Assessing the Working Memory Abilities of ADHD Children Using the Stanford-Binet Intelligence Scales, Fifth Edition

Christopher W. Marusiak
Henry L. Janzen
University of Alberta

Abstract: The present study investigated the working memory abilities of children with attention deficit/hyperactivity disorder (ADHD) as measured by the Stanford-Binet Intelligence Scales, Fifth Edition (SBV). In a retrospective causal-comparative design, the archival data of 46 ADHD children were compared to 59 nondiagnosed children. The ADHD children scored significantly lower in measures of working memory compared to the control group. Within the ADHD group, working memory was the lowest factor score, significantly lower than three of the four other factors. Significant differences were also revealed within the working memory factor, with ADHD children displaying significantly lower nonverbal working memory scores than verbal working memory. No such differences were evident in the control group. The results are interpreted within Baddeley’s working memory model.

Résumé: L’étude présente a examiné les capacités de mémoire de travail des enfants avec le désordre d’hyperactivité de déficit d’attention (ADHD) comme mesuré par l’Échelle d’Intelligence du Stanford-Binet, Cinquième Édition (SBV). Dans une conception causal-comparatif rétrospective, les données archivistiques de 46 enfants avec ADHD ont été comparées à 59 enfants non-diagnostiqués. Les enfants avec ADHD ont significativement marqué inférieur dans les mesures de mémoire de travail comparés au groupe de contrôle. Dans le groupe avec ADHD, la mémoire de travail était l’indice de facteur le plus bas, significativement plus basse que trois des quatre autres facteurs. Des différences significatives ont été également indiquées dans le facteur de la mémoire de travail, avec des enfants avec ADHD démontrant des indices non verbaux de la mémoire de travail significativement plus basses que des indices verbales de la mémoire de travail verbale. Aucune différence n’était évidente dans le groupe de contrôle. Les résultats sont interprétés dans le modèle de mémoire de travail de Baddeley.

Keywords: ADHD; psychoeducational assessment; Stanford-Binet; working memory

Attention-deficit/hyperactivity disorder (ADHD) is recognized as one of the most common disorders diagnosed in children (Barkley, 1998). It is estimated to affect between 3% and 7% of school-age children (American Psychiatric Association
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[APA], 1994) from diverse cultures and geographical regions (Tannock, 1998). Although ADHD is comprised of three primary symptom clusters (poor sustained attention, impulsiveness, and hyperactivity; APA, 1994), several theorists also consider impaired working memory to be a core feature of ADHD (Barkley, 1998; Denney & Rapport, 2000).

Studies investigating the working memory deficits associated with ADHD have generated many conflicting results (Barkley, 1998). For example, working memory abilities of children with ADHD have been found to vary from the average range (e.g., Kaplan, Crawford, Dewey, & Fisher, 2000) to the below-average range (e.g., Mayes, Calhoun, & Crowell, 1998) depending on the measures used and population studied (Barkley, 1998). The confusion surrounding the precise nature of working memory abilities in ADHD may be partly because of the inconsistent conceptualization and definition of working memory across research studies (Tannock, 1998). Similarly, many studies have been atheoretical or unsystematic in their approach (Karatekin, 2004), and numerous memory tasks have been used without a unifying theory to explicate the results.

Framing this research within Baddeley’s (1986; Baddeley & Hitch, 1974) working memory model may help to clarify the conflicting results and add meaning to their interpretation (Roodenrys, Koloski, & Grainger, 2001). The working memory model replaces previous theories of a single short-term memory system responsible for the simple storage and subsequent recall of information, with a three-component system of working memory responsible for the concurrent storage and processing of information (Baddeley, 2000). This processing requires some manipulation or operation to be performed (Baddeley, 1986; Roid, 2003a), such as reversing the information or separating it into categories. This model is comprised of two subsidiary systems, the visuospatial sketchpad and the phonological loop, and an attentional control system, the central executive. The function of the visuospatial sketchpad is to store and rehearse visual and spatial information, and the function of the phonological loop is to store and rehearse speech-based information (Baddeley, 1986; Baddeley & Hitch, 1974). The central executive acts as an attentional control system (Baddeley, 2000) and is responsible for tasks such as coordinating information from the two subsidiary systems and integrating information within one subsidiary system (Baddeley, 1986).

Assessing these components separately may more precisely indicate the nature of working memory deficits in ADHD. Measures that require the simple storage and rehearsal of verbal and spatial information assess the subsidiary systems, whereas measures that require the concurrent storage and processing of information are considered indicators of central executive functioning (Baddeley, 1992). In general, the research suggests that neither verbal nor spatial subsidiary systems (short-term memory) are impaired in ADHD (Barkley, DuPaul, & McMurray, 1990; Karatekin & Asarnow, 1998; Mariani & Barkley, 1997). Instead, discrepancies appear in tasks that require the simultaneous storage and processing of information (working memory), suggesting central executive impairments (Barnett et al., 2001; Karatekin, 2004; Roodenrys et al., 2001). In other words, the working memory deficits proposed by
Barkley (1998) and others (e.g., Denney & Rapport, 2000) may be best assessed through measures of the central executive.

**Measurement of Working Memory in Intelligence Tests**

Although there are many intelligence tests available, the Wechsler Intelligence Scale for Children, Third Edition (WISC-III; Wechsler, 1991) and the Stanford-Binet Intelligence Scale, Fourth Edition (SB-IV; Thorndike, Hagen, & Sattler, 1987) are employed most frequently to assess the general cognitive abilities of children (Saklofske, Schwean, Yackulic, & Quinn, 1994). The WISC-III, in which the majority of the ADHD research has been compiled, includes measures of both working and short-term memory in the Freedom From Distractibility index (FFD), including mental arithmetic and both forward and backward digit span.

Mental arithmetic is considered a good measure of working memory, as it requires concurrent storage (to correctly store the relevant numbers and operations) and processing (to correctly manipulate the information). However, mental arithmetic tasks also have a significant limitation as they depend on mathematical knowledge and skill (Barkley, 1998). Digit span tests generally assess the functioning of the phonological loop. Even if digits are presented visually, they are typically encoded sub-vocally and stored and processed in the phonological loop (Baddeley, 1986). Forward digit span is a measure of short-term memory and arguably not a valid indicator of working memory abilities (Daneman & Carpenter, 1980). Backward digit span tasks, which require the examinee to recall the numbers in reverse order (e.g., Wechsler, 1991), involve memory processes that are considered distinct from forward recall (Reynolds, 1997) and may reflect the simultaneous storage and processing characteristic of working memory span tasks. The fact that the WISC-III does not differentiate between forward and backward recall significantly reduces its validity as a measure of working memory (Reynolds, 1997). Coding is considered a measure of attention or ability to concentrate (Kaufman, 1994). However, it is not considered an indicator of either short-term memory or working memory (Schwean & Saklofske, 1998).

It is not surprising that there is considerable variation in the results of the WISC studies with ADHD children. Measured separately, scores in mental arithmetic and backward digit span are found to be significantly lower in ADHD children, whereas forward digit span and coding reveal no such deficits (Barkley, 1998). However, when each subtest is compiled within the FFD index, specific deficiencies associated with ADHD are blurred. As such, the FFD is not considered a reliable measure of ADHD (Cohen, Becker, & Campbell, 1990; Schwean & Saklofske, 1998). Still, some researchers have found it to be useful in differentiating diagnosed children from a nondiagnosed control group (Assesmany, McIntosh, Phelps, & Rizza, 2001; Lufi, Cohen, & Parish-Plass, 1990; Snow & Sapp, 2000).

Much less research has been compiled on the Stanford-Binet tests. In one study comparing the WISC-III to the SB-IV, the authors concluded that the WISC-III is a more sensitive measure of ADHD in children (Saklofske et al., 1994). This may be
because of the SB-IV’s focus on short-term memory, including digit span and pattern-replication tasks (Thorndike et al., 1987).

**Measures of Working Memory in the SBV**

Measures of memory shifted in focus from short-term memory on the SB-IV to working memory on the SBV (Roid, 2003a). Working memory is assessed in the SBV with both verbal (last word) and nonverbal (block span) tasks (Roid, 2003b). The last-word task requires the examinee to provide simple “yes” or “no” answers to a series of brief (and relatively simple) questions and then recall the last word of each question (Roid, 2003a). It involves both the processing of information (to correctly answer the questions) as well as the storage of information (to correctly recall the last word in each question).

In the block-span task, eight blocks are arranged into two rows coded with yellow and red stripes. First, the examiner touches a series of blocks at the rate of one tap per second. Then the examinee is required to tap the blocks in the yellow row first in the same order and then in the red row in the same order (Roid, 2003b). In this way, the examinee is required to sort the blocks into two categories, successfully sequencing the blocks within the category (yellow or red). Block span is a measure of working memory span as it involves both processing (sorting the blocks into categories) and storage (recalling the proper sequence).

The only information concerning the abilities of ADHD children on this IQ measure was collected during the production of the test. During the standardization procedures, the cognitive abilities of 104 children with ADHD were assessed as follows (Roid, 2003a): 24 had ADHD-Predominantly Inattentive Type (ADHD-I), 60 had ADHD-Combined Type (ADHD-C), and 20 had ADHD-Predominantly Hyperactive-Impulsive Type (ADHD-H). The working memory (WM) factor was found to be more than one half a standard deviation less than what was expected. In addition, WM was significantly lower than three of the other factor scores—fluid reasoning (FR), quantitative reasoning (QR), and visual-spatial processing (VS)—but not lower than knowledge factor (KN; Roid, 2003a). The author concluded that these results add to the validity of the WM factor as a measure of working memory.

The SBV may provide a useful tool in the measurement of working memory as both the last-word and block-span tasks are measures of working memory, and based on Baddeley’s working memory model (Roid, 2003a). As such, they are considered indicators of working memory abilities, assessing the subsidiary systems as well as central executive functioning (Baddeley, 1986). Also, these measures are relatively independent of academic knowledge or skill and are not correlated with mathematical ability (Roid, 2003a).

**Purpose of the Study**

This research aimed to assess the working memory abilities of children with ADHD utilizing the SBV. While the WM factor of the SBV has been conceptually
adapted from Baddeley’s model (Roid, 2003a), to date no study of the WM factor has been completed. Testing the WM factor with ADHD children may provide important results, as evidence of distinctive score profiles for special groups provide a type of criterion-related evidence of validity (Roid, 2003a). This study will also add to the growing body of literature on the working memory deficits associated with ADHD by assessing both verbal and nonverbal working memory abilities using working memory span tasks.

Method

This study is based on a causal-comparative design, in which archival data was collected and analyzed from the files of individuals assessed at the Faculty of Education Clinic at the University of Alberta. Between May 2003 and April 2004, approximately 200 children were assessed with the SBV in the Education Clinic as part of a comprehensive psychoeducational assessment. The tests were administered and scored according to standardized procedures (see Roid, 2003b) by graduate-level students enrolled in educational psychology at the University of Alberta, under the supervision of a chartered psychologist.

Participants

The participants were selected from a sample of 202 individuals referred to a university-based psychological counselling and assessment clinic for a variety of behavioral, emotional, cognitive, and/or academic concerns. This original sample consisted of 114 males and 88 females and ranged in age from 4 years 9 months to 55 years 11 months ($M = 12.92$, $SD = 7.7$). Each of these individuals was assessed with a variety of measures, including the SBV; a developmental history; semistructured interviews with the children, parents, and teachers; and child, parent, and teacher forms of the Behavior Assessment System for Children (BASC; Reynolds & Kamphaus, 1992), if applicable.

Individuals were selected for the current study if they were between the ages of 5 years 0 months and 17 years 11 months, matching the age range used during the SBV norming process. In addition, children were only selected if they were currently attending school. This selection procedure resulted in a sample of 172 individuals (100 males and 72 females), ranging in age from 5 years 0 months to 17 years 11 months ($M = 11.25$, $SD = 3.3$).

Procedures

Diagnostic procedures. The file of each individual was reviewed to determine whether the participant met the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) criteria for a diagnosis of ADHD. The evaluation of ADHD symptomatology was based on parent and teacher forms of the BASC;
semistructured interviews with the children, parents, and/or teachers (e.g., the SIDAC-R); medical, academic, and developmental histories; and clinical observation. Neither IQ scores nor factor scores were used in any way during the diagnostic procedure. Based on this information, participants were divided into four groups: ADHD-I, ADHD-C, ADHD-H), and a control group with no ADHD diagnosis. Children in the clinical groups met the diagnostic criteria specified in the *DSM-IV*.

*Exclusionary criteria.* Participants were excluded from the sample if (a) there was evidence of other neurological, developmental, or psychological disorders known to influence attention or cognitive functioning (i.e., epilepsy, head injury, fetal alcohol syndrome, and Asperger’s disorder); (b) they were using methylphenidate (Ritalin), dextroamphetamine (Dexedrine), or other central nervous system stimulants at the time of testing; and (c) they were learning English as their second language. In total, 52 participants were excluded from the study because of comorbid diagnoses, 23 children were excluded because they were using psychostimulants at the time of testing, and 5 children were excluded because English was their second language. The proportion of participants excluded from the study was equal across the ADHD subtypes.

This sampling process resulted in the selection of 109 children, with 23 participants in the ADHD-C group, 23 in the ADHD-I group, 4 in the ADHD-H group, and 59 participants in the control group. Because of the low occurrence of a predominantly hyperactive/impulsive subtype, the ADHD-H group was excluded from the final analyses. The WM factor scores for the ADHD-C group (*M* = 91.3, *SD* = 10.2) did not differ significantly from the WM scores for the ADHD-I group (*M* = 88.70, *SD* = 14.5; *t*(44) = -.48, *p* = ns). Similarly, the ADHD-C group did not significantly differ from the ADHD-I group on any of the factor scores or IQ scores, and the patterns of performance on the various subtests were consistent between the two groups. This suggests that the performance of these two groups on the SBV did not vary significantly and does not indicate any subtype differences in performance on the SBV. Because these groups do not appear to differ, they will be collapsed into a single ADHD group for the remainder of the analyses.

The final sample used in the data analysis consisted of 105 children (46 in the ADHD group and 59 in the control group). Of these, 50 were female (47.6%) and 55 were male (52.4%). The mean age of the entire sample was 10 years 8 months (*SD* = 3.3), ranging from 5 years 1 month to 17 years 11 months.

**Data Analysis**

Multiple *t* test comparisons were employed to test the various hypotheses. A two-tailed significance level of *α* = .05 was used in the analyses. However, because several independent tests were performed simultaneously, the alpha level was corrected using the Bonferroni correction. This technique lowers the alpha value to account for the number of comparisons being performed and reduces the chance of making a
Type I error (Shaffer, 1995). Because the between-group comparisons of WM are planned, the alpha level does not need to be changed (Evans, 1998). However, because it is part of a multiple comparison procedure, the alpha level was corrected to be consistent between the multiple comparisons. Prior to hypothesis testing, the data were analyzed to ensure that they met the assumptions of normality and equal variances; all data met these assumptions.

### Results

An independent-samples $t$ test analysis was performed with the corrected alpha level set at $\alpha = .01$. The WM factor scores for the ADHD group ($M = 90.00, SD = 12.4$) were significantly lower than the WM scores for the control group ($M = 100.20, SD = 12.6$; $t_{(103)} = 4.15, p < .01$). The factors of both the ADHD group and control group were further compared to ensure that the ADHD group was not simply lower on all measures and that the observed deficits were confined to the WM factor. Multiple $t$ test comparisons were performed with a corrected alpha level set at $\alpha = .01$. The ADHD group did not differ significantly from the control group on any of the other factors (i.e., FR, KN, QR, and VS; see Table 1). This finding supports the suggestion that performance on the WM factor is impaired in ADHD children in comparison to a non-ADHD clinical control group. In addition, these results indicate that deficits in the ADHD group are only evident in the WM factor and not in the other factors.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
<th>Control</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor Scores</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM</td>
<td>90.00</td>
<td>100.20</td>
<td>4.15</td>
<td>.000**</td>
</tr>
<tr>
<td>FR</td>
<td>96.67</td>
<td>101.02</td>
<td>1.69</td>
<td>.094</td>
</tr>
<tr>
<td>KN</td>
<td>92.63</td>
<td>99.10</td>
<td>2.27</td>
<td>.025</td>
</tr>
<tr>
<td>QR</td>
<td>94.02</td>
<td>97.42</td>
<td>1.53</td>
<td>.130</td>
</tr>
<tr>
<td>VS</td>
<td>97.80</td>
<td>99.88</td>
<td>0.91</td>
<td>.363</td>
</tr>
<tr>
<td><strong>IQ scores</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FSIQ</td>
<td>92.89</td>
<td>99.14</td>
<td>2.78</td>
<td>.006*</td>
</tr>
<tr>
<td>VIQ</td>
<td>94.02</td>
<td>100.66</td>
<td>2.81</td>
<td>.006*</td>
</tr>
<tr>
<td>NVIQ</td>
<td>92.80</td>
<td>97.86</td>
<td>2.13</td>
<td>.035</td>
</tr>
</tbody>
</table>

Note: ADHD = attention deficit/hyperactivity disorder; WM = working memory; FR = fluid reasoning; KN = knowledge factor; QR = quantitative reasoning; VS = visual-spatial processing; FSIQ = full scale intelligence quotient; VIQ = verbal scale; NVIQ = nonverbal scale.

* Significant at $p < .02$. ** Significant at $p < .01$.  

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In the ADHD group, the WM factor scores were significantly lower than the FR, QR, and VS factor scores (with a corrected alpha level set at $\alpha = .0125$). No such differences were evident in the analysis of the control group, which found no significant differences between the WM factor and the FR, QR, and VS factors. The WM factor was not significantly different from the KN factor in either the ADHD or the control group (see Table 2).

These findings were similar to Roid’s (2003a), which found WM to be significantly lower than all factors with the exception of KN. Figure 1 compares the current sample with Roid’s (2003a) sample and indicates a similar pattern of subtest scores.

The data were also analyzed to determine the number of individual cases in the ADHD and control groups that had significant differences between the WM and the other factor scores (see Table 3). Significance was determined according to the magnitude of the split between WM and the other factors, and was calculated with the SBV computer scoring program (Roid, 2003c). Compared to the control group, more individuals in the ADHD group had significantly lower WM scores related to the other factor scores, with the exception of KN. There also appeared to be more children in the control group, with WM scores significantly higher than the other factors. However, it is important to note that nearly 60% of individuals in the ADHD group did not have WM as their lowest score.

A paired-samples $t$ test analysis was performed to compare the verbal and nonverbal WM factor scores for the ADHD group. The nonverbal WM factor scores

### Table 2
Mean Differences Between the WM and Other Factor Scores for the ADHD and Control Group

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>$M$</th>
<th>$SD$</th>
<th>$df$</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADHD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM–FR</td>
<td>6.67</td>
<td>10.3</td>
<td>45</td>
<td>4.41</td>
<td>.000*</td>
</tr>
<tr>
<td>WM–KN</td>
<td>2.63</td>
<td>10.8</td>
<td>45</td>
<td>1.65</td>
<td>.107</td>
</tr>
<tr>
<td>WM–QR</td>
<td>4.02</td>
<td>10.0</td>
<td>45</td>
<td>2.73</td>
<td>.009*</td>
</tr>
<tr>
<td>WM–VS</td>
<td>7.80</td>
<td>9.8</td>
<td>45</td>
<td>5.38</td>
<td>.000*</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WM–FR</td>
<td>0.81</td>
<td>12.0</td>
<td>58</td>
<td>0.52</td>
<td>.606</td>
</tr>
<tr>
<td>WM–KN</td>
<td>–1.10</td>
<td>15.0</td>
<td>58</td>
<td>–0.56</td>
<td>.575</td>
</tr>
<tr>
<td>WM–QR</td>
<td>–2.78</td>
<td>11.2</td>
<td>58</td>
<td>1.91</td>
<td>.061</td>
</tr>
<tr>
<td>WM–VS</td>
<td>–0.32</td>
<td>13.9</td>
<td>58</td>
<td>–0.18</td>
<td>.860</td>
</tr>
</tbody>
</table>

Note: Please see Table 1 note.
*Significant at $p < .0125$. 
(M = 7.46, SD = 2.8) were significantly lower than the verbal WM scores for the ADHD group (M = 9.07, SD = 3.1; t(45) = -2.75, p < .01). The control group did not demonstrate differential abilities between verbal (M = 10.22, SD = 2.8) and nonverbal (M = 9.81, SD = 1.7) working memory tasks (t(58) = -0.94, p = ns). Similarly, verbal-nonverbal differences were not evident in the other factor scores.

Discussion

The results of this study suggest that children with ADHD experience deficits in working memory ability. Based on the conclusions of previous studies, the memory deficits associated with ADHD are evident in tests of working memory and not in tests of short-term memory (Benezra & Douglas, 1988; Karatekin & Asarnow, 1998; Roodenrys et al., 2001). It is therefore assumed that the memory deficits found in the
Current study are because of working memory impairments and not short-term memory deficits. Although no specific disorders were directly compared, working memory deficits were not evident in the clinical control group. As the control group was referred for various emotional, behavioral, and educational challenges, this study suggests that working memory deficits are not present in individuals who experience general difficulties in these areas.

Validity of the WM Factor

The results of this study provide initial support for the validity of the WM factor of the SBV as a measure of working memory. The ADHD group, as a whole, demonstrated impairment in the WM factor, evidenced by lower WM scores compared to both the control group and three of the four other factor scores. Because ADHD children are hypothesized to have impaired working memory, these results are interpreted as criterion-related evidence of validity (see Roid, 2003a). These results build on the results of the standardization process, which also found ADHD children to have lower WM scores (Roid, 2003a).

Again, these results should be interpreted with caution, as the WM factor does not provide a clear measure of both working memory and short-term memory processes. Although low WM scores may reflect true working memory impairments, it is also possible that they reflect deficient short-term memory processes. To add to the validity of the WM factor as a measure of working memory, this test could be compared to previously validated working memory span and short-term memory span tasks.

### Table 3

<table>
<thead>
<tr>
<th>Significant Differences</th>
<th>ADHD (n = 46)</th>
<th>Control (n = 59)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td>WM &gt; FR</td>
<td>2</td>
<td>4.3</td>
</tr>
<tr>
<td>WM &gt; KN</td>
<td>5</td>
<td>10.9</td>
</tr>
<tr>
<td>WM &gt; QR</td>
<td>2</td>
<td>4.3</td>
</tr>
<tr>
<td>WM &gt; VS</td>
<td>2</td>
<td>4.3</td>
</tr>
<tr>
<td>FR &gt; WM</td>
<td>14</td>
<td>30.4</td>
</tr>
<tr>
<td>KN &gt; WM</td>
<td>5</td>
<td>10.9</td>
</tr>
<tr>
<td>QR &gt; WM</td>
<td>7</td>
<td>15.2</td>
</tr>
<tr>
<td>VS &gt; WM</td>
<td>15</td>
<td>32.6</td>
</tr>
</tbody>
</table>

Note: Please see Table 1 note.
The Use of Baddeley’s Model in ADHD Research

Working memory deficits in ADHD have not been well researched, in part, because the concepts are neither well defined nor operationalized (Tannock, 1998). Baddeley’s (1986) working memory model may provide an important framework in which to structure the research (Karatekin, 2004; Roodenrys et al., 2001). The current study provides preliminary support for the use of this theory, as tasks in the WM factor are theoretically based on Baddeley’s model (Roid, 2003a). Within this framework, it is assumed that the working memory deficits found in the present study are caused by central executive impairments as neither the visuospatial sketchpad nor the phonological loop appear to be impaired in ADHD children (Karatekin, 2004).

In tests of working memory (as opposed to short-term memory), both verbal and nonverbal deficits are manifest in ADHD children (Barnett et al., 2001; Karatekin, 2004); however, no previous research was found that directly compares verbal and nonverbal working memory. Because there is no evidence of differential impairment between the phonological loop and visuospatial sketchpad (Karatekin, 2004), it was assumed that there would be no differences when these subsidiary systems were measured in conjunction with the central executive. However, scores on the nonverbal WM factor were significantly lower than scores on the verbal WM factor. No verbal-nonverbal discrepancies were evident in the other factors, and the control group did not demonstrate similar nonverbal difficulties in relation to verbal performance.

It has been suggested that compared to the phonological loop, the visuospatial sketchpad depends more strongly on the central executive (Baddeley, Cocchini, Sala, Logie, & Spinnler, 1999; Vandierendonck, Kemps, Fastame, & Szmalec, 2004). If both verbal and nonverbal abilities are held constant (as suggested by previous research), measures of nonverbal working memory may be more impaired than verbal working memory as a higher load is placed on the central executive. This hypothesis could be explored in future research by directly comparing performance of individual subsidiary systems and performance of these subsidiary systems in conjunction with the central executive.

The WM factor does not allow for a detailed analysis of the separate subsidiary system and central executive processes. Tests of this nature, which combine processing and storage tasks to predict other cognitive skills, fall under the general rubric of the psychometric approach to working memory research. This methodology allows for research of practical significance, such as investigations into the role that working memory plays in reading comprehension, reasoning, or other cognitive tasks (Baddeley, 1992). Therefore, the WM factor may be a useful instrument in the study of the cognitive and academic impairments associated with ADHD. This factor, however, may not be an appropriate tool to analyze the specific nature of working memory deficits in ADHD. A complementary group of tests are designated as a dual-task approach (Baddeley, 1992). This approach measures the ability to divide attention...
between memory tasks (Gathercole, 1999) and analyzes the separate components of the working memory system.

**Limitations**

A relatively high proportion of the sample (40%) was excluded from the study. Although excluding the various comorbid diagnoses from the ADHD and control groups may have resulted in a clearer understanding of the deficits associated with ADHD, it may have also limited the clinical validity. The comorbid conditions that were excluded from the study are often associated with ADHD (Shaywitz & Shaywitz, 1991), and a child referred to a mental health clinic may likely exhibit one or more of these diagnoses. Excluding these groups from this study may limit the generalizability of this research to ADHD children with comorbid diagnoses. This is particularly significant as comorbidity with ADHD is considered the rule rather than the exception in clinical samples (Shaywitz & Shaywitz, 1991).

The age range selected in this study (5 years 0 months to 17 years 11 months) was quite large. Systematic differences may exist between younger and older children in relation to the history of treatment and educational remediation as well as the severity and neurobiology of the disorder (Barkley, 1998; Karaketin, 2004). Similarly, normal developmental and neurological changes in working memory also occur during this age range (Baddeley, 1986). These factors may limit both the validity and reliability of the study. As previously discussed, this age range was selected to match the data collected for ADHD children during the SBV norming process and the small sample size restricted the groups from being divided by age.

This study is also limited by the decision to use data from the Education Clinic at the University of Alberta. These children were referred to the clinic for a variety of academic, behavioral, and emotional concerns and, as such, may not be considered a random sample. The results of this study are intended to apply only to clinic-referred children and do not reflect the full range of abilities of children with ADHD. Although this sample may not accurately represent the ADHD population as a whole or even a typical child with the disorder, this sample may be more indicative of cases seen in treatment and assessment (Carlson, Shin, & Booth, 1999). As such, this study may provide important information concerning the assessment and research of clinic-referred children.

**Future Research**

An in-depth study of working memory deficits in ADHD is required. To better understand the underlying memory deficits associated with ADHD, numerous working memory and short-term memory tasks may be employed. The objective of this research would be to elucidate the working memory processes in ADHD and to clarify what measures best reflect these processes. The psychometric and dual-task
approaches may be an important next step in future ADHD research because they may clarify the deficits associated with the subsidiary systems and the central executive (Karatekin, 2004).

In addition, to add to the validity of the WM factor as a measure of working memory, this test could be compared to previously validated working memory span and short-term memory span tasks. An important direction in this research may be to better understand how individual deficits in recall and storage perform in this factor when compared to individuals with working memory deficits (or impaired central executive).

References


**Christopher W. Marusiak** is a PhD candidate at the University of Alberta and a provisionally registered psychologist in the province of Alberta.

**Henry L. Janzen**, PhD, is a professor at the University of Alberta and the director of the Psychological Testing Centre in the Faculty of Education Clinic.