Open access • Journal Article • DOI:10.1348/026151005X26804

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Published on: 01 Sep 2005 - British Journal of Development Psychology (British Psychological Society)

Topics: Phonological awareness, Memory span, Cognitive skill, Short-term memory and Working memory

British Journal of Developmental Psychology (2005), 23, 417–426
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www.bpsjournals.co.uk

Brief report

Working memory and phonological awareness as predictors of progress towards early learning goals at school entry

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This study investigates whether working memory skills of children are related to teacher ratings of their progress towards learning goals at the time of school entry, at 4 or 5 years of age. A sample of 194 children was tested on measures of working memory, phonological awareness, and non-verbal ability, in addition to the school-based baseline assessments in the areas of reading, writing, mathematics, speaking and listening, and personal and social development. Various aspects of cognitive functioning formed unique associations with baseline assessments; for example complex memory span with rated writing skills, phonological short-term memory with both reading and speaking and listening skills, and sentence repetition scores with both mathematics and personal and social skills. Rated reading skills were also uniquely associated with phonological awareness scores. The findings indicate that the capacity to store and process material over short periods of time, referred to as working memory, and also the awareness of phonological structure, may play a crucial role in key learning areas for children at the beginning of formal education.

From 1998 to 2002, all state primary schools in England assessed children's abilities as they entered full-time education at 4 or 5 years of age. Each local educational authority was responsible for administering an accredited baseline assessment scheme that measured the children's progress towards early learning goals in domains such as language, literacy, mathematics, and physical and creative development (School Curriculum and Assessment Authority/The Qualifications and Curriculum Authority, 1997).

The aim of the present study was to relate these early indicators of children's skills in key scholastic domains to working memory abilities. Recent work has established close

This research was supported by a cooperative grant (no. G0000257) awarded by the Medical Research Council of Great Britain to Susan Gathercole, Catherine Willis, and Anne-Marie Adams.
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DOI:10.1348/026151005X26804

associations between children's capacity to store and manipulate material over short periods of time and their scholastic progress in the domains of language, mathematics, and science across the full range of school years (Bull, Johnson, & Roy, 1999; Gathercole & Pickering, 2000, 2001; Gathercole, Pickering, Knight, & Stegmann, 2004; Jarvis & Gathercole, 2003). The strongest links have been found between attainment levels and performance on complex memory span tasks that impose significant processing and storage loads.

One theoretical account of complex memory span performance is that it is supported by the central executive component of the working memory model (Baddeley & Hitch, 1974; also Baddeley, 1986, 2000). The recent version of the working memory model is based principally on data from adults and neuropsychological patients (Baddeley, 2000). However, we have found evidence that working memory has a similar functional organization in young children. Alloway, Gathercole, Willis, and Adams (2004) reported separate but associated constructs corresponding to the central executive, episodic buffer, and phonological loop, which were each distinct from phonological awareness and non-verbal ability in 4- and 5-year-olds. The distinction between the phonological loop and phonological awareness is particularly important, as it bears directly on current debates concerning the close association between these two measures (Siegal & Linder, 1984; Stanovich, Cunningham, & Cramer, 1984). According to one view, phonological memory and awareness measures tap a common underlying phonological processing construct (e.g. Bowey, 1996; Metsala, 1999; Passolunghi & Siegel, 2001). An alternative account is that although both these measures are constrained by the efficiency of phonological processing, they reflect distinct cognitive systems (e.g. Gathercole, Willis, & Baddeley, 1991; Hecht, Torgesen, Wagner, & Rashotte, 2001).

In the present article, we report data from a subset of 194 children participating in a large-scale study (Alloway *et al.*, 2004) for whom teacher-based assessments of progress towards learning goals in key learning domains were made using the Stockton-on-Tees Baseline Scheme. Together with most QCA-accredited baseline schemes, the Stockton on Tees Baseline Scheme involves class teachers rating the extent to which children have reached specific desirable learning goals as they enter school. For example, on the reading scale the teacher judges a child's ability to recognize simple letters and words, and on the mathematics scale the judgment relates to skills in recognizing numbers and carrying out simple mathematical operations.

The aim of the study was to investigate whether the links between aspects of working memory function and scholastic attainments established in the later school years (Gathercole & Pickering, 2000, 2001; Gathercole *et al.*, 2004; Jarvis & Gathercole, 2003) could be extended back to this earliest point in the child's school career. A further aim was to examine possible relationships between working memory skills and children's competence at school entry, as indexed by school baseline assessments. Preliminary evidence that working memory skills are related to baseline assessments of children's attainments has been provided by Gathercole, Brown, and Pickering (Gathercole, Brown, & Pickering, 2003; see also Taylor, Anselmo, Foreman, Schatschneider, & Angelopoulos, 2000).

Method

Participants

The 194 children participating in this study are taken from a larger sample for which data are reported in Alloway *et al.* (2004). The children attended reception class full-time in state schools in Stockton on Tees, an urban area of north-east England, and had a mean chronological age of 61.13 months ($SD = 2.6$, range = 52–68 months). In addition to providing consent for participation and access to the child's baseline scores, parents/guardians also supplied the following information: the number of years of the child's pre-school attendance, maternal educational level, and mother's age when leaving school. For the cognitive assessments, each child was tested individually in a quiet area of the school for three sessions each lasting up to 30 minutes.

Measures

Working memory

Complex memory involved three measures taken from the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001). In the backwards digit recall test, the child recalls a sequence of spoken digits in the reverse order. In the counting recall test, the child counts the number of dots in an array, and then recalls the tallies of dots. In the listening recall task, the child listens to a series of short sentences with a missing word at the end, produces a word to complete the sentence, and recalls the word they produced for each sentence in sequence.

Phonological short-term memory involved three measures: the digit recall test and the word recall test of the WMTB-C (Pickering & Gathercole, 2001), and the Children's Test of Nonword Repetition (Gathercole & Baddeley, 1996).

Episodic buffer involved two sentence repetition tasks, each consisting of 10 sentences. Full details of test materials are provided in Alloway *et al.* (2004). Accuracy of sentence repetition (1 for correct verbatim recall, 0 if any errors) was scored from the tape-recording.

Phonological awareness

The rhyme detection task from the Phonological Abilities Test (Muter, Hulme, & Snowling, 1997), and the initial consonant detection task (Byrne & Fielding-Barnsley, 1993) were administered. On each trial the child matched a target picture with one that shared the same rhyme pattern and same initial consonant, respectively.

Non-verbal ability

Two performance subtests from the Wechsler Preschool and Primary Scale of Intelligence-Revised (Wechsler, 1990) were administered: the block design task and the object assembly task.

Baseline assessment

Each child was evaluated using the Stockton on Tees Baseline Scheme (Stockton on Tees Local Educational Authority, 2001) within 6 weeks of school entry. This QCA-accredited scheme was developed by head teachers, reception teachers, and an early years adviser. The scheme assesses progress towards specialized learning goals in the areas of reading, writing, speaking and listening, mathematics, and personal and social development (see Table 1). The frequency with which a child achieves these goals is assessed; the number of goals ranges from 10 to 20 items across areas. For each item, the child receives a score of 0 (never), 1 (occasionally), or 2 (always). The total scores for each assessment subject are reported here.

Table 1. Abilities in a child that are assessed by the Stockton on Tees Baseline

In reading, a child should:	Be able to tell stories from pictures, Recognize simple letter sounds, Recognize simple words, Show an interest in books.
In writing, a child should:	Use and understand marks that are meaningful, Be able to write simple stories with an awareness of their audience, Communicate with accuracy in simple grammatical forms.
In speaking and listening, a child should:	Show an ability to listen and initiate conversation, Be willing to join group discussions, Be clear in their speech.
In mathematics, a child should:	Be able to identify, count, add, and subtract numbers 1-10 correctly, Identify similarities between objects and patterns, and 2D and 3D shapes, Have some knowledge of days of the week, time sequences and currency.
In personal and social development, a child should:	Have an interest in his/her environment, Order events, Distinguish similarities and differences in their environment, Seek solutions to problems, Engage in conversation about themselves and their family.

Results

Mean composite scores were calculated by averaging, for each construct, the individual scores of each contributing measure. Table 2 shows descriptive statistics for all variables.

The correlations between the composite scores for the cognitive measures and baseline assessments are reported in Table 3. Complex memory, phonological short-term memory, sentence repetition, and phonological awareness scores were highly associated with the baseline composite score (*r*s ranging from .47 to .52); the relationship between baseline scores and non-verbal ability was weaker ($r = .31$, $p < .01$). More specifically, complex memory, phonological short-term memory, sentence repetition, and phonological awareness scores were moderately highly associated with the reading, writing, speaking and listening, and mathematics baseline scales, with lower correlations in general between these four cognitive measures and the personal and social development scale.

For the full sample of 604 children from which the present participants were drawn, confirmatory factor analyses were carried out to explore the cognitive structure of the measures (Alloway *et al.*, 2004). The best-fitting model had a five-factor structure in which complex memory, phonological short-term memory, sentence repetition, phonological awareness, and non-verbal ability were distinct but associated latent constructs (see Fig. 1).[1] This model was used to guide the present investigation of the relationships between these cognitive constructs and baseline measures.

[1] *For this model,* $\chi^2(44) = 117.42$, $p < .001$; *CFI* = .96; *NFI* = .96; *RMSEA* = .05.

Table 2. Descriptive statistics of raw scores for the working memory, phonological awareness, non-verbal measures, and baseline assessments

Variable	Mean	*SD*	Range (min–max)
Complex memory span:			
Backward digit recall	4.42	3.18	0-14
Counting recall	8.53	2.95	0-17
Sentence completion and recall	11.94	5.06	0-28
Composite score	8.30	3.01	2-16
Phonological short-term memory:			
Digit recall	20.37	3.72	8-31
Word recall	14.61	3.09	0-23
Non-word repetition	18.44	6.51	1-34
Composite score	17.81	3.64	5-27
Episodic buffer:			
Sentence repetition set 1	6.76	2.20	0-10
Sentence repetition set 2	7.52	1.79	0-10
Composite score	7.14	1.78	1-10
Phonological awareness:			
Rhyme detection task	6.08	2.88	1-10
Initial consonant detection	7.88	2.12	2-10
Composite score	6.98	2.07	3-10
Non-verbal abilities:			
Block design	18.64	6.42	0-35
Object assembly	21.81	4.74	7-31
Composite score	20.23	4.69	9-32
Baseline assessments:			
Reading	10.93	3.86	1-20
Writing	7.51	3.42	0-18
Speaking and listening	11.66	4.80	0-26
Mathematics	20.03	7.24	3-37
Personal and social development	25.04	7.79	2-40
Composite score	15.04	4.66	3-26

Table 3. Correlations between composite scores for cognitive measures and baseline scores

Measures	1	2	3	4	5	6	7	8	9	10	11
1. Complex memory composite	–										
2. Phonological STM composite	.57	–									
3. Episodic buffer composite	.50	.63	–								
4. Phonological awareness ccomposite	.50	.57	.51	–							
5. Non-verbal abilities composite	.48	.33	.30	.29	–						
6. Reading	.43	.46	.46	.49	.33	–					
7. Writing	.34	.35	.31	.44	.21	.62	–				
8. Speaking and listening	.37	.47	.45	.46	.20	.66	.68	–			
9. Mathematics	.51	.49	.52	.49	.37	.75	.56	.78	–		
10. Personal and social d'ment	.34	.33	.40	.39	.20	.62	.55	.76	.63	–	
11. Baseline assessments composite	.47	.49	.51	.52	.31	.83	.75	.91	.89	.87	–

Note. All correlations are significant at the .01 level.

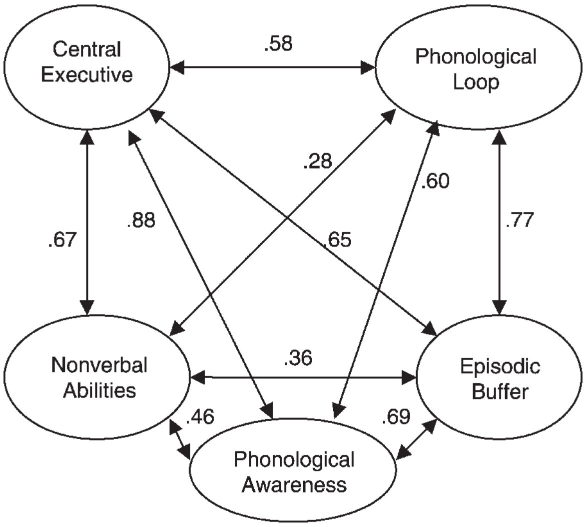

Figure 1. Summary of measurement model for Alloway *et al.* (2004). All factor loadings are significant at the $p < .05$ level.

A series of hierarchical regression analyses predicted each baseline scale. The first step always comprised external factors (age of child, number of years of the child's pre-school attendance, maternal educational level, and maternal age when left school) and the second step comprised non-verbal scores. The target set of variables was entered as the last step in the function, with the remaining tasks entered as the penultimate step. Table 4 summarizes the outcomes of these analyses.

Steps 1 and 2 (external factors and non-verbal ability) accounted for reasonably high proportions of variance (24.3% in total) in mathematics scores, but shared much weaker links with the other four baseline scores. With respect to the variables entered last, unique associations were found between the following: reading scores and phonological memory measures ($p < .05$); writing scores and both complex memory tasks and phonological awareness measures ($p < .001$ in both cases); speaking and listening scores and the phonological short-term memory measures ($p < .05$); mathematics and sentence repetition ($p < .05$); and personal and social development and sentence repetition ($p < .01$).

Discussion

Teacher-based assessments of children's progress towards key learning goals in the first few months of school were found to be strongly associated with many of the cognitive assessments conducted in this study. Teacher ratings of abilities in reading, speaking and listening shared unique links with phonological short-term memory ability, writing scores were uniquely associated with both complex memory span and phonological awareness performance, and both mathematics and personal and social development scores shared specific links with the sentence repetition measures. Non-verbal ability, on the other hand, was relatively weakly associated with the teacher assessments.

The study builds upon preliminary evidence relating working memory to baseline assessments reported by Gathercole *et al.* (2003), and provides new evidence concerning the cognitive skills that contribute to children's developing abilities at the point at which they enter school at 4 and 5 years of age. For some abilities, the data

Table 4. Hierarchical multiple regression analyses predicting each of the baseline-assessed skills

	Reading			Writing			Speaking and listening			Mathematics			Personal and social d'ment		
	R^2	change	F change	R^2	change	F change	R^2	change	F change	R^2	change	F change	R^2	change	F change
Step 1															
External factors	.083	.083	3.63*	.062	.062	2.64*	.048	.048	2.00	.170	.170	8.19**	.032	.032	1.34
Step 4															
CM tasks	.405	.011	0.90	.396	.080	6.52**	.353	.021	1.57	.517	.022	2.20	.313	.012	0.84
PSTM tasks	.405	.051	4.23*	.396	.027	2.18	.353	.035	2.70***	.517	.023	2.32	.313	.007	0.52
EB tasks	.405	.011	1.36	.396	.001	0.12	.353	.020	2.24	.517	.035	5.29*	.313	.057	6.12*
PA tasks	.405	.023	2.92	.396	.062	7.56**	.353	.014	1.63	.517	.010	1.46	.313	.021	2.31

CM = complex memory; PSTM = phonological short-term memory; EB = episodic buffer; PA = phonological awareness
***$p < .05$; *$p < .01$; **$p < .001$

reinforce previous findings from older children at more advanced levels of skill in the particular domain. In particular, phonological short-term memory scores were uniquely associated with ratings of proficiency in reading, consistent with many studies of reading ability in older children (e.g. Gathercole *et al.*, 1991; Hulme *et al.*, 2002; Swanson & Howell, 2001).

Teacher assessments of writing abilities, on the other hand, were linked specifically with performance on complex memory span tests. The cognitive underpinnings of early writing abilities have not been studied widely, although the developmental course of writing abilities at this age has recently been charted (Bourke & Adams, 2003; Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002; Sainsbury, Schagen, Whetton, & Caspall, 1999). In a recent classroom-based observational study of young children, writing was found to represent one of the most significant areas of difficulty for children with low complex memory span scores (Gathercole, Lamont, & Alloway, in press). These children made frequent errors, such as skipping and repeating letters and words, indicating that they frequently lost track of their place in the hierarchical structure of the task. Speculatively, these failures may have reflected poor central executive capacities that made the representation of task structure and updating progress within the task liable to errors. The present findings of specific links between complex memory performance and writing abilities at school entry suggests that the same constraints may also be operating at the earliest stage of writing.

Further support for this proposal that resources allocated to monitoring and processing information contribute to early writing skills can be drawn from the finding that these skills were also uniquely associated with phonological awareness. It has been suggested that the processing component of the central executive is involved in the encoding and storage of phonemes in phonological awareness tasks (e.g. Hecht *et al.*, 2001). It is possible that the executive memory function, also linked with performance in phonological awareness tasks, contributes to individual differences in writing.

Young children's speaking and listening abilities were uniquely linked with phonological short-term memory. This reinforces evidence for the specific role of the phonological loop in supporting the long-term learning of the phonological forms of new words in the course of vocabulary acquisition (Baddeley, Gathercole, & Papagno, 1998). The absence of a correspondingly specific association between speaking and listening and phonological awareness is consistent with the interpretation of the relationship in terms of a specific role for the phonological loop in learning (Baddeley *et al.*, 1998) rather than a more general contribution of a common phonological processing substrate (e.g. Bowey, 1996; Metsala, 1999).

The remaining two baseline scales, mathematics and personal and social development, were uniquely associated only with performance on the sentence repetition tasks, which we interpret as tapping the episodic buffer (Alloway *et al.*, 2004). This memory system has been suggested to integrate inputs from different short- and long-term memory systems in a multi-dimensional code. One possibility is that some of the mathematics skills tapped in the baseline scale, such as carrying out simple sums and comparisons of shapes, require the integration of learned knowledge (from long-term memory) with current information, and that successful performance requires the binding of these representations. Thus, children with relatively good episodic buffer function may be well placed to meet the complex tasks demands of these activities.

The basis of the corresponding link between sentence repetition ability and personal and social development scores is less easy to explain, particularly in the light of the finding that only 30% of the total variance in these scores was accountable in terms of age, external factors, and cognitive assessments in combination. The relatively weak relationship between these scores and the cognitive measures seems likely to be due partly to the fact that personal and social development is a more subjective area of assessment than the other, more scholastic, domains.

Finally, it should be noted that there was substantial variation in the baseline scores (35–50%) that was not explained by the cognitive measures. This seems likely to be due to multiple differences in the nature of the two types of assessment, including the degree of subjectivity (Singleton, Horne, & Thomas, 1999), and the extent to which they tap fluid cognitive ability rather than prior experiences in the home and pre-school environments (e.g. Dollaghan, Campbell, Needleman, & Dunlosky, 1997; Weismer *et al.*, 2000). In practical terms, the most accurate prediction of children's later likely achievement in school may, therefore, be achieved by combining ability-based and cognitive assessments to provide a well-rounded profile both of current abilities and future learning potential.

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Received 5 August 2003; revised version received 5 July 2004