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BRIEF REPORT

Visuo-Spatial Working Memory Span: A Sensitive Measure of Cognitive Deficits in Children With ADHD

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ABSTRACT

Working memory (WM) has been hypothesised to be impaired in attention-deficit/hyperactivity disorder (ADHD). However, there are few studies reported on tests measuring visuo-spatial WM (VSWM) in ADHD. Some of these studies used paradigms including episodic memory, others only used low memory loads. In the present study we used a VSWM test that has not been used previously in ADHD research. The sensitivity of the VSWM test and a choice reaction time (CRT) test was evaluated in a pilot study by comparing them to two commonly used tests in ADHD-research; the Continuous Performance Test (CPT) and a Go/no-go test, in children with and without ADHD. The groups differed significantly in performance on the VSWM test ($P < .01$) and CRT ($P < .05$) but not on the CPT ($P > .1$) or on the Go/no-go test ($P > .1$). The results from the VSWM and CRT tests were replicated in a larger sample of participants (80 boys; 27 boys with ADHD and 53 controls, mean age 11.4 years). The difference between the groups was significant for both the VSWM test ($P < .01$) and the CRT test ($P < .01$). The effect size (ES) of the VSWM test was 1.34. There was a significant age-by-group interaction on the VSWM test, with larger group differences for the older children ($P < .01$). Our results show that the VSWM test is a sensitive measure of cognitive deficits in ADHD and it supports the hypothesis that deficits in VSWM is a major component of ADHD.

INTRODUCTION

Attention deficit/hyperactivity disorder (ADHD) is defined as age-inappropriate behaviour, with symptoms of inattention, impulsivity and hyperactivity (American Psychiatric Association, 1994).

In search of the underlying causes of ADHD it has been suggested that it could be useful to identify *endophenotypes* (measurable cognitive characteristics), that underlie manifest behaviour (Castellanos & Tannock, 2002). A main candidate among these is deficits in working memory (Barkley, 1997; Castellanos & Tannock, 2002; Rapport, Chung, Shore, Denney, & Isaacs, 2000).

Working memory (WM) is the ability to keep information online during a short period of time (Goldman-Rakic, 1987) and is thought to underlie a wide range of mental activities, such as reading, arithmetic and problem solving (Barkley, 1997). In addition WM has been shown to be crucial for

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maintaining the prioritisation of test-specific information and thereby reducing distractions from irrelevant stimuli (de Fockert, Rees, Frith, & Lavie, 2001). This indicates how WM deficits could lead to greater distractibility in ADHD.

There is substantial research done on the neurophysiological substrates that underlie WM function and these substrates, of which the prefrontal cortex seems to be the most important, coincide with those known to be affected in ADHD. It is also well known that WM functioning is dependent on dopamine (Williams & Goldman-Rakic, 1995), which is consistent with the association of ADHD with atypical dopaminergic transmission (Cook et al., 1995). In addition, drugs such as methylphenidate and amphetamine, known to ameliorate the symptoms in ADHD, facilitate dopaminergic transmission (Volkow et al., 1995), and also improve WM (Luciana, Depue, Arbisi, & Leon, 1992; Tannock, Ickowicz, & Schachar, 1995).

Despite the proposed role of WM there are only a limited number of studies on visuo-spatial working memory (VSWM) in children with ADHD (Barkley, 1997; Barnett et al., 2001; Karatekin & Asarnow, 1998; Kuntsi, Oosterlaan, & Stevenson, 2001; Mariani & Barkley, 1997; Ross, Hommer, Breiger, Varley, & Radant, 1994; Shue & Douglas, 1992). Furthermore, there is a wide range of different types of visuo-spatial tests used in these studies and hence it is uncertain if they measure the same cognitive ability. Therefore, we investigated the sensitivity of a VSWM test, not previously used in ADHD research. This test was adapted from Fry and Hale (Fry & Hale, 1996) and has recently been used in a functional magnetic resonance study to identify areas that are activated during performance of the VSWM test, and to identify how brain activity changes with age during childhood development (Klingberg, Forssberg, & Westerberg, 2001).

Latency and variability in responding in reaction time tasks have been suggested to differentiate between children with and without ADHD. This could possibly be related to WM in that choice reaction time (CRT) tasks measure speed-of-processing, which in turn could determine WM capacity (Fry & Hale, 1996). In this view, speed-of-processing would be more fundamental, and tests such as the CRT would be more sensitive than the WM test. To further study this question, we also included a CRT test in the present study to see if the results on this test correlate with those from the VSWM test, and to see if it is was even more sensitive than the VSWM test.

Pilot Study

Before a larger sample was tested on the VSWM test, we compared its sensitivity to three other tests commonly used in ADHD research, by giving the tests to a sample of children ($N = 23$), both with ($N = 11$) and without ($N = 12$) ADHD. The tests were the CRT test, a Go/no-go test (Trommer, Hoeppner, Lorber, & Armstrong, 1988) and a CPT test (Gordon & Mettleman, 1987). Significant group differences were evident only for the VSWM test ($P < .01$; ES 1.27) and the CRT test ($P < .05$) but not for CPT accuracy ($P > .1$) or CPT Reaction time ($P > .1$), nor on the Go/no-go test ($P > .1$). The fact that the group differences on the CPT and the Go/no-go test did not reach statistical significance could be ascribed to the small sample size. However, all the tests were given to the same particular sample and the results indicate that the VSWM test was more sensitive than the other tests. The effect size for the CPT in the present study was 0.58, which is comparable to the results from other CPT studies (Losier, B.J., McGrath, P.J., & Klein, R.M., 1996). Although some studies conclude that children with ADHD are significantly impaired on the CPT (Halperin et al., 1988), other studies find the sensitivity to be low (Schachar, Logan, Wachsmuth, & Chajczyk, 1988).

Main Study

In order to confirm the findings on the sensitivity of the VSWM and CRT tests from the pilot study, an additional sample of 80 children performed these tests. In this second study we carefully matched the groups for age and also included only boys to control for gender-effects. Boys and girls with ADHD differ in symptomatology (Newcorn et al., 2001; Rucklidge & Tannock, 2001). For this reason we are at risk to bias the results when groups with mixed genders are used. We therefore included only boys in the main study.

METHODS

Eighty children aged 8.0–15.3 years participated in this study. There were 53 boys in the control group (mean age 11.4 years, $SD = 2.0$) and 27 boys in the ADHD group (mean age 11.4 years, $SD = 2.2$). The children with ADHD were diagnosed according to DSM-IV (American Psychiatric Association, 1994) criteria by experienced physicians specialised in paediatric neurology or child-psychiatry in local teams for child and adolescent psychiatry in Stockholm. The diagnosis was based on the physician's clinical impression taking DSM-IV rating scales from parents and teachers into account. ADHD combined type was the main diagnosis. Five of the children with ADHD were receiving medication with psycho-stimulants but they refrained from taking any medication during a 24 h period before testing.

Since co-morbidity and mild mental retardation were exclusion criteria in the recruitment to this study, none of the children had any major neurological or psychiatric co-diagnoses. The children with ADHD were rated to have a normal mental ability (IQ > 80) based on the WISC-III test, school history and on clinical evaluations from psychologists or psychiatrists as a part of the assessment required for diagnoses. The local ethical committee approved the study and informed consent was collected from parents. All children were provided with two movie tickets each for participation. Only the CRT and the VSWM test were administrated. Stimuli were presented using E-prime® software (Psychology software tools inc. Pittsburgh, USA). Response collection was made via the touch screen monitor for the VSWM test and by an E-prime® Stimulus Response Box in the CRT.

CRT

The task was to press a button as quickly as possible when a warning signal (grey circle) switches to target (yellow circle). This was first performed with one circle and one button at the far left side of the screen and the response was to be made with the left index finger, this was followed by the same procedure on the right screen side, and with the right index finger. Subsequently two horizontal circles were presented and two buttons were used, one for each finger. One of the two circles turned from grey to yellow in a pseudo randomised order, and the child had to make a decision between pressing the button with the left or right finger corresponding to the yellow circle and respond as quickly as possible. The Δ value was defined as the increase in median reaction time in the two-choice version compared to the one-choice version. A measure of the constancy of attention can be obtained by calculating the standard deviation (*SD*) for each child. The stimulus onset asynchrony (SOA) of the warning cue was randomised between 1000 and 4000 ms. Maximum response time allowed was 2000 ms. The inter-trial-interval was 2000 ms. The distance between the children's face and the monitor was 70 cm for standardisation of the visual angle of display. Fifteen trials were administrated on each side in the one-choice condition and 30 pseudo random trials (15 left and 15 right) in the two-choice condition.

VSWM

Circles (memory stimuli) were presented one at a time in a four by four grid on the computer screen. Responses were made by pointing with the index finger in the same locations as the memory stimuli in an empty grid on the touch screen. The response was to be made after all stimuli in each trial were presented. WM load increased after every second trial, starting at two and ranging to nine circles. The test terminated when the child failed to accomplish both trials at a certain level. Working memory capacity for each participant was determined by the highest level passed, cumulatively adding the numbers of correctly indicated circles (items) from all trials up to that level. Grid representation at display was 22 cm × 22 cm. The children were positioned so that the face was 40 cm from the display. The same stimuli sequences were administrated to all children. The display time was 2250 ms, and the inter-stimuli interval (ISI) was 750 ms. (The test scripts are available from the corresponding author.)

RESULTS AND DISCUSSION

The difference between the groups was significant for both the VSWM test and all measures on the CRT test (Table 1). The group difference on the VSWM test was the single most significant measure ($P < .01$), with an effect size (ES) of 1.34. ES were calculated by Cohen's d' ($M_1 - M_2/\sigma$ pooled). The correlation between the CRT Δ and VSWM tests was .40.

Performance on the VSWM test as a function of age is shown in Figure 1. The difference between the slopes for each of the regression lines suggested an interaction between age and group, which also proved to be significant when calculated using a least squares linear regression analysis ($P < .01$).

Positive and Negative Predictive Power

When performing a logistic regression analysis on the VSWM and the CRT (*SD*) tests taken together, with diagnosis as the dependent variable, the result showed a sensitivity of 74% and a speci-

Table 1. Results from the Main Study. Raw Scores (Mean and *SD*) on the VSWM and CRT Tests, Effects from Analyses of Variance and Effect Sizes Comparing the Test Results of Children With and Without ADHD.

Task	ADHD ($N=27$) 11.4 (2.2)	Control ($N=53$) 11.4 (2.0)	Group effect	Age effect
VSWM (items correct)	28 (8.7)	47 (17.2)	$F(1,77)=42.5$ $P<.01$ ES = 1.34	$F(1,77)=46.2$ $P<.01$
CRT Δ (two choice – one choice) (ms)	138 (64)	103 (46)	$F(1,77)=12.4$ $P<.01$ ES = 0.64	$F(1,77)=39$ $P<.01$
SD (ms)	146 (79)	92 (37)	$F(1,77)=19.4$ $P<.01$ ES = 0.87	$F(1,77)=9.5$ $P<.01$
One-choice latency (ms)	323 (65)	282 (38)	$F(1,77)=18.4$ $P<.01$ ES = 0.78	$F(1,77)=31.9$ $P<.01$

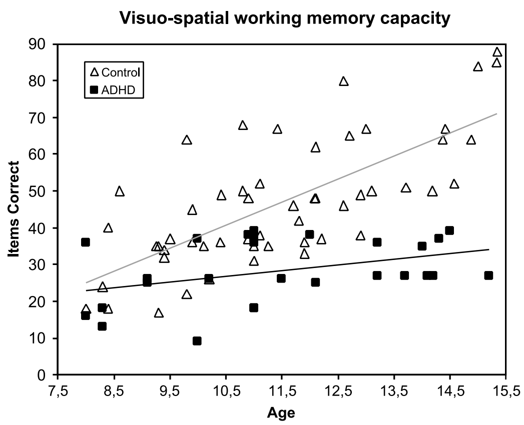

Fig. 1. Working memory scores for all participants in the main study ($N=80$). Linear regression lines for ADHD and control group, respectively.

ficity of 94%. Even if a cluster of tests shows high sensitivity and specificity, this information is of limited usefulness when applied to a population with a low base rate of the disorder. In terms of positive and negative predictive power (PPP/NPP), taking the base rate of 4% ADHD in the entire population into account, the PPP is 19% and the NPP is 99%.

If one considers the VSWM test as a screening instrument for ADHD in the entire population, a PPP of 19% is not promising. However, among children admitted to the neuropsychiatric clinic the base rate of ADHD is higher, and a higher base rate would lead to a corresponding increase in PPP.

VSWM

Several previous studies have found deficits in verbal WM, most commonly measured with the digit span test, in children with ADHD (Karatekin & Asarnow, 1998; Korkman & Pesonen, 1994; Mariani & Barkley, 1997). However, to date only a handful of studies have investigated visuo-spatial memory with short delays (Barnett et al., 2001; Karatekin & Asarnow, 1998; Mariani & Barkley, 1997; Ross et al., 1994; Shue & Douglas, 1992). The ES from these studies range between 0.36 and 1.06. One explanation for these differences could be that different test paradigms are used in these studies. The tests with the highest ES, Barnett et al. (2001) (ES = 1.06) and Mariani and Barkley (1997) (ES = 0.89) share some features. These are: (a) a visuo-spatial component; (b) more than one stimulus to keep in WM; (c) multiple response alternatives; (d) short delays with items being kept 'on-line' and (e) unique sequencing of stimuli-order in each trial. Another factor of importance could be the matching of gender. In the study by Mariani and Barkley (1997) only boys participated. In our study it was a rather specific sample, as only boys with ADHD combined type and with no co-morbidity participated. These circumstances can contribute to the high ES (1.34) because the *SD* in this group is probably lower than in a more heterogeneous sample.

A review of CPT tests found a mean ES of 0.73 ($SD = 0.56$) (Losier et al., 1996). One should be cautious in reaching conclusions by comparing one test based on a single population, to that of a meta-analysis that represents many studies with samples that may differ in clinical composition. However, the ES of the VSWM test (1.34) was higher than most of the ES in previously published results on the CPT. The result is also consistent with the higher ES of the VSWM test (1.27), when compared to the CPT in the pilot study.

The present study has some limitations that warrant further discussion. For example the ADHD and control group were not matched for IQ. It is well known that performance on WM tests has a high correlation with IQ scores (Engle, Kane, & Tuholski, 1999; Fry & Hale, 1996; Kyllonen & Christal, 1990). One reason why results from IQ tests correlate with WM scores is that these test batteries include WM tests such as the digit span test, or other tests requiring WM like reasoning and problem solving tests. The group-differences on WM-tests that are shown in a number of studies (Barkley, 1997; Barnett et al., 2001; Kuntsi et al., 2001) are consistent with the fact that some of these studies also show differences in IQ (Barnett et al., 2001; Kuntsi et al., 2001). The overlap between IQ and WM capacity makes matching of IQ between control and ADHD groups problematic. If IQ is controlled for, the group differences in WM capacity will be attenuated. A way of cancelling out the risk of confounds would have been to use an IQ index without WM-loaded subtests. To determine the degree to which the current findings would hold up after controlling for general cognitive ability level, further research should be conducted using a measure that is not confounded by Working Memory, for example the Wechsler Abbreviated Scale for Intelligence (Wechsler, 1999) to control for IQ.

It should be pointed out that WM capacity is not equivalent to general cognitive ability. For example children with ADHD are slower than age mates in achieving some academic skills, such as arithmetic and reading, while they are at age appropriate level in factual knowledge (Mariani & Barkley, 1997). Taken together, these results indicate that children with ADHD have problems specifically with those items in the IQ tests that demand WM.

In the present study, there was a significant interaction between the effects of age and group on the VSWM test ($P < .01$; Fig. 1), with the differences between children with and without ADHD being larger at older ages. One factor influencing the large interaction between age and group could be that the VSWM test used in this study, despite its sensitivity in discriminating older children and adolescents with ADHD, is a too crude measurement in detecting differences in younger children (see Fig. 1).

CRT

The ADHD group was significantly impaired in all three measures from the CRT test, but the Δ-value and the *SD* were the most significant (Table 1). The findings are consistent with previous reports of more variable and longer response latencies in children with ADHD (Kuntsi et al., 2001). The correlation between WM and CRT indicates a relation between these measures, but the lower ES for the CRT test does not suggest that speed of processing is more fundamental than VSWM in ADHD. We interpret the high variability of response latencies as a sign of inconsistently allocated selective attention, an ability which is thought to depend upon WM (Engle et al., 1999).

CONCLUSIONS

The present results indicate that the VSWM test is a sensitive measure of cognitive deficits in ADHD. This supports the WM-endophenotype-hypothesis, which suggests that WM deficits are a central cognitive mechanism underlying the symptoms in ADHD. This is also consistent with the results from a recent study showing that by intense WM training, not only WM improved but also attention, inhibition and problem-solving skills in children with ADHD (Klingberg, Forssberg, & Westerberg, 2002).

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