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
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, Arbis, & 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 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.
This page discusses a study on working memory in children with ADHD. It includes methods, results, discussion, and eventual conclusions. The methods section describes the recruitment of children aged 8.0–15.3 years, the criteria for diagnosis of ADHD, and the design of the study, including the use of the CRT and VSWM tests to assess working memory. The results section compares the performance of children with ADHD to a control group, highlighting significant differences in working memory capacity. The discussion section interprets these findings and discusses their implications for understanding ADHD and working memory.
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 VSTM 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 VSTM 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 VSTM 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 VSTM 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 $\Delta$-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 VSTM 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 VSTM 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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