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Working memory, psychiatric symptoms, and academic performance at school

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Abstract

Previous studies of the relationship among working memory function, academic performance, and behavior in children have focused mainly on clinical populations. In the present study, the associations of the performance in audio- and visuospatial working memory tasks to teacher reported academic achievement and psychiatric symptoms were evaluated in a sample of fifty-five 6–13-year-old school children. Working memory function was measured by visual and auditory *n*-back tasks. Information on incorrect responses, reaction times, and multiple and missed responses were collected during the tasks. The children's academic performance and behavioral and emotional status were evaluated by the Teacher Report Form. The results showed that good spatial working memory performance was associated with academic success at school. Children with low working memory performance, especially audiospatial memory, were reported to have more academic and attentional/behavioral difficulties at school than children with good working memory performance. An increased number of multiple and missed responses in the auditory and visual tasks was associated with teacher reported attentional/behavioral problems and in visual tasks with teacher reported anxiety/depressive symptoms. The results suggest that working memory deficits may underlie some learning difficulties and behavioral problems related to impulsivity, difficulties in concentration, and hyperactivity. On the other hand, it is possible that anxiety/depressive symptoms affect working memory function, as well as the ability to concentrate, leading to a lower level of academic performance at school.

Keywords: Spatial working memory; Academic performance; Psychiatric symptoms

1. Introduction

Intact function of memory and attention is essential for children to cope with the high scholastic demands of today. It has been shown that children with deficits in these functions have learning difficulties that are often accompanied by behavioral problems (De Jong, 1998; McLean & Hich, 1999). However, the relationship among memory function, academic performance and behavior has not been well documented in children. Of the memory functions, working memory has been most extensively studied and mainly in adult clinical populations (Conklin, Curtis, Katsanis, & Iacono, 2000; Farmer et al., 2000; Park, Puschel, Sauter, Rentsch, & Hell, 2000). In child populations, deficits in working memory functions have been reported in children with autistic spectrum disorders (Russell, Jarrold, & Henry, 1996), attention deficit hyperactivity disorder (Klorman et al., 1999), and learning disorders (Henry, 2001). We found no earlier studies relating working memory functions to behavioral and emotional symptoms or academic performance at school in nonclinical school-age children.

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Working memory refers to a temporary storage that holds and manipulates incoming, task-relevant information and integrates it with other information from the long-term memory. It enables one to manage in new situations and is necessary for fundamental aspects of normal behavior including learning, reasoning, language comprehension and acquisition of reading ability (Baddeley, 1988). Working memory can be further divided into 'central executive,' which is an attentional control system, and hierarchially lower 'slave' systems that are utilized in holding and manipulating modality-specific working memory information (Baddeley, 1992). Two main models have been proposed to explain the functional organization of frontal cortical regions in working memory. The "domain-" or "modality-specific" theory suggests that working memory processes within the lateral prefrontal cortex are organized according to the type of information being processed (Goldman-Rakic, 1987; Wilson, O'Scalaidhe, & Goldman-Rakic, 1993). An alternative "process-specific" model suggests that the functional organization of the PFC is based on different levels of executive processing (Petrides, 1995). Human neuroimaging studies have consistently demonstrated that both working memory and selective attention activate distributed networks of brain areas (Carlson et al., 1998; Corbetta, 1998; Martinkauppi, Rämä, Aronen, Korvenoja, & Carlson, 2000). The studies on the interactions between these two processes are scarce, presumably because the processes are difficult to separate from each other (Casey, Giedd, & Thomas, 2000). Inhibitory control is also an important factor in succesful executive function, as well as, in normal behavior and social adaptation (Tamm, Menon, & Reiss, 2002).

Several tasks have been developed to study the role of the prefrontal cortex in working memory. Tests that involve planning and the ability to flexibly change the strategy have been shown to measure frontal lobe functioning (Shallice & Evans, 1978). In working memory tasks verbal, spatial, emotional, or color stimuli have been used as memoranda (Martinkauppi et al., 2000; Rämä et al., 2001; Vuontela, Rämä, Raninen, Aronen, & Carlson, 1999). In human neuroimaging studies, the *n*-back task paradigm has been widely used to localize brain activity related to memory processing (Braver et al., 1997; Carlson et al., 1998; Cohen et al., 1997; Martinkauppi et al., 2000; Rämä et al., 2001). The *n*-back task paradigm requires continuous working memory processing and enables comparison of the effect of different memory load levels (Braver et al., 1997; Carlson et al., 1998). In these studies correct and incorrect responses and reaction times are recorded to enable evaluation of working memory performance.

Earlier, impairment of working memory functions have mainly been reported in children suffering from neuropsychiatric disorders (Klorman et al., 1999; McLean & Hich, 1999; Russell et al., 1996). The relationship between cognitive processes and behavior can be elucidated by studying how the working memory functions are associated with academic performance and behavioral and emotional status in a nonclinical child population. The information obtained could be used for finding ways to help children with learning difficulties and behavioral problems. The associations between psychiatric symptoms and higher cognitive functions should be first investigated in normative child populations because in clinical samples referral bias and the presence of multiple and severe disorders may limit the generalizability of the results (Caron & Rutter, 1991; Verhulst & Van der Ende, 1993). In the present study, we used the *n*-back paradigm to evaluate how the performance in audiospatial and visuospatial working memory tasks was related to academic performance and behavioral and emotional symptoms in a nonclinical sample of 6–13-year-old children. In the tasks incorrect responses and reaction times, reflecting working memory performance, and multiple and missed responses, reflecting inhibitory and attentional mechanisms, were recorded. We hypothesized that the number of incorrect responses and reaction times would be associated with academic performance at school. Multiple and missed responses were hypothesized to be correlated with such behavioral/emotional problems in which frontal lobe dysfunction has been reported (ADHD-type of symptoms and depressive symptoms).

2. Materials and methods

2.1. Subjects

A total of 66 schoolchildren (mean age 9.9, *SD* ± 1.9, female/male ratio 0.9) participated in the study: twenty-four 6–8-year-old (12 females, 12 males), twenty 9–10-year-old (8 females, 12 males) and twenty-two 11–13-year-old children (12 females, 10 males). The children were recruited by advertising from three elementary schools in Helsinki, Finland. All children were Caucasian and of Finnish nationality. A written permission was obtained from the parents and a verbal assent from the child. Of the parents 64% were classified as belonging to the socioeconomic class I, 24% to II, 8% to III, and 4% to IV (Helsinki city socioeconomic classification: I representing the highest and IV the lowest category). One child was excluded from the study because of dysphasia and another because of lack of cooperation. The Teacher Report Form (TRF, Achenbach, 1991) was not obtained from four children and in two cases the teachers had not filled in the academic performance part of the TRF, resulting in a total of 60 (58) subjects in the present study. The study protocol was approved by the Ethics Committee for Pediatrics, Adolescent Medicine, and Psychiatry at the Helsinki University Central Hospital.

2.2. Assessing psychiatric symptoms

The children were screened for psychiatric symptoms using TRF (Achenbach, 1991), Child Behavior Checklist (CBCL, Achenbach, 1991) and Children's Depression Inventory (CDI, Kovacs, 1985). The TRF and CBCL consist of competence and problem sections. The competence section of the TRF assesses the child's current performance in academic subjects using a scale of five grades ranging from far below grade level (score = 1) to far above grade level (score = 5). The child's academic performance sum score is the mean of the scores in different academic subjects. The problem sections are similar in both questionnaires measuring the quantity and quality of psychiatric symptoms by 113 questions with three alternative answers (scored 0, 1, and 2). In the Achenbach scoring system the symptoms are grouped into eight syndrome scales. These syndrome scales are further grouped under main headings called internalizing problems (including syndrom scales called withdrawn, somatic complaints, and anxious/depressed), externalizing problems (including delinquent and aggressive syndrome scales) and no internalizing or externalizing problems (syndrome scales called: social problems, thought problems, attention problems—including symptoms such as "cannot sit still," "nervous," "impulsive," "difficulties to concentrate," "twitches," etc.). The scoring system gives raw and standardized T-scores for the total of symptoms, internalizing and externalizing symptoms, and for each syndrome scale (Achenbach, 1991). In the present study the raw scores were used when studying the associations between the TRF scale scores and the performance in working memory tasks. The CDI is a self-report of depressive symptoms designed for children. Each of the 27 items included has three response alternatives scored 0, 1, and 2. The CDI total sum score ranges from 0 to 54 (Kovacs, 1985). Three children scored over the clinical borderline in CBCL and two in CDI. These children were excluded from the statistical analyses (leaving 55 cases for the study of associations between the TRF scores and WM parameters).

2.3. Assessing working memory performance

2.3.1. Test stimuli

The visual stimuli were light gray squares presented randomly in one of eight locations around a fixation cross (a detailed description of the working memory paradigm is presented in Steenari et al. (2003) and Vuontela et al. (2003)). The auditory stimuli were tones of 2250 Hz presented binaurally through earphones in one of three locations: left, right, and middle. Left and right locations were simulated by an interaural intensity difference. The tones in the middle location were of equal intensity. The presentation of the stimuli was controlled by a computer program (Presentation 0.31, Neurobehavioral Systems, San Francisco, USA), which also collected behavioral data (correct and incorrect responses, misses, multiple responses, and reaction times). The incorrect response rate and reaction time reflect working memory performance. Multiple responses reflect inability to control motor behavior. A multiple response occurs when the child presses the computer button when he/she should not do so, i.e., the child is unable to inhibit a motor response. A missed response is scored when the child "forgets" to press the computer button, e.g., he/she is inattentive.

2.3.2. *n*-Back tasks

0-, 1-, and 2-back visuospatial and audiospatial tasks were employed (Fig. 1). In the visual 0-back task, the subject pressed the left button of the mouse with the right index finger if the stimulus appeared in a predetermined location (upper left location), and the right button with the middle finger if in any other location. In the visual 1-back task, the subject pressed the left button

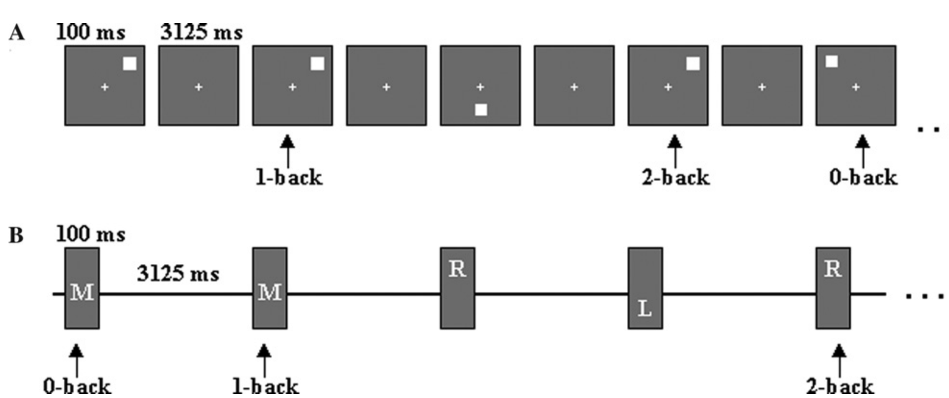

Fig. 1. The experimental design. (A) Five trials of the visuospatial working memory tasks. (B) Five trials of the audiospatial working tasks. L, left; M, middle, and R, right. Vertical arrows mark the match trials for 0-back, 1-back, and 2-back tasks. 100 ms refers to the duration of each stimulus and 3125 ms to the delay period between the stimuli.

whenever the stimulus was in the same location as the previous one (two trials back in the 2-back task), and the right button if in a different location. In the auditory 0-back task the predetermined match location was in the middle. Otherwise, the auditory tasks were performed as explained for the visual tasks. An instruction figure at the beginning of each condition indicated the type of task to be performed. The subjects were instructed to fixate a small cross in the center of the display throughout the tasks. The experiment consisted of six conditions: visuospatial 0-, 1-, and 2-back, and audiospatial 0-, 1-, and 2-back tasks, presented in six blocks of 120 trials. Each block had six conditions of 20 trials presented in a counterbalanced order. Thus, each subject received a total of 360 trials of visual and 360 trials of auditory tasks, altogether 720 trials including 30% match trials. There was a 10-s pause between the conditions in a block and the subjects were allowed to have a short break between the blocks.

2.3.3. General procedure

The memory tasks were presented with a portable computer. The subjects were tested individually in a quiet room in the school during a school day or in the Hospital for Children and Adolescents. To avoid possible problems of fatigue, the experiment was conducted in two separate sessions on different days. Approximately, half of the subjects performed the visual tasks during the first session and the auditory tasks during the second, for the other half the order was reversed. At the beginning of each session the memory task was explained and the children were allowed to practise until they understood the nature of the task; this was controlled by checking the log-file of the performance. On the average, the subjects practised 20 trials of each condition before starting the experiment. The subjects faced the computer screen with the chin on a chin rest 57 cm from the center of the screen.

2.3.4. Data analysis

The percentage of incorrect responses, reaction times, percentages of missed, and multiple responses in each condition were counted for the 120 trials in the 0-back, 114 trials in the 1-back and 108 trials in the 2-back tasks; the first stimulus in the 1-back and the first two stimuli in the 2-back tasks required no working memory processing. There was a high correlation between the error responses in the tasks with different memory load levels (0-, 1-, and 2-back) (all correlation coefficients >.781). The scores obtained at the different memory load levels were combined into one (mean) value for statistical analysis in order to get one outcome variable for each working memory parameter. In addition to zero-order correlations, partial correlations were calculated keeping the age and gender constant (i.e., their linear additive part was residualized). Additionally, the Hierarchical Linear Model (HLM) was used to control the variable of load level. The three memory load levels form a strongly dependent set of scores within each individual. The data are stacked to carry out the HLM procedure and the memory load levels are used as dummy variables. This increases the number of observations but the method takes this into account (Bryk & Raudenbush, 2002; Goldstein, 2003). This part of the analysis was carried out using the mixed-module of the SPSS version 11 (cf. SPSS, 2003). The standardized regression coefficient from the HLM is the third index of controlled association. When all three coefficients were significant we continued to examine visually the bivariate scatterplots in the three age groups (6–8-, 9–10-, and 11–13-year-olds), presented in Fig. 2.

3. Results

3.1. Descriptive data

The means, minimums and maximums of reaction times, the incorrect, multiple and missed responses in working memory performance, and the symptom scores (TRF, CBCL, and CDI) are presented in Table 1. The effects of age and gender on the performance in working memory tasks have been reported elsewhere (Vuontela et al., 2003). The partial correlations (controlling for age and gender) among the auditory and visual incorrect response rates, reaction times, and multiple and missed responses are presented in Table 2.

3.2. Working memory tasks and teacher reported academic performance

A high number of incorrect responses in auditory tasks was significantly associated with poorer academic performance at school. In visual tasks this association did not reach significant level when the effects of age and gender were controlled for in the analysis (Table 3). In the youngest age group (6–8-year-old), both the visual and auditory incorrect response rate were associated with the academic performance ($r = -.510$, $p = .022$; $r = -.282$, $p = .229$, respectively). In the older age groups (9–10- and 11–13-year-olds) only the auditory incorrect response rate was associated with the academic performance ($r = -.443$, $p = .098$; $r = -.403$, $p = .078$) (Fig. 2). No significant associations were found between the reaction times and academic performance at school, or between the multiple/missed responses and academic performance.

3.3. Working memory tasks and psychiatric symptoms

A high number of incorrect responses in both auditory and visual tasks was significantly associated with

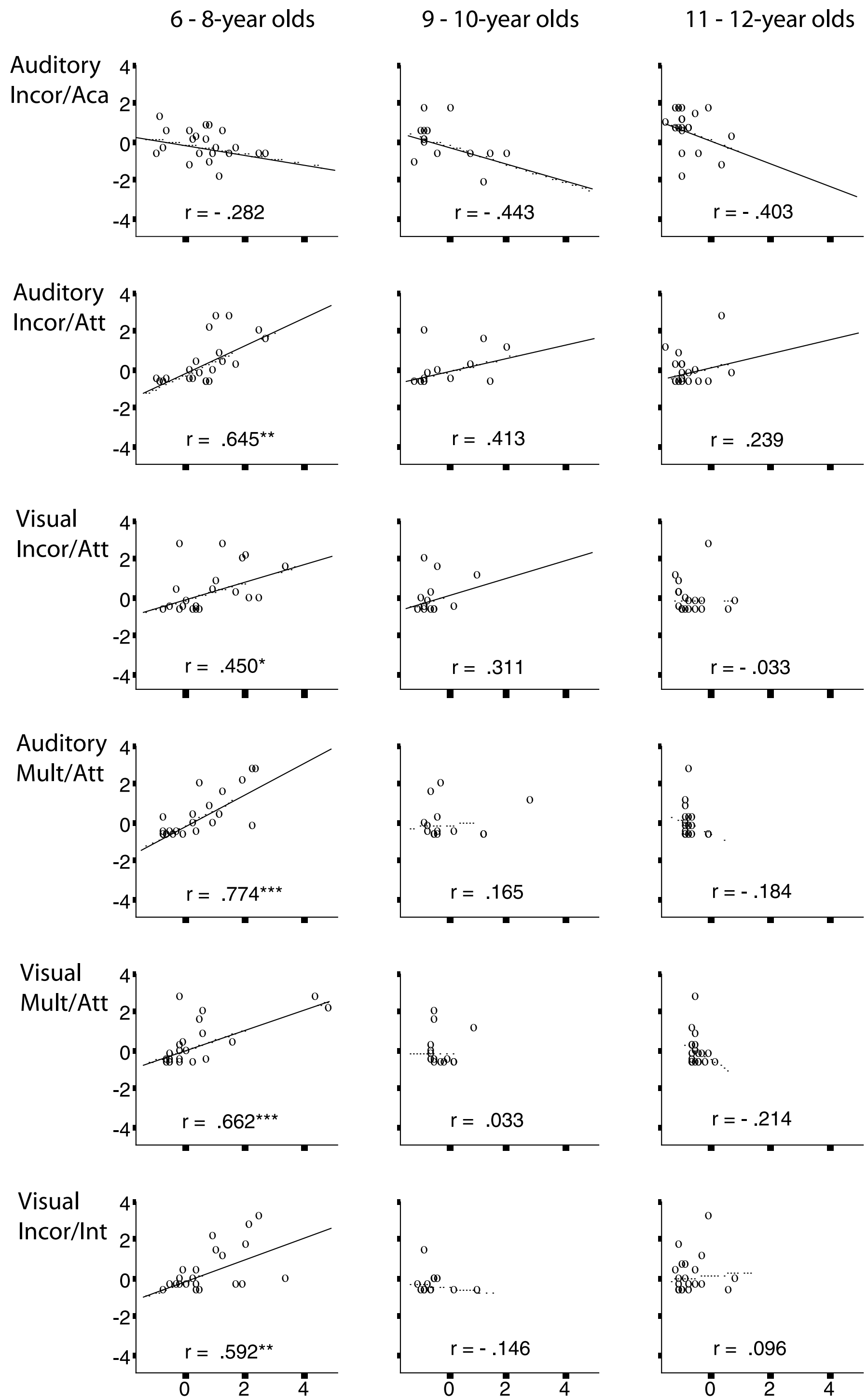

Fig. 2. Scatterplots between selected Working Memory and Teacher Report Form parameters in the three age groups. The scores are presented in scale mean = 0, standard deviation = 1 (e.g., in *z*-scores). Regression lines are presented for significant or nearly significant associations. Auditory incor = auditory incorrect response rate, Visual incor = visual incorrect response rate, Auditory mult, auditory multiple response rate; Visual mult, visual multiple response rate; Aca, teacher reported academic performance; Att, teacher reported attention scale score; Int, teacher reported internalizing scale score. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

a high score on the teacher reported attention syndrome scale. These correlations remained significant when age and gender, and the task load were controlled (Table 3). In visual tasks, the number of incorrect responses also correlated positively with the number of teacher reported emotional (internalizing) symptoms. Reaction times were not associated with any psychiatric symptoms (Table 3). A high number of multiple responses

Table 1
Minimum/maximum scores, means, and standard deviations on Teacher's Report Form scales (raw scores), Child Behavior Checklist (CBCL), Children's Depression Inventory (CDI), and Working Memory Parameters (WMPs: sums of incorrect, missed, and multiple responses in visual and auditory tasks)

	N	Minimum	Maximum	Mean	*SD*
TRF					
Total symptoms score	60	0	59	11.96	12.81
Internalizing	60	0	12	2.48	3.07
Anxious/depressed	60	0	5	1.17	1.63
Externalizing	60	0	24	4.05	6.05
Attention	60	0	30	4.22	5.69
Academic performance	58	1.75	5	3.70	.84
CBCL total score	58	1	48	20.79	12.96
CDI total score	54	0	19	4.19	3.81
Auditory WMP					
Incorrect (%)	60	3.78	160.4	54.3	37.8
Missed (%)	60	0	28.04	3.32	6.12
Multiple	60	0	13.15	2.99	3.65
Visual WMP					
Incorrect (%)	60	1.83	138	32.7	29.9
Missed (%)	60	0	43.36	3.42	6.60
Multiple	60	0	33.27	3.61	6.45

Table 2
Partial correlations among working memory task parameters

	Correlation coefficient	*p*-Value
Working memory task parameters		
Auditory incorrect (%)/auditory missed%	.199	.133
Auditory incorrect (%)/auditory multiple%	.300	.022
Auditory incorrect (%)/visual incorrect%	.633	.000
Auditory missed (%)/auditory multiple%	.386	.003
Auditory missed (%)/visual missed (%)	.621	.000
Auditory multiple (%)/visual multiple%	.544	.000
Visual incorrect (%)/visual missed%	.437	.001
Visual incorrect (%)/visual multiple%	.384	.003
Visual missed (%)/visual multiple%	.649	.000

Controlling for age and gender ($n = 60$).

in auditory and visual tasks was significantly associated with an increased score on the total scale of psychiatric symptoms and on the attention syndrome scale; In visual tasks, the number of multiple responses also correlated with an increased score on the internalizing scale, especially on the anxious/depressed syndrome scale. The number of missed responses in auditory and visual tasks was positively associated with the score on the attention syndrome scale; in visual tasks also with the scores on the total symptom scale (Table 3).

The scatter plots of the above-mentioned strongest correlations are presented for the different age groups (6–8, 9–10, and 11–13) in Fig. 2. The associations are clearest in the youngest age group and many associations diminish or even disappear in the older age groups. In both visual and auditory tasks, the strongest associations in the youngest age group are between the multiple response rate and the TRF total score and the attention subscore. Incorrect response rates in visual and auditory tasks were also associated with the TRF attention scale score in the youngest age group. No significant associations were found between performance in working memory tasks and psychiatric symptoms reported by the parents (CBCL) or the child (CDI).

4. Discussion

In the present nonclinical sample of 6–13-year-old children spatial working memory performance was associated with the teacher reported academic performance and attentional/behavioral difficulties (attention syndrom score: difficulties in concentrating and sitting still, impulsivity, etc.). Children with lower academic performance at school had more incorrect responses in spatial memory tasks than children with higher academic achievement. On the other hand, the children who according to the teachers' reports had attentional/behavioural difficulties made more mistakes in the memory tasks than the children with no such difficulties. These associations were more evident in the auditory than visual tasks. In the visual tasks, working memory performance (measured by the number of incorrect responses) was also lowered in children with internalizing type of symptoms (anxiety, depression). All these associations were most strongly seen in the youngest age group of children. Interestingly, the speed of performing the tasks (reaction time) was not associated with teacher reported academic performance or symptoms.

Earlier studies have demonstrated associations between learning disabilities and working memory function (Henry, 2001; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001; Swanson, 1993). Henry (2001) reported that children with mild and moderate

Table 3
Correlations, partial correlations (controlling for age and gender), and standardized regression coefficients from HLM (controlling in addition for the load of task) between Working Memory Task Parameters (WMPs) and Teacher Report Form (TRF) scores ($n = 55$)

WM-score	TRF-score total	Internal	External	Depressed/anxious	Attention	Academic performance
Auditory	.324*	.111	.086	.074	.493***	−.471***
Incorrect	.140	.050	−.067	−.073	.395**	−.273*
Response rate	.153	.192*	−.086	.096	.385**	−.251*
Auditory	−.110	.010	−.170	.117	−.028	−.113
Reaction	−.167	−.032	−.191	.062	−.063	−.059
Time	−.146	.052	−.171	.104	−.078	−.039
Auditory	.197	.181	−.040	.182	.267*	−.148
Missed	.213	.133	−.021	.115	.321*	−.118
Response rate	.267**	.128	−.009	.133	.397***	−.165
Auditory	.465***	.168	.249	.221	.475***	−.286
Multiple	.375**	.120	.186	.130	.404**	−.072
Response rate	.205**	.140	.124	.152*	.246***	−.061
Visual	.321*	.395**	−.014	.352**	.361**	−.354**
Incorrect	.200	.394**	−.139	.278*	.280*	−.162
Response rate	.133	.277**	−.106	.196*	.250*	−.131
Visual	.058	.062	−.064	.145	.125	−.145
Reaction	−.068	−.070	−.114	−.021	.078	.047
Time	−.020	−.014	−.087	.015	.111	−.014
Visual	.371***	.280*	.030	.284*	.464***	−.284*
Missed	.375**	.234	.024	.205	.522***	−.216
Response rate	.311*	.105	−.020	.091	.503***	−.167
Visual	.508***	.325*	.132	.374**	.491***	−.218
Multiple	.451***	.305*	.065	.326*	.444***	−.062
Response rate	.541***	.301*	−.028	.338*	.582***	−.041

* $p < .05$.
** $p < .01$.
*** $p < .001$.

learning difficulties were impaired in all measures of working memory when compared with children with average abilities. Passolunghi and Siegel (2001) studied the relations among short-term memory, working memory, inhibitory control, and arithmetic word problem solution in children with poor or good arithmetic problem solving abilities. They found that poor problem solvers were impaired when they had to retain numerical information but not if the material to be retained was formed of words. The main fault with the poor problem solvers was found to be a general deficit in their inhibitory processes (Passolunghi & Siegel, 2001). The results of the present study are not directly comparable with the earlier findings because our sample consisted of children from ordinary classes with no diagnosed learning difficulties. The present findings suggest that even in this normative sample a well functioning spatial working memory was reflected as good performance in academic subjects at school. The results suggest that deficits in working memory function may be an underlying factor in mild learning problems as well as in learning disabilities at school. Earlier studies have reported that working memory performance and general intelligence are related; however, they are not identical (Conway, Kane, & Engle, 2003). Our study did not include a general measure of intelligence; thus it is not possible to unequivocally attribute the associations to working memory. Henry (2001) found that children with borderline learning disabilities obtained significantly lower scores for phonological memory span than the control group, whereas in the visuospatial memory span measure children with borderline learning disabilities were indistinguishable from their average-ability peers. In both Henry's and our studies the ability to perform auditory tasks was associated more strongly with academic achievement than the performance of visual tasks. It is possible that auditory tasks require more attention than the corresponding visual tasks. There is some evidence that the visuospatial and audiospatial working memory systems may follow a different maturational course so that visuospatial working memory reaches the adult level earlier than audiospatial working memory (Vuontela et al., 2003). The present findings suggest that children who are good at retaining auditory information succeed well at school. Our results suggest that for children with learning difficulties teaching methods other than those based on the auditory modality could be helpful. In an earlier study, we found that visual memory tasks were performed faster and more accurately than corresponding auditory tasks, suggesting that there was a difficulty difference between the tasks (Vuontela et al., 2003). It is possible that the stronger association of auditory than visual memory task performance with academic success reflects differences in the difficulty level of the tasks. It is also possible that the statistical significance was due to the larger variation in the incorrect response rates in auditory than in visual tasks (i.e., visual tasks were not as sensitive as the auditory ones in the present normative sample).

The present findings are in line with the earlier studies reporting working memory deficits in children with attention deficit hyperactivity disorder (Klorman et al., 1999). Even in the present sample consisting of children from ordinary classes, the children with a lower working memory capacity (increased incorrect response rate) tended to have more attentional/behavioural difficulties at school. This association was seen more strongly in the auditory than visual tasks. It is possible that in some cases deficits in working memory capacity are reflected as inattentive, impulsive, or hyperactive behavior at school. However, since our study was cross-sectional by nature, no causal interpretations could be made. The TRF detects behavior that is typical of children with ADHD such as difficulties in concentration, inability to sit still, impulsivity, etc. The Achenbach questionnaires are dimensional measures of behavior and emotions and give a range of symptoms also in normative samples, thus reflecting the variability of behavior in general population (Achenbach, 1991). Earlier studies have demonstrated defects in spatial working memory in children with ADHD (Cairney et al., 2001). Stimulant medication has been found to improve working memory performance by modulating discrete frontal and parietal lobe regions in the human brain (Mehta et al., 2000). The present study supports the earlier findings indicating associations between spatial working memory capacity and ADHD-type of behavioral symptoms (Cairney et al., 2001; Klorman et al., 1999).

One important aspect of the executive function is inhibition. Cairney et al. (2001) found that children with ADHD made more errors in a spatial working memory test than the normal controls or medicated ADHD children. Furthermore, they found that ADHD children with or without medication were unable to voluntarily inhibit eye movements in an oculomotor paradigm. The authors suggest that deficits in the executive function and inhibitory control appear independently in children with ADHD (Cairney et al., 2001). Inhibition has been implicated as a potential locus of core deficit in ADHD (Quay, 1997; Schachar, Mota, Logan, Tannock, & Klim, 2000). Inhibition is important in situations requiring withholding or sudden interruption of an ongoing action or thought or in the suppression of information that one wishes to ignore. Deficient inhibitory control impairs the ability of children to engage other executive-control strategies to optimize their behavior. The direct and cascaded effects of deficient control of inhibition affect working memory, self-regulation, internal speech, and the ability to reconstruct behavior (Schachar et al., 2000). In the present study, a strong association was found between multiple responses in the memory tasks and teacher reported attentional/behavioral problems. Inhibitory control has mainly been studied using the stop-signal paradigm involving two concurrent tasks, a go task and a stop task This is a laboratory analog of a situation requiring a rapid and accurate execution of a simple motor action and an occasional and unpredictable cessation of this action (Schachar et al., 2000). In the present study, no such specific paradigm was used to study inhibitory control. However, multiple responses were errors resulting from an inability to inhibit motor behavior. Our results corroborate the earlier studies suggesting association between inhibitory control and ADHD-type symptoms (Slusarek, Velloing, Bunk, & Eggers, 2001). A positive association was also found between the teacher reported attention problems score and the number of missed responses in working memory tasks. In working memory, attention and memory are not easily separable and also involve inhibitory processes (Casey et al., 2000; Smith & Jonides, 1999). In the present study, the incorrect response rate (working memory performance level) and multiple (inhibition control) and missed responses (level of attention) were all associated with an increased ADHD-type behavior at school.

Interestingly, the performance in visuospatial memory tasks was associated with the teacher reported internalizing symptom score (as well as with the above-mentioned attention score) reflecting emotional problems such as depression and anxiety. Significant positive associations were found between the anxious/depressed syndrome score and the number of incorrect, multiple and missed responses in visual working memory tasks. Earlier studies have reported deficits in short-term memory and metamemory in children with depression (Kaslow, Rehm, & Siegel, 1984; Lauer et al., 1994). Impaired ability to concentrate has been found to be one of the major problems in child and adult patients with depression (Sund, Larsson, & Wichstrom, 2001). The present findings are in line with the earlier results; even mild symptoms of depression/anxiety are associated with poorer working memory performance and concentration difficulties.

In our sample of normative children the associations between working memory task performance and teacher reported symptoms were strongest in the youngest age group probably reflecting the larger variation rates of the studied parameters. Earlier, we found that in this age range age had a significant effect on the performance of working memory tasks (Vuontela et al., 2003). In the youngest age group, the variability in working memory responses was larger than in the older age groups. Also, the teachers reported more symptoms for the youngest age group. The working memory tasks and the TRF seemed not to be as sensitive tools in the older age groups of normative children than in the youngest age group; e.g., the older children did not make enough errors in the working memory tasks or have enough symptoms in the TRF for significant associations to arise. It is possible that with a larger sample size and with more demanding tasks the associations between the working memory performance and symptoms would be stronger also in older (9–13-year-old) children.

The present results implicate that academically weak children should be evaluated for behavioral and emotional problems, and working memory deficits. The results suggest that working memory deficits may underlie some learning difficulties and behavioral problems related to impulsivity, difficulties in concentration, and hyperactivity. On the other hand, it is possible that anxiety/depressive symptoms affect working memory function and the ability to concentrate, being thus the primary cause of poor academic achievement. As a next step, it is important to study working memory performance in children with clinical disorders. Furthermore, the association between verbal working memory and academic performance should be studied in normal children to learn more about the relationships between different working memory systems and school performance.

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