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The Cognitive and Behavioral Characteristics of Children With Low Working Memory

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This study explored the cognitive and behavioral profiles of children with working memory impairments. In an initial screening of 3,189 five- to eleven-year-olds, 308 were identified as having very low working memory scores. Cognitive skills (IQ, vocabulary, reading, and math), classroom behavior, and self-esteem were assessed. The majority of the children struggled in the learning measures and verbal ability. They also obtained atypically high ratings of cognitive problems/inattentive symptoms and were judged to have short attention spans, high levels of distractibility, problems in monitoring the quality of their work, and difficulties in generating new solutions to problems. These data provide rich new information on the cognitive and behavioral profiles that characterize children with low working memory.

Working memory is a multicomponent system providing temporary storage of information for brief periods of time that can be used to support ongoing cognitive activities (Baddeley, 1986; Baddeley & Hitch, 1974). The limited capacity of working memory varies widely between individuals and is closely associated with learning abilities during childhood (see Cowan & Alloway, in press, for a review). A large body of research has focused on working memory deficits in individuals with learning difficulties in reading (e.g., Gathercole, Alloway, Willis, & Adams, 2006; Gathercole, Lamont, & Alloway, 2006; Siegel & Ryan, 1989; Swanson, 2003), mathematics (Bull & Scerif, 2001; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Gersten, Jordan, & Flojo, 2005), language (e.g., Archibald & Gathercole, 2006b; Ellis Weismer et al., 2000; Montgomery, 2000), and attention (Barkley, 1997; Martinussen & Tannock, 2006). In this research tradition, the area of learning difficulty (reading, language, etc.) represents the primary impairment by which the children are identified, and any working memory deficits are secondary, associated characteristics. As a result, little is known about the consequences of low working memory capacity per se, independent of other associated learning difficulties. In particular, it is not known either what proportion of children with low working memory capacities have significant learning difficulties of these different kinds or what their behavioral characteristics are. The purpose of the present study is to redress this situation by providing the first systematic large-scale examination of the cognitive and behavioral characteristics of school-aged children who have been identified solely on the basis of very low working memory scores.

The dominant conceptualization of working memory is of a system comprising multiple components whose coordinated activity provides the capacity for the temporary storage and manipulation of information in a variety of domains. According to Baddeley's (2000) revision of the influential Baddeley and Hitch (1974) model, working memory consists of four limited capacity elements. The central executive is a domain-general component responsible for the control of attention and processing that is involved in a range of regulatory functions including the retrieval of information

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from long-term memory (Baddeley, Emslie, Kolodny, & Duncan, 1998). The temporary storage of information is mediated by two domain-specific stores: The phonological loop provides temporary storage of verbal material, and the visuospatial sketchpad specializes in the maintenance and manipulation of visual and spatial representations (see Baddeley & Logie, 1999, for a review). The fourth component, the episodic buffer, is responsible for binding information across informational domains and memory subsystems into integrated chunks (Baddeley, 2000). The episodic buffer is a relatively new component of the working memory model. As measurement tasks have yet to be standardized for children, this component was not considered in the present study (though see Alloway, Gathercole, Willis, & Adams, 2004, and Alloway & Gathercole, 2005, for the links between the episodic buffer and learning in children).

Individual differences in short-term memory and working memory capacity are assessed by a variety of techniques. In tests of verbal short-term memory, the participant is required to recall sequences of verbal material such as digits, words, or nonwords. Visuospatial short-term memory tests involve the presentation and recall of material such as sequences of tapped blocks or of filled cells in a visual matrix. More complex memory tasks have been designed to assess the central executive/attentional control aspect of working memory, and these typically depend also on relevant short-term memory stores. In these ''working memory'' tasks, the individual is typically required both to process and store increasing amounts of information until the point at which recall errors are made is reached. Studies that have administered large batteries of subtests of each of the four main types—verbal short-term memory, visuospatial short-term memory, verbal working memory, and visuospatial working memory—have shown that a model consisting of two domain-specific stores (verbal and visuospatial) and a single domain-general component supporting processing provide an excellent account of the data in studies of children (Alloway, Gathercole, & Pickering, 2006; Bayliss, Jarrold, Gunn, & Baddeley, 2003), adult participants (Kane et al., 2004), neuropsychological patients, and neuroimaging research (Jonides, Lacey, & Nee, 2005). The distinction between the mechanisms supporting short-term storage and the control of attention in this model is present also in several other current models of working memory (e.g., Cowan, 2001; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004). Often, the domain-general attentional component is referred to as working memory and the specialized stores as short-term memory.

With the development of a wider range of validated measures of each of the main components of working memory, it is possible to provide a better understanding of the working memory profiles associated with different kinds of atypical development. Gathercole and colleagues (Gathercole, Alloway, et al., 2006; Gathercole, Lamont, et al., 2006) recently reported findings that children with poor reading and arithmetic abilities scored poorly on tests of both verbal and visuospatial working memory, although their performance on verbal short-term memory tests fell within age-appropriate levels. A similar profile has recently been established for children with dyslexia (Pickering, 2006) and attention deficit hyperactivity disorder (ADHD; Martinussen & Tannock, 2006) and indicates a selective impairment of working memory. Other studies have also confirmed that poor verbal working memory skills are characteristic of children failing to progress normally in the areas of reading (e.g., De Jong, 1998; Swanson, 1994), mathematics (e.g., Bull & Scerif, 2001; Mayringer & Wimmer, 2000; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989), and language comprehension (e.g., Nation, Adams, Bowyer-Crane, & Snowling, 1999; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000).

The majority of research on working memory and learning has demonstrated relations among these two components. It is possible that poor working memory skills are the cause of the learning difficulties encountered by these children. Some insight into why working memory constrains learning has been provided by observations of children with low working memory in the course of their regular classroom activities (Gathercole & Alloway, 2008; Gathercole, Alloway, et al., 2006; Gathercole, Lamont, et al., 2006). These children struggled in learning activities that placed heavy demands on working memory. Common failures included forgetting lengthy instructions (see also Engle, Carullo, & Collins, 1991; Gathercole, Durling, Evans, Jeffcock, & Stone, 2008), place-keeping errors such as missing out letters or words in sentences, and failure to cope with the simultaneous processing and storage demands frequently imposed in structured learning activities. The unfolding route to task failure—in which the children typically started an activity and then either began to make errors or abandoned the task—is consistent with the loss of crucial task information from working memory due to overload. One suggestion is that frequent working memory failures in classroom activities are the cause of the slow learning progress of children with low working memory capacities (Gathercole & Alloway, 2008).

Other working memory problems that are associated with atypical development are not as readily explained in terms of core deficits of working memory. Consider, for example, children with specific language impairment (SLI) who fail to develop language at the typical rate in the absence of any obvious cognitive, sensory, or physical deficit. These children have marked deficits in both verbal short-term memory and verbal working memory, but not in either visuospatial short-term memory or visuospatial working memory (Archibald & Gathercole, 2006a, 2007). A contrasting profile has been reported for children with developmental coordination disorder (DCD), an impairment that primarily affects motor planning and coordination. Recent findings indicate that children with DCD have greater deficits in visuospatial short-term and visuospatial working memory tasks than in the corresponding verbal tests (Alloway, 2007b). The contrasting domain-specific patterns of strengths and weaknesses of these two developmental disorders suggest that their associated deficits negatively impact their working memory performance—verbal memory for children with SLI and spatial memory in the case of DCD. An alternative view is that deficits of these *specific* components of working memory may underlie the disorder.

The present study involved the identification, via routine screening, of a large sample of children aged 5–6 years and 9–10 years with very low working memory scores. Over 3,000 children were screened on two standardized tests of verbal working memory, and approximately 300 children with scores within the lowest 10th percentile for their age were selected as the low-working-memory sample. The children were selected for this study on the basis of their performance on verbal working memory tasks because most of the previous research in this area has used these measures rather than the more recently developed visuospatial working memory tasks. Following selection, each child completed a battery of standardized assessments of working memory, language, IQ, reading, and mathematics abilities.

The first objective was to confirm whether the low levels of performance of the sample selected on the basis of poor verbal working memory would also extend to their visuospatial working memory. This would lend support to the notion that working memory problems are pervasive, affecting both verbal and visuospatial domains, a finding that has implications for the development of effective means of supporting children with working memory impairments. It also addresses the debate as to whether working memory capacity is captured by a domain-general component or domain-specific aspects (e.g., Alloway et al., 2006; Bayliss et al., 2003; Kane et al., 2004) in children identified as having poor working memory skills.

The second objective was to establish the extent to which children with low working memory capacity make poor progress in key academic domains of reading and mathematics. Previous studies have established high correlations between working memory scores and children's attainment levels in National Curriculum assessments in these areas (Gathercole & Pickering, 2000; Gathercole, Pickering, Ambridge, & Wearing, 2004) and have also led to estimates that up to 70% of children who require special educational support in these areas have poor working memory (Alloway et al., 2005; Gathercole, Alloway, et al., 2006). If low working memory capacity in itself impairs academic learning as suggested by Gathercole and Alloway (2008), we would expect that the majority of the children selected to participate in this study would be struggling in reading and mathematics. The approach in the present study in the form of a large-scale screening study has, to date, not been adopted to establish whether this is, indeed, the case.

The third objective of the study was to investigate the classroom behavior of children with low working memory. We have previously found that when teachers are asked to describe the characteristics of these children, they tend to describe them first and foremost as being inattentive and lacking in concentration rather than recognizing their memory difficulties (Gathercole & Alloway, 2008; Gathercole, Alloway, et al., 2006; Gathercole, Lamont, et al., 2006). In the present study, more systematic evaluations of the behavioral characteristics of children with low memory scores were obtained by asking the children's teachers to complete a behavioral checklist that addresses such elements as inattentive, hyperactive, and oppositional behaviors (Conners, 2005). Data from this instrument allowed us to assess whether high levels of inattentivity typically accompany low working memory scores, as previous research suggests (e.g., Martinussen & Tannock, 2006). Teachers also completed a checklist consisting of behavioral descriptions of executive problems in areas such as planning, inhibition, shifting, and organization (Gioia, Isquith, Guy, &

Kenworthy, 2000). Finally, we assessed whether low working memory skills are associated with low levels of self-esteem (Morris, 2002). This is of interest as there appears to be little correlation between global self-esteem and academic performance (Baumeister, Campbell, Krueger, & Vohs, 2003; Marsh & Craven, 2006) in the general population or, indeed, for those with academic learning difficulties such as dyslexia (e.g., Snowling, Muter, & Carroll, 2007).

Method

Participants

In line with documented links between verbal working memory and learning, two verbal working memory measures from the Automated Working Memory Assessment (AWMA; Alloway, 2007a), listening recall and backward digit recall, were administered to 1,470 children aged 5 and 6 years during the last term of the 1st year of full-time education and 1,719 children aged 8 and 9 years in the final term of their 4th year of school. This comprised the screening phase of the study (Time 1). A total of 3,189 native English-speaking children were screened at the end of the 2004–2005 school year or at the end of the 2005–2006 school year. The children were recruited from 25 local education authority, rural, and urban schools in County Durham, North-East England. The majority of families served by the schools are of European heritage, with roughly 15% from immigrant families representing areas such as Pakistan, Bangladesh, China, Africa, and the Caribbean. Participating schools were selected to reflect the national demographic profile of children receiving free school meals (an index of socioeconomic status) and of performance on national assessments in reading, writing, and mathematics. Parental consent was obtained for all children participating in the study.

Of the screening sample, 361 children obtained scores at or below the 10th percentile for children tested in their age group. Data are reported here for 308 children (173 boys and 135 girls) who formed the low-working-memory group, as 53 children had either left the school by phase two of testing or declined to continue participating. Parents of these children provided consent for additional testing on the measures reported below in further testing sessions that took place 3–5 months after initial screening (Time 2). The younger group consisted of 165 children, with a mean age of 67.21 months at Time 2 of testing (SD = 3.88, range = 67–75). The mean age of the older group (n = 143) was 115.68 months at time two (SD = 4.42, range = 109–136). None of the children were diagnosed with physical or sensory impairments.

The gender balance of the cohort was approximately balanced, with 56% boys and 44% girls, in contrast with many developmental disorders involving language, motor skills, or behavior associated with much higher prevalence rates in males (see Alloway & Gathercole, 2006, for a review). The present pattern is consistent with findings that sex differences do not affect working memory performance in a typically developing population (Alloway et al., 2006; Gathercole et al., 2004).

Of the group of 308 children in the present sample, 165 of the children (53%) had been placed in small groups for additional learning support or were being monitored by their teachers as a result of their poor academic progress. They would typically receive a small number of additional itemized curricular or behavioral targets to achieve in the classroom. Children with inattention are not typically diagnosed as having ADHD in the United Kingdom. The children identified as having special educational needs were proportionally split over the two age groups.

Tasks and Procedure

Each child was tested individually in a quiet area of the school for two or three sessions lasting up to 40 min per session across a 2-week period. The following tests were administered by a member of the research team (H.K.) in a fixed sequence designed to vary task demands across the testing session. Classroom teachers completed the questionnaires between 3 and 6 months after Time 2.

Working memory. All 12 tests from the AWMA (Alloway, 2007a), a computer-based standardized battery, were administered. The three verbal short-term memory measures that correspond to the phonological loop in the Baddeley working memory model were digit recall, word recall, and nonword recall. In each test, the child hears a sequence of verbal items (digits, one-syllable words, and one-syllable nonwords, respectively), and has to recall each sequence in the correct order. The three verbal working memory measures associated with the central executive in the Baddeley working memory model were listening recall, backward digit recall, and counting recall. In the listening recall task, the child is presented with a series of spoken sentences, has to verify the sentence by stating ''true'' or ''false'' and recalls the final word for each sentence in sequence. In the backward digit recall task, the child is required to recall a sequence of spoken digits in the reverse order. In the counting recall task, the child is presented with a visual array of red circles and blue triangles. She or he is required to count the number of circles in an array and then recall the tallies of circles in the arrays that were presented. Test reliability of the AWMA is reported in Alloway (2007a). For digit recall, word recall, nonword recall, listening recall, counting recall, and backward digit recall, test–retest reliabilities are .89, .88, .69, .88, .83, and .86, respectively.

Three measures of visuospatial short-term memory, corresponding to the visuospatial sketchpad in the Baddeley working memory model, were administered. In the dot matrix task, the child is shown the position of a red dot in a series of 4 × 4 matrices and has to recall this position by tapping the squares on the computer screen. In the mazes memory task, the child is shown a maze with a red path drawn through it for 3 s. She or he then has to trace in the same path on a blank maze presented on the computer screen. In the block recall task, the child views a video of a series of blocks being tapped and reproduces the sequence in the correct order by tapping on a picture of the blocks. Three measures of visuospatial working memory associated with the central executive in the Baddeley working memory model were administered. In the odd-one-out task, the child views three shapes, each in a box presented in a row, and identifies the odd-one-out shape. At the end of each trial, the child recalls the location of each odd-one-out shape, in the correct order, by tapping the correct box on the screen. In the Mr. X task, the child is presented with a picture of two Mr. X figures. The child identifies whether the Mr. X with the blue hat is holding the ball in the same hand as the Mr. X with the yellow hat. The Mr. X with the blue hat may also be rotated. At the end of each trial, the child has to recall the location of each ball in the blue Mr. X's hand in sequence, by pointing to a picture with eight compass points. In the spatial recall task, the child views a picture of two arbitrary shapes where the shape on the right has a red dot on it and identifies whether the shape on the right is the same or opposite of the shape on the left. The shape with the red dot may also be rotated. At the end of each trial, the child has to recall the location of each red dot on the shape in sequence, by pointing to a picture with three compass points. Test–retest reliabilities are .85, .86, .90, 88, .84, and .79 for dot matrix, mazes memory, block recall, odd-one-out, Mr. X, and spatial recall, respectively. Standard scores (M = 100, SD = 15) for individual tests and composite scores for each memory component were generated automatically by the AWMA for each child on the basis of their age. Further details of test reliability and validity are reported in Alloway et al. (2006) and Alloway, Gathercole, Kirkwood, and Elliott (2008), respectively.

Learning. Two measures of learning abilities were administered to those children in the sample who were aged 6 years and older (n = 167). The Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) consists of tests of basic reading, reading comprehension, and spelling for children. Test–retest reliabilities are .95, .92, and .91 for basic reading, reading comprehension, and spelling, respectively. The Wechsler Objective Numerical Dimensions (WOND; Wechsler, 1996) assesses mathematical reasoning and number operations. Test–retest reliabilities are .89 and .85, respectively.

General ability. The British Picture Vocabulary Scale II–Short Form (BPVS; Dunn, Dunn, Whetton, & Burley, 1997) is a measure of receptive vocabulary that requires the child to select, from four options, the picture that correctly matches a word spoken aloud by the tester. As the minimum age for test administration is 3 years, all the sample were eligible and 301 children in the present study completed the measure. Split-half reliability is .86. The Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was also administered. In the vocabulary test, the child is required to provide definitions of words spoken aloud by the examiner; in the block design test, the child is required to construct a number of increasingly complex patterns as illustrated, beginning with two red and white blocks to a maximum of nine blocks. The raw scores were converted into scaled scores, with a mean of 10 and a standard deviation of 3. Corrected coefficients for test–retest reliabilities are .87 for both vocabulary and block design.

Behavior. The Conners' Teacher Rating Scale–Revised, Short Form (CRS–R; Conners, 2005) is designed to identify attentional failures and possible ADHD on the basis of classroom behaviors. Using this measure, teachers are asked to rate the extent to which the child has exhibited problem behaviors in school over the past month. Behaviors for consideration are described in 28 brief statements on the form. The response choices for each described behavior are *not true at all*, *just a little true*, *pretty much true*, and *very much true*. Responses are scored as sums of values on four subscales—

oppositional (e.g., spiteful or vindictive), cognitive problems/inattention (e.g., forgets things she or he has already learned), hyperactivity (e.g., is always ''on the go'' or acts as if driven by a motor), and ADHD index (e.g., restless, always up and on the go). The ADHD index is based on the best set of items for identifying children at risk of a diagnosis of ADHD. *T* scores (with population *M* = 50, *SD* = 10) are calculated for each of the four subscales. Higher scores indicate more executive function problems, with above average scores (i.e., 70) related to behavioral problems. Test–retest reliability coefficients for subscale scores reported for a sample of 50 children with a mean age of 11 years were as follows: oppositional (.62), cognitive problems/inattention (.73), hyperactivity (.85), and ADHD index (.72).

The Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000) assesses difficulties associated with executive function in school. The form consists of 86 brief descriptions of behavior problems, the frequency of which teachers are asked to rate as occurring either *never*, *sometimes*, or *often*. Responses are aggregated to form eight subscales. The inhibit scale measures the ability to control impulses and to stop one's own behavior at the proper time. The shift scale assesses the ability to move freely from one situation, activity, or aspect of a problem to another as the situation demands; it also taps behaviors relating to transition and to the ability to solve problems in a flexible manner. The emotional control scale relates to the ability to modulate emotional responses appropriately. The initiate scale measures the ability to begin a task or activity and to generate ideas independently. The working memory scale assesses the ability to hold information in mind for the purpose of completing an activity. The plan/organize scale assesses abilities to anticipate future events, set goals, develop appropriate steps ahead of time, carry out tasks in a systematic manner, and understand and communicate a main idea. The organization of materials scale relates to one's ability to maintain relevant parts of the environment in an orderly manner. The monitor scale relates to abilities to check work, assess performance, and to keep track of own and others' efforts. *T* scores (with population *M* = 50, *SD* = 10) were calculated for each measure. As with the Conners', higher scores indicate more executive function problems, with scores 1.5 *SD* above the mean (scores of 65 or greater) of potential clinical significance. Test–retest correlations for individual subscale scores reported for a sample of 41 children were as follows: inhibit (.91), shift (.83), emotional control (.92), initiate (.87), working memory (.87), plan/organize (.88), organization of materials (.83), and monitor (.87).

Self-esteem. The *Insight Primary* test (Morris, 2002), a teacher rating scale, measures three components of self-esteem: *Sense of self* measures how comfortable the individual is with their strengths, vulnerabilities, and preferences, *sense of belonging* refers to their ability in social relationships, and *sense of personal power* includes aspects such as self-confidence, assertiveness and self-appraisal. The rating scale provides scores for each of the above categories, as well as an overall self-esteem score, which leads to classification into one of four groups: very low, vulnerable, good, or high. Higher scores indicate higher levels of self-esteem.

Results

Working Memory

Descriptive statistics for the working memory tests are shown in Table 1. For all memory measures, standard scores (*M* = 100, *SD* = 15) are reported. For both age groups, mean scores were lowest for the verbal working memory (with mean composite standard scores of 70.47 for the younger group and 76.15 for the older group) and visuo-spatial working memory measures (mean composite scores of 81.92 for the younger group and 78.62 for the older group). The low level of performance on the visuospatial measures is important, as the children were selected only on the basis of low scores on two of the verbal working memory tests: listening recall and backward digit recall. Note that scores were comparably low on the unscreened verbal working memory measure (counting recall; *M* = 81.60). Performance on the verbal and visuo-spatial short-term memory measures was higher than on the working memory tests, although still markedly lower than the expected levels for the children's ages: Mean composite verbal short-term memory scores were 84.53 and 85.71 for the younger and older groups, respectively, and mean composite visuo-spatial short-term memory scores were 84.02 and 87.01, respectively. The memory profile derived from this sample of children is therefore of low performance in all aspects of working memory assessment, with greater decrements on the working memory tests than those for short-term memory.

To determine the consistency of working memory deficits within this sample, the cumulative proportions of children obtaining composite scores

Table 1
Descriptive Statistics for All Cognitive Measures as a Function of Age Group

	Younger					Older					All				
Measure	*n*	Min	Max	*M*	*SD*	*n*	Min	Max	*M*	*SD*	*N*	Min	Max	*M*	*SD*
V STM: Digit recall	165	63	127	82.12	15.11	143	70	134	85.32	12.20	308	63	134	83.60	13.90
V STM: Word recall	165	58	142	90.85	17.58	143	57	130	89.10	13.56	308	57	142	90.04	15.84
V STM: Nonword recall	165	49	126	89.71	16.47	143	56	132	89.29	12.60	308	49	132	89.51	14.78
V STM: Composite	165	55	139	84.53	17.10	143	63	140	85.71	12.66	308	55	140	85.08	15.19
V WM: Listening recall	165	67	87	74.44	4.77	143	69	87	76.34	5.00	308	67	87	75.32	4.96
V WM: Backward digit recall	165	61	96	74.58	7.33	143	74	89	80.42	4.58	308	61	96	77.29	6.85
V WM: Counting recall	165	56	115	79.36	13.06	143	62	136	84.19	14.12	308	56	136	81.60	13.76
V WM: Composite	165	54	87	70.47	7.51	143	63	103	76.15	7.15	308	54	103	73.11	7.86
VS STM: Dot matrix	165	54	126	84.38	14.71	143	58	137	84.87	17.08	308	54	137	84.61	15.83
VS STM: Mazes memory	165	74	129	91.87	14.11	143	58	129	95.28	18.84	308	58	129	93.45	16.53
VS STM: Block recall	165	64	127	85.17	13.65	143	59	131	87.43	16.43	308	59	131	86.22	15.02
VS STM: Composite	165	60	122	84.02	13.47	143	57	130	87.01	17.57	308	57	130	85.41	15.56
VS WM: Odd-one-out	165	61	130	83.98	11.58	143	62	121	81.62	13.03	308	61	130	82.88	12.31
VS WM: Mr. X	165	71	139	89.49	13.51	143	61	138	85.57	12.04	308	61	139	87.67	12.98
VS WM: Spatial recall	165	63	131	83.56	13.74	143	57	129	79.06	16.62	308	57	131	81.47	15.29
VS WM: Composite	165	58	134	81.92	13.25	143	58	120	78.62	13.44	308	58	134	80.39	13.42
General ability: BPVS	164	40	114	89.95	8.71	137	53	109	84.99	11.22	301	40	114	87.69	10.22
General ability: Vocabulary[a]	34	1	9	4.88	1.87	137	1	9	3.61	2.07	171	1	9	3.86	2.09
General ability: Block design[a]	34	1	11	7.65	2.20	137	2	14	6.93	1.74	171	1	14	7.08	1.85
Learning															
Basic reading	20	84	102	88.10	3.96	143	54	130	82.94	13.89	167	54	130	83.57	13.19
Spelling	20	72	108	86.44	9.74	143	59	117	83.36	12.12	167	59	117	83.95	11.74
Reading comprehension	20	81	94	84.05	4.40	143	47	107	79.68	13.87	167	47	107	80.21	13.15
WORD Composite	20	76	97	82.20	5.50	143	46	114	78.12	15.00	167	46	114	78.62	14.23
Math reasoning	34	75	99	86.62	6.04	143	58	126	84.54	12.19	177	58	126	84.94	11.29
Numerical operations	34	76	106	85.44	7.03	143	54	103	78.07	11.21	177	54	106	79.49	10.91
WOND Composite	34	73	118	85.35	8.89	143	50	116	78.00	12.75	177	50	118	79.41	12.43

Note. Standard scores except where stated otherwise. V = verbal; VS = visuospatial; STM = short-term memory; WM = working memory; BPVS = British Picture Vocabulary Scale II-Short Form; WORD = Wechsler Objective Reading Dimensions; WOND = Wechsler Objective Numerical Dimensions.
[a]Scaled scores = mean of 10 and a standard deviation of 3.

below particular cutoff values were calculated (< 81, < 86, < 91, < 96). These are shown in Table 2. As there is no discrete point at which typical and atypical performance can be unequivocally distinguished, cumulative proportions over a range of values that represent different degrees of severity of low performance are presented. For the present purposes, values below 1 *SD* from the mean (standard scores < 86) are viewed as indicative of mild deficit, with lower scores representing greater degrees of severity (see Gathercole, Alloway, et al., 2006; Gathercole, Lamont, et al., 2006). The majority of children scored less than 86 on the verbal and visuospatial working memory measures (95% and 71%, respectively). It is unsurprising that such a high proportion received standard scores of less than 86 in verbal working memory as the sample was selected on the basis of low scores on backward digit recall and listening recall; importantly, a substantial proportion (60%) also obtained comparably low scores on the counting recall test of verbal working memory. On the short-term memory measures, approximately half of the children achieved scores of less than 86 (52% and 50% in verbal and visuospatial short-term memory tasks, respectively).

The co-occurrence of low scores across different aspects of working memory was also investigated. Almost half of the sample (49%) obtained both verbal short-term and verbal working memory scores below 86, and 66% scored below 86 on both verbal and visuospatial working memory tests. Standard scores below 86 in all four measured aspects of memory were obtained by approximately one fourth (23%) of the sample.

The higher order factor structure underpinning variations between the different memory measures in children with low working memory was

Table 2
Cumulative Proportions of Children Obtaining Scores in Each Band as a Function of Age Group and Subtest

	Younger					Older					All				
Measure	*n*	< 81	< 86	< 91	< 96	*n*	< 81	< 86	< 91	< 96	*N*	< 81	< 86	< 91	< 96
Verbal STM composite	165	.42	.54	.62	.70	143	.36	.49	.66	.83	308	.39	.52	.64	.76
Verbal WM composite	165	.93	.98	1.00	1.00	143	.74	.91	.97	.99	308	.84	.95	.98	.99
Visuospatial STM composite	165	.44	.53	.66	.82	143	.40	.45	.54	.65	308	.42	.50	.60	.74
Visuospatial WM composite	165	.55	.67	.78	.87	143	.59	.75	.80	.88	308	.57	.71	.79	.87
Verbal STM & WM composites	165	.42	.53	.61	.69	143	.30	.43	.60	.78	308	.36	.49	.61	.73
Visuospatial STM & WM composites	165	.33	.40	.46	.52	143	.36	.41	.41	.44	308	.35	.40	.44	.48
Verbal & visuospatial WM composites	165	.54	.66	.76	.85	143	.51	.65	.71	.78	308	.53	.66	.74	.82
All memory composites	165	.25	.25	.25	.25	143	.17	.20	.21	.21	308	.21	.23	.23	.23
General ability: BPVS	164	.08	.24	.56	.77	137	.33	.50	.65	.84	301	.19	.36	.60	.80
General ability: Vocabulary[a]	34	.59	.85	.94	.94	137	.80	.91	.95	.96	171	.75	.89	.95	.96
General ability: Block design[a]	34	.12	.35	.47	.59	137	.15	.47	.67	.82	171	.14	.45	.63	.78
Learning: WORD Composite	34	.38	.63	.75	.79	143	.49	.68	.78	.89	177	.47	.67	.78	.87
Learning: WOND Composite	34	.29	.65	.79	.91	143	.57	.71	.87	.94	177	.51	.70	.86	.93

Note. < 81 corresponds to < 6, < 86 to < 7, < 91 to < 8, and < 96 to < 9. STM = short-term memory; WM = working memory; BPVS = British Picture Vocabulary Scale II-Short Form; WORD = Wechsler Objective Reading Dimensions; WOND = Wechsler Objective Numerical Dimensions.

Table 3
Factor Loadings > .45 From the Principal Components Analysis for Low-Working-Memory Children (*n* = *308*)

Measure	Factor 1	Factor 2	Factor 3
Digit recall		.801	
Word recall		.825	
Nonword recall		.773	
Listening recall			.811
Backward digit recall			.834
Counting recall	.554		
Dot matrix	.642		
Mazes memory	.645		
Block recall	.651		
Odd-one-out	.728		
Mr. X	.718		
Spatial recall	.771		

investigated by conducting a principal components analysis on the standard scores for all 12 memory measures, rotated to final solution with a varimax rotation. Three factors emerged with eigenvalues in excess of 1.00, accounting for 37.44%, 11.76%, and 11.27% of the variance, respectively. Factor loadings in excess of .45 on the rotated factor matrix are displayed in Table 3. The measures that loaded most highly on Factor 1 were the six visuo-spatial short-term memory and working memory measures. Counting recall also loaded on this measure. The highest loading measures on Factor 2 were the three verbal short-term memory tests. Factor 3 consisted of the two verbal working memory measures used for screening memory deficits: backward digit recall and listening recall. Thus, the first factor appears to tap storage and processing of visuospatial tasks. The second factor corresponds to storage only of verbal information, whereas the third factor relates to skills associated with both storing and manipulating information in the verbal domain.

General Ability

The mean score on the receptive vocabulary measure (BPVS) fell within 1 *SD* of the normative sample mean for the younger group, but was more than 1 *SD* below the mean for the older group (see Table 1). There was a similar pattern of performance for the mean scale scores for the general ability subtests: Vocabulary scores for both groups fell almost 2 *SD* below the mean; mean block design scores fell 1 *SD* below the mean.

Inspection of the proportion of scores indicate that vocabulary scores as measured by the BPVS were considerably lower in the older group: Only 24% of the younger children scored less than 86, half as many as the older group (50%; see Table 2). In the WASI subtests, 89% of the vocabulary scores fell below 81, and a little under half of the sample (45%) scored less than 86 in block design. It is worth noting that the children generally performed at considerably lower levels on the vocabulary test from the WASI than the BPVS vocabulary test. The two tests differ quite markedly in the word knowledge required to support accurate performance: The vocabulary WASI test required the retrieval of specific semantic information in response to the spoken word. Here, the child may understand the meaning of the target word but lack the language skills to provide a definition sufficient to succeed on the item. In contrast, the BPVS involved picture pointing, a purely nonverbal response on the part of the child, and could be mediated simply by recognition of the phonological form twinned with a sketchy conceptual representation sufficient to reject the foil items. The greater decrement on the WASI than the BPVS test may reflect the higher sensitivity of the former in measuring the quality of the child's semantic representations.

Learning

As only children in the sample who were aged 6 years and older were administered the learning measures, the sample sizes are provided in Table 1. On the reading test, the younger group performed in the low average range (mean scores range from 88 to 82 for the WORD subtests and composite score), whereas the mean scores for the older group were slightly lower. This pattern is similar for the subtests and composite score for the WOND: Mean scores for the older group fell below age-expected levels. Inspection of the proportion of children who struggled in the standardized assessments of reading and math indicated that the majority of the children achieved scores below 86: for the younger group; 63% and 65% for the reading and math measures, respectively; and for the older group, 68% and 71% for the reading and math measures, respectively (see Table 2). To compare differences in learning scores as a function of age, independent t tests were conducted separately on the standard scores of the WORD and WOND composites (equal variances were not assumed and alpha level was adjusted to .03 for multiple comparisons). For both tests, the older group performed significantly worse than the younger ones, $t(69) = 2.32$, $p = .02$, and $t(69) = 3.95$, $p < .001$, for the WORD and WOND, respectively.

Memory, General Ability, and Learning

To investigate the relations among memory, general ability, and learning in the present sample ($n = 167$), a series of hierarchical regression analyses was performed with sets of predictor variables entered for each of two learning variables: composite reading scores (WORD) and composite math scores (WOND). The goal of these analyses was to explore which cognitive abilities shared unique variance with the two measures of learning achievement. For example, the relations among memory and learning were assessed after the variance shared with general ability was taken into account. Any final steps that account for significant additional portions of variance thus share unique links with the dependent variable. It should be noted that this fixed-order hierarchical regression procedure is a highly conservative means of assessing unique relations when different variable sets are themselves highly correlated with one another, as in the present case. However, it does have the advantage of providing stringent tests of specificity of relations among those that are valuable for interpretation of the data; any residual associations that do meet the criterion for statistical significance are therefore of particular note.

In each model, all four memory composite scores were entered together on the basis of the close relations among these measures in typically developing populations (e.g., Alloway et al., 2006). Two models for each dependent variable were tested (see Table 4). In Model 1, the general ability subtests from the WASI, vocabulary and block design, were entered at the first step and all four memory composite scores as the final step, with reading as the outcome measure. Vocabulary and block design scores accounted for reasonably high proportions of

Table 4
Hierarchical Regression Analyses Predicting Reading and Math Skills

	R^2	R^2 change	F change
Model 1: Reading (WORD)			
Step 1: Vocabulary & block design (WASI)	.372	.372	45.64*
Step 2: Memory measures	.480	.108	7.78*
Model 2: Reading (WORD)			
Step 1: Memory measures	.324	.324	18.20*
Step 2: Vocabulary & block design (WASI)	.480	.156	22.53*
Model 3: Math (WOND)			
Step 1: Vocabulary & block design (WASI)	.405	.405	57.13*
Step 2: Memory measures	.539	.134	11.97*
Model 4: Math (WOND)			
Step 1: Memory measures	.408	.408	28.61*
Step 2: Vocabulary & block design (WASI)	.539	.131	23.35*

Note. WORD = Wechsler Objective Reading Dimensions; WASI = Wechsler Abbreviated Scale of Intelligence; WOND = Wechsler Objective Numerical Dimensions.
*$p < .001$.

variance (37.2%), and the four memory measures accounted for additional variance in reading (10.8%). In Model 2, the four memory scores were entered first, followed by the general ability subtests. The memory measures accounted for 32.4% of the variance, and performance on vocabulary and block design accounted for a further 15.6%.

In Model 3, with the composite math score as the outcome measure, both vocabulary and block design accounted for 40.5% of the variance, and the memory measures accounted for an additional 13.4% of variance. In Model 4, all four memory scores accounted for 40.8% of the variance and vocabulary and block design for a further 13.1%. Thus, general ability and working memory skills shared a substantial amount of variance with attainment scores, and both cognitive skills uniquely predicted outcomes in reading and mathematics.

Behavior Ratings

Descriptive statistics for the behavioral measures are provided in Table 5. The Conners' Teacher Rating Scale and BRIEF subscales are scored as *T* values, in which a score of 50 is the mean with a standard deviation of 10. For both measures, higher scores correspond to atypically elevated levels of problem behaviors. On the Conners' measure, mean scores in the younger group were almost 1 *SD* higher than that of the normative sample for the Oppositional and Hyperactive subscales (59 and 58, respectively), and over 1 *SD* (63) for the overall ADHD index. In contrast, the mean for the Inattentive subscale was over 2.5 *SD* from the typical performance (76), a level indicative of a clinically significant problem. A similar pattern of performance was obtained for the older group, with the mean scores for the Inattentive subscale approximately 2 *SD* above the mean. Such a high level offers cause for concern, as it is associated with a greater frequency of reported problems in this area (Conners, 2005).

T scores in the Conners' data were banded according to broader categories as identified by the BRIEF to allow for direct comparison between the two behavioral measures (Table 6). For scores that

Table 5
Descriptive Statistics for Measures of Behavior and Self-Esteem as a Function of Age Group

	Younger					Older					All				
Measure	*n*	Min	Max	*M*	*SD*	*n*	Min	Max	*M*	*SD*	*N*	Min	Max	*M*	*SD*
Conners' (*T* score)															
Oppositional	53	44	90	59.15	17.46	62	45	87	53.60	10.78	115	44	90	56.16	14.46
Cognitive Problems/Inattention	53	42	90	76.32	15.43	62	46	89	67.89	9.02	115	42	90	71.77	13.03
Hyperactive	53	1	90	58.08	17.29	62	43	90	53.53	11.29	115	1	90	55.63	14.49
ADHD index	53	14	90	63.17	16.35	62	41	89	58.92	10.88	115	14	90	60.88	13.78
BRIEF (*T* score)															
Inhibit	43	42	103	61.56	15.19	53	45	108	63.11	16.18	96	42	108	62.42	15.68
Shift	43	43	86	62.53	11.23	53	45	101	63.38	14.75	96	43	101	63.00	13.23
Emotional control	43	44	120	67.33	21.69	53	45	100	60.85	14.81	96	44	120	63.75	18.40
Behavior Regulation Index	43	54	85	70.79	9.13	53	42	88	70.94	9.61	96	42	88	70.88	9.35
Initiate	43	50	86	72.19	8.19	53	44	106	74.72	13.39	96	44	106	73.58	11.37
Working memory	43	46	87	65.14	9.43	53	47	89	71.58	10.53	96	46	89	68.70	10.50
Plan/organize	43	44	84	59.37	10.47	53	44	117	65.08	16.69	96	44	117	62.52	14.46
Organization of materials	43	48	101	68.81	12.39	53	43	91	69.15	10.83	96	43	101	69.00	11.49
Monitor	43	47	108	65.88	16.20	53	45	95	63.62	15.10	96	45	108	64.64	15.56
Metacognition Index	43	50	87	69.67	8.47	53	44	94	73.00	11.14	96	44	94	71.51	10.12
Global Executive Composite	43	51	92	70.51	11.05	53	46	104	72.34	13.60	96	46	104	71.52	12.49
Negativity score	43	0	4	0.74	1.11	53	0	4	0.64	1.16	96	0	4	0.69	1.14
Inconsistency score	43	0	8	3.47	2.05	53	0	8	3.06	2.07	96	0	8	3.24	2.06
Insight Primary (total)															
Sense of self	50	7	34	21.42	7.94	63	3	35	23.21	17.92	113	3	95	26.04	14.67
Sense of belonging	50	10	35	21.84	6.34	63	7	35	22.76	6.35	113	7	35	22.35	6.33
Sense of personal power	50	2	32	16.40	6.72	63	0	34	18.73	7.20	113	0	34	17.70	7.06
Total	50	7	101	58.38	19.68	63	7	93	56.60	23.60	113	7	101	57.39	21.88

Note. T scores except where stated otherwise. *T* scores = mean of 50 and a standard deviation of 10. ADHD = attention deficit hyperactivity disorder; BRIEF = Behavior Rating Inventory of Executive Function.

Table 6
Cumulative Proportions of Children Obtaining T *Scores for the Behavioral Measures in Each Band as a Function of Age Group and Subscale*

	Younger					Older					All				
Measure	*n*	< 46	< 56	< 66	> 65	*n*	< 46	< 56	< 66	> 65	*N*	< 46	< 56	< 66	> 65
Conners'															
Oppositional	53	.25	.58	.72	.28	62	.26	.66	.84	.16	115	.25	.63	.78	.22
Cognitive Problems/Inattention	53	.06	.09	.25	.75	62	0	.08	.42	.58	115	.03	.09	.34	.66
Hyperactive	53	.21	.45	.68	.32	62	.21	.66	.81	.19	115	.21	.57	.75	.25
ADHD index	53	.15	.34	.58	.42	62	.13	.47	.73	.27	115	.14	.41	.66	.34
BRIEF															
Inhibit	43	.05	.35	.67	.33	53	.02	.47	.60	.40	96	.03	.42	.64	.36
Shift	43	.02	.33	.63	.37	53	.02	.40	.60	.40	96	.02	.36	.61	.39
Emotional control	43	.07	.37	.60	.40	53	.17	.47	.64	.36	96	.13	.43	.63	.38
Behavior Regulation Index	43	0	.26	.56	.44	53	.06	.25	.42	.58	96	.03	.25	.48	.52
Initiate	43	0	.12	.23	.77	53	.02	.08	.28	.72	96	.01	.09	.26	.74
Working memory	43	0	.02	.16	.84	53	.04	.11	.21	.79	96	.02	.07	.19	.81
Plan/Organize	43	0	.14	.51	.49	53	0	.08	.32	.68	96	0	.10	.41	.59
Organization of materials	43	.02	.44	.79	.21	53	.08	.30	.58	.42	96	.05	.36	.68	.32
Monitor	43	0	.14	.44	.56	53	.02	.13	.32	.68	96	.01	.14	.38	.63
Metacognition Index	43	0	.07	.28	.72	53	.02	.08	.25	.75	96	.01	.07	.26	.74
Global Executive Composite	43	0	.07	.37	.63	53	0	.08	.36	.64	96	0	.07	.36	.64

Note. ADHD = attention deficit hyperactivity disorder; BRIEF = Behavior Rating Inventory of Executive Function.

are markedly atypical (> 65) on the Cognitive Problems/Inattention subscale, 62% and 37% of the younger and older cohorts, respectively, achieved this level. A smaller proportion also obtained ADHD index scores indicating a high risk for a diagnosis of ADHD (32% and 15%, respectively; see Conners, 2005). This indicates that a high proportion of the low working memory children in the present study exhibited the following behaviors: greater academic difficulties compared to their peers, difficulty organizing and completing tasks, and trouble concentrating on activities that require mental effort. In contrast, fewer children showed signs of restlessness and fidgetiness that are characteristic of hyperactive behavior.

On the BRIEF test of executive function behavior (see Table 5), mean scores on all subscales were more than 1 *SD* above the mean for the younger group, with the exception of the Plan and Organize subscale. It is notable that atypically high scores were obtained on the Working Memory subscale, which is composed of items such as ''when given three things to do, remembers only the first or last''; ''has a short attention span''; ''has trouble concentrating on schoolwork''; ''needs help from adults to stay on task''; and ''has trouble finishing tasks.'' A similar pattern of performance was also evidenced in the older children.

Inspection of the *T* scores as banded into different categories reveals that over 50% of the younger cohort achieved *T* scores considered to have potential clinical significance (> 65) in the following subscales: Initiate, Working Memory, Monitor, as well as the Metacognition Index and the Global Executive Composite. In the older group, the pattern was similar. In addition to the subscales previously listed, over 50% of the older group also had *T* scores > 65 in the Plan/Organize and Behavior Regulation subscales. The Initiate, Working Memory, Monitor, and Plan/Organize subscales comprise the Metacognition Index and are all related to the child's ability to plan and effectively manage information in working memory. This finding indicates that children with low working memory also struggled with abilities that relate to working memory in the classroom such as being proactive in initiating tasks, organizing large amounts of information, and monitoring their work to avoid errors.

Self-Esteem

In all cases of the Insight Primary (Morris, 2002), higher scores indicate higher levels of self-esteem. Mean scores for both the younger and older children were lowest for the component of personal power, which reflects the individual's sense of his or her ability to impact his or her surroundings (see Table 5). Although personal power encompasses feelings of self-confidence as well as skills such as assertiveness and coping, it is best characterized as an individual's knowledge that he or she can make a difference to the world (Morris, 2002). Children with low scores are often emotionally fragile and tend to require support to build up their confidence (Morris, 2002).

The findings indicate that most of the low-working-memory children were reported as having levels of self-esteem at either the good or vulnerable levels (43% and 39%, respectively). These endpoints of the scale are characterized by those who are confident and at ease with themselves at one end and those who may be depressed and need constant support and encouragement at the other. A very small proportion of children in the present sample achieved scores at either end of the scale: high or very low (6% and 12% of the total sample, respectively).

Discussion

The aim of the present study was to investigate the cognitive and behavioral profiles of children aged 5–6 and 9–10 years who were identified via population screening on the basis of very low scores on two tests of working memory. To our knowledge, this represents the first study in which participants were selected on the basis of working memory problems rather than learning difficulties, developmental disorders, or genetic syndromes. There were several key findings. First, working memory deficits extended to the visuospatial domain. The underlying structure of working memory scores was consistent with three distinct factors with verbal memory skills represented separately by a storage-only component and a storage-plus-processing component. These findings are consistent with previous research in developmental populations (Alloway et al., 2006; Gathercole et al., 2004) and in adult samples (Kane et al., 2004; Park et al., 2002). The third factor comprised both the visuospatial short-term memory tasks as well as the working memory tasks. This profile is very similar to that identified in a typically developing population of 4- to 6-year-olds (Alloway et al., 2006). This is in line with the suggestion that although cognitive mechanisms can develop at different rates (Hitch, 1990), children with poor working memory perform below age-expected levels, drawing more on executive resources (or controlled attention) than older children when performing the visuospatial short-term memory tasks (Cowan et al., 2005). This finding fits with theoretical views that working memory capacity is best captured by a domain-general component (Baddeley, 2000; Engle et al., 1999) rather than domain-specific components (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). This is an important theoretical point, as it can help distinguish between models of working memory in development.

A second key characteristic of these children was their poor academic progress. About two thirds of them performed poorly in the two key areas of learning assessed in the study, reading and mathematics, and in a third of the sample the severity of their learning problems was reflected in formal recognition by their schools that they required additional classroom support. This provides the most substantial evidence to date that low working memory skills constitute a high risk factor for educational underachievement for school children across the primary school years. The finding is entirely consistent with findings of subsequently poor academic progress in children with low memory skills at school entry (Alloway et al., 2005; Gathercole, Brown, & Pickering, 2003) and of substantial working memory problems for the majority of children identified on the basis of learning disabilities (e.g., Gathercole, Alloway et al., 2006; Swanson & Beebe-Frankenberger, 2004), including language impairments (Archibald & Gathercole, 2006b). The findings also provide evidence that even when students' general ability is statistically accounted, working memory skills predict reading and math scores. This fits well with the view that working memory may underlie learning difficulties, independent of related cognitive skills.

The older group performed significantly more poorly than the younger children on the learning measures, raising the possibility that without early intervention, children may find it difficult to catch up with their peers in key areas of learning. Although working memory is relatively stable with age (Alloway, in press), it is possible that the effect of poor working memory is cumulative across development, resulting in greater decrements in learning as a child gets older. This discrepancy in performance could also be due to the classroom environment of the two age groups. In older classrooms, teachers are more likely to use longer and more complex utterances. Furthermore, although younger children are more likely to have additional adult support and memory aids made available for them in the classroom, as they get older they are typically expected to be more autonomous in their learning and thus may be left to develop their own strategies. Studies investigating strategy use in individuals have found that those with low working memory skills struggle with strategies that are more complex such as storytelling and visual representations. Although using such strategies can support working memory by drawing on long-term memory resources, children with memory problems tend to use simpler but less effective tools such as rehearsal of information (Turley-Ames & Whitfield, 2003). Even when low-working-memory children are taught strategies in one area of learning, they tend not to transfer them to a different learning area. For example, being able to apply effective strategies in boosting working memory during a reading task does not mean that a child will apply the same strategies during math lessons. Thus, older children are disadvantaged because not only are there fewer learning supports available for them in the classroom, but also they tend not to develop efficient strategies independently or spontaneously use them on their own (see O'Shaughnessy & Swanson, 1998, for a review).

Children with low working memory have a highly distinctive profile of behavioral problems in the classroom. Teachers typically judged the children to be highly inattentive and having poor attention span and high levels of distractibility. In a similar vein, they were also commonly described as forgetting what they were currently doing and things they have learned, failing to remember instructions, and failing to complete tasks. In everyday classroom activities, they often made careless mistakes, particularly in writing, and had difficulty in solving problems. This behavioral profile fits well with accumulating evidence from both clinical and nonclinical populations linking the inattentive dimension of ADHD in particular to deficits in working memory (Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005; Klingberg et al., 2005; Martinussen & Tannock, 2006). It is important here to note that the elevated levels of all problem behaviors of the children in our study were relatively specific to inattention and forgetting: In particular, relatively few of the children were judged to exhibit the high levels of hyperactive and impulsive behaviors that are typically found in the majority of children with a clinical diagnosis of ADHD. It is worth noting that the teachers who participated in this study were aware that the children had been selected on the basis of poor working memory. Although this knowledge may have introduced some bias in their reports of children's classroom behaviors, there is little reason to suspect that this would have resulted in the biased reporting of inattentive rather than hyperactive/impulsive, behavior.

High teacher ratings of inattentive behavior and forgetting in this sample of low-memory children reinforce our own classroom observations of many of the children participating in this study, detailed accounts of which are provided in Gathercole and Alloway (2008); see also Gathercole, Alloway, et al., 2006; Gathercole, Lamont, et al., 2006. A highly consistent profile of behavior was observed across individuals. The children were typically reserved and struggled to maintain attention in large-group activities led by the teacher. Often, they seemed to lose attentional focus in mentally demanding activities. They frequently forgot instructions and, as a consequence, failed to complete tasks fully and accurately. This finding has also been upheld in a recent experimental study comparing children with low and typical working memory performing a task involving sequences of verbal instructions (Gathercole, Evans, Pratt, Jeffcock, & Stone, in press; see also Engle et al., 1991). Activities requiring the children both to engage in effortful mental processing and to store information were commonplace in the classrooms observed, and the low memory children frequently failed at these activities due to their failure to remember crucial information.

The finding that the majority of the children in the study did not achieve extreme scores on the measure of self-esteem—notwithstanding the fact that a significant proportion (39%) scored at a vulnerable level—is relatively unsurprising, but nonetheless important. The widespread belief in the importance of self-esteem for educational performance has been eroded by several high-profile challenges, most notably by Baumeister et al. (2003) and Baumeister, Campbell, Krueger, and Vohs, (2005). However, in response, Marsh and Craven, (2006) and Marsh and O'Mara (2008) have demonstrated that although global self-esteem appears largely unrelated to academic outcomes, more specific measures of self-concept are reciprocally related to the particular domains that they tap. As the measure of self-esteem employed in the present study focused, in part, upon social confidence, one might anticipate that our cohort, manifesting greater difficulties in adjusting to and coping with the classroom environment, would demonstrate a higher proportion of vulnerable self-esteem ratings than might be found in a normal cohort. However, as the measure did not also directly tap academic self-concept, the rather weak association is readily understandable.

At present, the origins of working memory are unknown; however, it does appear to be unaffected by environmental influences, such as parental educational level and financial background (Alloway et al., 2004; Dollaghan, Campbell, Needleman, & Dunlosky, 1997; Engel, Heloisa Dos Santos, & Gathercole, 2008), and there is strong evidence for heritability (Kremen et al., 2007). As a result, it has been suggested that working memory capacity cannot be increased (Cowan & Alloway, in press), although targeted strategies may help (Ericsson, 2005) and there is now substantial evidence that working memory capacity can be increased by intensive training (Klingberg et al., 2005).

In summary, this study has established that children with working memory problems identified via routine screening have an extremely high risk of making poor academic progress and have a highly distinctive profile of inattentive behavior and forgetting that disrupts their classroom functioning. The study extends evidence linking working memory with learning impairments from studies of children with diagnoses of deficits in reading, math, language, and attention to children within mainstream schooling who have not typically had a formal diagnosis of learning difficulties but who are nonetheless failing to make normal academic progress. These children are relatively common—in the present study, they represent approximately 10% of their age group in mainstream schooling—and, we argue, merit both research attention and practical support in school in their own right.

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