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The impact of specific language impairment on working memory in children with ADHD combined subtype

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Abstract

The objective of this study was to examine the impact of comorbid specific language impairment (SLI) on verbal and spatial working memory in children with DSM-IV combined subtype Attention Deficit Hyperactivity Disorder (ADHD-C). Participants were a clinical sample of $8\frac{1}{2}$- to $12\frac{1}{2}$-year-old children diagnosed with ADHD-C. A group of ADHD-C with SLI was compared to a group of ADHD-C without SLI, and a group of normal children, matched on age and nonverbal intelligence. The results show that ADHD-C children with SLI scored significantly lower than those without SLI and normal children, on verbal working memory measures only. Both ADHD groups performed normally on spatial working memory measures. It is concluded that working memory deficits are not a specific characteristic of ADHD but are associated with language impairments. The importance of screening for language disorders in studies of neuropsychological functioning in children with ADHD is emphasized.

Keywords: Attention Deficit Hyperactivity Disorder; (Specific) Language impairment; Children; Verbal working memory; Spatial working memory

Abbreviations: K-ABC, Kaufman Assessment Battery for Children; ADHD, attention/deficit hyperactivity disorder; TOLD-2I, Test of Language Development-2 Intermediate; LI, language impairment; SLI, specific language impairment; WM, working memory; SLQ, spoken language quotient

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Attention deficit hyperactivity disorder (ADHD) is the most common neuropsychiatric disorder of childhood, affecting approximately 1–7% of school-aged children, depending on the stringency of criteria used (American Psychiatric Association, 1994; Swanson et al., 1998). The main characteristics of the disorder are inattention, hyperactivity and impulsivity. DSM-IV differentiates three subtypes of the disorder according to levels of presenting symptoms: the combined subtype (ADHD-C), the predominantly inattentive subtype (ADHD-I), and the predominantly hyperactive-impulsive subtype (ADHD-HI). Denckla (2003) has proposed that many of the externally observable diagnostic characteristics of ADHD, particularly of the ADHD-I subtype, can really be caused by language processing difficulties.

Language impairment (LI) is a highly prevalent comorbidity in children with psychiatric disorders and behavioural problems (Beitchman, Nair, Clegg, Ferguson, & Patel, 1986a; Beitchman, Nair, Clegg, & Patel, 1986b; Beitchman, Wilson, Brownlie, Walters, & Lancee, 1996a; Beitchman, Wilson, Brownlie, Walters, Inglis, et al., 1996; Cantwell & Baker, 1987; Cohen, Barwick, Horodezky, Vallance, & Im, 1998; Cohen, Davine, Horodezky, Lipsett, & Isaacson, 1993; Young et al., 2002). The most common psychiatric diagnosis among children with LI is ADHD (Cohen et al., 1998), and conversely, LI is a frequent comorbidity found in children with ADHD (Cantwell, 1996; Kovac, Garabedian, Du Souich, & Palmour, 2001; Purvis & Tannock, 1997). One study found that approximately two thirds of a consecutively referred ADHD sample reached criteria for LI (Cohen et al., 1998). Despite the frequent co-occurrence of these two common disorders, there have been relatively few studies that specifically investigate language abilities of children with ADHD (Cohen et al., 2000; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003), and it is seldom screened for in studies on neuropsychological deficits in children with ADHD (Sergeant, Geurts, & Oosterlaan, 2002).

The term specific language impairment (SLI) has been used by many researchers to refer to children with normal nonverbal intelligence and a deficit in expressive and/or receptive language that does not appear to be a secondary manifestation of an associated medical disorder (Bartlett et al., 2002; Bishop, 1992; Williams, Stott, Goodyer, & Sahakian, 2000). SLI is believed to affect approximately 7% of children (Leonard, 1998; Tomblin, Smith, & Zhang, 1997). Neuropsychological studies of SLI have revealed deficits in verbal working memory (Hulme & Roodenrys, 1995; Kamhi, Catts, Mauer, Apel, & Gentry, 1988) which is believed by many researchers to be at the root of the language difficulties (e.g., Baddeley & Wilson, 1993; Gathercole & Baddeley, 1989; Swank, 1999). According to Montgomery (2003), some researchers have proposed, that deficient verbal working memory might serve as "a reliable, culture-free marker of SLI".

Decreased working memory, both verbal and spatial, are among the cognitive deficits purported to be characteristic of ADHD (Barkley, 1997, 2003; Karatekin & Asarnow, 1998; Tannock, 1998). Working memory is one of four executive functions considered to be impaired in ADHD as a result of a lack in behavioural inhibition (Oosterlaan, Logan, & Sergeant, 1998), which in turn has been proposed by Barkley (1997) to be the fundamental impairment in children with ADHD. Studies on working memory in ADHD have shown conflicting results (e.g., Bedard, Martinussen, Ickowicz, & Tannock, 2004; Cohen et al., 2000; Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Karatekin & Asarnow, 1998; McInnes et al., 2003; Muir-Broaddus, Rosenstein, Medina, & Soderberg, 2002; Scheres et al., 2004; Siklos & Kerns, 2004; Van Goozen et al., 2004). Verbal working memory has been studied more extensively in ADHD children than spatial working memory, but language impaired children have not been screened for in many of these studies and results have been mixed. Findings of studies of spatial working memory in ADHD have also been equivocal. Cohen et al. (2000) found, that verbal and spatial working memory measures, used to tap the core cognitive deficit of ADHD in executive functions, were more closely associated with language disorders than with ADHD. The authors concluded that caution must be exercised in attributing to children with ADHD what might be a reflection of problems for children with language disorders generally. The results of Cohen's study do not agree with those of McInnes et al. (2003) who found that working memory, both verbal and spatial, was impaired in ADHD children irrespective of language impairment.

Baddeley and Hitch (1974) have proposed a three component model of working memory comprised of a control system, *the central executive*, which is assisted by two subsidiary systems for maintaining information: a verbal storage system called the *phonological loop*, and a visual storage system called the *visuospatial sketchpad*. In this model, working memory is considered to be a limited-capacity system, which stores information for brief periods of time, and is believed to underlie human thought processes (Baddeley, 2003). Neuroimaging studies have indicated that spatial working memory is primarily localized in the right hemisphere, while the *phonological loop* has been associated with the left temporoparietal region. The *central executive* is believed to be mainly located in the frontal lobes (Baddeley, 2003). A recent meta-analytic study of the neural bases of working memory has shown that Brodmann's areas in the superior frontal cortex, respond most when working memory must be continuously updated and when temporal order must be maintained (Wager & Smith, 2003).

The purpose of the present study was to examine the impact that comorbid SLI has on verbal and spatial working memory in children diagnosed with ADHD-C. Children with ADHD-C, with and without SLI, and a normal control group were compared on measures of verbal and spatial working memory. The first hypothesis was that ADHD-C children with SLI would show deficits in verbal working memory, but not in spatial working memory. The second hypothesis was that ADHD-C children without SLI would not differ from normal children on verbal or spatial working memory measures.

1. Methods

1.1. Participants

The clinical sample included 127 children aged 6–13 years old who had been consecutively referred for neuropsychological assessment at the Department of Child and Adolescent Psychiatry, Landspitali-University Hospital in Reykjavík, Iceland. The department is a tertiary referral facility serving the whole population of Iceland with approximately 290,000 inhabitants.

Out of this group, children who fulfilled the following criteria were selected: (1) age between $8\frac{1}{2}$ and $12\frac{1}{2}$ years; (2) psychiatric diagnosis of ADHD combined subtype; (3) native Icelandic speaker; (4) no neurological or other medical disorders. A paediatrician or a child/adolescent psychiatrist assessed the children with the aid of a diagnostic interview based on DSM-IV (American Psychiatric Association, 1994) criteria, the Icelandic version of the Achenbach parent/teacher rating scales (Hannesdottir, 2002) and the Icelandic version of the ADHD Rating Scale (Magnusson, Smari, Gretarsdottir, & Thrandardottir, 1999). The ADHD-I subtype was excluded and no child had the diagnosis of ADHD-HI subtype. The number of children who fulfilled the aforementioned criteria were 47 in total, 76.6% were male and 23.4% female.

1.1.1. Criteria for specific language impairment (SLI)

Selection for SLI versus non-SLI ADHD groups was made on the basis of performance on the *Nonverbal Scale* of the Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983) (see later) and the Icelandic version of the Test of Language Development-2 Intermediate (TOLD-2I; Hammill & Newcomer, 1988; Símonardóttir & Guðmundsson, 1996). The TOLD-2I is comprised of six subtests which are combined to make composite scores of spoken language quotient (SLQ), receptive language, expressive language, semantics and syntax.

Although some researchers use the cutoff score of 85 on language measures when assessing LI children, we have chosen for somewhat stricter criteria, so that only children who received SLQ standard score of less than or equal to 80 on the TOLD-2I, were considered having LI. The score of 80 is approximately $1\frac{1}{2}$ S.D. below the standardized mean of 100 and falls at the ninth percentile rank. There were 20 children (43% of the sample) that fulfilled this stricter criterion. Children who received SLQ standard score of 90 (the 25th percentile) or above, were considered without LI and 15 children (31.9% of the sample) fulfilled that criterion.

In order to fulfill criteria for SLI, children are required to have nonverbal intelligence within the normal range (e.g., >85 standard score), in addition to impaired language ability. In the present study only children with nonverbal intelligence >85 on the K-ABC were included; one child was dropped from the LI group of 20 children because of this requirement. The above procedure provided two comparable groups: 19 (14 boys, 5 girls) ADHD children with SLI (ADHD + SLI) and 15 (11 boys, 4 girls) ADHD children without SLI (ADHD non-SLI). Also a control group of 15 (9 boys, 6 girls) normal children (NC) was included. The NC were screened for ADHD with the help of parent/teacher rating scales and a clinical interview.

The three groups of children did not show a significant difference with respect to age ($F(2, 46) = 0.486$, *ns*), gender ($\chi^2 = 0.890$, $df = 2$, *ns*), or nonverbal IQ ($F(2, 46) = 1.83$, *ns*) (for means and standard deviations, see Table 1).

1.2. Neuropsychological measures

Neuropsychological differences between groups were assessed with the K-ABC (Kaufman & Kaufman, 1983; Kaufman, O'Neal, Avant, & Long, 1987). The K-ABC is an individually administered measure of intelligence and achievement intended for children aged $2\frac{1}{2}$ through $12\frac{1}{2}$ years. It is based on research and theory in cognition and neuropsychology and is designed to measure ability (intelligence) on the basis of the processing style required

Table 1
Age, nonverbal intelligence, and performance of groups on the TOLD-2I

	Whole ADHD group ($n = 47$)		ADHD + SLI ($n = 19$)		ADHD non-SLI ($n = 15$)		Normal controls ($n = 15$)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Age (years)	10.49	1.28	10.74	1.15	10.67	1.29	10.33	1.29
Nonverbal IQ[a]	103.62	12.52	106.53	12.69	106.07	10.67	113.27	11.46
TOLD-2I Composites								
SLQ[b]	83.49	16.34	69.26	9.76	101.20	10.71	105.80	12.40
Receptive language	86.68	16.90	71.16	10.96	104.80	7.92	109.00	12.35
Expressive language	82.96	15.33	71.32	10.09	97.87	12.75	102.33	11.87
Semantics	85.89	15.08	72.79	10.73	99.93	10.05	108.13	10.86
Syntax	83.91	18.41	69.53	11.90	103.33	12.55	103.47	13.46
Subtests								
Sentence combining	6.45	2.68	5.00	1.97	8.93	1.98	9.20	2.11
Vocabulary	8.28	2.85	6.37	2.45	11.00	1.41	11.60	2.41
Word ordering	8.23	2.76	6.21	1.93	10.87	2.03	10.60	2.75
Generals	8.40	2.00	7.21	1.51	9.27	2.25	11.07	1.71
Grammatic Compr.[c]	8.77	3.01	6.47	2.55	11.40	1.99	11.47	2.62
Malapropism	8.19	2.70	6.21	2.42	10.20	1.86	11.33	1.99

[a] Nonverbal IQ = nonverbal intelligence.
[b] SLQ = spoken language quotient.
[c] Grammatic Compr.: grammatic comprehension.

to solve tasks. Problem solving abilities are measured on two mental processing scales: *Sequential* and *Simultaneous*. The *Sequential Processing Scale* is composed of the subtests *Hand Movements, Number Recall, and Word Order.* The *Simultaneous Processing Scale* is composed of the subtests *Gestalt Closure, Triangles, Matrix Analogies, Spatial Memory and Photo Series.* Sequential processing ability is believed to rely more on the functioning of the left cerebral hemisphere and simultaneous processing more on the right cerebral hemisphere.

The K-ABC also includes a *Nonverbal Scale*, which according to the authors, serves as a good estimate of intellectual potential of children who have problems in the areas of receptive or expressive language, who have language disorders, or use English as a second language. The *Nonverbal Scale* is composed of the subtests *Hand Movements*, *Triangles*, *Matrix Analogies*, *Spatial Memory* and *Photo Series*.

1.3. *Assessment of verbal and spatial working memory*

According to Barkley (1997), verbal and spatial working memory has often been assessed in neuropsychological research with the following tasks: “retention and oral repetition of digit spans (especially in reverse order); mental arithmetic, such as serial addition; locating stimuli within spatial arrays of information that must be held in memory; and holding sequences of information in memory to properly execute a task, as in self-ordered pointing tasks”. In the current study, the K-ABC subtests *Number Recall* and *Word Order* were considered measures of verbal working memory and the subtests *Hand Movements* and *Spatial Memory* were considered measures of spatial working memory.

1.4. Statistical analyses

Within the whole group of ADHD-C children ($n = 47$), paired *t*-tests were used to analyse the difference between the two mental processing scales of the K-ABC (*Sequential* and *Simultaneous*) and between spatial and verbal working memory.

In addition, analyses of variance (ANOVA) were performed with Group (ADHD + SLI, ADHD non-SLI, NC) as an independent variable and with K-ABC measures (Composite scores; Subtest scores, Spatial and Verbal Working Memory) as a dependent variable. In case of a main effect of Group, analyses were performed to determine three contrasts: (1) ADHD + SLI versus ADHD non-SLI, (2) ADHD + SLI versus NC, and (3) ADHD non-SLI versus NC. Effect sizes (eta squared: η^2) were calculated, that is, small <.01, medium <.06, and large ≥.14.

Furthermore, correlational analyses were employed to investigate the relationship between the K-ABC measures (Composite scores; Subtest scores, Spatial and Verbal Working Memory) and spoken language quotient (SLQ) on the TOLD-21 and to examine the relationship between working memory measures.

The SPSS-PC program was used to analyse the data.

2. Results

2.1. K-ABC composites and subtests

Table 2 shows the results (means, standard deviations, ANOVAs, and contrasts) of the different ADHD groups and the control group. Within the entire ADHD group, paired *t*-tests showed that ADHD children performed significantly better on the *Simultaneous Processing Scale* than on the *Sequential Processing Scale* ($t(46) = 6.73$, $P = .000$). The difference in performance was highly significant in the ADHD + SLI group ($t(18) = 6.72$, $P = .000$), but also, although smaller, significant in the ADHD non-SLI group ($t(14) = 2.29$, $P = .04$), and the control group ($t(14) = 4.47$, $P = .001$).

Subsequently, main effects of Group were calculated for K-ABC composites, and K-ABC subtests, by means of ANOVA. A significant main effect of Group was observed for *MPC*, *Sequential Processing Scale*, *Number Recall*, and *Word Order* (for means, standard deviations and ANOVAs, see Table 2). With respect to *MPC*, ADHD + SLI group scored significantly lower only in comparison with the control group (F (1, 32) = 7.75, $P = .009$). On the *Sequential Processing Scale*, the ADHD + SLI group performed significantly worse than the other two groups (control group and ADHD non-SLI) (F (1, 32) = 13.86, $P = .001$), and (F (1, 32) = 8.33, $P = .007$), respectively. The ADHD + SLI group performed also significantly worse than these two groups (control group and ADHD non-SLI) on the subtests *Number Recall* (F (1, 32) = 11.76, $P = .002$) and (F (1, 32) = 7.82, $P = .009$), respectively, and *Word Order* of the *Sequential Processing Scale* (F (1, 32) = 11.87, $P = .002$), and (F (1, 32) = 9.92, $P = .004$), respectively.

Table 2
Means, standard deviations, ANOVAs, and contrasts of the different ADHD groups and the control group

Measures	ADHD group (*n* = 47)		Group 1, ADHD + SLI (*n* = 19)		Group 2, ADHD non-SLI (*n* = 15)		Group 3, normal controls (*n* = 15)		Main effect of group ANOVA			Groups 1–3 contrasts
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	*F*	*df*	*P*	
K-ABC Composites												
MPC	100.47	11.75	100.05	10.71	105.53	10.42	110.33	10.68	3.98	2,46	.026	1 < 3
Sequential Prc.	91.21	13.34	87.37	12.25	99.40	11.84	101.53	9.19	7.99	2,46	.001	1 < 2,3
Simultaneous Prc.	107.02	12.81	109.16	11.05	109.07	12.49	114.40	11.83	1.05	2,46	*ns*	
Subsets												
Hand Movements	8.81	2.82	8.89	3.21	9.60	2.10	10.27	1.34	1.34	2,46	*ns*	
Gestalt Closure	11.13	3.00	10.74	2.71	11.47	2.72	10.87	2.17	.37	2,46	*ns*	
Number Recall	8.45	3.02	7.26	3.09	9.93	2.28	10.33	1.76	7.75	2,46	.001	1 < 2, 3
Triangles	11.51	2.79	11.84	2.39	12.60	2.44	13.53	2.10	2.23	2.46	*ns*	
Word Order	8.49	2.58	7.74	1.89	10.20	2.68	10.27	2.40	6.81	2,46	.003	1 < 2, 3
Matrix Analogies	11.43	2.48	12.00	2.16	11.53	3.11	12.27	2.46	.31	2,46	*ns*	
Spatial Memory	10.36	2.51	10.58	2.67	10.47	2.23	11.33	2.41	.56	2,46	*ns*	
Photo Series	10.64	2.63	11.47	2.65	10.40	2.69	12.20	2.37	1.85	2,46	*ns*	
Working Memory												
Spatial WM[a]	9.59	2.22	9.74	2.52	10.03	1.68	10.80	1.54	1.20	2,46	*ns*	
Verbal WM[b]	8.47	2.47	7.50	2.08	10.07	2.17	10.30	1.86	10.07	2,46	.000	1 < 2, 3

Means, standard deviations, and analyses of variance (ANOVA) and contrasts of the scores of the K-ABC Composites and Subtests, and the Spatial and Verbal Working Memory (WM) of the ADHD + specific language impairment (SLI), the ADHD non-specific language impairment (SLI) and the normal control groups. K-ABC: Kaufman Assessment Battery for Children; MPC: Mental Processing Composite; Sequential Prc.: Sequential Processing; Simultaneous Prc.: Simultaneous Processing.

[a] Spatial working memory (WM) is composed of Hand Movements and Spatial Memory.

[b] Verbal Working Memory (WM) is composed of Number Recall and Word Order.

2.2. Working memory

The entire ADHD group performed significantly worse on verbal working memory (Verbal WM) than on spatial working memory (Spatial WM) ($t(46) = 2.74$, $P = .009$) (see Table 2). Interestingly, this effect appeared to be only significant in the ADHD + SLI group ($t(18) = 3.29$, $P = .004$), and not in the ADHD non-SLI group ($t(14) = 0.06$, *ns*). There was no significant difference between Verbal WM and Spatial WM in the control group ($t(16) = 1.44$, $P = .168$).

Data analysis further indicated a main effect of Group only with respect to Verbal WM (see Table 2). ANOVAs of the contrasts showed that the ADHD + SLI group performed significantly worse than the ADHD non-SLI group ($F\ (1, 32) = 12.28$, $P = .001$) and the control group ($F\ (1, 32) = 16.64$, $P = .000$).

2.3. Relationship between K-ABC measures and spoken language quotient (SLQ)

Pearson's correlations were calculated within the whole group of 47 ADHD children in order to investigate the relationship between the K-ABC measures (composite scores, subtest scores, Spatial WM and Verbal WM) and SLQ on the TOLD-2I. The results showed that the SLQ is significantly correlated with the *Sequential Processing Scale* ($r = .48$, $n = 47$, $P = .001$), but not with the *Simultaneous Processing Scale* ($r = .09$, $n = 47$, *ns*). Moreover, SLQ was significantly related to Verbal WM ($r = .51$, $n = 47$, $P = .000$). No significant relation between SLQ and Spatial WM was observed ($r = .15$, $n = 47$, *ns*). In addition, SLQ appeared to be significantly related to *Word Order* ($r = .37$, $n = 47$, $P = .01$) and *Number Recall* ($r = .52$, $n = 47$, $P = .000$), but not with *Hand Movements* ($r = .21$, $n = 47$, *ns*).

2.4. Relationship between working memory measures

Pearson's correlations were calculated for the entire group of 47 ADHD children in order to investigate the relationship between the four working memory measures. The two verbal working memory measures *Number Recall* and *Word Order* were significantly correlated ($r = .55$, $n = 47$, $P = .000$). The two spatial working memory measures *Spatial Memory* and *Hand Movements* were also significantly correlated ($r = .39$, $n = 47$, $P = .007$). *Hand Movements* correlated significantly with both *Number Recall* ($r = .309$, $n = 47$, $P = .03$) and *Word Order* ($r = .41$, $n = 47$, $P = .004$). No other correlations were found to be significant.

3. Discussion

3.1. K-ABC composites and subtests

When examining the outcome of the ADHD-C group as a whole on the K-ABC, several things stand out (see Table 2). The group deviates from the standardized mean on the *Sequential Processing Scale*, consisting of the three sequential subtests, *Hand Movements*, *Number Recall* and *Word Order*. All these tasks may be considered to rely on working memory ability (e.g., Alloway, Gathercole, Willis, & Adams, 2004; Baddeley, 2003; Frencham, Fox, & Maybery, 2003; Helland & Asbjornsen, 2004; Montgomery, 2004). At first glance, this might indicate that children with ADHD-C in general are deficient in working memory, both verbal and spatial. When the ADHD-C group on the other hand has been divided according to language ability, interesting differences become apparent. The ADHD + SLI children scored significantly lower than ADHD non-SLI children and normal controls on the K-ABC *Sequential Processing Scale* and on the sequential subtests, *Number Recall* and *Word Order*, which both rely on verbal working memory. The performance of the ADHD + SLI children did not differ significantly from the ADHD non-SLI group and the control group on the subtest *Hand Movements*, which relies on nonverbal sequential processing. The three groups did not differ significantly from one another on the *Simultaneous Processing Scale* or any of its subtests. According to Kaufman and Kaufman (1983), the *Simultaneous Processing Scale* may be considered to depend on the functioning of the right cerebral hemisphere. These findings do not agree with those of researchers who have found right brain deficiency in ADHD children (e.g., Aman, Roberts, & Pennington, 1998).

The results of our study are comparable with studies on SLI in children. Preis, Schittler, Richter-Werkle, Sterzel, and Lenard (1997) used the K-ABC to describe the typical pattern of processing in 25 children with normal nonverbal intelligence and developmental language disorder (DLD) of the phonologic-syntactic subtype, a mixed receptive-expressive DLD with grammatical and phonologic deficits. The results of the K-ABC showed a significant deficit in sequential processing, whereas simultaneous processing was in the normal range. The children scored significantly below the norms on only two subtests, *Number Recall* and *Word Order* similarly to our ADHD + SLI sample.

The poor performance of the ADHD + SLI group on the *Number Recall* test in this study, is in agreement with studies on SLI children using the *Digit Span* test of the Wechsler Scales (Wechsler, 1991). As reported by Williams et al. (2000) most studies on the Wechsler Scales have also shown significant effects of ADHD on the *Digit Span* test and several studies have shown this subtest to be the most sensitive to attentional deficit. The *Digit Span Forwards* test of the Wechsler Scales has in the neuropsychological literature customarily been assumed to measure attention (Lezak, 1995; Spreen & Strauss, 1998). Our results indicate that repeating digits forward might be related to language ability rather than to attentional capacity, at least in ADHD children.

These findings suggest that ADHD children with language disorders are characterized by verbal sequential deficits, rather than by nonverbal sequential deficits.

3.2. *Working memory*

The findings of the present study show that the ADHD + SLI group performed significantly worse than the ADHD non-SLI group and the control group on Verbal WM (*Number Recall* + *Word Order*), but there were no significant differences between the three groups on Spatial WM (*Hand Movements* + *Spatial Memory*) which is within the normal range in all three groups (see Table 2). This is in agreement with previous studies that have not found spatial working memory deficits in ADHD (e.g., Scheres et al., 2004). Our findings agree with those of Cohen et al. (2000) who found that working memory deficits in children with ADHD were primarily related to their language abilities. Our results do not agree with their findings that

ADHD children with LI perform poorer than ADHD children without LI on spatial measures as well as verbal. The results of the present study are also not in line with those of McInnes et al. (2003) who found that working memory—both verbal and spatial—was impaired in ADHD children irrespective of language impairment. The reason for the difference in findings might be due to differences in groups examined, differences in diagnostic criteria or differences in diagnostic measures used. In this study, for example, the normal controls were matched with the ADHD groups on nonverbal intelligence, which was not the case in the McInnes study. We also examined only the ADHD-C subtype, while other subtypes were also included in the previously mentioned studies. In addition, our sample was a clinical ADHD sample with serious educational and/or behavioural problems and might not have the same characteristics as a community sample of ADHD children.

The finding that ADHD non-SLI do not have deficits in working memory, does not support Barkley's (1997) theoretical model of ADHD, which predicts that the executive function of working memory is a general deficit in ADHD.

3.3. Relationship between K-ABC measures and spoken language quotient (SLQ)

The present results indicate that SLQ is significantly correlated with the *Sequential Processing Scale* but not with the *Simultaneous Processing Scale*. More specifically, SLQ appeared to be significantly related to the sequential subtests *Word Order* and *Number Recall* but not with *Hand Movements*.

In addition, SLQ was also found to be significantly related to Verbal WM and not to Spatial WM. This finding is in agreement with numerous previous neuropsychological studies on SLI, that have shown a deficit in verbal working memory (e.g., Gillam et al., 1998; Montgomery, 2004). Taken together, our findings show that ADHD children with comorbid language disorders are characterized by verbal working memory deficits similarly to children with SLI (see review by Montgomery, 2003).

3.4. Relationship between working memory measures

The correlational analysis showed that the two verbal working memory measures, *Number Recall* and *Word Order* are significantly correlated and that the two spatial working memory measures *Spatial Memory* and *Hand Movements* are also significantly correlated. In addition, the *Hand Movements* test is significantly related to both verbal subtests, indicating that it is not a "pure" measure of spatial working memory. The *Hand Movements* test is an adaptation of Luria's fist-edge-palm test of motor function, which has been widely used as a neuropsychological assessment tool. In addition to the K-ABC, a similar test has also been included in another neuropsychological battery for children, the NEPSY (Korkman, Kirk, & Kemp, 1998). According to Frencham et al. (2003), there is some uncertainty as to which cognitive processes are involved in performing the *Hand Movements* test. Although Kaufman and Kaufman (1983) presented the *Hand Movements* test as a nonverbal task, they also commented that performance would benefit from using verbal labelling as a mediating strategy. Frencham et al. (2003) studied the *Hand Movements* test within a working memory theoretical framework and did indeed find that performance of the task relied on verbal recoding strategies. The findings of our study showed no significant differences between the ADHD + SLI, ADHD non-SLI and normal control groups on the *Hand Movements* test emphasizing the nonverbal nature of this task rather than the verbal one.

4. Conclusions

In sum, the results of our study show, that children with ADHD-C do not have a general working memory deficit. Only ADHD-C children with comorbid language disorders showed deficits in verbal working memory—but not in spatial working memory. ADHD-C children with normal language development, did not perform differently from normal children on verbal and spatial working memory measures. These results emphasize the importance of screening for language disorders when examining neuropsychological deficits in ADHD.

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