Neuropsychological performance deficits in adults with attention deficit/hyperactivity disorder

Diane E. Johnson\textsuperscript{a,*}, Jeffery N. Epstein\textsuperscript{a}, L. Randolph Waid\textsuperscript{b}, Patricia K. Latham\textsuperscript{b}, Konstantin E. Voronin\textsuperscript{b}, Raymond F. Anton\textsuperscript{b}

\textsuperscript{a}Attention Deficit Disorder Program, Department of Psychiatry, Duke University Medical Center; Box 3431, Durham, NC 27710, USA
\textsuperscript{b}Center for Drug and Alcohol Programs, Department of Psychiatry and Behavioral Sciences, Medical University of South Carolina, Charleston, SC, USA

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Abstract

Neuropsychological deficits in children diagnosed with attention deficit/hyperactivity disorder (ADHD) have been well documented utilizing various neuropsychological tests. Only recently has research begun to examine if similar deficits are present in adults with ADHD. A neuropsychological testing battery was constructed that assessed verbal learning and memory, psychomotor speed, and sustained attention — all demonstrated to be deficient in individuals with ADHD. Fifty-six self-referred nonmedicated adults with a DSM-IV diagnosis of ADHD and 38 normal comparison adults participated. ADHD adults demonstrated verbal and nonverbal memory deficits and decreased psychomotor speed compared to normal controls. Differences between ADHD and normal adults were not documented on traditional measures of executive functioning. A pattern of results emerged whereby ADHD adults’ performance, particularly with regard to psychomotor speed, became more impaired as task complexity increased. This study’s results largely corroborate similar neuropsychological testing results in ADHD children and recent ADHD adult findings, and support a frontal lobe dysfunction hypothesis of ADHD. © 2001 National Academy of Neuropsychology. Published by Elsevier Science Ltd.

Keywords: Attention deficit/hyperactivity disorder; Neuropsychological functioning; Frontal lobe dysfunction

A large body of research literature has examined neuropsychological functioning in children diagnosed with attention deficit/hyperactivity disorder (ADHD). Much of this
research has assessed specific domains of impairment by comparing the performance of ADHD children to normal children on neuropsychological tests. These studies have shown that ADHD children perform more poorly than non-ADHD children on neuropsychological tasks measuring sustained attention (Douglas, 1983; Seidel & Joschko, 1990), executive functioning (Chelune, Ferguson, Koon, & Dickey, 1986; Shue & Douglas, 1992), motoric inhibition (Iaboni, Douglas, & Baker, 1995; Oosterlaan & Sergeant, 1996), and verbal learning and memory (Loge, Staton, & Beatty, 1990; Seidman et al., 1995; Tannock, Purvis, & Schachar, 1993). These deficits have been consistent and replicable across most studies and are widely acknowledged to be the core neuropsychological deficits in children with ADHD (Barkley, 1997b).

Barkley (1997a), defines executive functions as those neuropsychological processes that permit or assist the person with self-regulation. With Barkley’s review of the literature, he concludes that most of the seemingly disparate abilities found to be discrepant in ADHD children (i.e., (1) motor coordination and sequencing; (2) working memory and mental computation; (3) planning and anticipation; (4) verbal fluency and confrontation communication; (5) effort allocation; (6) application of organizational strategies; (7) internalization of self-directed speech; (8) adherence to restrictive instruction; and (9) self-regulation of emotional arousal) fall within the domain of executive functions in the field of neuropsychology and are considered to be mediated by the frontal cortex, particularly the prefrontal lobes.

The aforementioned areas of neuropsychological impairment have associations with frontal lobe functions (Hynd, Hern, Voeller, & Marshall, 1991; Lezak, 1976; Shue & Douglas, 1992). Consequently, ADHD causality has been conceptualized in at least three different ways, as (1) frontal lobe dysfunction (Castellanos et al., 1996; Hynd, Semrud, Lorys, Novey, & Eliopoulos, 1990), (2) delayed frontal maturation functioning (Chelune et al., 1986), and (3) subcortical-frontal motor subsystems dysfunction (Castellanos et al., 1994; Giedd et al., 1994). Further evidence for attributing ADHD impairments to the frontal lobe comes from studies of frontal lobe-damaged adults who demonstrate similar behavioral and cognitive symptomatology as ADHD patients (Gualtieri & Hicks, 1985; Mattes, 1980). More recently, several neuro-imaging studies have shown abnormalities in the prefrontal cortex of ADHD patients who were participating in tasks requiring executive functioning (Castellanos et al., 1996; Hynd et al., 1990).

For most of its history, ADHD was conceptualized as a childhood disorder. Thus, the neuropsychological functioning of ADHD children has been well documented; however, little is known about the neuropsychological functioning of adolescents and even less is known about the more recently defined diagnosis of adult ADHD. With regard to adolescents, two studies have been conducted that document neuropsychological deficits similar to those found in younger ADHD children (Fischer, Barkley, Edelbrock, & Smallish, 1990; Seidman, Biederman, Faraone, Weber, & Oulette, 1997). Specifically, ADHD adolescents demonstrated impaired performance on neuropsychological tests that assess attention (Fischer et al., 1990; Seidman et al., 1997), executive functioning (Fischer et al., 1990; Seidman et al., 1997), impulse control (Fischer et al., 1990), and verbal learning (Seidman et al., 1997). These findings in adolescent ADHD individuals support the supposition that neuropsychological deficits do not attenuate over time. These studies
support the conceptualization of ADHD as a disorder with chronic, consistent deficits that persist beyond the elementary school years.

ADHD is now conceptualized as a disorder with a lifelong course (Shaffer, 1994; Wender, 1995). Approximately 30–50% of patients continue to meet diagnostic criteria for ADHD in adulthood (Klein & Mannuzza, 1991; Weiss & Hechtman, 1993). Assessing whether or not adult ADHD patients suffer from similar neuropsychological deficits as children and adolescents is a logical next step and helps address at least three theoretical questions. First, one explanation for the neuropsychological deficits found in ADHD is that the brain maturation of ADHD children is delayed (Chelune et al., 1986). Demonstration of concordant neuropsychological deficits in ADHD children and ADHD adults would seem to refute this explanation since the maturational brain development of an adult is complete.

A second theoretical issue is that ADHD is conceptualized as a developmental disorder with symptoms that persist across the life span (Weiss & Hechtman, 1993). Neuropsychological differences documented in ADHD children should be, in theory, similar to those documented in ADHD adults. Lastly, a controversy remains regarding the validity of ADHD as a disorder of adulthood. Indeed, a reliable set of diagnostic criteria has yet to be delineated for a diagnosis of adult ADHD. Objective measures, such as neuropsychological tests, that document differences between ADHD and non-ADHD adults in neurocognitive functioning provide further evidence of ADHD as a valid disorder of adulthood.

As ADHD has become recognized as a chronic and pervasive disorder, researchers began to assess areas of neuropsychological functioning in ADHD adults (Epstein, Conners, Erhardt, March, & Swanson, 1997; Epstein, Conners, Sitarenios, & Erhardt, 1998; Holdnack, Moberg, Arnold, Gur, & Gur, 1995; Horner, 1996; Riordan et al., 1999; Seidman, Biederman, Weber, Hatch, & Faraone, 1998). Many early studies of adults only required target adults to have a history of ADHD in childhood without assessing for adult symptomatology (Jenkins & Cohen, 1998; Klee, Garfinkel, & Beauchesne, 1986). While a childhood history of ADHD symptoms must be documented, the presence of symptoms in adulthood is required for an adult ADHD diagnosis (Wender, 1995).

Only a few studies have been published that assessed a sample of adults with current ADHD symptoms using a standard battery of neuropsychological tests with demonstrated discriminability in childhood and adolescent populations (Holdnack et al., 1995; Seidman et al., 1998). Holdnack et al. used Wender Utah Criteria (Wender, 1995) to identify 25 ADHD adults and 30 non-ADHD adults. All participants completed a neuropsychological battery that assessed sustained attention, psychomotor speed and integration, executive functioning, response inhibition, and verbal learning. The only differences found between ADHD and normal adults were on measures of verbal learning on a list-learning task and psychomotor speed. More recently, Seidman et al. identified 64 ADHD adults using DSM-III-R criteria and compared their neuropsychological performance to that of 73 non-ADHD control subjects. A similar pattern of deficits to that of Holdnack et al. was found with slower psychomotor speed and impaired verbal learning. Seidman et al. also demonstrated differences between groups on auditory sustained attention. As with the Holdnack et al. study, differences were not documented on traditional measures of executive function or response inhibition.

Riordan et al. (1999) assessed the neuropsychological functioning of 21 adults with ADHD based on DSM-IV criteria, 19 adults with ADHD and comorbid affective disorder, and 15
normal control subjects. Via factor analysis, the authors identified eight neuropsychological summary scales. Adults with ADHD were found to have relatively intact verbal reasoning and visual memory but demonstrated impaired performance on measures of verbal memory, motor and processing speed, visual scanning, and auditory and visual distractibility. While these three studies documented some specific neuropsychological deficits, no study demonstrated the pervasive pattern of neuropsychological differences that has been documented in ADHD children and adolescents.

In order to better understand the neurocognitive functioning of adults with ADHD, the current study examines the performance of nonmedicated ADHD adults compared to normal controls on a traditional battery of neuropsychological tests designed to assess neurocognitive deficits documented in the childhood ADHD literature. We hypothesize that ADHD adults would perform statistically significantly worse on a battery of neuropsychological measures designed to assess executive functions believed to be impaired in this population. These measures include tests of verbal and nonverbal memory, fluency of speech and reading, visuomotor tracking, abstract behavior/shifting sets, psychomotor speed, and sustained attention.

1. Method

1.1. Participants

Two groups of adults volunteered to participate in the study. The ADHD group consisted of 56 adults between the ages of 20 and 53 years old. There were 40 males (71% of sample). The racial composition was 95% Caucasian and 5% African-American. This group of individuals was self-referred to an outpatient psychological assessment center at the Medical University of South Carolina for an ADHD assessment. Each participant paid an initial screening fee to register through the clinic and was given the option to enroll in the study to obtain an ADHD assessment. A diagnosis of ADHD was determined via the Schedule for the Assessment of Conduct, Hyperactivity, Anxiety, Mood, and Psychoactive Substances (CHAMPS) interview, ADHD component (Mannuzza & Klein, 1987). The CHAMPS is a semistructured interview that assesses ADHD symptoms in childhood and adulthood utilizing DSM-III, DSM-III-R, and DSM-IV (American Psychiatric Association, 1994) criteria. The CHAMPS interview allows for the assessment of the age of onset and chronicity of each ADHD symptom, current symptom severity, and domains of impairment. All ADHD individuals met DSM-IV criteria for one of the three types of ADHD, Predominantly Inattentive Type, Predominantly Hyperactive-Impulsive Type, or Combined Type, via this instrument.

Further evidence of childhood ADHD was obtained via completion of the Tarter HK/MBD childhood symptom checklist (Tarter, McBride, Buonpane, & Schneider, 1977). Hyperkinesis/minimal brain dysfunction (HK/MBD) described the syndrome of ADHD prior to the DSM nosology. It is a 50-item, retrospective self-report checklist that assesses for the presence of impulsive behavior, hyperactivity, attentional problems, social interaction, and acquisition of language skills prior to the age of 13 years old. A mean score of 12 or above
identified hyperkinetic/minimal brain dysfunction in Tarter et al.’s original sample. The Tarter Scale was not used as a diagnostic tool.

Another aspect of the diagnostic protocol involved ruling out other diagnoses that might better account for the individual’s current difficulties. All ADHD adults were administered two components (mood disorders and substance use disorders) of the Structured Clinical Interview for DSM-III-R (SCID; Spitzer, Williams, Gibbon, & First, 1990). Participants were excluded if they met current DSM-III-R (American Psychiatric Association, 1987) criteria for a current mood or substance use disorder. There was a less formal screening for anxiety and other Axis I disorders. If any other Axis I disorder was suspected, further assessment via the SCID was conducted. A comorbid anxiety disorder did not necessarily exclude the participant. ADHD participants also completed the Beck Depression Inventory (BDI; Beck & Steer, 1987) but their scores were not exclusionary since they did not meet DSM-III-R criteria for a “mood disorder.” Participants who were taking medication at the time of study entry were adequately washed out of medication before the neurocognitive battery was administered.

The comparison group consisted of 38 adults between the ages of 21 and 63 years old. There were 24 males (63% of sample). The racial composition was 92% Caucasian and 8% African-American. These individuals were paid volunteers recruited via newspaper advertisement and were from the same catchment area as the ADHD group. For ADHD diagnostic purposes, the comparison group sample completed the CHAMPS interview and could not meet adult ADHD criteria. They also completed the Tarter Scale to assess childhood ADHD symptoms but scores were not exclusionary. The comparison sample also completed the substance use disorders component of the SCID and could not meet DSM-III-R criteria. They were screened for depression via the BDI and excluded if their score was above the clinical cut-off of greater than or equal to 16, with proper follow-up, if required. Participants were excluded if they were taking psychotropic medication.

1.2. Measures

As part of an extensive assessment battery, all participants completed the following neuropsychological test battery, listed in order of presentation.

1.2.1. Gordon Diagnostic System

The Gordon Diagnostic System (GDS; Gordon, McClure, & Aylward, 1989) consists of several visual attention tasks; the two tasks utilized in this study were the “vigilance task” and the “distractibility task.” These tasks were administered to assess sustained attention, response inhibition, and psychomotor speed. The GDS is a self-contained computerized system with a display screen and a response button below the screen. During the vigilance task, a series of numbers are shown in the middle of the display screen, one at a time, and the subject is required to press the button each time they see a “1” that is followed by a “9.” Correct responses (out of 30 total targets in the series) are summed by counting the number of times the subject pressed the button after a “1–9” sequence. Also, errors of commission are computed by summing the number of times the bar was pressed after a numerical sequence other than “1–9.” Last, response latency, in milliseconds, is recorded by computing the time
it takes to press the bar after a “1–9” sequence. Data are presented in three blocks so that
performance over time can be computed. The distractibility task is similar to the vigilance
task except that distractor numbers appear on either side of the center of the display screen
throughout the task while the subject is asked to respond only to the numbers on the center of
the screen. The same dependent measures as on the vigilance task are assessed.

1.2.2. Shipley Institute of Living Scale (Shipley, 1939)

This self-administered paper and pencil instrument measures (1) vocabulary and (2)
abstract reasoning and serves to estimate intellectual functioning. Raw scores for each are
obtained by adding the number of correct vocabulary and abstraction responses, and a total
score is obtained by adding these together. Raw scores can be converted to age-corrected T-
scores. With regard to the order of administration of tests, the vocabulary subtest was
administered first, and the abstract reasoning subtest was administered following the Stroop
Test mentioned below.

1.2.3. Wechsler Memory Scale-Revised: Logical Memory and Visual Reproduction

These subtests assess verbal and nonverbal (visual) memory via immediate and delayed
recall. The “logical memory” portion of the Wechsler Memory Scale-Revised (WMS-R;
Wechsler, 1987) consists of two auditorily presented paragraphs (stories), read one at a time
by the tester. The participant is asked to recall as much of the story as he/she can immediately
following each presentation (Logical Memory I) and as much of each story after a 30-min
delay (Logical Memory II). The visual reproduction portion of the WMS-R requires subjects
to recall by drawing four briefly presented abstract drawings both immediately after each
presentation (Visual Reproduction I) and all four after a 30 min delay (Visual Reproduction
II). The raw score is number of recalled pieces of the story and details correctly drawn. The
logical memory (immediate recall) was administered first, followed by the visual reproduc-
tion (immediate recall). The “delayed recall” for each test occurred, 30 min later, after the
Shipley Abstraction Test and before the Wisconsin Card-Sorting Test.

1.2.4. Controlled Oral Word Association Test (FAS; Benton & Hamsher, 1976)

This is a test of fluency of speech that is associated with frontal lobe functioning.
Subjects are required to generate as many words as possible that begin with the letter F, for
a time period of 1 min. Then, they are asked to do the same with the letter A and then the
letter S. The total number of words generated for all three letters serves as the score on this
test for this study.

1.2.5. Stroop Color–Word Interference Test (Stroop, 1935)

This classic neuropsychological test of reading fluency and mental flexibility requires
subjects to read lists of words and colors. First, the subject reads out loud a list of names of
colors printed in columns on the page in black on white paper (Word Score). Then, using a
second stimuli sheet, the subject states the name of the color of colored X’s printed in
columns on a white page of paper (Color Score). Last, the interference task requires the
subject, presented with a third stimuli sheet, to name the color of the ink that each word is
printed in (and not to read the word that is a different color name than the color of the ink)
presented in the columns (Color–Word Score). The number of responses during a 45-s period is assessed for each task.

1.2.6. Wisconsin Card-Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993)
This is a measure of frontal lobe (executive) functioning, originally designed to study “abstract behavior” and “shift of set” (Lezak, 1976). The subject is given a pack of 64 cards on which are printed one to four symbols (star, triangle, cross, and circle) in one of four colors (red, yellow, blue, and green). The task is to place each card under one of the four stimulus cards without being told the rule (match by number, color, or symbol). The subject must deduce the pattern based on the tester’s comment of right or wrong to each response. Once the subject deduces the pattern (rule) and has 10 correct responses, the rule changes. The number of categories (patterns) completed (5 are possible with 64 cards) and the number of correctly laid cards were computed.

1.2.7. Trail-Making Test A and B (Reitan, 1958)
The Trail-Making Test is a timed psychomotor task of visual conception requiring visuomotor tracking of one sequence (part A) or two alternating sequences (part B). In part A, the subject, as quickly as possible, connects the numbers 1 through 25 in numerical order that are scattered on a page. In part B, the subject, as quickly as possible, connects the numbers 1 through 12 and the letters A through L in the following order: 1-A-2-B-3-C, etc. The dependent measure for this study is the time taken, in seconds, to complete each test.

1.2.8. 3RT: Reaction Time Tests (Teng, 1990)
The 3RT consist of a simple, a choice, and a conditional visual reaction time task used to assess psychomotor speed. The simple reaction time task has two segments. The simple left segment has 16 left trials in which a left arrow is shown on the screen and the subject uses their left index finger to press the “z” key on the keyboard after each presentation. The second segment of the simple task has 16 trials in which a right arrow is presented and the subject presses the “?” key on the keyboard after each presentation. The computer determines the reaction time from presentation of the stimulus to key press. During the choice reaction time task, there are 16 left and 16 right trials presented in a random order. The subject is instructed to respond with the hand indicated by the arrow. Last, on the conditional reaction time task, there are 16 left and 16 right arrows, randomly presented, each with an additional (=) or (X) sign, indicating whether to respond in the direction of the arrow or in the opposite hand, respectively. Response times were measured in milliseconds.

1.3. Design and procedure

All participants were administered, individually, an ADHD diagnostic assessment and a neurocognitive test battery selected to evaluate hypothesized deficits of ADHD. These assessments were part of a larger assessment battery. All ADHD group participants were diagnosed by one of two licensed clinical psychologists (DEJ, LRW). The CHAMPS
interview was administered to the comparison group by a research psychiatrist (KEV). The neuropsychological battery for both groups was administered in one uninterrupted session, individually, in a standardized fashion by experienced psychometrists who were not blinded to group identity. The total assessment took approximately 4 h to complete.

2. Results

2.1. Demographic and clinical characteristics

The ADHD (71% male) and non-ADHD groups (63% male) did not differ on gender composition \((\chi^2 = 0.71, p = \text{ns})\). The two groups did differ on age with the ADHD group \((M = 33.3 \text{ years})\) being significantly younger than the non-ADHD group \((M = 40.8 \text{ years})\; \text{see Table 1}\). In order to account for the age differential, age was used as a covariate in all subsequent analyses unless otherwise stated. Subject groups also differed on the level of educational attainment with the comparison group having more years of education (17 years); the ADHD group had a mean education of 14 years. Scores on the Tarter Scale, a measure of childhood ADHD, were consistent with expectations. ADHD adults \((M = 23.6, \text{SD} = 6.4)\) had significantly higher scores on the Tarter Scale (the cut-off score of \(\geq 12\) is indicative of childhood symptomatology) than non-ADHD adults \((M = 5.5, \text{SD} = 5.6; F(91) = 196.2, p < 0.01)\), confirming more self-reported childhood symptoms of inattention and hyperactivity in the ADHD group. Though adult patients were excluded if they met a categorical depression diagnosis as determined by the SCID, self-report on the BDI demonstrated that ADHD adults \((M = 13.5, \text{SD} = 9.9)\) reported significantly higher levels of depressive symptomatology than the non-ADHD group \((M = 2.0, \text{SD} = 3.2; F(92) = 47.9, p < 0.01)\). Mild depression, as measured on the BDI, is defined as a score between 10 and 15 points.

Most of the neuropsychological tests below are categorized by the function(s) they assess based on Lezak’s (1976) definitions. The 3RT and GDS are not categorized in Lezak’s text.

### Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>ADHD ((N = 56)) (M)</th>
<th>ADHD ((N = 56)) SD</th>
<th>Non-ADHD ((N = 38)) (M)</th>
<th>Non-ADHD ((N = 38)) SD</th>
<th>(F)</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (in years)</td>
<td>33.3</td>
<td>8.42</td>
<td>40.8</td>
<td>10.24</td>
<td>15.10</td>
<td>0.0002</td>
</tr>
<tr>
<td>Education (in years)</td>
<td>13.93</td>
<td>2.82</td>
<td>17.29</td>
<td>3.29</td>
<td>28.08</td>
<td>0.0000</td>
</tr>
<tr>
<td>Tarter Scale(^a)</td>
<td>23.62</td>
<td>6.40</td>
<td>5.52</td>
<td>5.60</td>
<td>196.16</td>
<td>0.0000</td>
</tr>
<tr>
<td>BDI(^b)</td>
<td>13.52</td>
<td>9.90</td>
<td>2.00</td>
<td>3.21</td>
<td>47.90</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

\(^a\) Raw score \(\geq 12\) is indicative of childhood HK/MBD (now ADHD) symptoms.

\(^b\) Raw score >16 is indicative of clinically significant depression; a score of 10–15 is indicative of mild depression.
2.2. Intelligence

T-scores on the Shipley Intelligence Scale were compared across ADHD and non-ADHD adults (Table 2). As the T-scores on the Shipley are age-adjusted, age was not used as a covariate in these comparisons. Though the ADHD group had lower mean T-scores on the vocabulary, abstraction, and total scales of the Shipley than non-ADHD adults, none of these differences were significant. Furthermore, these T-scores translate into estimated mean IQ scores [based on Wechsler Adult Intellectual Score-Revised (Wechsler, 1981) norms] of 105.23 (SD = 7.84; average range) for the ADHD group and 111.61 (SD = 8.16; high average range) for the comparison group. While IQ differences are often controlled for either statistically (e.g., ANCOVA) or methodologically (e.g., matching) in studies of neuropsychological functioning, the argument has been made that controlling for IQ in studies of ADHD may end up removing variance attributable to ADHD (Seidman et al., 1997). Our a priori decision was to not use IQ as a covariate, and the findings are reported as such. However, since the decision whether or not to covary for IQ is controversial, we conducted

<table>
<thead>
<tr>
<th>Variable</th>
<th>ADHD</th>
<th>Non-ADHD</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipley Intelligence</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vocabulary T-score</td>
<td>52.50 6.62</td>
<td>53.82 7.52</td>
<td>0.80</td>
<td>0.37</td>
</tr>
<tr>
<td>Abstraction T-score</td>
<td>58.25 6.02</td>
<td>60.29 5.04</td>
<td>2.95</td>
<td>0.09</td>
</tr>
<tr>
<td>Total T-score</td>
<td>56.54 6.11</td>
<td>58.23 5.45</td>
<td>1.91</td>
<td>0.17</td>
</tr>
<tr>
<td>Wechsler Memory Scales</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logical Memory Ia</td>
<td>23.55 7.03</td>
<td>26.87 6.20</td>
<td>6.97</td>
<td>0.01</td>
</tr>
<tr>
<td>Logical Memory IIa</td>
<td>18.96 7.35</td>
<td>22.97 6.90</td>
<td>10.12</td>
<td>0.002</td>
</tr>
<tr>
<td>Visual Rep Ia</td>
<td>35.89 3.56</td>
<td>35.76 3.96</td>
<td>0.67</td>
<td>0.41</td>
</tr>
<tr>
<td>Visual Rep IIa</td>
<td>32.14 6.82</td>
<td>33.87 4.15</td>
<td>5.55</td>
<td>0.02</td>
</tr>
<tr>
<td>FAS (total words)a</td>
<td>37.98 11.60</td>
<td>39.58 8.88</td>
<td>0.09</td>
<td>0.77</td>
</tr>
<tr>
<td>Trail-Making (in s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aa</td>
<td>27.91 8.64</td>
<td>26.66 6.28</td>
<td>0.76</td>
<td>0.39</td>
</tr>
<tr>
<td>Ba</td>
<td>66.00 20.52</td>
<td>58.03 14.89</td>
<td>6.83</td>
<td>0.01</td>
</tr>
<tr>
<td>Stroop</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Worda</td>
<td>100.22 17.67</td>
<td>106.37 12.63</td>
<td>4.72</td>
<td>0.03</td>
</tr>
<tr>
<td>Colora</td>
<td>74.60 11.44</td>
<td>77.47 10.48</td>
<td>3.04</td>
<td>0.08</td>
</tr>
<tr>
<td>Color–Worda</td>
<td>42.33 9.22</td>
<td>45.97 13.98</td>
<td>2.28</td>
<td>0.13</td>
</tr>
<tr>
<td>Wisconsin Card Sort</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Categories completea</td>
<td>3.46 1.43</td>
<td>3.53 1.50</td>
<td>0.00</td>
<td>0.97</td>
</tr>
<tr>
<td>Number correcta</td>
<td>47.57 8.56</td>
<td>48.92 8.82</td>
<td>0.00</td>
<td>0.99</td>
</tr>
<tr>
<td>3RT Response Time (in ms)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simplea</td>
<td>332.71 88.30</td>
<td>341.08 124.76</td>
<td>0.05</td>
<td>0.82</td>
</tr>
<tr>
<td>Complexa</td>
<td>446.35 94.59</td>
<td>428.35 48.13</td>
<td>6.56</td>
<td>0.01</td>
</tr>
<tr>
<td>Conditionala</td>
<td>936.81 277.81</td>
<td>927.19 247.75</td>
<td>4.12</td>
<td>0.05</td>
</tr>
</tbody>
</table>

a Raw scores.
ANCOVA utilizing the vocabulary T-score of the Shipley as a covariate. The between-group differences did not change statistically.

2.3. Verbal and nonverbal (visual) memory

On tasks of both immediate and long-term verbal memory, assessed via the Logical Memory scale of the Weschler Memory Scales, ADHD adults performed significantly worse than comparison adults (see Table 2), recalling fewer details of the stories. Subjects were also administered the Visual Reproduction scale of the WMS. On this scale, ADHD adults demonstrated comparable performances to non-ADHD adults on immediate visual memory. However, long-term visual memory appeared to be impaired in ADHD adults compared to the non-ADHD comparison groups.

2.4. Fluency of speech

On the test of Oral Word association (FAS), a test of fluency of speech, the ADHD adults generated a comparable number of words as compared to the non-ADHD comparison group, suggesting no impairment in the verbal fluency of ADHD adults. Verbal association frequencies reported in a normal adult sample for F, A, and S were in the 31–34 words/minute range. Both groups in this study generated more words than expected.

2.5. Fluency of reading

On the Stroop, a test of reading fluency, overall, ADHD adults displayed a pattern of fewer correct responses than non-ADHD controls on all three subtests. However, scores on the color and color-word subtests were not statistically significantly different between groups. Differences between group scores on the word subtest were significant and demonstrated that ADHD adults gave fewer correct responses than non-ADHD controls ($F(1,90)=4.72, p<0.05$). All raw scores (correct responses) for both groups across all three subtests translate roughly to T-scores in the range of 46–51, indicating performances in the 34th to 54th percentile. As the word subtest of the Stroop requires subjects to simply read the words with little cognitive interference, this difference may be better interpreted as a measure of general verbal processing speed rather than executive functioning (see discussion).

2.6. Abstract behavior/shift of set

On the Wisconsin Card-Sorting Test, no between-group differences were observed on any of the dependent measures, and the groups had scores comparable to published control group data (Lezak, 1976).

2.7. Visual conceptual/visuomotor tracking

On the Trail-Making Test A, there were no differences between ADHD and non-ADHD subjects in the amount of time it took to complete the number sequence. On the Trail-Making
Test B, which requires a higher level of psychomotor integration, ADHD subjects (66.00 s) were statistically slower in completing the task than non-ADHD controls (58.03 s). Both groups scores are within normal limits and do not indicate clinical deficits.

2.8. Psychomotor speed

A 2 × 3 ANCOVA using age as a covariate was employed to assess for differences on the 3RT task. Group was entered as a between-subjects variable while task (simple, complex, or conditional) was entered as a within-subjects variable. Significant effects of group ($F(1,71) = 4.02, p < 0.05$) and task ($F(2,144) = 352.53, p < 0.001$) were found. There was no group × task interaction effect ($F(2,144) = 0.16, p = ns$). The statistically significant main effect for task was expected given the increasing difficulty of the three tasks compared to one another. Planned comparisons were conducted examining differences between groups on each task. These comparisons are presented in Table 2. No between-group differences were found on the simple task while slower reaction times were exhibited by the ADHD group on both the complex and the conditional tasks, indicating slower psychomotor processing speed in the ADHD group.

Another measure of psychomotor speed can be derived from examination of response latencies on the vigilance and distractibility tasks of the GDS. Separate 2 (group) × 3 (blocks of time) ANCOVAs were conducted to explore between group differences and to assess whether psychomotor speed remained constant during each task. The distractibility task had a significant group main effect ($F(1,91) = 4.03, p < 0.05$), while the group main effect for the vigilance task was nonsignificant ($F(1,91) = 1.61, p = ns$). This finding indicates that ADHD adults had significantly slower reaction times ($M = 47.73, SD = 10.27$), compared to the comparison group ($M = 43.76, SD = 13.74$), in a distracting situation (the GDS distractibility task), but had reaction times similar to the comparison group on the GDS vigilance task (ADHD $M = 48.52, SD = 10.84$; comparison group $M = 46.50, SD = 11.36$). Analyses for both tasks demonstrated significant interaction effects (vigilance task: $F(2,184) = 4.37, p < 0.05$; distractibility task: $F(2,184) = 4.52, p < 0.05$). These interaction effects were highly similar and demonstrated that non-ADHD controls had slower reaction times as the task progressed while ADHD subjects showed faster reaction times as the task progressed (see Fig. 1).

2.9. Sustained attention and response inhibition

Omission errors and commission errors on computerized continuous performance tasks (CPT) have been related to the constructs of inattention and impulsivity/response inhibition respectively (Corkum & Siegel, 1993). The number of omission errors and number of commissions on the GDS were analyzed using 2 (group) × 3 (blocks of time) ANCOVAs. Across tasks and both dependent variables, there were no significant main effects of time nor were there any interaction effects. There were also no main effects of group on commission errors on either task. The lone main effect of group was for errors of omission on the vigilance task ($F(1,91) = 9.81, p < 0.01$), with ADHD adults being less accurate ($M = 28.52, SD = 2.32$) than normals ($M = 28.52, SD = 2.32$) than normals.
3. Discussion

ADHD adults demonstrated memory deficits, poor visual-motor integration (visuomotor tracking), and slowed psychomotor speed compared to a normal comparison sample on a battery of neuropsychological tests. Differences between ADHD and a comparison group of adults were not documented on some of the traditional measures of executive functioning (e.g., WCST and FAS). Compared to the deficits documented in ADHD children, the deficits in ADHD adults are similar in some domains (e.g., memory) and inconsistent in others (e.g., executive functioning). While it appears that areas of deficit may change over the course of the lifespan based upon cross-sectional neuropsychological data such as those presented in this study and others (Holdnack et al., 1995; Riordan et al., 1999; Seidman et al., 1998), longitudinal data that repeatedly assess an afflicted population are needed in order to determine the evolution and development of neuropsychological deficits in ADHD patients as they mature.

Neuropsychological deficits in the memory functioning of ADHD adults has been investigated largely using list learning tasks (e.g., California Verbal Learning Test; CVLT). Using these tasks, prior studies have shown deficits in verbal memory on list learning tasks (e.g., Riordan et al., 1999; Seidman et al., 1998). Similarly, using the Wechsler Logical
Memory scales as a measure of verbal learning in the present study, deficits were seen in both the immediate recall of information from the stimulus stories and in later recall 30 min later. Given that the memory deficits were present at both time points, these memory deficits do not suggest that ADHD adults have problems with forgetting information (or a deficit in retrieval from LTM). Rather, it appears that the problem is with the encoding of verbal information at the time the story is being read. This encoding problem, as opposed to forgetting, is similar to the conclusions offered by Seidman et al. using the CVLT as a measure of verbal memory.

Nonverbal memory deficits in ADHD adults are not as consistent as verbal memory deficits. The present study found that ADHD adults performed similarly to the comparison group on the “visual reproduction” subtest of the Weschler memory scales when they were asked to reproduce a figure immediately after viewing it, but they produced less accurate reproductions after a 30-min delay. Seidman et al. (1997, 1998) have used the Rey–Osterreith Complex Figure Test with adolescents and adults that has an incidental recall component similar to the Visual Reproduction I subtest. ADHD adolescents and adults did not demonstrate deficits in accuracy on this subtest at immediate recall. This finding was also supported by Riordan et al. (1999). Thus, ADHD adults consistently have demonstrated no short-term deficits in recall of visual information. The present study’s finding that ADHD adult demonstrate longer term visual memory deficits is unique mainly because it has not been examined previously. This long term visual memory deficit coupled with the absence of immediate visual memory deficits does not support an encoding problem for visual memory. Rather, the present data suggest that ADHD adults may (1) be more apt to forget visual information compared to non-ADHD adults, (2) become distracted by information presented between immediate and delayed recall, or (3) have a deficit in long-term storage retrieval of visual information. Given this finding’s uniqueness and the lack of supporting results from either the child or adult literature, this result requires replication before being integrated into the current body of neuropsychological knowledge concerning ADHD.

ADHD adults demonstrated deficits in cognitive flexibility and integration as evidenced by their poorer performance on the Trail-Making B test, compared to the non-ADHD sample. Similar deficits were not observed on the Trail-Making A test suggesting that general psychomotor speed is not impaired in ADHD adults, rather psychomotor speed shows impairment when the cognitive complexity of the task is increased. Interestingly, these results are contradictory to the Trail-Making Test results reported by Holdnack et al. (1995). In their study, Holdnack et al. found differences between ADD adults and normal controls on the Trail-Making A subtest and no significant difference on the Trail-Making B subtest. Holdnack et al. argued that their results suggested a general deficit in psychomotor speed. While much of the present study’s data do support slowed psychomotor speed, this slowed psychomotor speed is only present on tasks with some degree of cognitive complexity. Thus, this study’s observed pattern of results on the Trail-Making Test are consistent with the general pattern of results of the present study. It could therefore be argued that the pattern of results on the Trail-Making Test in this study are more consistent with an overall performance pattern and more accurately reflect the performance deficits in ADHD adults than the pattern found in Holdnack et al.

Indeed, on all of the neuropsychological tests utilized in the present study, there was a general trend demonstrating increased reaction times for ADHD adults compared to normal
controls that became evident as the cognitive demands of the tasks increased. ADHD adults also demonstrated slower mean reaction times on the 3RT as the 3RT tasks became increasingly complex. When ADHD adults were required to respond by reacting to target stimuli by emitting a predetermined bar press to all target stimuli (simple task), they performed similarly to control subjects. However, when ADHD subjects were required to cognitively process the stimuli, decide on the appropriate response, and respond accordingly (choice and conditional tasks), ADHD subjects demonstrated much slower reaction times compared to control subjects. Also, on the continuous performance test (i.e., GDS), ADHD subjects’ response latencies were comparable to controls on the simpler vigilance task but were significantly slower than control subjects during the distraction task. Data from the Trail-Making, 3RT Test, and Gordon Diagnostic Systems Tests all suggest that psychomotor speed and reaction time is not slower in ADHD subjects when the reaction time task is simple in nature. However, as the complexity of the task increases, there seems to be a slowing in reaction time in ADHD subjects that is greater than the slowing observed in normal control subjects. This pattern of impairment has also been documented in children. Several studies utilizing ADHD children (Sergeant & van der Meere, 1990; Van der Meere, 1996) have shown that ADHD is associated with slower and inaccurate performance as the demand for effortful processing increases.

Also compelling is the pattern of ADHD adults’ responses across time while participating in an effortful task. On both the vigilance and distraction tasks of the GDS, ADHD adults displayed psychomotor speeds that were highly discrepant and slower than normal controls during the initial phases of the task, but the ADHD adults became faster and more similar to normal controls as the tasks progressed. This pattern suggests that it is the initial stages of the task, when the task is novel and more effort is expended, that ADHD adults are slower in responding. However, once the task becomes learned and easier, ADHD adults in this sample demonstrate a pattern of responding in line with normal controls.

While ADHD adult subjects did demonstrate slower psychomotor speed with increased cognitive complexity that could be indicative of difficulties with their executive functioning, ADHD adult subjects did not demonstrate expected deficits on three classic measures of executive functioning (i.e., Stroop, FAS, and WCST). This is consistent with other studies of adult ADHD (Holdnack et al., 1995; Seidman et al., 1998). Interestingly, these results are not consistent with study results examining the performance of ADHD children on these same measures. ADHD children have been found to demonstrate deficits on these tests (Barkley, Grodzinsky, & DuPaul, 1992; Grodzinsky & Diamond, 1992; Seidman et al., 1997). The lack of differences on classical measures of executive function is perplexing. One explanation for this pattern of results may be that the ADHD adults used in this study were all self-referred and likely represent a higher functioning sample of ADHD adults than is representative of ADHD adults in the general population. In fact, the educational attainment in the ADHD sample (14 years) was comparable to the normal sample (17 years), which is not true of ADHD adults in more representative samples (Barkley, Murphy, & Kwasnik, 1996; Weiss & Hechtman, 1993). These higher functioning ADHD adults may be better able to perform normally on these relatively simple tests of executive function. Conversely, a similar type of sampling bias would not be likely in child samples since parents are the referral agent and the level of functioning of the child does not create a sampling bias.
One neuropsychological construct that has shown consistent results in ADHD children is their inability to inhibit responding on neuropsychological tests (Oosterlaan, Logan, & Sergeant, 1998; Schachar & Logan, 1990; Schachar, Tannock, Marriott, & Logan, 1995). Using the GDS, the present study found no differences between ADHD adults and the comparison sample on errors of commission, generally used as a dependent measure for response inhibition. Holdnack et al. (1995) also did not find differences on errors of commission using the GDS. In addition, Seidman et al. (1998) found no differences using an auditory CPT task. It seems that the difficulty of the CPT task has much to do with the area in which deficits are found. The GDS task, for example, has a low target rate thereby requiring the subject to respond infrequently. This predisposes the subject to make more errors of omission than errors of commission. Both the present study and Seidman et al. found differences between ADHD and normals on errors of omission. However, if a task is used that has a high target rate requiring subjects to respond on most of the trials, subjects are much more likely to make errors of commission. Using such a CPT task, Epstein et al. (1998) and Barkley et al. (1996) have found large differences in errors of commission in ADHD adult samples. Thus, the lack of results on the errors of commission variable is likely attributable to the CPT task parameters rather than suggesting equality in response inhibition between the ADHD and normal groups.

While a fairly comprehensive neuropsychological test battery was used to assess the performance of ADHD and normal controls in this and other studies of adults with ADHD, a weakness of these studies is the use of traditional neuropsychological tests. Except for tests like the GDS, none of the tests used in this protocol were designed specifically to assess neuropsychological functioning in ADHD populations. Rather, the strategy utilized in this study and others has been to choose traditional neuropsychological tests aimed at targeting frontal lobe functioning because evidence continues to accumulate that frontal lobe deficits are associated with ADHD symptomatology. Very few tests have been developed that actually target areas of ADHD deficits specifically.

The limitations of the present study include the use of numerous statistical tests on a relatively small sample of subjects. This strategy increases the likelihood of type I error. However, the results of the present study are largely consistent with previous studies and mostly serve to replicate and expand prior findings. The other limitations of this study concern the sampling procedure used to derive the sample. First, subjects were self-referred and self-selected. This likely raised the level of functioning in the sample of ADHD subjects and may have had some impact on the results (see discussion of executive functioning tests above). Also, ADHD adults with comorbid disorders such as depression, substance use, and anxiety were excluded. While comorbidity among ADHD adults is typically the norm rather than the exception (Barkley et al., 1996; Jenkins & Cohen, 1998), the ADHD adults used in this study again may not be representative of ADHD adults in general. However, the advantage of using a non-comorbid group of ADHD subjects is that neuropsychological deficits that are associated with comorbid disorders can be methodologically ruled out as alternative explanations for any observed deficits.

In conclusion, the results from the present study largely corroborate neuropsychological findings in previous studies with ADHD adults. ADHD adults demonstrated performance deficits in memory functioning. Also, there was a general pattern in which ADHD adults
demonstrated slower psychomotor speed and reaction time as task parameters became increasingly complex, compared to a group of non-ADHD adults. The results from the present study suggest that ADHD adults have similar deficits in executive functioning as ADHD children. Lastly, the nature and parameters of the tasks on which ADHD patients demonstrated deficient performances compared to the normal sample appear to be tests of frontal lobe functioning, suggesting frontal lobe involvement in the manifestation of ADHD symptomatology.

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