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Working memory assessments at school entry as longitudinal predictors of National Curriculum attainment levels

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Abstract

A longitudinal study of 54 children aged between 4 and 7 years of age investigated whether measures of working memory skills taken shortly after school entry served as useful predictors of children's attainment levels in National Curriculum assessments at Key Stage 1. Early working memory scores were found to be highly significant predictors of children's subsequent levels of attainment in literacy, but not in mathematics. Compared with the local education authority baseline assessments also administered at 4 years of age that are designed in large part to predict later attainments, working memory scores accounted for unique variance in children's spelling and writing scores at 7 years. These findings point to the utility of combining knowledge-based assessments with measures of fluid cognitive ability in order to obtain the best estimates of a child's chances of future academic success.

From 1998 to 2002, all local education authorities (LEAs) in England were required to evaluate children's abilities at 4 or 5 years of age, within six weeks of school entry. Termed 'baseline assessments', these evaluations were recommended to tap areas of the child's competence including literacy, language, mathematics, and personal and social skills (SCAA/ QCA, 1997). One of the principal purposes of the assessments was to evaluate the extent to which schools provided value-added education, allowing comparison of the attainments of pupils on National Curriculum assessments at later points across schools with intakes of children with comparable baseline assessment profiles.

Ninety different baseline assessment schemes were developed by LEAs. Although their composition varied considerably, many incorporated items and scales from the baseline assessment scheme advanced by Qualifications and Curriculum Authority (QCA) (1998), with some common items featuring in the majority of schemes. For example, most schemes assess early literacy skills by a combination of measures such as letter identification, word recognition, simple spelling and writing the child's own name. Similarly, numerical ability was usually assessed using one or more of the following measures: counting, identification of digit symbols and simple sums.

Studies that have analysed the relationship between baseline assessment scores and pupils' subsequent attainments in Key Stage 1 assessments two and a half years later have established the importance of what Tymms (1999) has referred to as 'general developed abilities'

at school entry as predictors of children's achievements at 7 years. For example, Key Stage 1 attainments in both English and mathematics are highly predicted by children's abilities when they start school to identify letters, to spell and to display knowledge about reading, and to count (Singleton, Horne & Thomas, 1999; Tymms, 1999). Thus children who have already mastered the component skills that lie at the foundations of literacy and mathematics tend to progress well and achieve highly following several years of structured education at school in these domains.

The purpose of the present study was to compare the extent to which children's attainment levels in English and mathematics at Key Stage 1 were predicted by two alternative types of assessment at school entry: baseline assessments, and measures of short-term working memory. Working memory refers to the capacity to store and manipulate material for brief periods of time, and is widely understood in terms of the multicomponent model advanced by Baddeley & Hitch (1974) and developed subsequently by Baddeley (1986, 2000). Tasks which impose both processing and storage demands are believed to tap the central executive component of the working memory model, and possibly also the recently identified episodic buffer subsystem (Baddeley, 2000). Recent studies have established that children's performance on a range of complex memory span measures that require both processing and storage is closely associated with their attainments levels in National Curriculum assessments of English at 7 and 11 years, and in mathematics at all three assessment points, at 7, 11 and 14 years (Gathercole & Pickering, 2000a; Gathercole, Pickering, Knight & Stegmann, in press; Jarvis & Gathercole, 2003). These relationships were not unexpected. It has long been established that working memory skills are closely linked with children's performance in literacy (e.g. de Jong, 1998; Gathercole & Pickering, 2000b; Swanson, 1994), arithmetic and mathematics (Bull & Scerif, 2001; Gathercole & Pickering, 2000b; McLean & Hitch, 1999; Passolunghi & Siegel, 2001; Shah & Miyake, 1996) and vocabulary (Daneman & Green, 1986), as well as more general aspects of cognitive capacity as indexed by college entrance scores (Daneman & Carpenter, 1980; Jurden, 1995) and occupational success (Kyllonen & Christal, 1990). The generality of the relationship between scores on working memory assessments and on such indicators of learning suggests that individual differences in the capacity to store and process material in complex tasks can directly constrain a child's ability to develop knowledge and skills in key domains over the school years.

The capacity to store phonological material in situations in which concurrent processing is not required is considered to reflect the phonological loop component of working memory (Baddeley, 1986). Close links between individual differences in young children's phonological loop capacities and their abilities to learn the phonological structure of new words has led to the proposal that the primary function of the phonological loop is to support language learning (Baddeley, Gathercole & Papagno, 1998).

It is notable that in contrast with baseline assessments, short-term memory tasks do not directly index the component skills involved in the key domains of English and mathematics. The tasks require the child to store memory items in sequence (such as numbers or words) while processing material in a variety of ways (such as listening to sentences, reversing the sequence of a series of numbers, and counting a small number of objects). Children do not fail the tasks because they are unable to carry out the particular processing activity due to lack of knowledge relevant to the assessment domain, but because they are

unable to store and process larger amounts of material simultaneously. Thus whereas baseline assessments tap previously acquired crystallised knowledge acquired, working memory assessments tap fluid cognitive abilities that do not depend on prior experience. They use tasks and materials that are unfamiliar to all children, and that are relatively impervious to demographic factors such as ethnic background (Dollaghan, Campbell, Needleman & Dunlosky, 1997) and maternal education level (Gathercole *et al.*, 2003). In this way, measures of cognitive processing skills provide assessments of the child's future abilities to learn that minimise the influence of prior experience (Baddeley & Gathercole, 1999).

The children participating in the present study completed both the local baseline assessment scheme and a battery of working memory assessments within the first term of school entry, at between 4 and 5 years of age. The working memory assessments included two tests of complex span (backwards digit recall and naming recall) and three storage-only measures (non-word repetition, word list recall and word list matching). Two and a half years later, at 7 years, the children participated in the tests and tasks involved in National Curriculum assessments of English and mathematics, resulting in classification of their attainment levels. The purpose of the study was to determine the extent to which the school baseline assessments and working memory test scores uniquely predicted these later attainment levels.

Participants

The 54 children (27 boys and 27 girls) who participated in the study had a mean age of 4 years 11 months (SS = 3.76 months, range = 4 years 5 months to 5 years 5 months) at the time of completing the working memory assessments in the period January to March 1999. The children were tested within one term of joining the reception class of an LEA primary school in a suburban area of a city in south-west England. The school had a predominantly middle-class intake, with one of the highest rates of achievements in Key Stage 2 results in the area. All participants had completed the Avon Reception Assessment scheme in the two months prior to their recruitment to the study, and also the working memory tests outlined below. The children participated in the Key Stage 1 assessments of English and mathematics during the third year of school (Year 2) in 2001, when they were aged 6 and 7 years of age.

Working memory assessments

Each child was tested individually on five measures of short-term working memory, outlined below. Two measures (backwards digit recall and naming recall) were complex working memory tasks involving significant storage and processing demands. Three measures (non-word repetition, word list recall and word list matching) involved storage only, and were designed to tap the phonological loop component of working memory.

Backwards digit recall

On each trial, the child was presented with a spoken sequence of digits and asked to recall the sequence in backwards order. The concept of backwards order was explained and demonstrated in a training session prior to testing. Test trials commenced with four trials containing two digits, followed by sequences that increased by one item in length if three

or more lists were correctly recalled. The total number of lists correctly recalled was scored. Fuller details of the procedure are provided in Gathercole & Pickering (2000b). This test was an earlier version of the backwards digit recall test of the Working Memory Test Battery for Children (Pickering & Gathercole, 2001), which has a test–retest reliability of .53 for children aged 5 to 7 years.

Naming recall

This test was devised for use with children below 6 years of age, who are generally unable to meet the demands of the listening recall test of the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). On each test trial, the child named line drawings depicting familiar objects, and then attempted to recall the object names in the sequence in which they had been presented. Testing began with four trials consisting of a single line drawing only, with the number of drawings increasing by one every four trials until the point at which the child incorrectly recalled the object names in two or more trials at a particular level. The number of correct trials was scored.

Non-word repetition

The Children's Test of Nonword Repetition (Gathercole & Baddeley, 1996) was administered to each child. The test consists of 40 non-words, 10 each containing two, three, four and five syllables. The non-words are presented auditorily via an audio cassette recorder. The child is asked to repeat each non-word following presentation, and the repetition attempt is scored as either correct or incorrect. The number of non-words repeated correctly is scored. Split-half reliability for this test is .66 (Gathercole & Baddeley, 1996), and test–retest reliability for a sample of 5-year-old children was .77 (Gathercole, 1995).

Word list recall

On each trial, the child was presented with lists of spoken words (high frequency, containing one syllable) for immediate recall in the same sequence as presented. List length commenced with two items, increasing by one item every four trials until the point at which the child incorrectly recalled the word sequence in two or more trials at a particular level. The number of correct trials was scored. For fuller details of this procedure, see Gathercole & Pickering (2000b). This test is an earlier version of the word list recall test of the Working Memory Test Battery for Children (Pickering & Gathercole, 2001), which has a test–retest reliability of .72.

Word list matching

One each trial, spoken pairs of lists were presented, separated by a short delay. The lists in each pair contained the same monosyllabic familiar words, either in identical sequence or with an adjacent paired transposition in the order of two items. The child's task was to state whether the two sequences were the same or different. Testing began with four sets of two-item sequences, increasing in length by one item every four trials until the point at which the child failed to respond correctly on two or more lists at a particular level. The number of correct trials was scores. For fuller details of this procedure, see Gathercole & Pickering (2000b). This test is an earlier version of the word list matching test of the Working Memory

Test Battery for Children (Pickering & Gathercole, 2001), which has a test–retest reliability of .45 for children aged 5 to 7 years.

Baseline assessments

Baseline assessments were carried out by the class teacher within six weeks of the child commencing part-time or full-time education at 4 or 5 years of age. The Avon Reception Entry Assessment scheme contained five scales corresponding to five areas of experience: language, reading, writing, mathematics and social skills. In each area, assessment usually began at stage 3 reaching a maximum of 7, with progression through stages dependent upon the number of activities that a child was able to perform at a particular stage. If children successfully completed more than half of the activities associated with a particular stage, they proceeded to the next stage. The highest stage reached in each area was recorded. Examples of items from each stage are shown in Appendix A.

National Curriculum assessments

National Curriculum assessments at Key Stage 1 in 2001 consisted of tasks (administered and scored by the teacher) and tests (administered by teacher and scored by the LEA) developed and validated by the QCA, in addition to broader based teacher assessments. The assessments are carried out in the latter half of the third full-time year of schooling, when the children are aged 6 and 7 years of age, and the results are reported in the final month of the school year. For the purposes of the present study, children's scores on three English measures (the reading comprehension test, the writing task and the spelling test) and on the mathematics test were analysed. These measures were chosen as they involved the use of materials standardised by the QCA, and in each case led to classification of achievements in terms of performance that was either below, at, or above the nationally expected levels.

Scores consisted of the attainment level of each child, using a scale in which level 1 is below the nationally expected standard (coded L in the case of the spelling test), level 2 is the nationally expected standard, and level 3 is above nationally expected standard. National data show that in 2002, the following percentages of children obtained level 2 in the following measures: reading comprehension (53), writing (76), spelling (52), and mathematics (72). For the reading comprehension, writing, and mathematics tests, level 2 performance was further divided into three bands (a, b, c), with 2a representing the highest attainment within the level, and 2c representing the lowest. The levels on each of these tests were recoded for the purposes of analysis into numerical scores: 1 (1/L), 2 (2c), 3 (2b), 4 (2a), and 5 (3).

Results

Descriptive statistics for the principal measures are shown in Table 1. Scores on each of the working memory tests showed wide variation, with no apparent restrictions in range. The baseline assessments showed reasonable degrees of variation, with scores ranging from 4 to 7 for the language and mathematics scales, from 3 to 7 for the reading and writing scales, and from 2 to 7 for the social skills scale. Key Stage 1 scores were positively skewed, with no children scoring below level 2 (i.e. obtaining a score of 1) on either the reading compre-

Table 1. Descriptive statistics for principal measures

Measure	Mean	SD	Minimum	Maximum
Age (years; months)	4;11	3.76 mos	4;05	5;05
Working memory:				
Backward digit recall	5.86	1.84	2	11
Naming recall	14.48	3.22	5	26
Nonword repetition	23.85	6.08	12	36
Word list recall	8.00	1.70	5	12
Word list matching	7.63	3.49	1	14
AREA Baseline assessments:				
Language	5.63	0.9	4	7
Reading	5.31	0.84	3	7
Writing	4.91	0.76	3	7
Mathematics	5.89	0.88	4	7
Social skills	5.52	1.14	2	7
Key Stage 1 scores:				
Reading comprehension	4.43	0.86	2	5
Writing	3.48	1.08	1	5
Spelling	3.57	1.31	0	5
Mathematics	4.39	0.81	2	5

hension or mathematics tests, and a relatively large proportion of children obtaining level 3 (re-scored as 5): 63 per cent for reading comprehension, and 56 per cent for mathematics. Scores on the writing and spelling measures were more evenly distributed, with the 20 per cent and 39 per cent of children attaining level 3, respectively.

The matrix of correlation coefficients for these measures is shown in Table 2. Consider first the correlations between individual measures for the three kinds of assessment (working memory, baseline assessments, and Key Stage 1 scores). All five working memory measures correlated significantly with one another, with coefficients ranging from .31 (backwards digit recall and non-word repetition) to .56 (naming recall and word list recall). Correlations between scales in the baseline assessments were also high, ranging from .34 (reading and social skills) to .68 (language and reading). Although all Key Stage 1 scores were significantly intercorrelated, the three literacy-based assessments (reading comprehension, writing, and spelling) were much more highly associated with one another (with coefficients ranging between .70 and .89) than with mathematics scores (with coefficients of between .41 and .56). These findings indicate that the school-based assessments were reliable and valid.

Correlations between working memory scores and the baseline assessment scores were low to moderate in strength. It is, however, notable that the naming recall measure had consistent and fairly high correlations with the four academic scales of the baseline assessments (i.e. excluding social skills), with coefficients ranging from .34 to .46. The working memory and baseline assessments scores showed differing patterns of association with Key Stage 1 scores. Baseline assessments showed uniformly significant correlations with all Key Stage 1 measures, with the majority of coefficients falling in the range .40 to .56,

Table 2. Correlation coefficients for principal measures

Measure		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Age	–													
2	Backward digit recall	22	–												
3	Naming recall	26	**35**	–											
4	Nonword repetition	**42**	**31**	**44**	–										
5	Word list recall	16	**42**	**56**	**40**	–									
6	Word list matching	**36**	**52**	**45**	**31**	**41**	–								
7	B/L language	**30**	26	**44**	**27**	**33**	**29**	–							
8	B/L reading	16	**43**	**46**	14	**34**	**33**	**68**	–						
9	B/L writing	**57**	**29**	**45**	**34**	**20**	**31**	**56**	**58**	–					
10	B/L mathematics	23	**32**	**34**	**34**	21	**32**	**57**	**40**	**38**	–				
11	B/L social skills	**47**	**28**	**30**	**28**	23	**29**	**56**	**34**	**60**	**49**	–			
12	KSI reading comprehension	20	**36**	**38**	18	**30**	**43**	**45**	**46**	**35**	**49**	**33**	–		
13	KSI writing	**30**	**52**	**43**	**38**	**35**	**36**	**56**	**56**	**56**	**51**	**51**	**75**	–	
14	KSI spelling	12	**42**	**48**	**43**	**42**	**40**	**42**	**45**	**45**	**43**	**36**	**70**	**89**	–
15	KSI mathematics	20	27	17	03	15	26	**51**	**51**	**34**	**51**	**39**	**49**	**56**	**41**

Note: Coefficients printed in bold are signidicant at the .05 level. Decimal points on coefficient values are omitted

although it was notable that the social skills measure generally correlated the least strongly, below .40. The working memory measures showed more a selective pattern of associations. The writing and spelling measures were significantly associated with all five working memory measures, to a comparable degree with the baseline scores. Reading comprehension showed a weaker pattern of association, with a non-significant correlation with non-word repetition, and significant but low to moderate correlations with the other four memory scores (ranging from .30 to .43). Finally, the mathematics measure was significantly correlated with only one measure (backwards digit recall), with a correlation coefficient of .27.

As the working memory measures and baseline assessment scores were themselves moderately intercorrelated, it was important to assess the specificity of the links of the working memory and baseline assessments with the Key Stage 1 outcome measures. A series of partial correlations was therefore computed. Composite scores were calculated for the working memory and baseline assessments, consisting of the average *z*-score for the five relevant measures for each child. For example, the working memory composite score was the average of the child's *z*-scores on each of the backwards digit recall, naming recall, nonword repetition, word list recall and word list matching measures. Simple correlations between the two composite scores and each Key Stage 1 score were calculated. The variance associated with chronological and score in the other assessment was then partialled out in each case (i.e. the baseline measure in the case of partial correlations involving working memory and Key Stage 1 scores, and vice versa). It should be noted that this method of evaluating unique contributions is highly conservative given the intercorrelations between the working memory and baseline scores, which are likely to reflect at least partly the contribution of working memory to progress towards early learning goals at school entry. In this respect, there is a danger of eliminating the variance of interest. However, this method does have the advantage of providing stringent tests of specificity of relationships

Table 3. Partial correlations between overall scores taken at school entry (working memory and baseline assessments) and KSI test scores; age and the other score patialled out in each case

KSI measure	Working memory		Baseline assessment	
	Coefficient	Probability	Coefficient	Probability
Reading comprehension	0.25	0.077	0.38	0.005
Writing	0.31	0.026	0.55	0.000
Spelling	0.46	0.001	0.38	0.005
Mathematics	-0.09	0.525	0.54	0.000

that are valuable for interpretation of the data. Correlation coefficients that remain significant after the partialling procedure are therefore worthy of note.

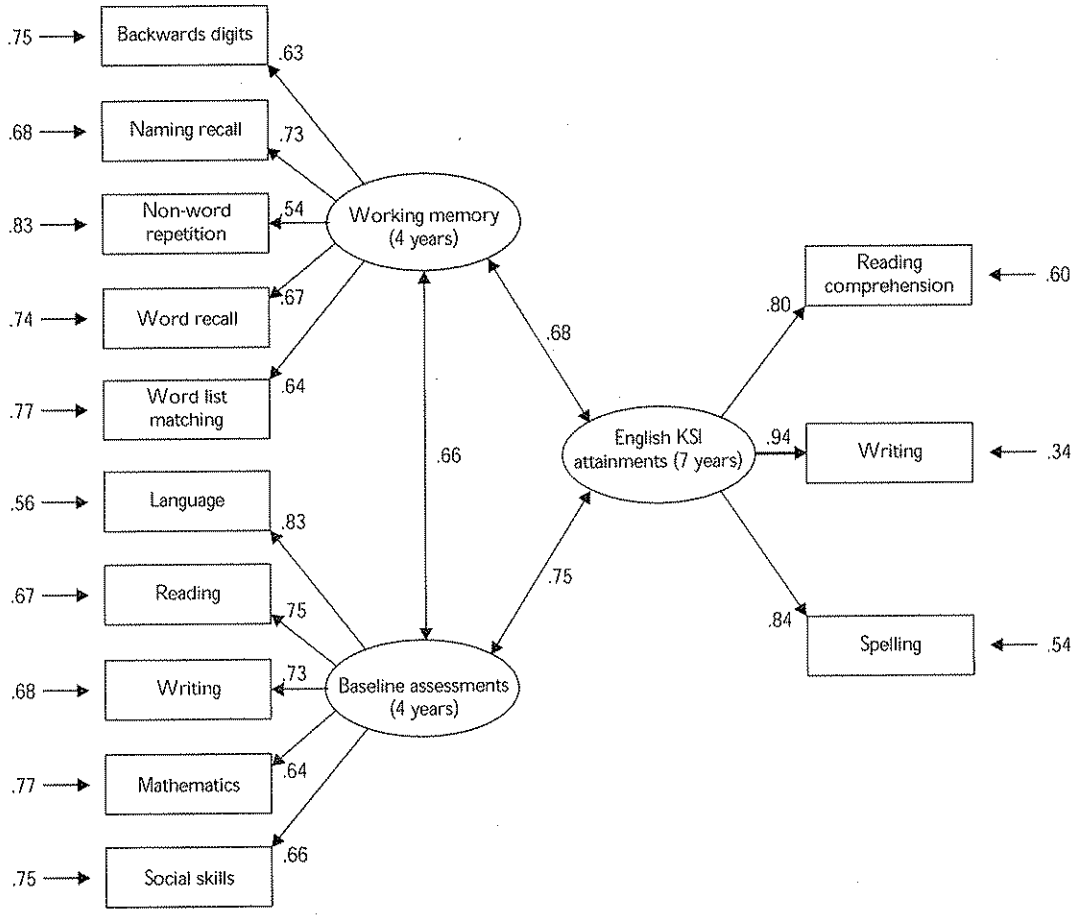
The results of these analyses are summarised in Table 3. High to moderate correlations were found between working memory scores and reading comprehension (r = .45), writing (partial r = .56, $p < .001$), and spelling (r = .59, $p < .001$), although the correlation with mathematics scores was non-significant (r = .24). When baseline assessment scores were partialled out to provide a test of the degree of unique association between working memory and later attainment levels, significant associations remained with the writing and spelling measures, partial $r(50)$ = .31, $p < .05$, and partial $r(50)$ = .46, $p < .001$, respectively.

Baseline assessment score were highly associated with all four Key Stage 1 scores ($p < .001$), with rs ranging from .53 (reading comprehension and spelling) to .69 (writing). When working memory scores were taken into account, all associations remained highly significant, with partial rs ranging from .38 (reading comprehension and spelling, $p < .005$) to .54 (mathematics, $p < .001$) and .55 (writing, $p < .001$).

These analyses indicate that although there is some overlap in the individual differences tapped by the working memory measures and baseline assessments, the cognitive and achievement-based assessments each uniquely predict different aspects of children's later scholastic achievements. In order to provide a more general evaluation of the relationships between working memory and baseline scores, and of the contributions of each to children's achievements at Key Stage 1, a structural equation modelling approach was adopted using the EQS structural equation program (Bentler & Wu, 1995). This approach allows the test of specific hypotheses concerning the relationships between latent constructs tapped by multiple assessments, and is ideal for evaluating competing causal hypotheses relating to the developmental precursors of Key Stage 1 scores. Each model generates coefficients for the paths between constructs and variables that indicate strength of relationships, and a range of statistics that indicate the goodness of fit of the model to the input correlation matrix. By comparing the fit indices across competing models, it is therefore possible to find the best theoretical account of the data.

The input to the program was the correlation matrix for the 14 measures, with variance associated with differences in chronological age partialled out. The program computes standardised coefficients for each path on the specified model that denote strength of association, and correspond approximately to regression weights. As a rule of thumb, models are judged to be acceptable if they have non-significant χ^2 values (indicating no significant

Figure 1. Measurement model comprising working memeory,baseline assessment, and Key Stage 1 English factors. Numbers represent standardised path coefficients (for paths to and from latent constructs) and error covariances (for observed variables)

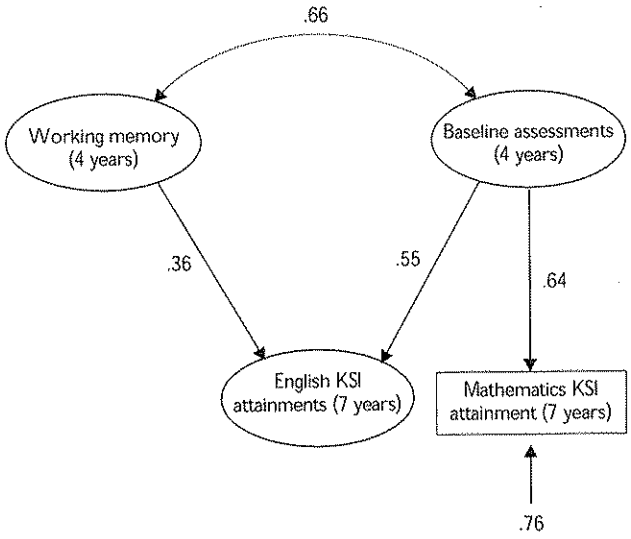


difference between the data and the model), fit indices such as the comparative fit index (CFI) in excess of .9, and root mean-square error of approximation (RMSEA) values that fall below .07 (McDonald & Ho, 2002).

First, we tested the adequacy of the measurement model shown in Figure 1, consisting of three correlated latent constructs corresponding to working memory and baseline assessments at 4/5 years, and English scores at 6/7 years. The mathematics score was not associated with a latent construct as it was a single observed variable. The model yielded a non-significant χ^2 (68.893, 61 d.f., $p > .05$), CFI = .975, RMSEA = .049. This indicates that the data provide a satisfactory fit to this three-factor structure.

The principal interest was in evaluating the extent to which the working memory and baseline assessment factors predicted later National Curriculum test scores. This was tested in the causal model shown in Figure 2, using the path weights (from observed to latent variables) from the measurement model shown in Figure 1. In this model, causal paths (repre-

Figure 2. Causal model comprising working memory and baseline assessment factors at 4/5 years, and English factor and mathematics measure at 7 years. Numbers represent standardised path coefficients (for paths to and from latent constructs) and error covariances (for observed variable)



sented by unidirectional arrows) ran from each of the working memory and baseline assessments constructs to a Key Stage 1 English construct (associated with the reading comprehension, spelling and writing measures). A further causal path was included from the baseline assessment construct to the Key Stage 1 mathematics score. On the basis of the absence of significant correlations between the individual working memory measures and the mathematics score, no corresponding link from working memory to mathematics attainments was included in this model. The model provided a good account of the data, $\chi^2 = 87.746$, 70 d.f. ($p > .05$), CFI = .943, RMSEA = .069. All three causal paths in the model were highly significant ($p < .001$, in each case), with the following standardised path coefficients: working memory to English, .36; baseline assessments to English, .55; baseline assessments to mathematics, .64.

Discussion

This longitudinal study investigated the relationships between children's skills at storing verbal material for brief periods of time soon after they started school at 4 or 5 years of age, and their subsequent attainment levels in National Curriculum assessments at 7 years of age. Working memory skills were found to be closely associated with children's attainment levels in writing and spelling two and a half years later, moderately associated with reading comprehension abilities, and unrelated to mathematics achievements.

The findings reinforce earlier evidence of close links between children's National Curriculum achievements and working memory abilities in cross-sectional studies of children aged 7 to 14 (Gathercole & Pickering, 2000a; Gathercole *et al.*, in press; Jarvis & Gathercole, 2003). The present longitudinal study provides substantial support for the view that the previously reported associations arise because working memory plays a causal role

in children's developing skills and knowledge, particularly in the domain of literacy (see also, de Jong, 1998; Gathercole & Pickering, 2000b, 2001; Siegel & Ryan, 1989; Swanson & Alexander, 1997). The absence of a significant link between working memory and mathematical ability in the present study is noteworthy, and runs counter to the view that constraints in working memory capacity impair learning in this domain (Bull & Scerif, 2001; Gathercole *et al.*, 2003; Mayringer & Wimmer, 2000; Siegel & Ryan, 1989). Recent findings reported by Jarvis & Gathercole (2003) indicate that in later National Curriculum assessments of children at 11 and 14 years of age, non-verbal working memory is a highly significant predictor of mathematical ability, although not of attainment in English assessments. Similar findings were obtained by Shah and Miyake (1996) with adult participants. As our study did not incorporate measures of non-verbal working memory, it is not possible to determine whether mathematical abilities at 7 years in the present sample were constrained by this other important aspect of working memory capacity.

A major aim of this study was to investigate whether working memory skills at 4 and 5 years would complement the assessments of children's abilities routinely carried out at school entry. The AREA baseline assessment scheme employed by this school measured the children's achievements in the areas of language, reading, writing, and mathematics, and also their social skills. Consistent with previous findings (see Tymms, 1999), baseline assessment scores were significant predictors of the children's later National Curriculum test scores at 7 years, accounting for about 25 per cent of variance in scores on average. Although the associations are not exceptionally high, this finding certainly points to the value of baseline assessments in predicting later achievements.

It should, however, be noted that the baseline assessments in this scheme involve in large part the direct measurement of early stages of skills tapped subsequently in the National Curriculum tests. For example, the reading and writing scales in this particular scheme assess factors such as children's understanding that words convey meaning, the extent of their sight vocabulary, and their rudimentary spelling skills. The maths scale taps abilities to match by colour, to sort into series on the basis of size, and to count. The National Curriculum in English and mathematics measure more advanced forms of the same skill domains. Given the part-whole relationship between the baseline and National Curriculum assessments, their close statistical relationship is not too surprising. In contrast, the working memory tests did not involve the children in any activities that would be constrained by their emerging literacy skills: none of the test stimuli was presented in printed form, and the children did not have to provide written responses. Score on these measures were nonetheless consistently and highly significantly predictive of later attainment levels in both writing and spelling, accounting for unique variance in both measures even after differences in earlier baseline scores had been taken into account. Thus, assessing working memory skills appears to tap aspects of a child's future abilities to learn that extend beyond measures of their current domain-specific achievements.

The longitudinal relationship between working memory and later literacy achievement demonstrated here establishes that measures of working memory skills at school entry can complement the knowledge-based assessments provided in baseline assessment schemes, possibly by measuring fluid cognitive ability that is relatively independent of current achievements and prior experiences (Dollaghan *et al.*, 1997; Gathercole *et al.*, 2003). An interesting possibility is that strong working memory skills may provide the child was a

greater potential to benefit from the value added nature of the classroom environment, and thus may provide relatively pure assessments of the quality of the education delivered.

Implications of the work for educational practice

The present findings of close, specific and predictive relationships between working memory skills at school entry and later educational attainments have two main implications for educational practice. The first relates to assessment. The cognitive measures employed in this study predicted important aspects of National Curriculum achievements at Key Stage 1 above and beyond the ability-based assessments provided by school baseline scheme. This points to the utility of combining knowledge-based assessments with cognitive measures in order to obtain the best estimates of a child's chances of future academic success. The second implication relates to classroom practice. Given that working memory skills constrain children's learning success, it is important for teachers to minimise the possibilities of children failing on a learning activity simply because their working memory capacity is exceeded. Two actions are recommended. Working memory skills should be assessed in children with learning difficulties in order to determine whether these are a possible source of lack of educational progress. If memory skills are found to be poor, steps should be taken to alleviate working memory load (Gathercole, in press). Ways of doing this include breaking down complex tasks into self-contained steps, and provision of external memory support whenever possible.

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Appendix A

Examples of activities at stages 3 to 6 in the five areas of experience in AREA scheme

Language	
Stage 3	Carry out a simple instruction
Stage 4	Answer open questions in simple phrases
Stage 5	Contribute to whole class discussions
Stage 6	Maintain a dialogue with an adult
Reading	
Stage 3	Turn pages of a book one at a time
Stage 4	Re-tell part of story using pictures in the book
Stage 5	When shown one word find the same word on the page
Stage 6	Have a sight vocabulary of at least 15 words
Writing	
Stage 3	Scribble in circles
Stage 4	Be aware that writing conveys meaning
Stage 5	Produce random letters on a page
Stage 6	Begin to use invented spellings
Maths	
Stage 3	Match items by colour
Stage 4	Sort into sets by shape
Stage 5	Arrange 5 objects in order of size
Stage 6	Count out 10 and 11 objects from a larger set
Social skills	
Stage 3	Play in parallel with other
Stage 4	Sustain a play activity for 15 minutes
Stage 5	Act out part of a story
Stage 6	Move on to a new activity on completion of tasks