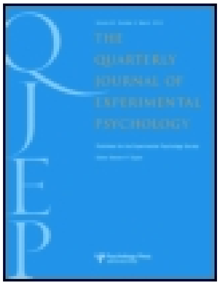

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# Deficits in verbal long-term memory and learning in children with poor phonological short-term memory skills

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# Deficits in verbal long-term memory and learning in children with poor phonological short-term memory skills

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Possible links between phonological short-term memory and both longer term memory and learning in 8-year-old children were investigated in this study. Performance on a range of tests of long-term memory and learning was compared for a group of 16 children with poor phonological short-term memory skills and a comparison group of children of the same age with matched nonverbal reasoning abilities but memory scores in the average range. The low-phonological-memory group were impaired on longer term memory and learning tasks that taxed memory for arbitrary verbal material such as names and nonwords. However, the two groups performed at comparable levels on tasks requiring the retention of visuo-spatial information and of meaningful material and at carrying out prospective memory tasks in which the children were asked to carry out actions at a future point in time. The results are consistent with the view that poor short-term memory function impairs the longer term retention and ease of learning of novel verbal material.

Close links have been established between children's capacities to retain verbal material in short-term memory and their abilities to learn novel phonological material in the course of both natural vocabulary acquisition and word learning in laboratory paradigms. The purpose of the present study was to assess the specificity of the association, by comparing the performance of children with very poor short-term memory function on a wide range of tests of longer term memory and learning of verbal, visuo-spatial, and semantic material. Findings of specific deficits in memory and learning of arbitrary verbal material would lend substantial support to claims that

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phonological short-term storage supports long-term phonological learning (Baddeley, Gathercole, & Papagno, 1998; Gathercole, 2006b).

Phonological short-term memory skills are commonly assessed using either serial recall measures such as digit span or by nonword repetition, in which the child is asked to repeat a previously unfamiliar phonological form such as *loddernaypish*, and the accuracy of the repetition attempt is scored (Gathercole, Willis, Baddeley, & Emslie, 1994). Performance on these tasks is widely considered to be mediated by the phonological loop component of the Baddeley and Hitch (1974; Baddeley, 1986) working-memory model. The phonological loop consists of a short-term store that holds material in a phonological code and is subject to rapid decay, the contents of which can be refreshed by a time-based subvocal rehearsal process.

There is substantial individual variation in phonological memory skills, particularly during the early and middle childhood years, and this variation is closely linked with children's abilities to learn new words (see Gathercole, 2006b, for review). Young children with relatively poor phonological memory skills but age-appropriate nonverbal cognitive abilities typically perform at low levels on tests of native language vocabulary (Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994). They are also slower to learn the sound patterns of new words under controlled experimental conditions than are their peers with typical short-term memory skills (e.g., Avons, Wragg, Cupples, & Lovegrove, 1998; Gathercole & Baddeley, 1989; Gathercole, Hitch, Service, & Martin, 1997; Michas & Henry, 1994). A corresponding association has also been established between phonological memory skills and the acquisition of foreign-language vocabulary (Masoura & Gathercole, 1999, 2005; Service, 1992; Service & Kohonen, 1995).

We have proposed that links between short-term memory and vocabulary learning reflect the role played by the phonological loop in the construction of the durable phonological representations of words in the mental lexicon (Baddeley et al., 1998; Gathercole, 2006b). The suggestion is that across multiple exposures to a novel phonological form, its structure is abstracted from the temporary phonological representation and forms the basis for its eventual lexical specification. Under conditions in which phonological storage is compromised, this gradual process abstracting a type representation from short-term phonological representations is likely to be relatively lengthy and error prone. Convergent evidence for this view is provided by findings that experimental conditions that impair phonological loop functioning—such as high degrees of phonological similarity and articulatory suppression—lead to poor learning of nonword forms (Papagno, Valentine, & Baddeley, 1991; Papagno & Vallar, 1992). It is also proposed that individuals with poor phonological storage skills will similarly be impaired in learning novel phonological forms.

One challenge for this view is provided by our recent study of children with very poor phonological memory skills but otherwise intact cognitive functioning between 5 and 8 years of age (Gathercole, Tiffany, Briscoe, Thorn, & the ALSPAC Team, 2005). Given the substantial developmental period over which the poor memory functioning of these children extended, a marked deficit in word learning was expected. Contrary to this prediction, the children performed at age-appropriate levels on measures of vocabulary and also on standardized tests of language processing and reading.

A possible explanation of these findings is that while phonological memory limits vocabulary acquisition during the earlier childhood years, its influence declines in older children. There is other evidence that storage-mediated learning is most important during the early stages of acquiring a language. In a longitudinal study of children aged 4 to 8 years, Gathercole et al. (1992) found that correlations between measures of phonological short-term memory and vocabulary scores declined from .56 to .28 across the duration of the study. A corresponding reduction in the association between short-term memory skills and vocabulary knowledge has also been documented in more advanced foreign-language learners (Cheung, 1996; Masoura & Gathercole, 2005).

Perhaps, then, relatively experienced language learners are able to use their substantial lexicons to mediate learning of novel phonological forms, rather than relying on the more basic phonological learning mechanism (Gathercole, 2006b). Lexically supported learning has the advantage of capitalizing on knowledge structures (which may be semantic, visual, or phonological in form) that have already been constructed. The greater the size of the lexicon, the more effective this scaffolding will be. Under learning conditions that do not favour the use of a lexical mediation strategy, however, even older word learners will need to fall back on the more primitive storage-mediated learning strategy (Atkins & Baddeley, 1998; Gupta, 2003; Service & Craik, 1993). Such conditions are exemplified by the use of novel phonological stimuli that share little correspondence to familiar lexical items (Papagno et al., 1991).

It should also be noted that exposure to the vocabulary of the native language is highly redundant, characterized by repeated encounters with new vocabulary items. With time and sufficient exposure, even children with poor phonological learning ability will succeed in forming the stable lexical representation of the sound of a new word. This may explain why even children with very low phonological-memory skills may eventually achieve age-appropriate levels of native vocabulary knowledge by the middle childhood years (Gathercole et al., 2005).

The present study investigated the hypothesis that although the native vocabulary knowledge of the low-memory children participating in the Gathercole et al. (2005) study was typical for their age, they did nonetheless have an underlying impairment in learning new verbal material that was caused by their weak phonological short-term memory that may not have been undetected in the standardized vocabulary assessments employed in that study. Data are reported here from the same groups of low-phonological-memory and comparison children, who also completed a range of assessments of long-term memory and multitrial learning. These tests included a variety of stimulus forms, ranging from nonwords, names, stories, spatial routes, and meaningless visual patterns, to faces. Multiple measures of prospective memory—the ability to remember to perform an intention at some point in the future—were also included. Prospective memory is fundamental to the organization and execution of goal-directed actions in everyday life and draws on both long-term episodic memory for the content of intentions and the higher level executive processes involved in forming, initiating, and executing the intentions (Einstein & McDaniel, 1996). The duration over which memory and learning performance was assessed varied across tests but in all cases, the nature of the assessment prevented the use of short-term storage to mediate performance due to the interpolation of other material between presentation and test.

Two paired-associate learning tasks from the Wechsler Memory Scales for Children (Wechsler, 1987) were included, in which the participants were presented with pairs of verbal items over successive trials. One set consisted of word–word pairs, half of which were semantically associated with one another (e.g., *baby–cries*) and half of which had low association values (e.g., *school–grocery*). The other set contained word–nonword pairs such as *house–tokramud*. It was predicted that the low-phonological-memory group should be relatively poor at learning the word–nonword pairs, as this condition involves the learning of novel phonological forms without the possibility of lexical mediation. There is already substantial evidence from studies of both children and adults that phonological memory constraints impair nonword learning in this paradigm (Baddeley, Papagno, & Vallar, 1988; Gathercole et al., 1997; Papagno & Vallar, 1992). In contrast, learning of pairs of already-familiar words is typically found to show reduced sensitivity to phonological storage constraints, presumably due to opportunities for semantic and other kinds of linkage between the items (Baddeley et al. 1988; Papagno et al., 1991). In the present study, semantic mediation would be expected to be most readily available for semantically associated word pairs.

The children also completed a test of repeated free recall in which a sequence of unrelated words was presented on four successive trials for immediate recall. Free recall, particularly under conditions where the list is re-presented on several occasions, shows evidence of organization reflecting the subjective use of categories and linkages between items to form chunks and enhance recall accuracy (e.g., Tulving, 1962). Due to the lexical nature of the memory items, it was expected that any potential contribution of temporary phonological storage would be minimal, overshadowed by the more powerful contribution of organizational factors to performance. Group differences were therefore not expected in this task.

Participants also completed two standardized tests of episodic memory, a longer term memory system than working memory, which retains information about experienced events for intervals spanning minutes to days and possibly weeks. The Doors and People Test (Baddeley, Emslie, & Nimmo-Smith, 1994) consists of recall and recognition measures of memory for verbal and visual stimuli. Distinguishing between recall- and recognition-based assessments of long-term memory is important, as the two kinds of remembering have distinct cognitive and neural mechanisms: Recall but not recognition is heavily dependent on medial temporal lobe structures including the hippocampal formation, deficits in which are associated with the amnesic syndrome (e.g., Baddeley, Vargha-Khadem, & Mishkin, 2001). The inclusion of these measures in the present study allowed us to explore whether the phonological loop also plays a significant role in the recall or recognition of verbal material in episodic memory. If this is the case, the low-phonological-memory group would be expected to show decrements relative to the comparison group on the verbal but not the visual measures.

The second measure of longer term memory was provided by the Rivermead Behavioural Memory Test for Children (Wilson, Ivani-Chalian, & Aldrich, 1991), a broad-ranging test of everyday memory spanning tens of minutes for materials such as faces, objects, names, stories, and spatial routes in paradigms that involved recall and recognition. Prospective memory is also assessed by requiring the child to remember belongings, appointments, and a verbal message. If the phonological loop does support longer term memory for novel verbal material, poorer performance of the low-phonological-memory group would only be expected in tasks that require the retention of verbal material and do not provide ready opportunities for nonphonological mediation. There are two verbal measures in the test—memory for a person's name and story recall. A new name such as *Katherine Taylor* is relatively unlikely to have been previously encountered by a child and consists of meaningless verbal content that cannot easily be recoded into a non-phonological form. In contrast, story recall is likely to be more strongly influenced by conceptual representations of the narrative structure and of activated lexical semantics. It was therefore predicted that the low-phonological-memory group would have selective difficulties only with the name recall task. In the story recall tasks and remaining nonverbal tests, their performance should be comparable with that of the comparison group.

Phonological awareness abilities were also tested in this study. There continues to be controversy about whether phonological short-term memory represents a distinct source of individual differences during childhood or is a manifestation of other underlying phonological processing and organization skills that are sometimes termed phonological sensitivity (Bowey, 1996, 2006; de Jong, 1998; Gathercole, 2006b; Metsala, 1999). The conflict between these alternative theoretical positions remains unresolved, due principally to the absence of techniques for assessing phonological memory that do not require phonological processing, or of measuring phonological awareness that do not impose significant memory loads. Despite these interpretational problems, measures of phonological awareness appropriate for the age of the children—involving the detection of phoneme oddities at the beginnings and ends of words—were included in the present study in order to provide the opportunity to explore the extent to which possible differences in phonological awareness between the groups are related to differences in their profiles of memory and learning.

## Method

### *Participants*

The participants were members of the Children in Focus study, a subgroup of approximately 1,000 children from the Avon Longitudinal Study of Pregnancy and Childhood (ALSPAC) *www.alspac.bristol.ac.uk*. Each child attended the Children in Focus clinic at 5 years of age where assessments included two measures of phonological short-term memory. The digit recall procedure involved the presentation of spoken sequences of digits for immediate serial recall, using the stimuli and method employed by Gathercole and Pickering (2000). Following a practice session, a maximum of four lists were presented at each length, starting with two-item sequences; if the first three lists at a particular sequence length were correctly recalled, the list length was increased by one. Items were presented at a rate of one every 750 ms. The number of lists correctly recalled by the child (with credit for three lists at a particular length being given if the child correctly recalls the first two) was scored. A test–retest reliability correlation coefficient for digit span of .68 was obtained in a study of 70 four- and five-year-old children (Gathercole, 1995). The Children's Test of Nonword Repetition (Gathercole & Baddeley, 1996) involves the spoken presentation (via an audio cassette) of 40 nonwords ranging in length from two to five syllables. The child attempts to repeat each nonword following its presentation, and the total number of nonwords correctly repeated is scored. The test–retest reliability correlation coefficient in a sample of five- and six-year-old children was .81.

A total of 926 children completed both memory tests. For each child, the $z$-score for each of the measures was averaged to produce a composite phonological short-term memory score. Poor phonological memory at 5 years was defined by the following criteria: (a) a $z$-score score equal to or less than $-1.33$ on at least one of the individual measures, and (b) a composite score equal to or less than $-1.00$. A total of 95 children met these criteria, and 85 of these were invited to attend a day of further testing at the University of Bristol at 8 years of age. Parents of 42 children gave consent to participation in this further individual testing session. The children completed seven tests from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). There were four measures of phonological loop function. Digit recall involves the presentation of spoken sequences of digits that the child is asked to recall in correct serial order. Lists constructed randomly and without replacement from the digits ranging from 1 to 9 are spoken by the tester, at the rate of one digit per second. Following a practice session, a maximum of six lists is presented at each length. List length is increased by one if the child recalls four lists at that length correctly. If the first four trials are correct, the child is credited with correct recall all six lists at that length, and the next list length commences. Testing commences with single-digit lists and continues until three lists of a particular length are recalled incorrectly. The number of lists correctly recalled is scored. The mean test–retest reliability coefficient for this measure is .81.

The span procedure outlined for the digit recall test is shared by all other tests in the Working Memory Test Battery. The word list recall and nonword list recall tests differ from digit recall only in the nature of the list items (words or nonwords). In each case, stimulus items are monosyllabic words with a consonant–vowel–consonant structure, and no stimuli are repeated. Items must be recall with full accuracy (i.e., with all three phonemes correct) and in the correct serial position. Mean test–retest reliability coefficients are .72 for word list recall and .56 for nonword list recall. The final phonological loop test was word list matching, in which two sequences of monosyllabic words are presented with a 2-s delay between the final item of the first sequence and the first item of the second sequence. On half of the trials the two sequences are identical, and on the remaining trials the order of a pair of words located randomly in the sequence is transposed in the second sequence. The child's task is to judge whether the sequences are the same or different.

Two complex memory span tests that reflect central executive functioning were also administered. In the listening recall test, the child listens to a series of short sentences, judges the veracity of each sentence in turn by responding "yes" or "no", and then recalls the final word of each of the sentences in sequence. Test trials begin with a single sentence and increase by a single sentence following the span procedure outlined above. The mean test–retest reliability coefficient for this measure is .61. The backward digit recall test is identical to the digit recall test in all respects except that the child is required to recall the sequence of spoken digits in reverse order. Practice trials are given in order to ensure that the child understands the concept of "reverse". The mean test–retest reliability coefficient is .62. The final measure was a test of visuo-spatial short-term memory: block recall. In this test, the child views nine wooden cubes located randomly on a board. The test administrator taps a sequence of blocks, and the child's task is to repeat the sequence in the same order. Testing begins with a single block tap and increases by one additional block following the span procedure outlined above. The mean test–retest reliability coefficient for this measure is .53.

A total of 16 children obtained standard scores of 85 or less on two or more of the four phonological loop tests and obtained standard scores calculated from raw scores on the Raven's Progressive Matrices test of nonverbal ability (Raven, 1986) in excess of 85. These children constitute the phonological memory deficit group and consist of 5 girls and 11 boys, with a mean chronological age at testing of 8 years 6 months ($SD$ = 1.69 months, range = 8 years 2 months to 8 years 8 months). As reported in Gathercole et al. (2005), this group at 4 years of age had a mean verbal IQ score of 87.96 ($SD$ = 12.68) and a mean performance IQ score of 99.63 ($SD$ = 9.69) on the Wechsler Preschool and Primary Scale of Intelligence–Revised UK (WPPSI-R[UK]; Wechsler, 1989).

A comparison group of children was also recruited from the cohort attending the Children in Focus clinic at 5 years. A total of 40 children, selected on the basis of composite phonological memory scores at 5 years great than −1.00, attended the University of Bristol for a one-day testing session at 8 years of age. A total of 16 of these children were matched as closely as possible with the phonological memory deficit group on age, sex, scores on the Raven (1986) nonverbal measure, number of years of schooling, and maternal education level. The mean verbal IQ score of this group at 4 years was 99.13 ($SD$ = 14.56), and mean performance IQ score was 100.87 ($SD$ = 10.75) from the WPPSI (Wechsler, 1989). These children constituted the comparison group reported in this article. The mean chronological age of the group was 8 years 4 months ($SD$ = 2.33 months, range = 8 years 0 months to 8 years 8 months).

Detailed demographic data are available for the children and their families. The mother's highest educational qualification at the time of initial recruitment to the Children in Focus study was recorded for the majority of the children and coded as 0 (no qualifications), 1 (CSE or GSCE grades D, E, F or G), 2 (qualifications in shorthand/ typing or other skills, e.g., hairdressing/ apprenticeships/City & Guilds intermediate technical), 3 (O-level or GCSE grades A, B or C), 4 (1 or more A-levels/registered nurse/City & Guilds final or full technical/teaching qualification), or 5 (university degree). The mean level of maternal education was 3.20 ($SD$ = 1.01) for the low-phonological-memory group and 3.13 ($SD$ = 0.83) for the comparison group.

### *Procedure*

Each child attended a one-day testing session in the Child Development Laboratory at the University of Bristol, accompanied by a caregiver. The session consisted of a wide range of cognitive assessments including the standardized measures of reading (Wechsler Objective Reading Dimensions, 1993), mathematics (Wechsler

Objective Numerical Dimensions, 1996b), and language (Wechsler Objective Language Dimensions, 1996a) reported by Gathercole et al. (2005). The children were tested individually in quiet room free from distractions. The long-term memory and learning tasks administered during this session are described below.

*Repeated free recall*. Each child received four trials of free recall of a 12-word list spoken aloud by the experimenter at the rate of 1 word every second. The words were all high-frequency items containing one or two syllables (*bed, car, country, door, food, girl, hand, money, mother, office, party, water*). Following each presentation, the child was asked to recall as many of the items from the list as possible, in any sequence. The same set of items was presented four times, in different randomized sequences in each case. The total number of items correctly recalled on each trial was scored.

*Rivermead Behavioural Memory Test for Children (Wilson et al., 1991)*. This test battery is designed to tap a range of different aspects of children's everyday memory abilities and takes approximately an hour to administer. In the Remembering a Name subtest, the child is told the name of a person shown on a photograph and is asked to remember the name later, prompted by the photograph. In the Remembering a Hidden Belonging subtest, a packet containing gold stars is hidden in the room, and the child is asked to remind the tester where they have been hidden, following a cue later in the session. In the Remembering an Appointment subtest, an alarm is set for 20 minutes later, and the child is told to ask the tester a question when the alarm rings. In the Picture Recognition subtest, the child views and names 10 line drawings of familiar objects and is then asked to identify these pictures from a set of 20 after a filled delay. In the Prose Recall subtest, the child listens to a short prose passage and is asked to remember as much as possible. Prompt questions are then asked. Credit is given for verbatim recall of story units and for recall of close synonyms. Memory is retested later after a delay. In the Face Recognition subtest, the child views a series of five pictures for 5 seconds each and states in each case whether the person is a man or a woman and whether the person is young, middle-aged, or old. The child is later asked to choose the 5 original faces from a set of 10 faces. In the Remembering a Route subtest, the tester traces a short route within the room, and the child is asked to retrace it. Memory for the route is retested later, after a filled delay. In the Remembering to Deliver a Message subtest, an envelope containing a message is placed in the route outlined above. If the child does not spontaneously pick up the message, he or she is prompted. Finally, in the Orientation subtest the child is asked 11 questions relating to themselves (e.g., *When is your birthday*? and *What is the name of your school*?) and the present time (e.g., *What month is it now*?).

Raw scores for each subtest are converted into standardized profile scores in which a score of 0 is classed as impaired, 1 is borderline, and 2 is normal. The standardized profiles scores are summed to produce a single score for which, at this age range, 20–22 is normal, 16–19 is borderline, and 0–15 is impaired.

*Doors and People Test (Baddeley et al., 1994)*. This test battery is standardized for use with adults, but employs simple procedures to measure the recall and recognition of long-term memory for verbal and visual material that are suitable for use with children. The battery consists of the four subtests outlined below and takes about 20 minutes to administer.

**Verbal Recall: People**. Stimuli comprise four forename/surname pairs (e.g., *Cuthbert Cattermole*), each presented on each of three learning trials. Each name is paired with an occupation and is presented to the subject as a caption to a coloured photograph for three seconds. The child is asked to recall the names using the occupation as a cue. Part names are scored 1, with a bonus score of 1 for correct recall of each full name (maximum score of 3 per name pair). The maximum possible score on the test is 36.

**Verbal Recognition: Names**. The stimuli for this subtest consist of two sets of 12 forename/surname pairs: one female and one male set. The learning phase for each set consists of the sequential presentation of each item written in black font on a white page. In the test phase, children are asked to select a target name from four names (including three foils) displayed in a vertical written list. Male and female sets vary in the ease of discrimination of the target surname from the foil surname, with the male name foils being most similar to the target pairs (e.g., *Matthew Brownlee* is a foil for *Matthew Brownhill*). The maximum possible test score (the number of correctly recognized names) is 24.

**Visual Recall: Shapes**. Stimuli for this test consist of four line drawings of schematic crosses. Initially, the child is asked to copy each shape. The copying attempts are then removed, and the child is asked to reproduce each cross from memory. One mark is given for the correct end features, one for the central features, and one for the overall shape, with a maximum score of three points per shape. Three learning trials are administered: Shapes are presented at a rate of one per second. If the child correctly recalls all stimuli on the first trial, testing is discontinued, and credit for all remaining trials is given. The maximum possible test score is 48.

**Visual Recognition: Doors**. The stimuli in this subtest consist of two sets of 12 colour photographs of doors. For each set, the 12 stimuli are presented in the learning phase for 3 s each, with an accompanying verbal description (e.g., *This is a barn door. This is a pub door*). In the test phase that immediately follows the learning phase, the child is asked to identify doors from one target and three foils presented in a 2 × 2 matrix. The recognition tests for the two sets vary according to the ease of discrimination of the target from the foils in the test phase (easy versus hard). In the hard test, the foils are not discriminable from the target on the basis of the verbal description. One point is given for each correctly identified target door, with a maximum possible total score of 24 points.

*Paired-associate learning*. Each child was tested in two main paired-associate learning conditions.

**Word–word pairs**. Children received eight pairs of familiar words on each trial, using the stimuli and procedure employed in the Paired-Associate Learning test of the Wechsler Memory Scale–Revised (Wechsler, 1987). The words in four of the pairs were highly associated with one another (e.g., *baby–cries*), whereas the other four pairs consisted of unrelated words of low association value (e.g., *obey–inch*). The following events took place on each of the six trials. The word pairs were spoken aloud by the experimenter in the learning phase, with the order of presentation of the pairs randomized across trials. Following presentation, the child was cued with the first word of each pair (again presented in randomized sequence) and was asked to recall the associated word. A cued delayed-recall trial was administered 40 minutes after the six initial learning trials. The numbers of response words in each of the high- and low-association sets of four words that were correctly recalled on each of the six initial trials and on the delayed trials were recorded for each child.

**Word–nonword pairs**. The word–nonword pairs were constructed for the purposes of the present study. The word items were matched for number of syllables, frequency of occurrence, and word type with the cue words in the word–word condition. The nonword items were matched for syllable length with the response items in the word–word condition and were selected as being low in rated wordlikeness. Paired-associate learning of word–nonword pairs followed the same procedure as that reported above for word–word pairs. The stimuli are listed in Appendix A.

*Phonological awareness*. Two tests of phonological awareness were given: onset oddity detection and end oddity detection. On each trial of the onset oddity detection task, the child viewed an array of four black-and-white line drawings each depicting a familiar monosyllabic word. The child's task was to identify the word that did not share the same initial phoneme as the three remaining items. On each trial, three of the four words belonged to a common semantic category; the odd word out was always a member of this category. A total of 4 practice trials preceded 12 experimental trials. The first 8 experimental trials used the stimuli constructed by Stuart and Coltheart (1988), such as *cow, cup, cat, dog*. A further 4 more difficult trials were added in which the child needed either to detect an initial consonant cluster versus no cluster (e.g., *twenty, ten, twelve, twig*) or to differentiate initial consonant clusters (e.g., *climb, creep, crawl, crow*). Stimuli are listed in Appendix B.

The end oddity task developed by Kirtley, Bryant, Maclean, and Bradley (1989) was also administered to each child. Children received two practice trials, and eight experimental trials were given, in each of which the experimenter spoke aloud three familiar consonant–vowel–consonant (CVC) words, each of which shared a common vowel and two of which shared a common consonant (e.g., *hat, fat, man*). The child's task was to identify the word that did not share the common final consonant. The number of correct trials was scored for each child.

## Results

Table 1 provides descriptive statistics for the short-term memory, phonological awareness, reading, mathematics, language, and nonverbal ability measures. The standard scores of the two groups on the short-term memory tests (with a mean of 100 and standard deviation of 15) and raw scores on the phonological awareness and nonverbal ability measures are summarized in Table 1. A multivariate analysis of variance (MANOVA) performed on the four phonological short-term memory test scores from the Working Memory Test Battery for Children (WMTB-C) established a highly significant group effect by Hotelling's *T*, $F(4, 27) = 10.814$, $p < .001$. The group difference in Children's Test of Nonword Repetition (CNRep) nonword repetition test scores was also significant, $F(1, 30) = 89.751$, $p < .001$. In both cases, the comparison group outperformed the low-phonological-memory group. A significant group difference was not, however, found in a corresponding MANOVA performed on the remaining three measures from the WMTB-C, $F(3, 28) = 1.447$, $p > .05$. The groups also did not differ significantly on Raven test scores, $F(1, 30) = 1.050$, $p > .05$. A further MANOVA established a significant group difference in scores on the phonological awareness tests, $F(2, 29) = 6.456$, $p < .01$, reflecting superior performance in the comparison group. In further MANCOVAs in which verbal IQ scores at 4 years were entered as a covariate, the group effects on both phonological short-term memory and phonological awareness scores remained significant: by Hotelling's *T*, $F(4, 24) = 8.050$, $p < .001$, and $F(2, 26) = 4.739$, $p < .05$, respectively.

Potential group differences on the attainment measures were explored in a MANOVA performed on the subtest scores from each of the measures of reading, mathematics, and language. The group effect was nonsignificant by Hotelling's *T*, $F(7, 23) = 1.870$, $p > .05$. However, examination of univariate *F*-tests established significant group differences on the following individual subtests: number operations, $F(1, 29) = 6.390$, $p < .05$, reading comprehension, $F(1, 29) = 6.653$, $p < .05$, and spelling, $F(1, 29) = 5.345$, $p < .05$. In each case, the significant terms reflected lower scores of the low-phonological-memory than the comparison group.

The performance of the two groups on the paired associated learning tasks is summarized in Figure 1, which shows recall accuracy of the two groups for the word–nonword and the word–word pairs, as a function of trial. Performance was generally poorer for the low-phonological-memory than the comparison group, a difference that was most marked over later trials in the word–nonword learning task. A three-way analysis of variance (ANOVA) performed on scores as a function of group, material (words, nonwords), and trial established significant main effects of group, $F(1, 30) = 9.527$, $p < .01$, materials, $F(1, 30) = 752.638$, $p < .001$, and trial, $F(5, 150) =$

**Table 1.** *Descriptive statistics for the short-term memory, phonological awareness, reading, mathematics, language, and nonverbal ability measures by group*

| | *Group* | | | |
|---|---|---|---|---|
| | *LPM* | | *Comparison* | |
| *Measure* | *Mean* | *SD* | *Mean* | *SD* |
| Phonological STM: | | | | |
| Digit recall | 80.10 | 5.05 | 103.43 | 14.10 |
| Word recall | 80.86 | 9.57 | 105.35 | 15.61 |
| Nonword recall | 76.61 | 12.18 | 102.65 | 18.83 |
| Word matching | 90.24 | 8.33 | 99.46 | 18.16 |
| Nonword repetition[a] | 7.25 | 4.77 | 21.50 | 8.36 |
| Other STM: | | | | |
| Block recall | 89.94 | 17.74 | 98.58 | 16.50 |
| Backwards digit recall | 91.25 | 12.36 | 98.11 | 23.80 |
| Listening recall | 97.62 | 12.80 | 105.72 | 12.69 |
| Phonological awareness: | | | | |
| Onset oddity | 8.87 | 2.06 | 10.75 | 1.37 |
| End oddity | 6.00 | 1.00 | 6.85 | 1.48 |
| Reading (WORD): | | | | |
| Basic reading | 99.88 | 12.62 | 109.93 | 14.06 |
| Reading comprehension | 98.31 | 10.72 | 108.73 | 11.96 |
| Spelling | 98.06 | 11.77 | 108.6 | 13.59 |
| Mathematics (WOND): | | | | |
| Number operation | 96.13 | 16.53 | 108.53 | 9.68 |
| Mathematical reasoning | 105.44 | 11.56 | 108.2 | 7.91 |
| Language (WOLD): | | | | |
| Oral expression | 103.00 | 9.24 | 102.6 | 5.56 |
| Language comprehension | 108.88 | 8.75 | 112.2 | 11.15 |
| Nonverbal ability[a] | 24.56 | 3.86 | 25.88 | 3.36 |

*Note:* Standard scores except where otherwise indicated. LPM = low phonological memory. STM = short-term memory. WORD = Wechsler Objective Reading Dimensions. WOND = Wechsler Objective Numerical Dimensions. WOLD = Wechsler Objective Language Dimensions.
[a]Raw scores.



149.10, $p < .001$. These terms reflected, respectively, the superior performance of the comparison than of the low-phonological-memory group, with word–word than with word–nonword pairs, and on later than on initial trials. The only further significant term that included group as a factor was the interaction between group, materials, and trial, $F(5, 150) = 2.952$, $p < .05$. This reflects the increasing decrement of the low-phonological-memory group over the later word–nonword trials. In an analysis of covariance (ANCOVA) performed on these data, the onset and end oddity detection measures of phonological awareness were entered as covariates. In this analysis, the main effect of group now declined to a nonsignificant level, $F(1, 28) = 3.381$, $p = .077$, and the three-way interaction between group, lexicality, and trial was also nonsignificant, $F(5, 140) < 1$.

A further ANOVA was performed on the delayed-recall scores as a function of group and material (word, nonwords). Significant main effects were found of both group, $F(1, 30) = 4.589$, $p < .05$, and materials, $F(1, 30) = 655.310$, $p < .001$, arising from, respectively, the superior performance of the comparison than of the low memory group and of word–word than of word–nonword pairs. The interaction between group and materials was nonsignificant,

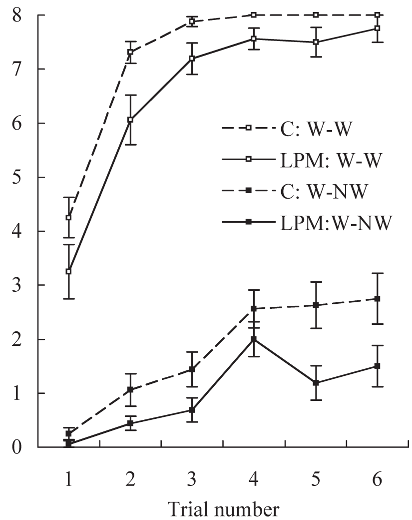


**Figure 1.** *Mean number of cued items recalled correctly as a function of group (LPM = low phonological memory, C = comparison), trial, and materials (word–word, W–W, and word–nonword, W–NW pairs), with standard error bars.*

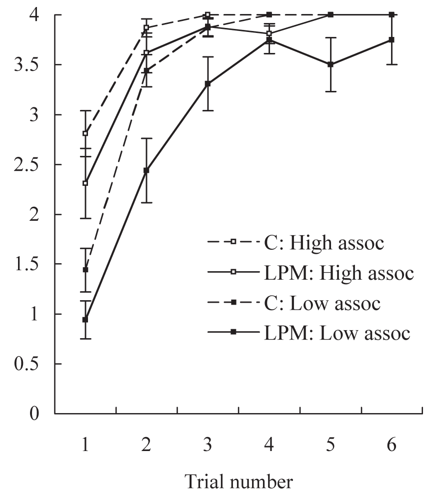


**Figure 2.** *Mean number of cued items in word–word pairs recalled correctly as a function of group (LPM = low phonological memory, C = comparison), trial, and materials (high and low association), with standard error bars.*



$F(1, 30) < 1$. When the onset and end oddity tasks were included as covariates, the main effect of group was nonsignificant, $F(1, 28) < 1$.

Figure 2 summarizes the learning performance on the word–word pairs as a function of the strength of association between the pairs, as well as both group and trial number. Learning is fast and accurate for the associated word pairs in both groups, with no differences in accuracy between groups, although the low-phonological-memory group scored more poorly on the low- than on the high-association word pairs. An ANOVA performed on the scores as a function of group, word type (high association, low association), and trial revealed significant main effects of group, $F(1, 30) = 5.630$, $p < .05$, association, $F(1, 30) = 36.674$, $p < .001$, and trial, $F(5, 150) = 127.356$, $p < .001$. Two interaction terms reached significance: group by association, $F(1, 30) = 4.250$, $p < .05$, and association by trial, $F(5, 150) = 16.578$, $p < .001$. Simple main effects analysis established that the former term arose from the presence of a significant group difference for the words with low associations, $F(1, 30) = 6.176$, $p < .05$, but not for the highly associated words, $F(1, 30) = 2.437$, $p > .05$. The association by trial interaction resulted from the reduction in the beneficial effect of high association value in later test trials. In the ANCOVA performed on these data that included the onset and end oddity measures as covariates, the group effect was nonsignificant, $F(1, 28) = 2.981$, $p = .095$.

An ANOVA was performed on the delayed recall scores as a function of group and association. All three terms in this analysis were significant: group, $F(1, 30) = 18.778$, $p < .001$, association, $F(1, 30) = 33.092$, $p < .001$, and group by association, $F(1, 30) = 13.855$, $p < .001$. The two main effects reflected, respectively, the higher scores of the comparison than the low memory group, and of the word pairs with high than with low associations. Simple main effects analysis established that the interaction term arose from a significant group difference (comparison group advantage) for the neutral pairs, $F(1, 30) = 6.176$, $p < .05$, but not the associated pairs, $F(1, 30) = 2.437$, $p > .05$. This group difference declined to a nonsignificant level in an ANCOVA in which onset and end oddity detection measures were entered as covariates, $F(1, 28) = 1.489$, $p > .05$.

**Table 2.** *Descriptive statistics for the measures of long-term memory, by group*

| *Measure* | | *LPM* *Mean* | *LPM* *SD* | *Comparison* *Mean* | *Comparison* *SD* |
|---|---|---|---|---|---|
| RBMT-C scaled scores: | | | | | |
| Verbal | Remember name | 1.31 | 0.95 | 1.88 | 0.50 |
| | Prose recall: immediate | 1.88 | 0.50 | 1.81 | 0.54 |
| | Prose recall: delayed | 1.88 | 0.50 | 1.56 | 0.81 |
| Spatial | Route recall: immediate | 2.00 | 0.00 | 2.00 | 0.00 |
| | Route recall: delayed | 2.00 | 0.00 | 1.94 | 0.25 |
| Prospective | Remember belonging | 1.25 | 0.58 | 1.38 | 0.62 |
| | Remember appointment | 1.75 | 0.58 | 1.81 | 0.54 |
| | Remember message | 2.00 | 0.00 | 2.00 | 0.00 |
| Recognition | Picture recognition | 2.00 | 0.00 | 2.00 | 0.00 |
| | Face recognition | 1.94 | 0.25 | 1.88 | 0.34 |
| Orientation | | 2.00 | 0.00 | 2.00 | 0.00 |
| Doors and People Test raw scores: | | | | | |
| People (verbal recall) | | 20.00 | 6.12 | 22.44 | 7.98 |
| Names (verbal recognition) | | 14.88 | 3.52 | 18.06 | 3.11 |
| Shapes (visual recall) | | 30.31 | 4.25 | 32.56 | 3.44 |
| Doors (visual recognition) | | 16.13 | 2.78 | 15.69 | 2.77 |
| Free recall raw scores: | | | | | |
| Trial 1 | | 4.44 | 1.71 | 5.69 | 1.92 |
| Trial 2 | | 6.81 | 1.56 | 7.69 | 2.02 |
| Trial 3 | | 7.63 | 1.78 | 8.44 | 1.75 |
| Trial 4 | | 8.44 | 1.86 | 8.94 | 1.44 |

*Note:* LPM = low phonological memory. RBMT-C = Rivermead Behavioural Memory Test for Children.

Table 2 summarizes performance of the two groups on the remaining memory tests. A MANOVA performed on the scores on the subtests of the Rivermead Behavioural Memory Test for Children as a function of group did not reveal a significant difference between groups, $F(7, 24) < 1$. Univariate $F$-tests performed on individual subtest scores did, however, establish a significant main effect of group on a single measure, the Remembering a Name test, $F(1, 30) = 4.418$, $p < .05$. In a subsequent multivariate analysis of covariance (MANCOVA), in which scores on the onset and end oddity measures were included as covariates, the group effect on the names subtest was nonsignificant, $F(1, 28) < 1$.

Scores on the Doors and People test were analysed in a MANOVA that included all four subtest scores. This analysis established a significant difference between groups, $F(4, 27) = 4.620$, $p < .01$. Univariate $F$-tests performed on the individual subtest scores established a significant group difference only on the Names test of verbal recognition, $F(1, 30) = 7.289$, $p < .05$. This term reflected the poorer performance of the low-phonological-memory group on this measure. In the MANCOVA performed on these data, including the onset and end oddity scores as covariates, the group effect on the Names test was marginally nonsignificant, $F(1, 28) = 4.078$, $p = .053$.

A further MANOVA was performed on the free-recall scores as a function of group and trial. The only significant term in this analysis was that of trial, $F(13, 90) = 55.41$, $p < .001$. The remaining terms were: group, $F(1, 30) = 2.898$, $p > .05$, and group by trial, $F(3, 90) < 1$. There was therefore no impairment in free-recall performance in the low-phonological-memory group.

## Discussion

The long-term memory and learning abilities of 8-year-old children with poor phonological short-term memory skills were investigated with the aim of establishing whether their immediate memory difficulties were accompanied by specific impairments in the retention and learning of new verbal material, in line with proposals by Baddeley et al. (1998) and Gathercole (2006b). Long-term memory and learning of a diverse range of material were tested, including spatial and conceptual material such as faces, patterns, and stories, and verbal information including nonwords, names, familiar words, and stories. Prospective memory for a variety of future actions was also assessed.

In comparison with an age-matched group of typical short-term memory abilities, the low-phonological-memory children were significantly impaired on a number of tests that required the storage of novel verbal material. In particular, they had difficulties in recalling the spoken names of unfamiliar people shown in photographs and in distinguishing the forename and surname combination of names previously from nonpresented foils. The group also failed to learn associations between word–nonword pairs over multiple trials to the same degree as the comparison group and had particular problems in learning associations between word–word pairs with low but not high semantic associations. These learning decrements persisted over a 40-minute delay. On all other tests, the performance of the low-phonological-memory group was similar to that of the comparison group. They were able to achieve comparable levels of performance on a task involving remembering a small set of new names accompanying photographs, re-presenting over multiple trials. The low-memory group also showed normal memory and learning of visuo-spatial information such as faces, patterns, and routes and was unimpaired in their retention of material mediated by conceptual representations, such as meaningful prose and lists of words presented over multiple trials for free recall. The prospective and recognition memory performance of the two groups was also equivalent.

The long-term memory and learning abilities of the low-phonological-memory group therefore closely mirrored their immediate memory profiles, with deficits in both cases found only with unfamiliar verbal material. This pattern of findings fits well with the proposal that the learning of novel phonological material such as new words and new names is mediated, in part at least, by the temporary storage of phonological representations associated with the phonological loop component of working memory (Baddeley et al., 1998; Gathercole, 2006b). According to this view, the phonological structure of novel phonological events is abstracted from the temporary phonological representations across multiple exposures to relevant tokens. In this way, learning will proceed more slowly and less efficiently in individuals with relatively poor phonological loop function, such as the group participating in the present study.

A further key finding was that the long-term memory and learning deficits of the low-phonological-memory group were eliminated when the children's scores on measures of phonological awareness were taken into account. The measures consisted of identifying which two words out of a set of three shared either an initial or a final consonant (Kirtley et al., 1989). These findings are consistent with claims that it is phonological sensitivity rather than phonological short-term memory that influences ease of language learning (Bowey, 1996; de Jong, 1998; Metsala, 1999). There continues to be a strenuous debate as to which of these factors is the underlying causal factor in this relationship (Bowey, 2006; Gathercole, 2006a, 2006b). Unfortunately, distinguishing between the phonological sensitivity and storage hypotheses is far from straightforward as the methods commonly employed for assessing phonological awareness themselves impose substantial loads on temporary storage. For example, the oddity detection paradigm requires the retention and systematic pairwise comparison of the phonological structures of three words, a process that is demanding of both the limited storage capacity and the temporal endurance of phonological short-term memory (Barrouillet & Camos, 2001; Towse, Hitch, & Hutton, 2002). The extent to which the elimination of group differences in phonological memory and learning in this study when scores on this task are taken into account reflects either the role played by an underlying phonological processing substrate or the sensitivity of the task to phonological storage constraints, or both, is therefore far from clear.

The low-phonological-memory children also obtained significantly lower scores than the comparison group on measures of reading comprehension and spelling and on the number operations test involving arithmetic calculations such as addition and subtraction. Thus although their standard scores fell well within the typical range for their age, there was some evidence that they were making slower rates of academic progress in reading and mathematics than were the comparison group. As the children have both poor phonological memory and phonological awareness skills, it is not possible to gauge to what extent their learning difficulties may arise from the two sources. Of the long-term memory and learning measures that we employed, the low-phonological-memory group were found to be impaired on only one measure involving written presentation—the name verbal recognition measure of the Doors and People Test (Baddeley et al., 1994). Poor reading abilities of the low-memory group therefore cannot account for the broad pattern of deficits in the retention of verbal material reported in this study.

It is important to note that the phonological-memory deficit group were only impaired on some but not all verbal tasks, performing at equivalent levels to the comparison group in the recall of the names of a small set of unfamiliar faces that were re-presented over multiple trials. The group were also unimpaired on a multitrial free-recall task in which a supraspan sequence of words was presented over four successive trials. Under such conditions, participants engage in strategic organization of the memory material, exploiting semantic associations as well as other links between items (Tulving, 1962). Differences between the groups in their capacities to store detailed phonological structure were therefore likely to have been overshadowed by the influences of more powerful strategic coding activities. Recall of stories in the Rivermead Behavioural Memory Test for Children (RBMT-C; Wilson et al., 1991) was also comparable in the two groups. This finding was predicted, as the thematic coherence and narrative structure of the stories would be likely to encourage reliance on the conceptual representations of the text to support the recall attempts rather than the phonological representations of the sentence forms (Potter & Lombardi, 1990, 1998). Weak phonological memory and learning abilities would therefore be expected to have little impact on performance on this task. However, it should be acknowledged that because the RBMT-C was designed primarily to identify deficits in children with neuropsychological impairments of memory, with the majority of children in both groups obtaining standardized scores of 2, classed as "normal", on most subtests. The measure may therefore lack sufficient sensitivity to detect relatively subtle variation in everyday memory abilities, although it was capable of detecting the substantial difficulties in learning the names of new faces in the low-phonological-memory group.

The low-phonological-memory group also showed normal rates of learning semantically associated word pairs. This task also provides rich opportunities for semantic mediation, and indeed performance on word–word learning tasks has consistently been found to be independent of phonological short-term memory constraints (Baddeley, Papagno, & Vallar, 1988; Papagno et al., 1991; Papagno & Vallar, 1992).

A further aspect of long-term memory investigated in this study was prospective memory: the ability to carry out intended actions at some point in the future. Across a range of tasks involving remembering to remind the tester to retrieve a hidden object, to ask a question in response to an auditory prompt, and to deliver a message, the two groups of children did not differ. Although performance on two of the measures—remembering an appointment and to deliver a message—was almost perfect, it is notable that the groups also did not differ on the remembering a belonging task, performance on which was considerably below ceiling levels. On balance, therefore, there is little evidence from this study that abilities to remember and perform intentions in the future is limited by phonological short-term memory abilities, consistent with the view that prospective memory is subject to multiple constraints that include executive processes as well as the long-term retention of the content of the intended action (Einstein & McDaniel, 1996).

In summary, the present findings provide an important qualification to our recent report that the same group of children performed at age-appropriate levels on standardized tests of vocabulary knowledge and language ability (Gathercole et al., 2005). It is clear that these children had subtle but significant difficulties in learning phonological or verbal stimulus forms that were previously unfamiliar to them. We suggest that the findings from these studies are consistent with the view that these individuals are indeed impaired in learning new phonological structures from temporary phonological representations, but that this is a primitive word-learning mechanism that is used most extensively in the early stages of acquiring a language. More experienced language users may be able to compensate for slow and relatively inefficient learning via this mechanism both by employing other strategies for word learning that capitalize on existing knowledge structures where possible and by capitalizing on the degree of redundancy in exposure to the native language. The adverse consequences for phonological learning will therefore only be uncovered in such individuals when the learning conditions prevent the operation of these compensatory factors. The impact of other possible contributory factors such as phonological sensitivity to this mechanism remains an important but unanswered issue.

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## APPENDIX A

Word pairs employed in the paired-associate learning tasks

| | *Word–word:* | *Word–nonword* |
|---|---|---|
| *Associated* | metal–iron | plastic–zirky |
| | baby–cries | person–woms |
| | rose–flower | squeeze–jorm |
| | fruit–apple | house–tokramud |
| *Neutral* | crush–dark | oak–piri |
| | school–grocery | seed–arge |
| | obey–inch | adapt–yok |
| | cabbage–pen | mushroom–usnat |

## APPENDIX B

Stimuli employed in onset oddity detection task

| *Trials* | *Stimuli* | | | |
|---|---|---|---|---|
| *Practice* | | | | |
| | bread | cake | crisps | cot |
| | key | comb | brush | clip |
| | foot | fish | leg | face |
| | bird | bee | bell | fly |
| *Test* | | | | |
| | cow | cup | cat | dog |
| | moon | sun | saw | star |
| | pink | blue | purple | pen |
| | pear | grapes | peach | purse |
| | spade | bone | bricks | ball |
| | shoe | sun | sock | shirt |
| | bed | bus | car | bike |
| | door | duck | dog | pig |
| | twenty | ten | twelve | twig |
| | stand | staple | sew | stick |
| | black | brown | blue | blind |
| | climb | creep | crawl | crow |