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Working memory abilities in children with special educational needs

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Abstract

This study investigates the distinctive working memory profiles of children with learning difficulties. A sample of 64 children aged 7 to 11 years with recognised special educational needs at varying stages participated in this study. They were tested on measures of the central executive, phonological loop and visuo-spatial skills. The children in all three special needs subgroups performed below the expected attainment levels for their age in central executive and visuo-spatial tasks, but not in measures of the phonological loop. Very low levels of working memory performance were many times more common in the special needs sample than in a large sample of children without special educational needs. Deficits in working memory performance were more marked in children with statements of special needs than those at earlier stages of recognition of the need for educational support, particularly in measures of the central executive. These children struggle to meet the demands of complex tasks that require them to process, maintain, and store information simultaneously. It is suggested that this difficulty may underpin their failures to make normal educational progress.

ACCORDING TO the Special Educational Needs Code of Practice (DfES, 2002), any pupil who requires extra support to succeed in a regular classroom is a child who has special education needs. The term 'special educational needs' reflects a broad spectrum of problems, including physical or sensory difficulties, emotional and behavioural difficulties, or difficulties with speech. As many children at some point during their school years have special educational needs, it is important to identify the cognitive mechanisms that underlie these learning difficulties. The present study explores possible contributions of working memory abilities to learning problems in the classroom and whether these skills differ as a function of special needs severity, as indicated by the Code of Practice (DfES, 2002).

Working memory is the term used to refer to a system responsible for temporarily storing and manipulating information needed in the execution of complex cognitive tasks, such as learning, reasoning, and comprehension. According to the most widely accepted model and the one that guided the present study, working memory consists of four components (Baddeley & Hitch, 1974; Baddeley, 2000). The central executive is responsible for the high-level control and coordination of the flow of information through working memory, including the temporary activation of long-term memory. It has also been linked with control processes such as switching, updating, and inhibition (Baddeley, 1996). Other theoretical accounts of general working memory that correspond in some respects to the central executive include the notion of a limited resource that can be flexibly allocated to support either processing or storage (e.g. Daneman & Carpenter, 1980; Just & Carpenter, 1992), and of a limited attentional resource responsible for the temporary activation of information from long-term memory (e.g. Cowan, 1988, 1995; Engle, Kane & Tuholski, 1999).

The central executive is supplemented by two slave systems specialised for storage of information within specific domains.

The phonological loop provides temporary storage for linguistic material, and the visuo-spatial sketchpad stores information that can be represented in terms of visual or spatial structure. The fourth component is the episodic buffer, responsible for integrating information from different components of working memory and long-term memory into unitary episodic representations (Baddeley, 2000). This model of working memory has been supported by evidence from studies of children (e.g. Alloway, Gathercole, Willis & Adams, 2004), adult participants, neuropsychological patients (see Baddeley, 1996; and Gathercole & Baddeley, 1993, for reviews), as well as neuroimaging investigations (Vallar & Papagno, 2002).

Working memory capacity varies widely across individuals. One method of assessing these individual differences involves complex memory span tasks that require the simultaneous storage and processing of information. An example of such a task is reading span, in which the participant makes judgments about the semantic properties of sentences while remembering the last word of each sentence in sequence (Daneman & Carpenter, 1980). It has been suggested that whereas the processing components of such tasks are mediated by the central executive, their storage demands are supported by the verbal slave system in the working memory model, the phonological loop (Baddeley & Logie, 1999; Duff & Logie, 2001).

Individual differences in the capacity of working memory appear to have important consequences for children's ability to acquire knowledge and new skills. Poor performance on complex span measures are characteristic of children failing to progress normally in the areas of reading (e.g. Swanson, 1994; de Jong, 1998), mathematics (e.g. Bull & Scerif, 2001; Mayringer & Wimmer, 2000; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989), and language comprehension (e.g. Nation *et al.*, Adams, Bowyer-Crain & Snowling, 1999; Signeuric, Ehrlich, Oakhill & Yuill, 2000). There are also links between performance on tasks measuring phonological loop capacity of working memory and vocabulary acquisition (see Baddeley, Gathercole & Papagno, 1998 for a review). Associations have also been reported between measures of the visuo-spatial sketchpad component of working memory and mental arithmetic (Lee & Kang, 2002; McLean & Hitch, 1999).

Consistent with these findings, low achievement in National Curriculum assessments of English and mathematics between 7 and 14 years of age is associated with poor working memory function (Gathercole & Pickering, 2000, 2001; Gathercole *et al.*, 2004; Jarvis & Gathercole, 2003). Links between scholastic performance and working memory capacities have been extended to the earliest point in the child's school career. In particular, working memory skills are related to teacher assessments of children's abilities in key areas at school entry (Alloway, Gathercole, Adams & Willis, in press). Recent research has also found that working memory abilities at school entry are good predictors of attainments three years later (e.g. Gathercole, Brown & Pickering, 2003).

Associations between working memory abilities and learning have also been found in children with special educational needs. In particular, children experiencing learning difficulties that are sufficiently severe to warrant special education provision have been found to perform very poorly on measures of complex memory (Gathercole & Pickering, 2001). Pickering and Gathercole (2004) extended this research and identified distinctions in working memory abilities as a function of the nature of learning difficulties. They found that children with problems of a behavioural or emotional nature performed normally on all of the memory assessments, whereas children identified as having general learning difficulties that included both literacy and mathematics performed poorly in all areas of working memory.

Previous research has demonstrated that learning difficulties severe enough to warrant special educational support are closely linked with poor working memory capacities. This study builds upon these findings and examines whether severity of special needs is associated with severity of memory impairment. In particular, we investigate whether children whose special needs are of greatest severity, as indexed by their stage, show commensurately greater cognitive deficits than children with milder learning difficulties. To address this issue, children at each of the three stages of assessment and provision of special educational support specified by the Code of Practice (DfEE 2002) participated in this study. At the first stage, School Action, a teacher or Special Educational Needs Co-Ordinator (SENCO) identifies a child who needs additional or different support from that provided within the general curriculum. At the next assessment stage, School Action Plus, the school requests assistance from an external specialist to meet the child's needs. In the final stage, children who require additional resources (greater than or different to those generally available) to support their learning needs will be issued a statement of special educational needs. Some children initially placed in the School Action stage will progress through to receiving a statement of special educational need. It bears noting that the allocation of a child to a particular stage is not entirely objective, as some schools may use progress in literacy and numeracy as a determining factor, while others may rely on access to support services as an indication. However, the different stages do provide an approximate index of severity of special needs.

In this study, children identified by their school as having special needs arising from learning difficulties were tested on assessments of three components of working memory: central executive, phonological loop, and visuo-spatial sketchpad. We assessed whether working memory skills were impaired in these children, and whether possible impairments varied in severity as a function of the stage of special needs level reached by the child.

Method

Participants

The data reported in this article are taken from a larger study of 72 children, involving a wide range of cognitive measures. Only the data from the children classified as having moderate learning difficulties are reported here. The participants were 64 children attending state primary schools in Durham, an urban area of North East England. In each case, the schools stated the area/s of difficulty that provided the basis for the child's SEN classification, and the child's stage in the Special Educational Needs Code of Practice (DfEE, 2002).

The children ranged in age from 7 to 11 years (mean = 9.0 years; *SD* = 12.5 months). Of these children, 44 were at the School Action stage, 12 at the School Action Plus stage, and eight received statements of special educational needs. Each child was tested individually in a quiet area of the school for six sessions lasting up to 30 minutes per session across five to six weeks. The tests were administered in a fixed sequence designed to vary task demands across successive tests.

Abilities in the areas of literacy, numeracy and language were tested in addition to working memory skills. The Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) provided assessments of reading, spelling and reading comprehension abilities; the Wechsler Objective Numerical Dimensions (WOND; Wechsler, 1996b) assessed understanding of numerical operations and mathematical reasoning; and the Wechsler Objective Language Dimensions (WOLD; Wechsler, 1996a) contained measures of listening comprehension and oral expression. In all three Wechsler Objective Dimensions test batteries, the standard scores were recorded. A measure of intelligence, the Wechsler Intelligence Scale for Children – 3rd UK Edition (WISC-III; Wechsler, 1992) was also administered. This test consisted of five verbal (Information, Similarities, Mathematics, Vocabulary and Comprehension) and five performance measures (Picture completion, Coding, Picture arrangement, Block design and Object assembly). Details of the children's performance on all these measures are supplied in Table 1.

Performance of all three special needs subgroups is below levels of expected attainment on the basis of age. Literacy, numeracy, and language skills were lower in children with statements compared to children in the School Action stage, with intermediate performance in these areas by children in the School Action Plus stage. Children with statements of special educational needs also obtained the lowest scores in measures of verbal and performance intelligence compared to the other two groups. A series of one-sample *t*-tests were conducted to compare the performance of children with special needs with the expected standardised score of 100. In all cases, the results indicate that children with special educational needs perform significantly below age-appropriate levels (see Table 1). These data provide a summary of the achievement profiles of children with special educational needs. Below-average performance levels in standardised achievement measures and intelligence tests are associated with learning difficulties. In particular, children identified as having statements of special educational needs struggle the most in these knowledge-based assessments. We now investigate possible contributions of working memory abilities that underlie these failings characteristic of children with special educational needs.

The working memory tests were selected to tap the central executive (backwards digit recall, the counting recall and the listening recall), the phonological loop (digit recall, word list recall, and word list matching), and the visuo-spatial sketchpad (blocks recall and the Visual Patterns Test). Note that the first three tasks are verbal complex memory span measures that are believed to impose both a processing load on the central executive and a storage load on the phonological loop (e.g. Baddeley & Logie, 1999). For convenience however, they will be referred to as 'central executive' measures.

Working memory measures

Three central executive measures were administered. The *backwards digit recall* test, the *counting recall* test and the *listening recall* test were taken from the Working Memory Test Battery for Children (WMTB-C, Pickering & Gathercole, 2001). In the backwards digit recall test, the child is required to recall a sequence of spoken digits in the reverse order. The number of digits in each list increases across trials, and the number of lists correctly recalled is scored. In the counting recall test, the child is required to count the number of dots in an array, and then recall the tallies of dots in the arrays that were presented. The number of dots in the array increases across trials, and the number of correct trials completed by each child is scored. In the listening recall test, the child listens to a series of short sentences, determines the veracity of the statements by responding 'true' or 'false', and recalls the final word of each sentence in sequence. The number of sentences in each block increases across trials, and the number of correct trials is scored. Testing was discontinued if the child was unable to recall a minimum of four correct trials out of six in each block of lists.

Three measures of the phonological loop component were administered. The *digit recall* test and the *word list recall* test of the WMTB-C (Pickering & Gathercole, 2001) both involved spoken recall of sequences of spoken items (either single digits or high frequency monosyllabic words). In each case, the number of items in each sequences increased across trials, and the number of correct trials is scored. The *word list matching* test (WMTB-C) involves the child detecting whether words in a second list are in the same order as in the first word list. The number of lists increased in each block, and the number of correct trials is scored. Testing was discontinued if the child was unable to recall a minimum of four correct trials in each block of lists.

Two measures of the visuo-spatial component were administered. In the *block recall*

Variable	School Action (N = 44)		School Action Plus (N = 12)		Statements (N = 8)	
	Mean (SD)	Sig level of 1-sample t-test	Mean (SD)	Sig level of 1-sample t-test	Mean (SD)	Sig level of 1-sample t-test
Reading: WORD	84.61 (9.57)	.000	80.33 (11.13)	.000	76.88 (11.66)	.001
Numeric: WOND	89.32 (9.75)	.000	86.17 (13.46)	.004	77.38 (14.53)	.003
Language: WOLD	90.23 (10.59)	.000	89.75 (8.57)	.002	83.75 (8.00)	.001
Verbal IQ: WISC	84.27 (10.74)	.000	89.50 (9.84)	.004	75.63 (10.24)	.000
Performance IQ:WISC	84.25 (11.66)	.000	82.75 (12.33)	.000	70.88 (5.19)	.000

Table 1: Descriptive statistics of standard scores for achievement measures

test of the WMTB-C (Pickering & Gathercole, 2001), a child views nine cubes randomly located on a board. The test administrator taps a sequence of blocks, and the child has to tap that sequence in the correct order. The number of correct trials is recorded. If the child was unable to recall four correct trials in a block, testing was discontinued. In the Visual Patterns Test (Della Sala, Gray, Baddeley & Wilson, 1997), the child views a two-dimensional grid of black and white squares. After viewing the grid for three seconds, the child has to mark the black squares on an empty grid. The number of correctly marked grids is scored. This test was normed for use with children (Pickering & Gathercole, 2001). Testing was discontinued if the child committed three consecutive errors in each block.

Results

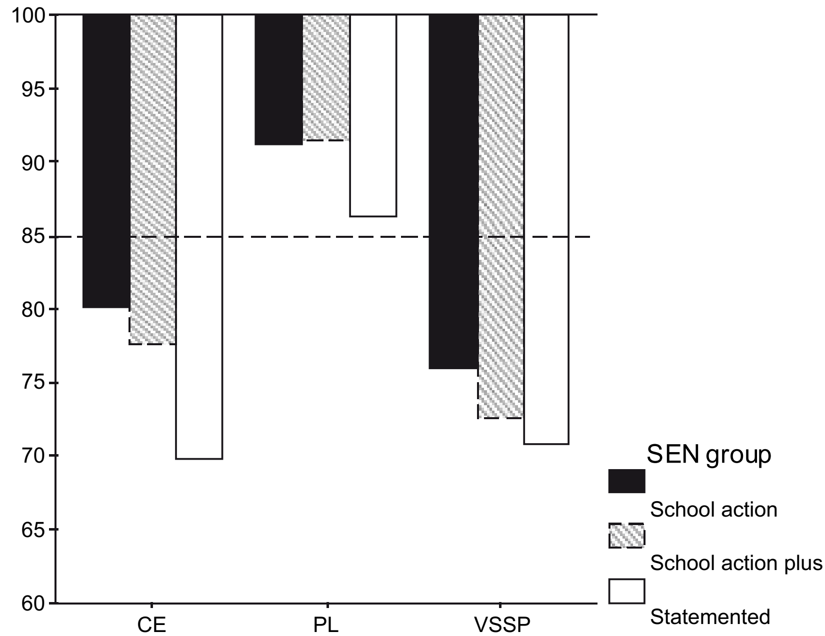
Group profiles

Descriptive statistics for children in each special educational needs group on the principal working memory measures are shown in Table 2. Children with statements performed more poorly on all working memory measures than children in the School Action and School Action Plus groups. When comparing the children's performance to the test standardised score of 100, all three special needs subgroups fell within one standard deviation of the mean (i.e. 15 points from the norm of 100) in measures of the phonological loop. Although this level of performance is below expected levels for age, average phonological loop scores do fall within one standard deviation from the mean and so are not exceptionally low. Performance levels in measures of the central executive and the visuo-spatial sketchpad are considerably lower, with the majority of children scoring below one standard deviation of the mean. The performance of the three special needs subgroups is summarised in Figure 1.

Of particular interest was whether performance of the different groups varied as a function of stage of the Code of Practice. Separate ANOVAs were conducted on the composite scores of the central executive, phonological loop, and visuo-spatial measures as a function of special educational needs status. The group term was significant for the central executive, $F(2,61) = 4.98$, $p = .01$, and a *post-hoc* Scheffé's test established that children with statements performed more poorly than children in the

Variable	School Action (N = 44)		School Action Plus (N = 12)		Statements (N = 8)	
	Mean	SD	Mean	SD	Mean	SD
Central executive:						
Backward digit recall	79.75	10.91	80.42	8.83	71.75	4.95
Counting recall	75.82	13.04	73.58	9.70	66.88	12.35
Listening recall	84.98	14.53	78.92	13.18	70.75	8.45
Phonological loop:						
Digit recall	91.25	14.68	95.08	23.01	90.13	17.91
Word list recall	89.30	10.59	90.42	14.61	86.38	14.16
Word list matching	93.09	12.20	88.83	13.29	82.38	19.89
Visuo-spatial sketchpad:						
Block recall	73.00	13.96	68.42	13.38	62.25	8.66
Visual patterns test	78.91	13.09	76.75	13.21	79.25	11.40

Table 2: Descriptive statistics of standard scores for working memory measures as a function of special educational needs severity



Note: CE = central executive; PL= phonological loop; VSSP = visuo-spatial sketchpad

Figure 1: Comparison of working memory profiles as a function of special educational needs severity

School Action stage ($p < .05$). No significant performance differences were found between the different special needs groups on measures of the phonological loop, $F(2,61) = 0.80$, $p > .05$; or visuo-spatial memory, $F(2,61)$ 1.20, $p > .05$.

Severity of working memory deficits

Further analyses were performed to identify the rate of incidence of working memory deficits in the special needs groups. To this end, composite standard scores were calculated by averaging the standardised scores (with a mean of 100 and a standard deviation of 15) for each working memory component. Corresponding composite scores for the same combination of measures were calculated for the sample children with no identified special educational needs from the WMTB-C (Pickering & Gathercole, 2001). This sample consisted of 636 children without special educational needs, with a mean age of 9.1 years (*S.D.* = 3.0). The data from this non-special educational needs sample indicate that 6 per cent or less of the children obtained standard scores below 81 on any working memory component.

In order to compare the incidence of this level of working memory performance of special educational needs groups with children in an unselected population, likelihood ratios were computed (e.g. Sackett, Haynes, Guyatt & Tugwall, 1991). A likelihood ratio is calculated by taking the proportion of participants in the affected group who score at a set criterion on a test and comparing it to the proportion of participants in the unaffected group who score at this level. The likelihood ratio of the children in the present study were calculated for working memory scores below 81.

Likelihood ratios and proportions of children obtaining particular patterns of deficits from the special needs groups and standardisation (no SEN) sample are shown in Table 3. The post test probabilities values

Variable	School Action	School Action Plus	Statements	All SEN groups	Non SEN	Likelihood Ratios			
						School Action	School Action Plus	Statements	All SEN
CE: <81	.50	.67	1.00	.59	.06	8.33 (.89)	11.17 (.92)	16.67 (.94)	9.83 (.91)
PL: <81	.14	.33	.25	.19	.03	4.67 (.83)	11.00 (.92)	8.33 (.89)	6.33 (.86)
VSSP: <81	.61	.75	1.00	.69	.04	15.25 (.94)	18.75 (.95)	25.00 (.96)	17.25 (.95)
Combinations:									
CE & PL: <81	.11	.25	.25	.16	.01	11.00 (.92)	25.00 (.96)	25.00 (.96)	16.00 (.94)
CE & VSSP: <81	.41	.58	1.00	.52	.00	*	*	*	*
PL & VSSP: <81	.11	.33	.25	.17	.01	11.00 (.92)	33.00 (.97)	25.00 (.96)	17.00 (.94)
CE, PL & VSSP: <81	.09	.25	.25	.14	.00	*	*	*	*

Table 3: Likelihood ratios for working memory cutoff scores in the special educational needs subgroups. Note: In parentheses are the post-test probability values using the unselected sample without SEN as comparison (n = 636). *Likelihood ratios could not be computed as none of the children in the unselected population obtained scores <81 in this combination of assessments

shown in the table correspond to the proportion of the total group of children comprising each special needs comparison group plus the standardisation sample who obtained this particular profile of scores who were members of each of the special needs group.

The incidence of working memory scores below 81 was very low for the standardisation sample with no special needs, ranging from .03 to .06 for individual components. In contrast, scores at this low level were found for the majority of the children with SEN on the central executive and visuo-spatial sketchpad measures (.59 and .69, respectively, corresponding to likelihood ratios of 9.83 and 17.25). Scores below 81 on the phonological loop composite were found for 19 per cent of the children with special educational needs (a likelihood ratio of 6.33).

The increase in frequencies of working memory deficits in the children with SEN compared with the standardisation sample becomes even more marked when combinations of working memory deficits are considered. Children with special needs were at least 16 times more likely to obtain scores below 81 than those in an unselected population (e.g. CE & PL, and PL & VSSP). Of the children across all levels of special needs, 52 per cent performed very poorly in both central executive and visuo-spatial tasks, and 43 per cent of them scored below in all three areas of working memory function. It was not possible to compute likelihood ratios for these deficits patterns, as they were never observed in the large standardisation sample. They therefore reflect patterns of impairment that are extremely rare in a population of children without special needs.

Consider now the three special needs groups. In general, working memory deficits were more common in the School Action Plus and statemented groups than in the School Action group. All of the children with statements of special needs had deficits in both the central executive and the visuo-spatial sketchpad. This proportion was 58 per cent for the School Action Plus group and 41 per cent for the School Action group. This deficit pattern did not exist in the much larger standardisation sample. Impairments of all three working memory components was found for 25 per cent of both the School Action plus and statement groups, and for 9 per cent of the School Action children. Again, this pattern of working memory deficit never occurred in the standardisation population.

Discussion

This study provides a detailed investigation of working memory skills in children with special educational needs of varying severity. Deficits were observed in measures of the central executive and visuo-spatial sketchpad. The impairments in working memory varied in severity according to stage of the Code of Practice for special educational needs. In particular, children with statements of special educational needs performed at significantly lower levels than children at the School Action stage on central executive tasks. The strong and specific patterns of association between the severity of special needs and working memory scores reported here suggests that the stages of the Code of Practice genuinely do discriminate between children with different cognitive abilities.

These findings correspond closely to those reported in a previous study of children with special educational needs by Pickering and Gathercole (2004). In this study too, children with learning difficulties were found to have greater deficits in working memory than a population of children without special needs. In the present study, the magnitude of working memory deficits was even higher than in the Pickering and Gathercole (2004) study. Indeed some profiles of severe deficits in two or three components of working memory that were present in a sizeable proportion of the special needs children were never observed in a sample of over 600 children without learning difficulties. Working memory deficits of this severity are clearly very rare in a normal population.

The findings also establish a degree of specificity to the profiles of cognitive skills of children with special educational needs. Deficits were greater for the measures of central executive and visuo-spatial sketchpad. Scores on the central executive measures declined with increasing severity of special needs, with the statemented group performing more poorly than either the School Action or the School Action Plus groups. This link between impaired performance on measures of complex memory and severity of learning difficulties fits well within the existing literature in key areas of learning such as reading (e.g. Swanson, 1994; de Jong, 1998), mathematics (e.g. Bull & Scerif, 2001; Mayringer & Wimmer, 2000; Siegel & Ryan, 1989), and language comprehension (e.g. Nation *et al.*, 1999; Signeuric *et al.*, 2000), as well as attainments in National Curriculum assessments of English and mathematics (Gathercole & Pickering, 2000; Gathercole, Pickering, Knight & Stegmann, 2004; Jarvis & Gathercole, 2003).

Some clues as to why poor central executive function might impair learning abilities were recently identified in an observational study of a small group of children with very poor complex memory span scores at four and five years of age (Gathercole, Lamont & Alloway, in press). These children frequently failed to complete satisfactorily a range of relatively common classroom activities imposing simultaneous demands on monitoring, processing and storage. Examples of such activities include writing sentences from memory, carrying out numerical calculation abstracted from questions couched in everyday language, and counting words in sentences. In these situations, children with poor working memory function frequently lost track of their place in the complex task structure, resulting in repetitions, place-skipping, and task abandonment. Given the severity of the central executive deficits in the special educational needs sample investigated in the present study, it seems likely that they too would encounter difficulties in these situations that would impair their capacities to learn.

In the present study, very poor performance on visuo-spatial memory tasks was found at all three special needs stages, irrespective of severity. Pickering and Gathercole (2004) also found evidence of marked deficits in visuo-spatial memory in children with learning difficulties of a general nature, although not in children with learning difficulties that were specific to language. They speculated that parallel impairments of the visuo-spatial sketchpad as well as the central executive may rule out the possibility of using visual strategies to support memory and learning, leading to learning difficulties across the academic curriculum.

Although the children who took part in the present study performed below average levels on phonological loop measures, their deficits in this aspect of working memory were not as severe as in the two other components. On first consideration, this finding might seem counter-intuitive on the basis of the established links between the phonological loop and language learning (e.g. Baddeley *et al.*, 1998). It may, however, be due to the fact that the children participating in the study have already passed through the most intensive period of language learning. The strongest link between vocabulary knowledge and phonological memory occurs in children between the ages of four to six years and diminishes thereafter, possibly due to the emergence of other crucial determinants of vocabulary development such as reading experience (e.g. Gathercole, Willis, Emslie & Baddeley, 1992). The present finding is also consistent with previous research showing that phonological loop deficits alone are generally not associated with substantial failures in educational progress (e.g. Gathercole, Tiffany, Briscoe, Thorn & ALSPAC, in press; Gathercole, Pickering *et al.*, 2004; Jarvis & Gathercole, 2003).

In summary, working memory deficits may be much more common in children with special educational needs than those without, and may be more marked in children with statements of special needs than those at earlier stages of recognition of the need for educational support. Given these low levels of working memory function, it seems likely that such children could struggle greatly to meet the memory demands of many learning activities, and that this in itself may lie at the root of at least some of their failures to make normal educational progress.

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