing speed deficits on all three academic fluency measures.

Pairwise comparisons using Bonferroni correction revealed that the ADHD group with processing speed deficits performed more poorly than the ADHD without processing speed deficits on Broad Reading, Writing Composite, Reading Fluency, and Math Fluency but not the Broad Math, Broad Written Language, Reading Composite, Math Composite, or Writing Fluency. Notably, the ADHD group with processing speed deficits and the control group with processing speed deficits did not have significantly different scores on any of the academic achievement measures that were included in analyses (See Table 14).

Table 14. Mean scores and standard deviations for Research Question 6.

Academic Achievement Measures	ADHD group without PS deficit (n = 113)	ADHD group with PS deficit (n = 32)	Control group without PS deficit (n = 148)	Control group with PS deficit (n = 11)
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Broad Reading	100.43 (10.84)^{a}	89.88 (8.44)^{b}	100.77 (11.60)^{a}	89.18 (14.57)^{b}
Broad Math	99.81 (11.93)^{a}	93.78 (9.24)^{ab}	99.1 (11.63)^{a}	84.45 (10.89)^{b}
Broad Written Language	104.96 (10.72)^{ab}	98.69 (11.61)^{ac}	105.10 (12.31)^{b}	91.64 (18.00)^{c}
Reading Composite	102.17 (8.60)^{a}	97.98 (9.07)^{ab}	100.75 (9.00)^{ab}	93.86 (15.81)^{b}
Math Composite	101.31 (11.26)^{a}	96.98 (9.30)^{ab}	99.71 (11.16)^{a}	86.95 (10.08)^{b}
Writing Composite	104.05 (10.92)^{a}	98.13 (9.43)^{bc}	103.20 (10.89)^{ab}	93.45 (11.74)^{c}
Reading Fluency	98.08 (12.40)^{a}	84.38 (10.05)^{b}	99.67 (13.70)$^{a+}$	85.82 (13.83)^{b}
Math Fluency	93.72 (12.45)^{a}	85.56 (10.98)^{b}	97.30 (12.66)$^{a+}$	82.18 (13.18)^{b}
Writing Fluency	104.50 (11.20)^{ab}	98.19 (13.20)^{a}	106.78 (12.30)$^{b+}$	95.27 (16.14)^{a}

Note. Means sharing the same superscript are not significantly different from each other at $\alpha = .05$ using Bonferroni correction. PS = processing speed.
$^{+}$n = 147.

Research Questions 7a, 7b, and 7c (Will adults with ADHD exhibit poorer processing speed performance than controls? What is the association between processing speed performance and academic achievement scores? Does processing speed mediate the relationship between ADHD and academic fluency in adults?)

A one-way ANCOVA with group membership (ADHD group versus control group) as the independent variable; education and gender as the covariates; and the WAIS-III Processing Speed Index as the dependent variable was significant, $F(1, 296) = 7.79$, $p = .006$, partial $\eta^2 = .026$. The ADHD group ($M = 96.47$, $SD = 13.57$) had significantly poorer WAIS-III Processing Speed Index scores than the control group ($M = 101.17$, $SD = 12.98$). Additionally, the WAIS-III Processing Speed Index was significantly ($p < .001$) positively correlated with the following WJ-III academic achievement subtests: Letter-Word Identification, $r(298) = .178$, $p = .022$; Passage Comprehension, $r(298) = .185$, $p = .001$; Reading Fluency, $r(298) = .529$, $p < .001$; Applied Problems, $r(298) = .263$, $p < .001$; Calculations, $r(298) = .180$, $p = .002$; Math Fluency, $r(298) = .435$, $p < .001$; Spelling, $r(298) = .150$, $p = .009$; Writing Samples, $r(297) = .185$, $p = .001$; and Writing Fluency, $r(297) = .395$, $p < .001$.

The PROCESS macro for SPSS (Hayes, 2013) employed a bootstrapping strategy to investigate whether processing speed mediated the relationship between ADHD and academic fluency performance. The following analyses used 1000 bias-corrected bootstrapped samples. Results yielded a non-significant direct effect of ADHD status (ADHD versus control) on Reading Fluency (Direct Effect = -1.61, $t = -1.20$, $p = .23$) and a significant indirect effect (Indirect Effect = -2.45, lower 95% Confidence Interval = -4.10, upper 95% Confidence Interval = -.88). Thus, processing speed was found to fully mediate the relationship between ADHD status and reading fluency. The direct effect of ADHD status (ADHD versus control) on Math Fluency was significant (Direct Effect = -2.81, t = -2.07, p = .04), and the indirect effect was also significant (Indirect Effect = -1.90, lower 95% Confidence Interval = -3.27, upper 95% Confidence Interval = -.71), indicating processing speed partially mediated the relationship between ADHD status and math fluency. Processing speed was found to fully mediate the relationship between ADHD and writing fluency. The direct effect of ADHD status (ADHD versus controls) on Writing Fluency was not significant (Direct Effect = -1.66, t = -1.27, p = .21), but the indirect effect of ADHD status (ADHD versus controls) on Writing Fluency was significant (Indirect Effect = -1.65, lower 95% Confidence Interval = -2.95, upper 95% Confidence Interval = -.62). Results from mediation analyses were unchanged when education and gender were included as covariates, except that processing speed fully mediated the relationship between ADHD status and math fluency.

Discussion

ADHD and Neuropsychological Functioning

This study originally sought to investigate the relationship between ADHD, verbal working memory performance, and academic achievement. Barkley's (1997a, 1997b) model links ADHD to verbal working memory deficits; however, ADHD and control groups in this study did not differ significantly in their performance on composite working memory measures. When working memory subtest performance was examined, there were no group differences on the Digit Span and Letter-Number Sequencing subtests. The ADHD group surprisingly obtained higher scores on the Arithmetic subtest than the control group. This finding appears to be related to the ADHD group having higher verbal IQ and vocabulary scores than the control group. After statistically controlling for WAIS-III Vocabulary subtest performance, the effect of group membership on working memory subtest performance was not significant. The finding that adults with ADHD did not exhibit poorer working memory performance than controls raises questions regarding the pervasiveness of the association between ADHD and working memory which has been demonstrated in several meta-analyses (Alderson et al., 2013; Boonstra et al., 2005; Hervey et al, 2004). The results of the current study are consistent with Stearns et al.'s (2004) findings that ADHD symptoms were not significantly associated with scores on the WAIS-III Working Memory Index.

Several hypotheses may explain why ADHD and control groups did not differ in working memory performance. It is possible that theories of ADHD with working memory as a core deficit are not applicable to adult populations with certain characteristics such as higher education levels. Working memory deficits in childhood may be attenuated or ADHD may have less of an impact on working memory as individuals mature and receive more education. Notably, in Gremillion and Martel's (2012) study, verbal working memory mediated the relationship ADHD and reading comprehension in children aged six to nine but not ten to twelve. Also, the construct of working memory has been difficult to define, and the tasks included in the WAIS-III Working Memory Index may not sufficiently capture the construct. To further investigate this hypothesis, a working memory composite, which excluded the Arithmetic subtest, was calculated to obtain a purer measure of working memory; however, ADHD and control groups did not differ in their scores on that composite. Another possible explanation for no group differences in working memory performance between controls and adults with ADHD is that working memory deficits may be present only in a subgroup of individuals with ADHD (Barkley, 1997a; Barkley, 1997b; Nigg et al., 2005b; Stearns et al., 2004). Nigg et al. (2005b) report that there is substantial overlap in the performance of individuals with ADHD and controls on measures of executive functioning, including working memory, with many individuals with ADHD not displaying deficits. Nigg et al. (2005b) state that "group effects reported in the literature are apparently carried by a subset" (p. 1225). The ADHD sample in this study with over thirteen average years of education included few individuals (<10%) with working memory deficits (defined as $\leq$ -1 SD below the population mean).

Nigg et al. (2005b) posits that there are likely other causal pathways to ADHD distinct from executive functioning deficits. One of those potential pathways may be slowed processing speed (Nigg et al., 2005b). Barkley (1997a, 1997b) specified that his model of ADHD involving executive dysfunction was developed to explain ADHD combined type and ADHD hyperactive-impulsive type but not ADHD inattentive type. Barkley categorized ADHD inattentive type as a distinct condition characterized by impairments in processing speed. In the current sample, the ADHD group exhibited poorer processing speed performance than the control group. This finding is consistent with meta-analyses that have found that ADHD is associated with slower processing speed (Boonstra et al., 2005; Hervey et al., 2004). However, the effect size of ADHD on processing speed was small, possibly suggesting this effect too is only present in a subset of individuals with ADHD. Processing speed deficits ($\leq$ - 1 SD) were present in approximately 22% of the ADHD group in this study. These findings are consistent with views of ADHD as a heterogeneous condition that has multiple causes. In this study, a causal pathway or manifestation of ADHD associated with processing speed deficits appears to be more prevalent than one associated with working memory deficits.

ADHD and Academic Achievement

This study also examined the relationship between ADHD in adults and performance on standardized measures of academic achievement. The ADHD group demonstrated poorer performance on the academic fluency measures (i.e., Reading Fluency, Math Fluency, and Writing Fluency). The ADHD group did not perform more poorly than controls on the other WJ-III subtests included in analyses. Notably, although the ADHD and control groups had equivalent FSIQ scores, the ADHD group had higher crystalized/verbal intelligence than the control group. The ADHD group's higher verbal intelligence may have helped them achieve over 12 average years of education and attenuated or buffered them from deficits in academic skills despite poorer processing speeds observed among the ADHD group. Processing speed deficits would likely have more of an effect on academic achievement in the real world (e.g., GPA, ACT/SAT scores, etc.) where tests are usually timed and time-management is more crucial than on short, mostly untimed subtests of the WJ-III. On the three subtests where timing is more significant, namely, the fluency subtests, the ADHD group performed more poorly than the controls. ADHD adults with thirteen or more years of education and average intelligence may have sufficient academic skills but have a harder time applying these skills in environments where time management and speed of processing are important (e.g., fluency measures of the WJ-III, timed tasks, completing homework on time). The poorer performance of individuals with ADHD on fluency measures provides basis for further investigating the mechanisms through which ADHD is affecting academic fluency. Further research may also seek to investigate what variables discriminate adults with ADHD who exhibit academic underachievement and those who do not. Additionally, this study's findings suggest extended time may be a helpful academic accommodation for adults with ADHD, as ADHD was related to poorer performance on measures where timing was most significant although sufficient academic skill scores were obtained by adults with ADHD on untimed measures. Scores on the WJ-III Reading Fluency subtest and the WJ-III Academic Fluency Cluster, a composite of Reading Fluency, Math Fluency, and Writing Fluency, have been found in a previous study to significantly predict whether college students would need and/or benefit from extended time on the multiple-choice Nelson Denny Reading Comprehension subtest (Ofiesh, Mather, & Russell, 2005). Lower scores on the WJ-III academic fluency measures were associated with an increased likelihood that college students would need and/or benefit from extra time (Ofiesh et al., 2005).

Neuropsychological Functioning and Academic Achievement

As hypothesized, working memory and processing speed were significantly positively associated with academic achievement. This is consistent with previous literature demonstrating a positive relationship between these neuropsychological functions and academic achievement in children and adults (Alloway & Alloway, 2010; Berg, 2008; Biederman et al., 2006; Bull & Johnston, 1997; Catts et al, 2002; Christopher et al., 2012; Macaruso & Shankweiler, 2010; Plaza & Cohen, 2005; Rohde & Thompson, 2007; Swanson & Kim, 2007). The relationship between working memory and academic achievement provides some support for the component of Barkley's (1997a, 1997b) model which predicts that verbal working memory impacts reading comprehension performance. Although causation cannot be assumed, there is at least a significant positive relationship demonstrated between verbal working memory and passage comprehension in this study.

Neurocognitive Mediators of ADHD and Academic Achievement

Regarding potential neurocognitive mediators between ADHD and academic achievement, no significant relationship between ADHD status and verbal working memory performance was found. However, processing speed was examined as a mediator. ADHD status was associated with poorer performance on processing speed and academic fluency measures. Processing speed was positively correlated with academic achievement measures, and processing speed was found to mediate the relationship between ADHD status and academic fluency in reading, writing, and math. For at least some individuals with ADHD, academic interventions aimed at improving processing speed may be helpful.

Neuropsychological Subtypes of ADHD

As previously stated, this study's finding as well as other inconsistencies in the literature regarding the association between ADHD and neurocognitive deficits suggest ADHD may be a heterogeneous condition that has multiple causes (Nigg et al, 2005b). Nigg et al. (2005b) propose that the heterogeneity of ADHD should be explored in research by investigating potential subtypes of ADHD based on neuropsychological deficits. The development of subtypes of ADHD based on neuropsychological deficits may prove clinically useful in treatment planning and in identifying risk of academic underachievement and other functional outcomes. Therefore, the academic achievement performance of potential subtypes of ADHD characterized by working memory deficits or processing speed deficits was examined. However, these results should be interpreted with extreme caution due to very small sample sizes. Having ADHD and working memory deficits or processing speed deficits did not seem to place individuals at a greater disadvantage on measures of academic achievement than working memory deficits or processing speed deficits alone. Even when working memory and processing speed deficits were liberally defined, they appeared to have a negative impact on academic achievement performance. While working memory and processing speed deficits are not diagnostic of ADHD, screening for these deficits may be helpful in identifying individuals at greater risk for academic underachievement.

Limitations

This study has several limitations. First, participants included only adults who presented for psychoeducational evaluations, and the participants were mostly Caucasian with over 12 years of education. This limits the generalizability of these results. Because the control group presented for psychoeducational evaluations, it is possible that they were experiencing more psychiatric symptoms or academic problems than control groups recruited from the community that have been used in other studies.

Another limitation of this study is that the test scores of participants were considered when diagnoses were established. This could potentially inflate the Type 1 error rate of research questions investigating the relationship between ADHD and neuropsychological performance. Clinicians may have been more likely to diagnose individuals with low working memory or processing speed as having ADHD due to literature documenting the association (Boonstra et al., 2005; Hervey et al., 2004).

Another limitation of this study is that analyses examining potential neuropsychological subtypes of ADHD consisted of groups with very small sample sizes, thus restricting generalizability. Additionally, working memory and processing speed deficits were defined very liberally as scores less than or equal to one standard deviation below the population mean instead of one and a half standard deviations which is more commonly used in the literature (Biederman et al., 2004; Biederman et al., 2006). This may have reduced the ability of analyses to identify between group differences.

Conclusions

This study helps further elucidate the relationships between ADHD, verbal working memory, processing speed, and academic achievement in adults. ADHD was associated with poorer processing speed and academic fluency performance, but no significant differences in verbal working memory performance were noted between ADHD and control groups. These findings are consistent with hypotheses that working memory or executive functioning deficits may only be present in a subgroup of individuals with ADHD and other subgroups may have different cognitive correlates such as slowed processing speed. If neuropsychological subtypes can be identified, they may be helpful in identifying individuals at risk for functional impairments and clarify the neuropsychological profile of ADHD. In this study, processing speed was found to at least partially account for the relationship between ADHD status and academic fluency, suggesting extended time accommodations and interventions that target improving processing speed may be helpful for some adults with ADHD. Although processing speed and working memory deficits are certainly not diagnostic of ADHD, screening for these deficits may be helpful for identifying adults at risk for impairments, given processing speed and working memory deficits were generally associated with poorer academic achievement in both adults with ADHD and controls.

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Appendix

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Robert Mathews, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
P: 225.578.8692
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TO: Wm. Drew Gouvier
Psychology

FROM: Robert C. Mathews
Chair, Institutional Review Board

DATE: April 25, 2014
RE: **IRB#** 3480

TITLE: Adult ADHD and Academic Achievement

New Protocol/Modification/Continuation: New Protocol

Review type: Full ___ Expedited X   **Review date:** 4/24/2014

Risk Factor: Minimal X Uncertain ______ Greater Than Minimal______

Approved X **Disapproved**__________

Approval Date: 4/24/2014 **Approval Expiration Date:** 4/23/2015

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: N/A

LSU Proposal Number (if applicable): ________

Protocol Matches Scope of Work in Grant proposal: (if applicable)_______

By: Robert C. Mathews, Chairman Robert C Mathews

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. SPECIAL NOTE:

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

Vita

Alyse Barker Blanchard is a native of Louisiana. She received her Bachelor of Science degree in psychology from Louisiana State University in 2007. In 2008, Alyse enrolled in Louisiana State University's clinical psychology doctoral program under the direction of Dr. Wm. Drew Gouvier. She earned her Master of Arts degree in clinical psychology in 2011. She completed her pre-doctoral internship at VA Gulf Coast Veterans Health Care System in Biloxi, Mississippi. Her research and clinical interests include neuropsychology, malingering, and behavioral medicine.