

The Children's Test of Nonword Repetition: A Test of Phonological Working Memory

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This article presents findings from the Children's Test of Nonword Repetition (CNRep). Normative data based on its administration to over 600 children aged between four and nine years are reported. Close developmental links are established between CNRep scores and vocabulary, reading, and comprehensive skills in children during the early school years. The links between nonword repetition and language skills are shown to be consistently higher and more specific than those obtained between language skills and another simple verbal task with a significant phonological memory component, auditory digit span. The psychological mechanisms underpinning these distinctive developmental relationships between nonword repetition and language development are considered.

INTRODUCTION

The Children's test of Nonword Repetition (CNRep) is described in this article. In this test, the child hears a single unfamiliar phonological item such as "barrazon", and attempts to repeat it immediately. The accuracy of the repetition attempt is scored for 40 such nonwords. Here, we provide an overview of findings arising from a research program that was designed to

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evaluate the use of this nonword repetition test as a means of assessing children's language skills. Normative data on the test are presented, based on a large sample of children aged between four and nine years. Links between test scores and a number of important aspects of language learning in children are also reported which establish the test's utility as a developmental indicator of language ability.

The task of repeating single nonwords is one that is particularly appropriate for use with young children. Throughout the course of childhood, many thousands of unfamiliar words are encountered by the child, who seems to be innately equipped with both a desire and a facility to learn new words (Carey, 1978; Rice, 1990). Exposure to unfamiliar phonological forms is a natural and common occurrence for the child. Furthermore, a frequent and spontaneous response by children to new words is to imitate them, and this strategy is believed to play an important role in facilitating natural vocabulary acquisition (Snow, 1981; Speidel, 1989). Nonword repetition therefore provides a convenient laboratory analogue of imitation in natural language situations, and it is probably for this reason that children as young as two years of age appear to have few difficulties in understanding the task demands of repeating an unfamiliar phonological form (Gathercole & Adams, 1993).

PREVIOUS USES OF NONWORD REPETITION

The nonword repetition paradigm has been widely used by psychologists over the past 15 years or so, and deficits in nonword repetition ability have been found in a variety of subject populations. Poor nonword repetition scores have consistently been found to distinguish groups of children of low reading ability from normal children of the same age and even from younger reading-matched controls (Brady, Mann, & Schmidt, 1987; Brady, Poggie, & Rapala, 1989; Brady, Shankweiler, & Mann, 1983; Kamhi & Catts, 1986; Kamhi et al. 1988; Snowling, 1981; Snowling, Goulandris, Bowlby, & Howell, 1986). The very low performance of reading-impaired individuals in repeating nonwords has been confirmed in detailed single case investigations of older dyslexic children (Campbell & Butterworth, 1985; Funnell & Davison, 1989; Hulme & Snowling, 1992; Snowling & Hulme, 1989). Impairments in nonword repetition have also been demonstrated in children with more general developmental language problems (Baddeley & Wilson, 1993; Gathercole & Baddeley, 1990a; Kamhi & Catts, 1986; Kamhi et al., 1988; Taylor, Lean, & Schwartz, 1989) and in adults with a history of unusual language development (Baddeley, 1993; Campbell & Butterworth, 1985; Funnell & Davison, 1989). Finally, nonword repetition deficits have been identified on several occasions in neuropsychological patients with acquired disorders of language processing (Baddeley, Papagno, & Vallar, 1988; Bisiacchi, Cipolotti, & Denes, 1989; Bub, Black, Howell, & Kertesz,

1987; Caramazza, Miceli, & Villa, 1986). Indeed, a selective impairment in repeating nonwords is one of the principal characteristics associated with the neuropsychological syndrome 'deep dysphasia' (Romani, 1992; Trojano, Stanzione, & Grossi, 1992).

There is compelling evidence that one of the major factors constraining nonword repetition performance is the capacity of the specialised verbal component of working memory, the phonological loop (Baddeley, 1986; Baddeley & Hitch, 1974). In each of the subject populations showing deficits in nonword repetition performance, impairments have also been found on conventional tests of phonological short-term memory such as digit span and immediate serial recall. Poor performance on such tasks is well-documented in children with poor reading development (for reviews see Gathercole & Baddeley, 1993a; Jorm, 1983; Wagner & Torgesen, 1987) as well as in individuals with more general disorders of language development (Baddeley & Wilson, 1993; Gathercole & Baddeley, 1990a; Campbell & Butterworth, 1985; Graham, 1980; Kirchner & Klatzky, 1985; Locke & Scott, 1979; Wiig & Semel, 1976). Impaired performance on conventional phonological memory tests also usually accompanies nonword repetition deficits in neuropsychological patients (Baddeley et al., 1988; Bisiacchi et al., 1989; Romani, 1992; Trojano et al., 1992). The association between nonword repetition and other phonological memory measures is therefore a very strong one. This pattern of strong association between nonword repetition ability and scores on well-established measures of phonological short-term memory has led us to believe that nonword repetition task is particularly sensitive to individual differences in phonological memory skill.

DEVELOPMENT OF THE CNRep

We first became interested in the task of repeating nonwords when studying a group of children with disordered language development (Gathercole & Baddeley, 1990a). The nonverbal intelligence of these children was within the average range for their age (the mean age of the group was eight years), but they had very poor language skills. On standardised tests of vocabulary, reading, and language comprehension, the children performed on average at levels appropriate for six year-olds, lagging nearly two years behind their own chronological ages.

As a preliminary investigation, the language-disordered children were tested on the Auditory Skills Test Battery (Goldman, Fristoe, & Woodcock, 1974). They performed particularly poorly on one subtest, Sound Mimicry, which involves the repetition of single unfamiliar phonological items. Although the mean chronological age of the children in this group was over eight years, their

mean performance age on this test was only four years. This deficit seemed large and potentially of theoretical importance, although we had reservations about some features of the test. There were unequal numbers of stimuli at each syllabic length: of the 55 stimuli in the test, there were 37 one-syllable nonwords, 14 two-syllable nonwords and 4 three-syllable nonwords. The stimuli themselves also provided cause for concern. Many of the multisyllabic stimuli have little natural syllabic stress contour; the syllables often contain consonant–vowel–consonant combinations whose initial and final consonants infrequently if at all combine with adjacent consonants at syllable boundaries in any other familiar words in spoken English. An example of this is the item “defnonlel”, in which the adjacent consonants “fn” and “nl” do not correspond to clusters that occur naturally in spoken English and which therefore cannot be coarticulated. The result is that such nonwords lack prosodic pattern and are difficult to articulate. One possibility is therefore that the language-disordered children may have failed to repeat such stimuli accurately simply because of their unusual articulatory demands.

We constructed a new set of nonwords which minimised articulatory output demands. There were 40 nonwords in the set, 10 each containing one, two, three, and four syllables. The phoneme sequences in each nonword conform to the phonotactic rules of English and within each number of syllables, the items were constructed to correspond to the dominant syllable stress patterns in English for words of that length (Chomsky & Halle, 1968). The stress structure of the syllables is strong–weak for the two-syllable nonwords, and strong–weak–weak for the three-syllable nonwords. No single stress pattern dominates for four-syllable English words, and this was reflected in the variable stress patterns in the nonword stimuli at this length. By constructing the stimuli in this way, the phoneme sequences within each nonword were all phonotactically and prosodically legal.

The performance of the language-disordered children on this new nonword repetition test was compared both with normal children of similar chronological ages and matched scores on a test of nonverbal intelligence, and with younger control children of matched language abilities. Once again, a dramatic impairment in the disordered group was found, indicating that the poor performance of the disordered group on the Sound Mimicry test was not simply a consequence of using nonword stimuli that were difficult to articulate. In fact, scores on the nonword repetition test perfectly discriminated the disordered children from their controls, with all of these children performing more poorly than the younger control group on the lengthiest stimuli in the test (see Fig. 1). As this test was also administered to a large cohort of normal children as part of a longitudinal study (Gathercole, Willis, Emslie, & Baddeley, 1992), age norms were available for comparison with the test scores for the language-disordered children. The test scores of the language-disordered children corresponded to

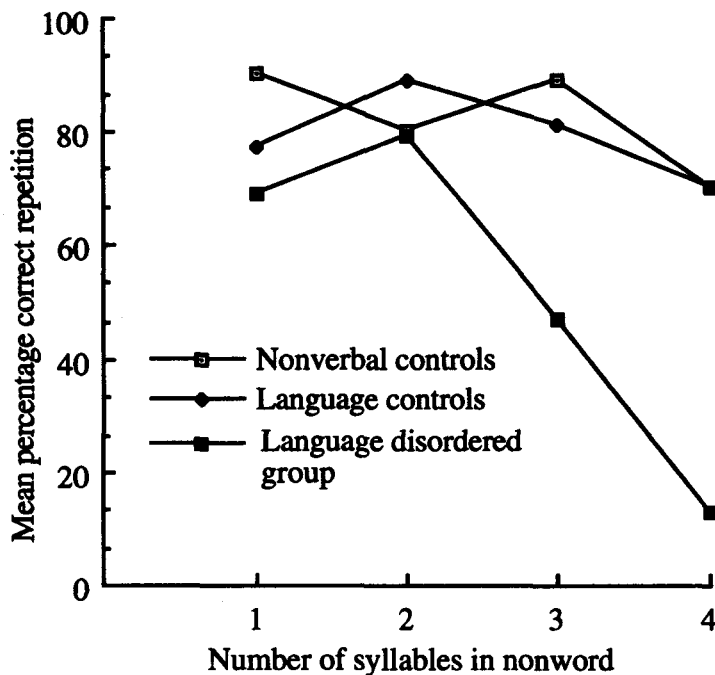


FIG. 1. Mean percentage of nonwords correctly repeated by the language-disordered group, and their nonverbal and language-matched controls, as a function of the number of syllables in the nonwords. Adapted from Gathercole & Baddeley (1990a).

those of normal four-year-old children, confirming the four-year deficit found with the Sound Mimicry test¹. Because the children had been selected on the basis of general language delay, these results suggested that nonword repetition ability and other language abilities go hand in hand.

¹ Subsequent comparison of scores on the Sound Mimicry test and the CNRep with unselected samples of children has established that the CNRep is a much more sensitive indicator of both vocabulary and reading development than the Sound Mimicry test. Gathercole & Baddeley (1989) tested 94 four-year-old prereading children on both the original version of the CNRep and the Sound Mimicry test. CNRep scores were highly associated with children's current scores on the British Picture Vocabulary Scales ($r=0.56$) and were also significantly correlated with the scores one year later, when the children were five years of age ($r=0.62$).

Corresponding correlations between Sound Mimicry scores and the vocabulary measures were significantly lower at both times: $r=0.30$ at age four, and $r=0.33$ at age five. A similar pattern of interrelations between measures emerged for the reading data, based on the single word reading test of the British Abilities Scales. Whereas scores on the CNRep at age four were highly associated with reading scores at both ages five ($r=0.44$) and six ($r=0.46$), scores on the Sound Mimicry test were not significantly correlated with reading achievement at either time ($r=0.17$ and 0.19 at ages five and six, respectively).

Much of the subsequent program of research has been designed to check the validity of these conclusions, and to develop a comprehensive account of why nonword repetition provides such a good indicator of a range of language skills. A revised version of the nonword repetition test has subsequently been developed, in which the one-syllable nonwords in the original version were replaced with five-syllable stimuli. There were two reasons for making this change. First, repetition scores for the one-syllable stimuli were less reliable than the other stimuli: they had low test-retest reliability, were less highly correlated with total test scores than the multisyllable stimuli, and also gave an unexpectedly low level of performance (see Gathercole, Willis, Emslie, & Baddeley, 1991, for more details). Second, the nonword repetition test as a whole needed to be made more difficult so that its use could be extended to older children.

The 40 nonwords and their standard phonetic transcriptions are shown in the Appendix. In administering the test, the nonwords are presented to each subject in randomised sequence. The data reported here were obtained by asking the child to listen to a cassette recording of a female speaker reading aloud the nonword sequence in a neutral English accent. On the recording, a three-second interval occurred between the end of one nonword and the onset of the next. It should be noted that in our experience, children's scores on the test are generally higher if they hear each nonword spoken by the experimenter (while covering the mouth in order to prevent the availability of additional visual gestural information) than if the recorded nonword sequence is used. This difference in repetition accuracy is presumably due to the improved acoustic quality of a live presentation. As a consequence, we do not recommend that the normative data for the CNRep should be used for direct comparison with test scores obtained with 'live' nonword presentation.

Each child is tested individually, and told that when the cassette recorder is switched on, a voice will say a "funny made-up word" which the child should try to repeat. The experimenter then gives an example of a nonword, and explains how the child should attempt to make the same sound. If the child appears to understand the instructions, the cassette recording is played. Usually, the three-second interval between nonwords provides sufficient time for the child to complete a repetition attempt. If an attempt is not made, the experimenter stops the cassette recorder and allows the child as much time as is needed to make the response. The child's repetition attempt is immediately scored by the experimenter as either phonologically incorrect or correct, with allowance being made for any regional accent or other cases where an individual is known consistently to pronounce one phoneme as another. The test is completed when the child has attempted to repeat the full set of 40 nonwords. Test administration typically takes no longer than three minutes. The total test score is provided by the number of correct repetition attempts made by the child (maximum=40). Separate scores for each of the syllable lengths are also calculated for each child.

The binary scoring procedure is coarse because we have developed the test for on-line administration and scoring, and there is not sufficient time for the test administrator to make more than such a simple decision. Deciding whether a child's response is phonologically correct or not can be difficult for some responses, due to the immature phonological systems of some children. For example, the average child cannot accurately produce the phoneme /k/ until about four years of age (Berry & Eisenson, 1956). Prior to this age, /k/ is often produced as /t/, a process known as 'fronting' in which the place of articulation is brought forward from a velar to an alveolar position (Grunwell, 1982). Using our scoring system, an incorrectly produced phoneme in the nonword repetition attempt will lead to an error being scored, unless the child is known to replace systematically the target phoneme with the error phoneme. So, the child's response "dommerine" to "commerine" would be scored as an error unless the test administrator had noted that the child consistently made this phoneme substitution. This procedure was introduced in order to prevent test scores being distorted by gross differences in articulatory abilities between children, although we readily acknowledge that without a prior systematic analysis of the individual child's phonological systems, this type of on-line correction for differences in speech production skills is inevitably approximate.

As a check on the reliability of the on-line binary scoring system, the nonword repetition attempts of 104 four-year old children on the first version of the test were recorded on an audio cassette recorder, and later scored independently by another experimenter. Scorers agreed on 97% of items (Gathercole & Baddeley, 1989).

Normative Data

The test was administered to a total of 612 children aged between four and nine years of age. A total of 481 children were sampled from schools in two urban areas of Lancashire (North-West England), 52 children from schools in a rural area of Yorkshire (North England), and 78 children from the city of Cambridge (South-East England). In all cases, the children participating in the study attended schools funded by the Local Education Authorities (i.e. they were state schools), and at least two schools were selected in each area in order to provide a representative cross-section of the local population. The children were tested on a complete class by class basis, yielding an approximately equal distribution of boys and girls. Because the sex of the child was not recorded in all cases, the precise distribution of boys and girls of each age participating in the study cannot be provided here.

Table 1 shows the centile points for each of the six 12-month age bands on the test. Scores show a regular developmental progression between the ages of four and eight years, with total scores increasing on average by between three and four points every year. Within year bands, the test scores were symmetrically

TABLE 1
Summary of Normative Data on the Children's Test of Nonword Repetition

Age range (years:months)	N	Mean	S.D.†	Centile points				
				10th	25th	50th	75th	90th
4:00-4:11	142	18.70	6.02	11	15	19	23	26
5:00-5:11	84	21.39	6.24	13	16	21	26	30
6:00-6:11	128	24.56	6.10	16	20	25	29	32
7:00-7:11	113	28.40	6.15	21	25	29	33	35
8:00-8:11	129	32.30	3.95	27	30	33	35	37
9:00-9:11	16	32.87	4.33	29	30	33	36	38

† Standard Deviation

distributed around mean values in close approximations to a normal distribution. It is notable that test scores did not increase in terms of mean values between eight and nine years of age, and also that the standard deviations at these ages were considerably smaller than those found between the ages of four and seven years. It may therefore be that the test is approaching a functional ceiling by eight years in normal children and that nonword repetition ability may develop very slowly beyond this age. However, the number of children tested at nine years of age was very small ($N=16$), and other investigators using the CNRep have found it to be sensitive to individual differences in children's language abilities as late as 10 years of age (Aguiar, 1993). The developmental limits on the sensitivity of the test have therefore yet to be identified.

Subtest scores at the four syllable lengths were also obtained for each subject, and these data are summarised in Fig. 2. Within each age band, repetition accuracy declined as a function of the number of syllables between syllable lengths two and four. This linear function corresponds closely to that found for an earlier version of the nonword repetition test over the same range of syllables (Gathercole, Willis, Emslie, & Baddeley, 1991). However, repetition performance was slightly but consistently better for the five-syllable than the four-syllable nonwords. This may be due to the distinctive morphemic constitution of the five-syllable nonwords. On a count of the total number of morphemes present within each nonword (including root, inflectional, and derivational morphemic forms), the mean number of morphemes was 0.9 for the two-syllable items, 1.2 for the three-syllable items, 1.7 for the four-syllable nonwords, and 2.4 for the five-syllable stimuli. This sizeable increase in number of morphemes with five-syllable items is due primarily to the prevalence of grammatical morphemes at this length: "altupatory", "confrantually", "defermentation", etc. The presence of these familiar morphological and phonological multisyllabic sequences, which are present in many words likely to be familiar to young children, may have offset the decline in accuracy of maintaining increasingly lengthy phonological sequences in working memory.

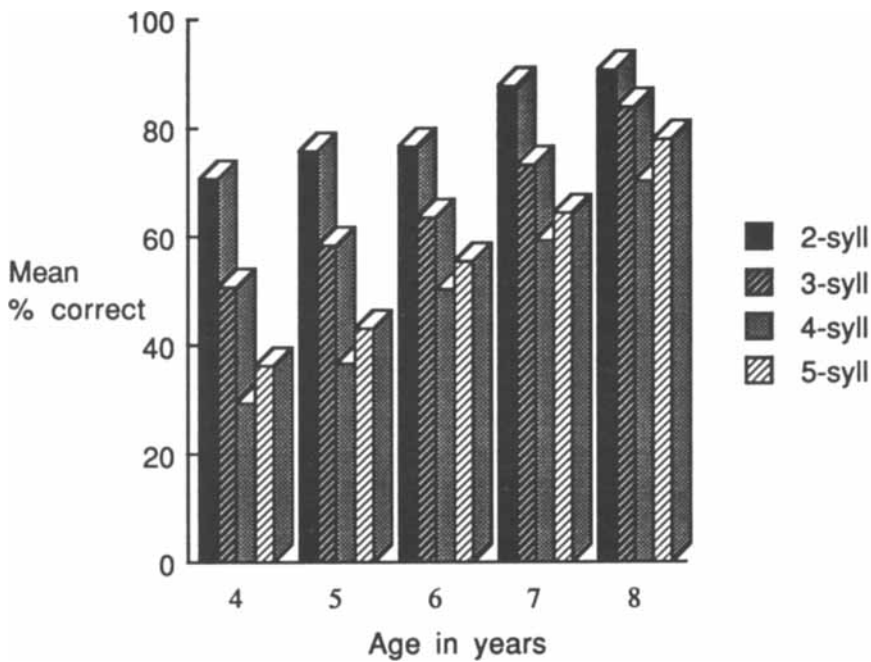


FIG. 2. Mean percentage of nonwords correctly repeated at each age as a function of the number of syllables in the nonwords.

Test-retest Reliability

Test-retest reliability of the CNRep was assessed by administering the test twice to 63 five-year old children and 25 seven-year old children, with a four-week period separating successive test administrations. The reliability of the measure across this period was high: the correlation coefficients for test-retest scores were 0.77 for the 5-year-old group and 0.80 for the 7-year-old group. These levels of reliability are satisfactory for psychometric purposes and it is notable that across this age range, there is little variation in the reliability of the test.

Errors in the CNRep

The data already reported were based on a binary scoring procedure in which repetition attempts were classified at the time of testing as either correct or incorrect. We undertook qualitative analyses of the errors made in nonword repetition by 27 four-year-old children. The children were selected on the basis of having either relatively low or high scores on the CNRep (one standard deviation above and below the means for an unselected cohort of 57 children, respectively), but for the present purposes of classifying the relative

frequency of different kinds of repetition errors, the data from both groups are combined.

Each child's repetition attempts were recorded on an audio cassette, and the recording was used as the basis for classifying the repetition errors. A similar classification of repetition deviations to that reported by Bisiacchi et al. (1989) was used. Most of the categories are applied to distortions of the nonword at the phonemic level. Substitutions occur when a target phoneme is replaced by a nontarget one, as in "glistering" → "gristering". (Note that although *glister*, meaning to glisten or glitter, is a word according to the *Oxford English Dictionary*, it was not in the authors' vocabularies when the test stimuli were constructed. For this reason, it seems unlikely that it will have been familiar to a significant proportion of the children who have been given the test.) The deletion category is used when a target phoneme is absent in the repetition attempt, as in "voltularity" → "volutarity". An insertion arises when an additional phoneme is inserted in the target phoneme sequence, e.g. "commerine" → "commegrine". The multiple phoneme error categories are composed of combinations of these single-phoneme error types. For example, "woogalamic" → "woogabramic" is a substitution plus insertion error. The response "woobalam" to the same nonword is a substitution plus deletion error, whereas "woogalam" represents a multiple deletion error. In addition, three other error categories were used: phoneme transpositions, e.g. "loddnapish" → "loddnaship"; lexicalisations, e.g. "trumpeting" in response to "trumpetine"; partial lexicalisations, e.g. "blonterstaping" → "blonterstating". These categories were not used exclusively: errors of these kinds were also classified into the single and multiple error categories outlined earlier.

The frequencies of occurrence of each class of repetition error are shown in Table 2. The most frequent errors were single phoneme substitutions, comprising 26% of the total repetition errors detected in this corpus. Other common errors were substitutions plus deletions (22%), single phoneme deletions (16%), multiple phoneme substitutions (12%), and multiple phoneme deletions (12%). Transpositions, lexicalisations and partial lexicalisations all had very low frequencies of occurrence within this error corpus, each representing only 1% of the repetition errors made.

THE CNREP AND OTHER LANGUAGE ABILITIES

Children's scores on the CNRep have now been shown to be closely related to several aspects of language skill. This section provides detailed information on the nature of the links between CNRep scores and three language skills—vocabulary acquisition, reading and comprehension—in children aged four and five years (Gathercole, Willis, & Baddeley, 1991) and eight years (Gathercole et al., 1992). In each case, the children participating in the studies were also tested on a widely-used index of short-term memory capacity, auditory digit span. This

TABLE 2
Mean Percentage of Each Type of Error of 5-year old Children
on the CNRep

	<i>Percentage of total repetition attempts</i>	<i>Percentage of total errors</i>
Single phoneme errors:		
Substitution	11	26
Deletion	7	16
Insertion	1	2
Multiple phoneme errors:		
Substitutions	5	12
Deletions	5	12
Insertions	0	1
Substitution & deletion	9	22
Substitution & insertion	3	7
Deletion & insertion	1	2
Other error categories:		
Transposition	1	3
Lexicalisation	1	2
Partial lexicalisation	1	3

Note that the single and multiple phoneme error categories are mutually exclusive. However, some single and multiple phoneme errors are also classified as either transpositions, lexicalisations, or partial lexicalisations.

provided the opportunity for direct comparisons of the relationships between language skills and scores on the two immediate recall measures. In these studies, digit span was calculated as the greatest list length at which the child correctly recalled two out of three lists of digits. The test–retest reliability of this method, with a four-week period separating successive test administrations, was 0.67 for 70 five-year-old children, and 0.70 for 25 seven-year-olds.

CNRep and Digit Span

Scores on the CNRep and auditory digit span test were highly and significantly correlated with one another at all three ages tested: at age 4, $r = 0.524$; at age 5, $r = 0.667$ (Gathercole, Willis, & Baddeley, 1991), and at age 8, $r = 0.445$ (Gathercole et al., 1992). This close relationship between the two measures is consistent with the view that the nonword repetition, like auditory digit span, is influenced by children's phonological memory skills. A question of particular theoretical and practical interest concerns which measure provides the best predictor of language abilities. In the sections to follow, correlations between both CNRep and digit span scores with aspects of language skill are reported for direct comparison.

Vocabulary

Across several studies, the relationships between scores on the CNRep and children's vocabulary knowledge in their native language were investigated. Both experimental and neuropsychological investigations of adults have provided evidence that phonological memory constrains the long-term learning of new phonological forms in experimental tasks (Baddeley et al., 1988; Papagno, Valentin, & Baddeley, 1991; Papagno & Vallar, 1992). Our primary concern was to establish whether children's abilities to maintain unfamiliar words over a short period (ie nonword repetition) are also linked with natural vocabulary acquisition. The measure of receptive vocabulary knowledge used in our studies is the Short Form of the British Picture Vocabulary Scale (BPVS; Dunn & Dunn, 1982). This test is standardised for the British population, and was developed from the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981). The BPVS is a receptive vocabulary test in which the subject's task is to identify which of four pictures corresponds to the target word spoken by the test administrator. The test items are ordered in increasing difficulty, and testing stops after four errors have been made on six successive items. A raw score is obtained for each subject, which can be translated into a standardised score. In all of the analyses using this test that are reported in this article, raw scores were used. The median reliability coefficient for the test, based on split-half reliability scores for three- to 17-year-olds, is 0.80. For the four- to nine-year-old age range sampled in our studies, the median reliability coefficient is 0.81.

Correlations between scores on the BPVS, the CNRep, and auditory digit span for samples of four-, five- and eight-year-olds are shown in Table 3. Significant correlations between vocabulary knowledge and nonword repetition

TABLE 3
Simple and Partial Correlations of CNRep and Digit Span Measures
with Scores on the BPVS Vocabulary Test

<i>Correlate with current vocabulary scores</i>	<i>Age 4¹ n = 57</i>	<i>Age 5¹ n = 51</i>	<i>Age 8² n = 80</i>
CNRep	0.413**	0.419**	0.284*
CNRep (with digit span partialled out)	0.397**	0.387**	0.151
Digit span	0.284*	0.376**	0.355**
Digit span (with CNRep partialled out)	0.107	0.122	0.266*

* $P < 0.05$

** $P < 0.01$

¹ Gathercole, Willis, & Baddeley (1991)

² Gathercole, Willis, Emslie, & Baddeley (1992)

ability were found at each age, although it is notable that the association between the two measures was stronger at ages four and five (with r s of 0.413 and 0.419, respectively) than at age eight ($r = 0.284$). A corresponding pattern of very strong association between vocabulary and nonword repetition measures during the early school years was also found for the original version of the nonword repetition test (Gathercole et al., 1992).

Table 3 also shows the correlations between digit span scores and the BPVS vocabulary measure. Span scores too were significantly associated with vocabulary knowledge at ages four, five, and eight, and although the correlation coefficients were lower at the two youngest ages than the corresponding ones for nonword repetition scores ($r = 0.284$ and 0.376 at ages four and five, respectively), they did not differ significantly from one another. An issue of particular interest concerns whether the CNRep and digit span scores share the same developmental relationship with vocabulary or not. One way of addressing this issue is by calculating partial correlations between vocabulary and CNRep scores, controlling for differences due to digit span scores. This provides an indication of whether nonword repetition ability shares a unique relationship with vocabulary knowledge above and beyond digit span scores. These partial correlations are also shown in Table 3. At both ages four and five years, the link between CNRep and vocabulary scores remained significant even after differences due to digit span scores had been statistically controlled. At age eight, though, when the simple correlation between CNRep and BPVS scores was, as already noted, at a lower level, the partial correlation was nonsignificant. In corresponding analyses of the links between the digit span and vocabulary measures, however, scores on the two tests fell to a nonsignificant level at ages four and five years when CNRep scores were partialled out. Note, though, that the corresponding partial correlation between digit span and vocabulary scores (adjusting for scores on the CNRep) was low ($r = 0.266$) but significant. The CNRep measure is therefore a stronger predictor of vocabulary knowledge than digit span during the early school years. Although the two immediate recall tests are highly correlated with one another, scores on the CNRep are more effective at discriminating vocabulary knowledge in these early years than are digit span scores.

Detailed analyses of the correlational structure of the nonword repetition and vocabulary measures in the longitudinal study have cast considerable light on the causal relationships underpinning the changing developmental associations between nonword repetition ability and vocabulary knowledge across time (Gathercole et al., 1992). Cross-lagged correlations between the two measures across the four waves of a longitudinal study were computed for the 80 children who contributed to these measures at each wave. The purpose of this statistical method is to identify the causal links between nonword repetition and vocabulary ability by comparing the forward associations between the measures across successive waves of the study. By the logic of cross-lagged correlations

(e.g. Crano & Mellon, 1978), there will be significantly greater correlations between measures across time in the hypothesised causal than non-causal direction. If, for example, a child's ability to repeat unfamiliar phonological forms directly constrains vocabulary learning, there should be a higher correlation between early nonword repetition scores and later vocabulary knowledge than between early vocabulary scores and later nonword repetition ability.

Figure 3 shows cross-lagged partial correlations obtained across the four waves of the longitudinal study. In computing these coefficients, age, nonverbal intelligence scores, and scores on the outcome variable one year earlier were partialled out in order to control for earlier converse influences (from 'outcome' to 'predictor' variable). This method provides a very conservative estimate of the forward links between measures across time. A clear pattern of developmental causal links emerged from this analysis. Between the ages of four and five years, nonword repetition ability exerted a strong causal influence on vocabulary knowledge (partial $r = 0.424$, $P < 0.001$); over the same period, earlier vocabulary scores did not predict later nonword repetition scores. The difference between these partial correlations was statistically significant ($P < 0.05$). Thereafter, however, it was the vocabulary measure that was the pacemaker in the developmental relationship. Vocabulary scores at age five were highly significant predictors of nonword repetition ability at age six (partial $r = 0.391$, $P < 0.001$), whereas repetition scores at five were statistically independent of the age six vocabulary measure. The same pattern of a stronger forward causal association between vocabulary and nonword repetition than vice versa was also found between six and eight years, although the strength of the association appeared to have diminished by this point.

These findings attest to a dynamic interactive relationship between nonword repetition ability and vocabulary learning. A child's abilities to retain unfamiliar

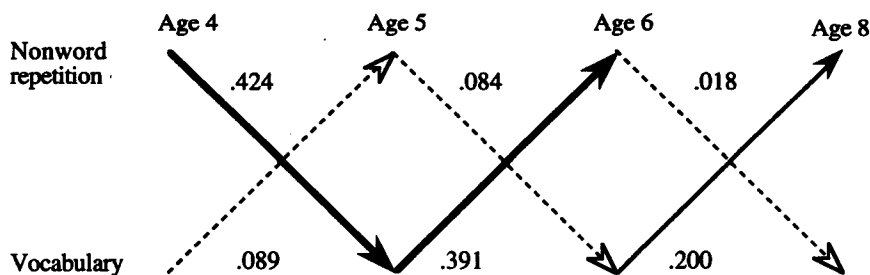


FIG. 3. Cross-lagged partial correlations (with age, nonverbal intelligence scores, and scores on the outcome variable one year earlier controlled) between CNRep and vocabulary scores. Lines shown in bold denote partial correlations that are significantly greater than the converse cross-lagged partial correlation. Broken lines reflect nonsignificant partial correlations. From Gathercole, Willis, Emslie, & Baddeley (1992).

sound sequences significantly limits the ease of learning new words up to the age of five years or so (see, also, Gathercole & Baddeley, 1990b). So, unsurprisingly, an individual who has difficulties in accurately repeating unfamiliar items immediately following presentation also encounters difficulties in learning a new phonological form, and hence in subsequently using that form as a vocabulary item. Beyond this age, however, the causal underpinnings of the relationship appear to shift, with the child's current vocabulary knowledge exerting an increasing influence on the accuracy of nonword repetition. Possible reasons for this shift are discussed in detail elsewhere (Gathercole & Baddeley, 1993a; Gathercole et al., 1992). One of the reasons for the emergence of vocabulary knowledge as the causal agent may be that children use their existing vocabulary knowledge to mediate the immediate repetition of nonwords (Gathercole, Willis, Emslie, & Baddeley, 1991). By this account, children with more extensive vocabulary knowledge are more likely to have access to long-term memory representations of familiar words that closely match the nonword, and hence are more accurate at repeating those nonwords (Gathercole & Adams, 1993).

However, findings from other studies have established that the developmental association between nonword repetition ability and word learning remains significant throughout middle and later childhood to adulthood. Using the CNRep test, Aguiar (1993) has shown that nonword repetition skills are closely related to the retention by 10-year-old children of newly-acquired words. Similarly, Service (1992) found that the accuracy of nonword repetition in nine-year-old Finnish children about to start learning English as a second language was an excellent predictor of their English vocabulary proficiency well over two years later. In combination with findings from the neuropsychological adult patient PV (Baddeley et al., 1988) discussed earlier, it is apparent that although the link between repetition ability and vocabulary learning may be strongest during the early school years, its significance extends into adulthood.

Reading

A further issue of interest is whether nonword repetition ability shares a developmental link with reading achievement. Findings reviewed earlier indicate that such a relationship might well exist. Impaired nonword repetition skills have consistently been shown to be characteristic of poor readers and children classified as dyslexic (e.g. Brady et al., 1983; Snowling, 1981). At the start of our studies, however, it was unknown whether the same developmental relationship extended to unselected samples of children: is reading achievement in normal children associated with their abilities to repeat unfamiliar forms?

This issue was addressed by assessing children's scores on the CNRep and their reading abilities, using Reading Test A of the British Abilities Scales (BAS, Elliott, 1983). This test involves the child reading aloud single unrelated

TABLE 4
Simple and Partial Correlations of CNRep and Digit Span Measures
with Scores on the British Abilities Scales Reading Test

<i>Correlate with current vocabulary scores</i>	<i>Age 4¹ n = 57</i>	<i>Age 5¹ n = 51</i>	<i>Age 8² n = 80</i>
CNRep	0.133	0.473**	0.439**
CNRep (with digit span partialled out)	0.056	0.343*	0.360**
Digit span	0.164	0.306*	0.295**
Digit span (with CNRep partialled out)	0.112	0.054	0.124

* $P < 0.05$

** $P < 0.01$

¹ Gathercole, Willis, & Baddeley (1991)

² Gathercole, Willis, Emslie, & Baddeley (1992)

words arranged in rows on a large reading card, and was administered to groups of four- and five-year-old children (Gathercole, Willis, & Baddeley, 1991) and to a further eight-year-old sample (Gathercole et al., 1992). The test is standardised for British children, and has a Hoyt reliability coefficient (a measure of internal reliability) of 0.98. Test-retest/alternate form reliability is 0.97. The findings with this test are summarised in Table 4.

Nonsignificant correlations were found between reading achievement at four years and scores on both the CNRep and a digit span test. However, very few children were able to read any of the words at this age, yielding a measure of very low sensitivity. By five years, however, both the CNRep and digit span were significantly correlated with BAS reading ($r = 0.473$ and 0.306 , respectively). With digit span scores partialled out, the correlation between CNRep scores and BAS reading remained significant (partial r of 0.343). When the nonword repetition scores were controlled, however, digit span scores were no longer significantly correlated with BAS scores. At eight years, a similar pattern of associations emerged. Although both nonword repetition and digit span scores were significantly correlated with the reading measure ($r = 0.439$ and 0.295 , respectively), only the repetition scores accounted for significant unique variance in reading. When digit span scores were partialled out, repetition scores had a partial correlation of 0.360 with the BAS reading measure. When repetition scores were taken into account, in contrast, the partial correlation between the span and BAS measures were nonsignificant. So, paralleling the vocabulary data reported in the previous section, the CNRep is a more powerful predictor of single word reading ability than auditory digit span.

In summary, scores on the CNRep and reading skills are closely related to one another between the ages of five and eight years, and the repetition test is a

better discriminator of reading skill than auditory digit span. The precise theoretical underpinnings of the relationships between nonword repetition and reading achievement have yet to be established (see Gathercole & Baddeley, 1993a; 1993b), although some possibilities can be ruled out. It seems unlikely that nonword repetition ability is simply a *consequence* of early reading success; using the earlier version of the CNRep, the repetition scores of four-year-old prereading children accounted for a further significant 10% of variance in reading achievement at age eight, even after differences due to age and intelligence were controlled (Gathercole & Baddeley, 1993b). It also appears unlikely that both nonword repetition and reading skills are simply byproducts of the child's linguistic development. Contrary to this hypothesis, the predictive relationship between nonreading nonword repetition scores and later reading achievement remains significant even when differences due to vocabulary knowledge are controlled (Gathercole & Baddeley, 1993b).

One hypothesis that is compatible with the available data is that children's phonological short-term memory skills constrain both nonword repetition and reading development. This view is certainly consistent with the close associations established between nonword repetition ability and conventional measures of short-term memory such as memory span. The linkage between short-term memory and the acquisition of literacy has been noted by many researchers (see Brady, 1991, and Wagner & Torgesen, 1987, for reviews). However, the precise locus of the contribution of short-term memory to reading development is not fully understood. Possibilities that have been considered are that short-term memory may be critical either in the long-term learning of grapheme-phoneme correspondences (Gathercole, 1990), or in the storage of the phonological segments prior to blending when a phonological recoding strategy is used (Baddeley, 1978). It is clear that more direct investigations are necessary to clarify the nature of the developmental relationship between phonological memory and reading. The impact of the finding of a strong predictive relationship between scores on prereading children on the CNRep and later reading achievement (Gathercole & Baddeley, 1993b) is to substantiate further the notion of a genuine unidirectional link between repetition ability and reading.

Comprehension

We have also explored whether there is a developmental association between nonword repetition ability and children's skills at understanding spoken language. There is already some evidence in support of such an association. First, the language-disordered children who we found to be so impaired at nonword repetition (Gathercole & Baddeley, 1990a) also had comprehension deficits; indeed, such deficits are one of the hallmarks of developmental dysphasia (Stark & Tallal, 1981). Second, there have been some reports that children of low reading ability, who also have poor phonological memory skills,

have difficulty in understanding spoken sentences (Crain, Shankweiler, Macaruso, & Bar-Shalom, 1990; Mann, Shankweiler, & Smith, 1984). Both of these findings are consistent with the notion that the comprehension of spoken language depends on the availability of a phonological memory representation of the sentence form that is used as the basis for its syntactic and semantic analysis. By this account, individuals with relatively poor phonological memory capacities will be less able to maintain a reliable representation of the phonological form of the sentence, and this will impede their higher-level analysis of its meaning. Detailed investigations of adults' comprehension have revealed that language understanding is only limited by phonological memory constraints for very complex and lengthy sentences (see Gathercole & Baddeley, 1993a, for review), and this has led to the widespread view that phonological memory representations of spoken language are necessary only to support the off-line processing of complex language structures (e.g. Vallar & Shallice, 1990). It is, however, entirely possible that phonological memory support for language comprehension plays a much more important role during childhood, while syntactic analysis skills are still under development (Martin, 1990).

Willis & Gathercole (1992) have investigated the relationship between CNRep scores and children's language comprehension ability. Comprehension ability was assessed using a test standardised for British children, Bishop's (1983, 1989) Test for the Reception of Grammar (TROG). The test consists of 20 blocks which increase in difficulty, each of which employs a particular type of grammatical contrast or construction. Within each block, there are four test sentences, and the child's task is to point to one of a set of four pictures which corresponds to a sentence spoken by the test administrator. An example of a test sentence located early in the TROG is "the cow is looking at them"; later sentences include "not only the bird but also the flower is blue" and "the circle the star is on is red". Testing stops after the child has made an error on five consecutive blocks, and the total number of blocks that the child has completed without error is scored. The mean split-half reliability coefficient (based on scores on odd and even blocks) for four- and five-year-old children on the TROG test is 0.785. Test-retest reliability data are not available for the test.

Correlations between TROG scores and scores on both the Children's Test of Nonword Repetition and auditory digit span are shown in Table 5, for groups of four- and five-year-old children. Nonword repetition scores were very highly correlated with the TROG measure at ages four and five, with coefficients of 0.404 and 0.593, respectively. The corresponding correlations between TROG scores and digit span were lower, but nonetheless significant: 0.295 for the four-year-olds, and 0.496 for the five-year-olds. The association between repetition and vocabulary scores remained significant after digit span scores had been partialled out, at both ages four (partial $r = 0.320$) and five (partial $r = 0.457$). The corresponding correlations between the digit span and vocabulary measures

TABLE 5
Simple and Partial Correlations of CNRep and Digit
Span Measures with Scores on the TROG Language
Comprehension Test

<i>Correlate with current vocabulary scores</i>	<i>Age 4 n = 57</i>	<i>Age 5 n = 51</i>
CNRep	0.404**	0.593**
CNRep (with digit span partialled out)	0.320*	0.457**
Digit span	0.295*	0.496**
Digit span (with CNRep partialled out)	0.130	0.132

* $P < 0.05$

** $P < 0.01$

Data from Gathercole, Willis, & Baddeley (1991)

were not, however, significant when adjustment had been made for scores on the nonword repetition test.

To summarise, children's abilities to understand spoken sentences are most closely linked with their skills at repeating nonwords than their digit spans at four and five years of age. So with language comprehension as well as vocabulary acquisition and reading development, the CNRep test provides a reliable indicator of language ability during early and middle childhood.

COGNITIVE PROCESSES INVOLVED IN NONWORD REPETITION

Phonological Working Memory

One of the main reasons for our interest in the nonword repetition paradigm is that it requires the temporary storage of an unfamiliar phonological sequence. The link between nonword repetition and phonological working memory is well established. Scores on the CNRep are closely associated with the most widely used measure of verbal short-term memory, auditory digit span. Furthermore, poor auditory digit spans typically accompany deficits in nonword repetition in poor readers (e.g. Brady et al., 1987), language-disordered children (e.g. Gathercole & Baddeley, 1990a), and neuropsychological patients (e.g. Baddeley et al., 1988). This close association fits well with the notion that nonword repetition, like digit span, is limited by an individual's phonological working memory skills.

According to the working memory model, the memory system specialised for this task of maintaining phonological information is the phonological loop. The loop consists of the *phonological short-term store*, which automatically holds

incoming auditory speech material in a phonological code, and a *subvocal rehearsal process*, which can be used to refresh the decaying representations in the phonological store (Baddeley, 1986).

Which of these components are used when a nonword is repeated? According to the model, auditory speech material achieves obligatory access to the phonological store, so it has to be assumed that the spoken form of the nonword achieves representation in the store. A more difficult question to answer concerns whether the nonword is rehearsed while being held in the phonological store. Children typically respond very rapidly in the CNRep, starting their repetition attempt almost immediately after they hear the target nonword spoken. Given that subvocal rehearsal is believed to operate in real time (Baddeley, Thomson, & Buchanan, 1975), it seems unlikely that the entire phonological representation is usually rehearsed prior to output, although the child may engage in partial rehearsal of the early segments of a nonword as it is being presented. There is also no obvious reason why the item should be rehearsed, given that the child is free to respond immediately by articulating the nonword, which is of course itself an explicit form of rehearsal. The available evidence therefore does not provide a sufficiently strong basis for drawing conclusions about the possible nature and involvement of subvocal rehearsal in nonword repetition.

Long-term Knowledge

It has become increasingly apparent during the course of our research program that the accuracy of repeating a nonword does not only depend on phonological memory capacity; in addition, children use their existing vocabulary knowledge to support nonword repetition, where possible. In a detailed items analysis of the CNRep, we found that nonword repetition accuracy in young children was highly correlated with the rated 'wordlikeness' of the nonwords, so that nonwords that were highly similar in sound structure to familiar words were most likely to be correctly repeated (Gathercole, Willis, Emslie, & Baddeley, 1991). This result and related findings (Gathercole & Adams, 1993) indicate that nonword repetition should not be interpreted as a strictly *nonlexical* task, particularly when the nonword stimuli are very similar to real words (Gathercole, submitted). Indeed, according to current models of spoken word recognition, lexical entries receive partial activation when perceived speech stimuli share common phonological structures, even if the stimuli are nonwords (e.g. Marslen-Wilson, 1987). Instead, nonwords vary on a continuum of phonological familiarity, with long-term memory contributions to nonword repetition being least for the most unfamiliar structures and most for the most familiar ones. The ways in which long-term lexical memory and temporary representations in the phonological loop can be combined to guide output are of theoretical importance, but are as yet little understood (for discussion of this issue, see, Hulme, Maughan, & Brown, 1991).

Phonological Analysis

There are also processes *prior* to storage in working memory and access to long-term memory which are also likely to constrain the accuracy of nonword repetition. The phonology of the target nonword has to be correctly perceived and analysed into its appropriate phonological constituents. This latter process of phonological segmentation has been suggested by other authors to be a major source of low levels of performance in nonword repetition in both poor readers (Snowling, 1981; Snowling et al., 1986) and normal children (Snowling, Chait, & Hulme, 1991).

In fact, it remains to be seen whether experimental techniques can be developed to distinguish phonological analysis from phonological memory processes. It is virtually impossible to design phonological processing tasks that do not require temporary phonological storage, and certainly impossible to construct auditory phonological memory tasks that do not involve phonological segmentation of the incoming speech information. More importantly, it is unclear whether phonological segmentation and phonological memory processes can be theoretically distinguished from one another, given that representations in the phonological loop are necessarily the direct products of these perceptual and analytic processes. Thus although it is practicable, and indeed desirable, to test for the presence of auditory sensory deficits via standard audiometric procedures as a possible cause of a child's unexpectedly poor performance on nonword repetition, both technical and theoretical problems are raised if attempts are made to discount phonological analysis processes as a possible source of the repetition deficit.

Output Processes

To repeat nonword accurately, the child also has both to form a plan of the articulatory movements that correspond to the stored phonological sequence and to execute this plan. This too represents a potential source of individual variation in nonword repetition performance which is quite independent of temporary memory storage (Snowling et al., 1991). Differences in articulatory output skills are likely to be particularly notable for children during the preschool years, who differ widely in the maturity of their phonological systems. However, by the age of four or five years it seems likely that for most children, production skills are more than adequate for nonword repetition, and that the most significant limits on repetition accuracy are set by memory constraints. Also, scores on the CNRep are sufficiently highly and consistently associated with measures of phonological memory such as digit span, which do not place the same robust demands on the child's articulatory skills to rule out any explanation of variation in nonword repetition ability in terms of output processes alone. Nonetheless, children with known deficits in speech motor programming and/or output will inevitably perform poorly in nonword repetition (Hulme & Snowling, 1992;

Snowling & Hulme, 1989). In such cases, memory deficits should not be assumed to be the primary source of the repetition problem.

SUMMARY

Scores on the Children's Test of Nonword Repetition presented in this article show highly specific links with three important language abilities—vocabulary acquisition, reading and language comprehension—during the early school years. These developmental associations are significantly stronger than the parallel links between the same language measures and two other phonological tasks—auditory digit span and a nonword repetition task using phonotactically illegal combinations. Consideration of the psychological mechanisms involved in nonword repetition reveals that the task involves phonological working memory, phonological analysis, and articulatory output processes. Findings also clearly demonstrate that stored lexical knowledge may also contribute to nonword repetition.

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APPENDIX

Nonword Stimuli in the CNRep

Two syllables		Four syllables	
Ballop	'baləp	Blonterstaping	'bləntə'steipɪŋ
Bannow	'bənəʊ	Commeecitate	'kəm'isəteɪt
Diller	'dɪlə	Contramponist	'kən'trəmpənɪst
Glistow	'glɪstəʊ	Empliforvent	empli'fɔvənt
Hampent	'həmpənt	Fenneriser	fend'raɪzə
Pennel	'pen!	Loddenapish	lɒdðneɪpɪʃ
Prindle	'prɪnd!	Pennerriful	pən'eri:f!
Rubid	'rubɪd	Perplisteronk	pɜ'plɪstəronk
Sladding	'sladɪŋ	Stopograttic	stɒpəgrætik
Tafflest	'təfləst	Woogalamic	wuɡə'læmɪk
Three syllables		Five syllables	
Bannifer	'bənɪfə	Altupatory	altʃu'peɪtəɪ
Barrazon	'bərəzən	Confrantly	kən'fræntʃuɪ
Brasterer	'bræstərə	Defermication	dɪfɜ'mɪ'keɪʃn
Commerine	'kəmərɪn	Detratapillic	dɪtrætə'pɪlɪk
Doppelate	'dɒpələɪt	Pristoractional	pɪstərə'ækʃən!
Frescovent	'freskəvənt	Reutterpation	rɪntə'peɪʃn
Glistering	'glɪstərɪŋ	Sepretennial	sɛprə'tɛnɪəl
Skiticult	'skɪɪkʊɪt	Underbrantuand	ʊndə'bræntʃuænd
Thickery	'θɪkəri	Versatrationist	vɜsət'reɪʃənɪst
Trumpetine	'trʌmpətɪn	Voltularity	vɒltʃu'lærɪti