Phonological Memory Deficits in Language Disordered Children: Is There a Causal Connection?

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The phonological memory skills of a group of children with disordered language development were compared with those of two control groups, one group matched on verbal abilities and the other matched on nonverbal intelligence. The language-disordered children were poorer at repeating single nonwords and recalling word lists than even the younger children of matched verbal abilities. The language-disordered children were, however, sensitive to both the phonological similarity and word length of the memory lists, except for the longest lists. The results of two further experiments indicate that the poor memory performance of the language-disordered children is unlikely to be due to either impaired perceptual processing or to slow articulation rates. Our proposal is that a deficit of phonological storage in working memory may underpin the poor memory performance of the language-disordered children, and could play a central role in their disordered language development.

Recent research suggests that working memory may be directly involved in the acquisition of language in children. Working memory skills have been found to be closely linked with important aspects of language development such as vocabulary acquisition (Gathercole & Baddeley, 1989a) and the acquisition of reading skills (e.g., Mann & Liberman, 1984). The present project develops the hypothesis that memory plays a central role in language development further, by evaluating whether impaired memory skills in children may result in developmental language disorders.

A central principle of the working memory approach is that the temporary storage of information may play an important role in a range of complex cognitive tasks such as learning, comprehension and reasoning.

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Baddeley and Hitch (1974) suggested that many short-term memory phenomena could be best conceptualized within a working memory framework. They proposed a system that had three main components: an attentional system known as the central executive, and two subsidiary slave systems. The visuo-spatial scratchpad was concerned with constructing and manipulating visual imagery, and the articulatory loop was specialized for the temporary storage of phonological material. The model has continued to be fruitful and is described in more detail by Baddeley (1986). One of the most actively investigated aspects of working memory is that of the articulatory loop, where a relatively simple two-component model has proved to be able to account for a range of experimental phenomena.

The current view of the articulatory loop is that it comprises a phonological store and an articulatory rehearsal process. Information can be registered in the phonological store either auditorily, or by subvocal rehearsal. Phonological representations within the store are assumed to fade within about 2 s unless refreshed by rehearsal, a process which operates in real time, with
long words taking longer than short. This simple model is able to account for a relatively complex pattern of experimental results including the effects on memory of phonological similarity (Baddeley, 1966; Conrad, 1964), unattended speech (Salame & Baddeley, 1982), word length (Baddeley, Thomson, & Buchanan, 1975), and articulatory suppression (Baddeley, Lewis, & Vallar, 1984). In fact, though, recent research suggests that overt articulation is not necessary to setting up the rehearsal process (Baddeley & Wilson, 1985; Bishop & Robson, 1989). For this reason in the present paper, the more neutral term “phonological memory” will be used to denote the phonological component of the working memory system.

While this model of phonological memory gives a simple and coherent explanation of this relatively complex pattern of laboratory findings, the question remains as to whether this system is of any great significance in cognition outside the laboratory. Although the model has proved successful in accounting for the memory deficits of neuropsychological patients (e.g., Vallar & Baddeley, 1982), such patients often appear to cope in everyday life with remarkably few problems except in the linguistic processing of very complex linguistic material (Baddeley, Vallar, & Wilson, 1987).

Impairments of working memory may, however, have disastrous consequences for the learning of novel verbal material. Baddeley, Papagno, and Vallar (1988) showed that a patient with a highly specific short-term phonological memory deficit was unable to acquire vocabulary items in a new language, despite being unimpaired in learning to associate pairs of familiar words. This finding suggests that the phonological loop system may be more directly involved in phonological long-term learning than in the operation of language skills that, by adulthood, are fully developed. Based on this idea, the hypothesis that guided the present project was that the phonological component of working memory may be crucial to the acquisition of language abilities in children.

Phonological memory seems to be involved in the acquisition of vocabulary during childhood. By the age of 6, most children have vocabularies of more than 2000 words (Smith, 1926); for each word, the child must have a stable representation of its phonological form. Recent findings suggest that the phonological loop is involved in the process of constructing this stable phonological representation. In a longitudinal study of a large normal cohort of 4- and 5-year olds, Gathercole and Baddeley (1989a) found that children’s scores on a test of phonological memory—immediate nonword repetition—at both ages 4 and 5 were highly associated with their receptive vocabulary scores, even after the contribution to vocabulary achievement of nonverbal intelligence and age had been taken into account. Phonological memory scores at age 4 were also a good predictor of vocabulary scores one year later, when the children were aged 5.

Children of high and low phonological memory skills from this longitudinal sample—but matched nonverbal intelligence—also took part in an experiment designed to simulate natural vocabulary acquisition (Gathercole & Baddeley, 1989c). In this study, the children’s task was to learn names of a set of four toys. The low-memory group took significantly longer to learn unfamiliar names than the high-memory group, and speed of learning was found to be more highly associated with the memory score than measures of nonverbal intelligence, vocabulary, or reading. The results from these two studies indicate that phonological memory skills in children may play a central role both in natural vocabulary acquisition, and in tasks requiring explicit name learning.

There is also considerable evidence linking phonological memory skills to early reading achievement. Phonological memory scores of young children entering school are significantly associated with
reading achievement one year later (Mann, 1984), and children of low reading skill typically have poor verbal memory abilities (see Wagner & Torgesen, 1987, for review). As yet, the precise nature of the contribution of phonological memory to reading development is not known, although we have findings which suggest that phonological memory processes are particularly critical at the time when the child is learning and applying simple letter–sound correspondences (Gathercole & Baddeley, 1990a).

The findings reviewed above suggest that the phonological component of working memory may be directly involved in at least two important aspects of language acquisition in children—vocabulary development and the acquisition of early reading skills. A simple prediction follows from this interpretation: children with impaired phonological memory skills should experience problems in vocabulary development and learning to read. This hypothesis was tested in the present study, which provides a detailed evaluation of the phonological memory characteristics of children with disordered language development.

Children with deficits in aspects of language development (such as reading, vocabulary, and comprehension) but with normal nonverbal intelligence are typically described as having a developmental language disorder. A large body of research has documented the multiple verbal and cognitive deficits of language disordered children (e.g., Aram & Nation, 1975; Benton, 1978; Tallal & Piercy, 1975). Most critically for the present purposes, a few studies have indicated that language-disordered children have impaired short-term memory skills (e.g., Graham, 1980; Kirchner & Klatzky, 1985; Wiig & Semel, 1976). A number of questions remain, however, about the nature of the memory deficits associated with language disorders. First, it is not clear what components of working memory are impaired in language disordered children. Second, it is not known as yet whether the poor memory skills of language disordered children relative to age-matched controls of normal language are nonetheless appropriate for their language abilities. If they are, the memory deficits can be simply explained as a consequence of delayed language development, rather than a cause of it.

The aim of the present study was to provide answers to these questions. A detailed assessment of the phonological memory characteristics of a group of language-disordered children was carried out, using the memory techniques developed in the context of the current working memory model. In each experiment, the memory performance of the language-disordered children was compared both with the performance of children of comparable nonverbal mental age and younger children of normal language, matched on reading and vocabulary abilities. If the language-disordered children are found to have even poorer phonological memory skills than their matched verbal controls, the possibility that their poor working memory skills are merely a consequence of their immature language development could be ruled out. This result would lend strong support to the view that impaired phonological memory skills play a central role in developmental disorders of language development.

**Subjects**

The language-disordered group consisted of six children, three boys and three girls, who were attending a Local Education Authority Language Unit in Cambridgeshire. Each child had been classed by a team of educational psychologists and speech therapists as having disordered language development but general intellectual abilities within the normal range. Case notes where available reveal histories of slow progress at acquiring language and, for the majority of the group, language problems had received professional attention by the time the child was aged 3. Hearing problems had been ruled out for each child included in this project. At the beginning of the study,
the chronological ages of these children ranged from 7:02 to 8:10 years. One child was unavailable for part of the testing period, and only participated in Experiments 2 and 3. In the remaining studies, data from only five children in each group are reported.

A range of standardized psychometric tests were administered to each child assigned to the language disordered group. On each test, the performance age corresponding to the score obtained by the child was calculated. The mean age-equivalent scores of the language disordered group on each of the standardized tests are shown in Table 1. The age-equivalent scores of the two groups of control children on the standardized tests are also shown in the table. Each child in the language disordered group was matched as closely as possible with one control child of equivalent nonverbal intelligence and with one verbal control child, the matching being based on the vocabulary, reading, and nonverbal tests described below. The control children all attended Local Education Authority schools in Cambridge.

Receptive vocabulary was assessed by the Short Form of the British Picture Vocabulary Scale (Dunn & Dunn, 1982). Reading abilities were tested by administering the reading test of the British Abilities Scales (Elliott, 1983). Oral comprehension was tested using Bishop's (1982) Test for Reception of Grammar. Nonverbal intelligence was tested using Raven's Coloured Progressive Matrices (Raven, 1984).

The language-disordered group had a mean disparity between performance age and chronological age of 20 months on the vocabulary test, 20 months on the reading test, and 18 months on the comprehension test. Of the six children, all showed deficits equivalent to more than one year in reading, and only one child had a deficit of less than 12 months for the vocabulary and comprehension test. On the measure of nonverbal intelligence, though, the mean score across the group was only one month less than expected on the basis of chronological age, and no child had a deficit of more than 10 months. Thus, these children fit well the classic characterization of disordered language development as a selective impairment of language skills.

An estimate of the range of memory skills of the language disordered group was obtained by administering selected subtests from the Goldman-Fristoe-Woodcock (1974) Auditory Skills Test Battery. Each of the subtests has standardized norms for a wide range of chronological ages. There was a general tendency for performance of the group to be impaired relative to the standardized norms, but the deficits were particularly dramatic for two particular subtests.

On the Memory for Sequence tests, a list of unconnected words ranging from two to seven items in length is presented auditorily. The child is then given a set of pictures corresponding to the words in the list, and is required to order them in the same sequence as the spoken list. This is essen-

<table>
<thead>
<tr>
<th>Measure</th>
<th>LDG</th>
<th>Verbal controls</th>
<th>Nonverbal controls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chron. age</td>
<td>8:06 (0:08)</td>
<td>6:06 (0:06)</td>
<td>7:08 (0:06)</td>
</tr>
<tr>
<td>Vocabulary AE</td>
<td>6:10 (1:06)</td>
<td>6:08 (1:05)</td>
<td>7:11 (0:10)</td>
</tr>
<tr>
<td>Reading AE</td>
<td>6:10 (0:08)</td>
<td>6:08 (0:09)</td>
<td>8:08 (1:08)</td>
</tr>
<tr>
<td>Comprehension AE</td>
<td>7:00 (1:00)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Nonverbal AE</td>
<td>8:04 (0:11)</td>
<td>6:05 (0:08)</td>
<td>8:04 (0:10)</td>
</tr>
</tbody>
</table>

Standard deviations in years; months are shown in parentheses.
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tially equivalent to a measure of verbal memory span with response by pointing, a procedure often used in testing young children (Conrad, 1972; Hitch & Halliday, 1983). Large disparities between performance and chronological age of the language disordered group were found on this test, ranging in magnitude from -11 months to -50 months, with a mean disparity of 32 months.

The Sound Mimicry subtest involves the child repeating back unfamiliar phonological forms—nonwords—one at a time after the test administrator. The nonwords range in length from one to three syllables, and the test is graded in difficulty. The minimum disparity scores of the language disordered children on this test was -38 months, with a mean performance age corresponding to 50 months below chronological age. In fact, most of the children scored at the floor level, corresponding to a performance age of 3:10, suggesting that their deficits maybe underestimated by this test.

In summary, the battery of auditory memory tests showed dramatic impairments in two immediate measures—repetition of nonwords and ordered recall of a list of unconnected items. Indeed if the standardized norms available with the auditory memory tests are applied, the deficits of the disordered group on these two measures (more than three years) were substantially greater in magnitude than the vocabulary, comprehension, and reading deficits reported above (around 18 months). Clearly, this relationship requires further exploration in the context of experimental studies with matched control children. Nonetheless, these screening data do provide encouraging support for the hypothesis that impaired short-term memory skills may play a central role in disordered language development.

**Nonword Repetition**

Results from the standardized battery of memory tests indicated that the language-disordered children were performing at a level considerably below their chronological age on all measures involving short-term verbal memory. Thus we have preliminary evidence that the disordered group does have an impairment of immediate verbal memory (see, also, Graham, 1980; Kirchner & Klatsky, 1985). On the test involving the immediate repetition of single nonwords, the disordered children performed at a mean level corresponding to more than three years below their chronological age. The magnitude of this deficit is important, as it exceeds the extent of the delay in vocabulary and reading skills of the language-disordered children; according to the standardized norms available for these measures, the mean repetition performance corresponded to that of a child a further 20 months younger than the 6-year-old verbal-control children.

We decided to further pursue this indication that on a simple immediate memory test involving the repetition of an unfamiliar sound sequence, the language-disordered children show a deficit even greater in magnitude than their impaired acquisition of vocabulary and reading skills. In particular, it was important to test whether the disordered children had even poorer repetition skills than younger control children, matched for vocabulary and reading abilities. If this was found to be the case, we would have clear evidence that the deficits of the disordered group on this measure of immediate memory do not just result from their delayed language development, but may plausibly play a more central role in causing the language problems encountered by these children.

Experiment 1 consisted of two subexperiments, 1A and 1B, which will be reported together. In each case, the nonword repetition abilities of the language disordered, verbal control, and nonverbal control groups were compared. In Experiment 1A, the nonwords were all one syllable in length, whereas in Experiment 1B, the nonwords ranged from one to four syllables in length, and contained either single conso-
nants or consonant clusters. In both subexperiments, a deficit in the nonword repetition performance of the language-disordered children even when compared to the younger verbal control children is predicted, as the repetition deficit of the language-disordered group detected in the memory screening test was apparently greater in magnitude than their vocabulary, reading, or comprehension deficits.

The language-disordered children were also expected to show the greatest repetition deficits for the multisyllabic nonwords in Experiment 1B. If the poor repetition performance of the language-disordered children reflects impaired phonological storage, this group would be expected to have problems in storing the longest items, as the phonological loop component of working memory is known to be limited in capacity with respect to number of syllables (Baddeley et al., 1975).

Experiments 1A and B

Method

Subjects. One child was not available for testing at this time; the remaining five language-disordered children and their respective matched nonverbal and verbal controls participated in the two subexperiments.

Design and materials. In Experiment 1A, the nonword stimuli were taken from Bishop (1985), and consisted of 21 consonant-vowel-consonant stimuli. The subject’s task was to repeat each nonword immediately. A cassette recording was made of a female speaker saying the nonwords at a rate of one item every 3 s.

In Experiment 1B, a set of 40 nonwords used by Gathercole and Baddeley (1989a) was employed. The items ranged in length from one to four syllables, and contained either single consonants or clustered consonants. There were five stimuli in each of the eight conditions obtained by combining the four syllable lengths with the two consonant types. In each case, the syllabic stress structure of the items conformed to the dominant stress structure for words of that length in spoken English. Thus, they were “wordlike” nonwords. The 40 nonwords were unsystematically ordered at presentation, with each subject receiving the same sequence. A cassette recording was made of the experimenter saying aloud each item at the rate of one every 3 s.

Procedure. All subjects were tested initially in Experiment 1A. Experiment 1B was carried out about a month later. The same procedure was followed for each subexperiment. Children were always tested individually. At the beginning of the experimental session, the child was seated opposite the experimenter. It was explained that the experimenter would say a “funny made-up word,” and that the child should try to produce the same sound. Three practice trials were given, in which the experimenter spoke each item in full view of the child. The cassette recording of the experimental stimuli was then initiated. The child was instructed to repeat each item as soon as it was heard, before the next one in the sequence. The experimenter covertly scored each response as correct or incorrect.

For each child, the entire experimental session was recorded, and the recording used to check the initial scoring by the experimenter. The re-scoring was carried out by the same experimenter in the absence of the initial scores. Where a disparity was obtained, an error was scored. Reliability of scoring ranged between 95% and 98% for the two subexperiments.

Results

The number of correct repetitions made in Experiments 1A and 1B was calculated for each child. The mean scores for each group are shown in Table 2. In both cases, the repetition performance of the language-disordered children was much poorer than the repetition of either of the control groups. In the one-way analysis of variance
TABLE 2
MEAN NUMBER OF CORRECT REPETITIONS IN EXPERIMENT 1A (max. = 21) AND EXPERIMENT 1B (max. = 40) AS A FUNCTION OF GROUP

<table>
<thead>
<tr>
<th>Group</th>
<th>Experiment 1A</th>
<th>Experiment 1B</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDG*</td>
<td>15.2 (1.9)</td>
<td>21.0 (1.6)</td>
</tr>
<tr>
<td>Verbal controls</td>
<td>19.0 (2.9)</td>
<td>33.8 (3.1)</td>
</tr>
<tr>
<td>Nonverbal controls</td>
<td>20.6 (0.5)</td>
<td>33.6 (4.2)</td>
</tr>
</tbody>
</table>

Standard deviations are shown in parentheses.
* Language-disordered group.

The mean number of correct repetitions made by each child in Experiment 1A, the group effect was significant $F(2,8) = 7.374, Mse = 5.217, p < .05$. Planned comparisons showed that the language disordered children made significantly more errors than either the verbal controls, $F(1,8) = 6.920, Mse = 4.310, p < .05$, or the nonverbal controls, $F(1,8) = 13.974, Mse = 4.159, p < .05$. The difference between the two control groups was not significant, $F(1,8) = 1.400, Mse = 4.986, p > .05$.

We have normative data on the repetition test used in Experiment 1B which enable us to interpret raw repetition scores in terms of age-standardized norms (Gathercole & Baddeley, 1990b) for children between the ages of 4 and 7. These norms provide a useful way of scaling the magnitude of the repetition deficit of the disordered children. The mean score of 21.0 of the language-disordered children corresponds to a point just below the 50th centile of 4- to 5-year-olds, whereas the mean control scores of about 34 of the two control groups correspond to the 75th centile for the 6- to 7-year-old sample. Thus, whereas the control children have repetition skills which are slightly better than average for their chronological age, the age-equivalent of the mean repetition score for the disordered group is about four years below their mean chronological age of 8 years.

The repetition attempts made by each child in Experiment 1B were also scored as a function of length of nonword, complexity of nonword, and group. The mean repetition accuracy of the three groups for the different nonword types is shown in Fig. 1. The repetition performance of the disordered group appears to be particularly poor for the three- and four-syllable nonwords. Whereas the repetition accuracy of this group declined sharply with increasing length, this effect was relatively weak for the two control groups.

An analysis of variance was performed on the number of correct repetitions made by each subject as a function of group, length, and consonant type. All main effects were significant: group, $F(2,12) = 21.098, Mse = 1.358, p < .001$; nonword length, $F(3,36) = 18.782, Mse = .842, p < .001$; and consonant type, $F(1,12) = 12.517, Mse = .725, p < .005$. Planned comparisons established that the repetition scores were significantly lower for the disordered group than for either of the control groups ($p < .01$, both cases). There was no significant difference between the two control groups, possibly because some of the subjects were approaching ceiling in these groups. A series of Newman–Keuls post hoc tests established that the length effect was due to the poorer repetition of four-syllable nonwords than nonwords of any other length ($p < .01$, all cases). The effect of consonant type was due to the poorer repetition of items containing consonant clusters rather than single consonants.

The interaction between group and length was also significant, $F(6,36) = 5.182, Mse = .842, p < .001$. Analysis of simple effects showed that a group difference exists only for three- and four-syllable nonwords, $F(2,46) = 12.395, Mse = .971, p < .001$, and $F(2,46) = 26.918, Mse = .971, p < .001$, respectively. The group effect was nonsignificant for one-syllable nonwords, $F(2,46) = 2.712, Mse = .971, p > .05$, and two-syllable items, $F(2,46) < 1$. Furthermore, repetition of the language-disordered children was significantly influenced by length, $F(3,36) = 24.35, Mse =$
.842, p < .001. There was, however, no effect of length for either the verbal controls, $F(2,36) = 2.099$, $Mse = .842$, $p > .05$, or the nonverbal controls, $F(2,36) = 2.693$, $Mse = .842$, $p > .05$. The remaining terms in this analysis were nonsignificant.

**Discussion**

The results of both Experiments 1A and 1B show that the language-disordered children are poorer at nonword repetition than either control group. The magnitude of the deficit was particularly notable in Experiment 1B, where both the number of correct repetitions of four-syllable nonwords and the total number of correct repetitions made by each child in the language-disordered group were lower than the corresponding scores of every child in the two control groups. Thus the nonword repetition scores obtained in Experiment 1B perfectly discriminated the language-disordered children from the control children. Moreover, the results from this experiment indicate that the repetition skills of the disordered children are appropriate for children four years younger than themselves. Thus, the magnitude of the repetition deficit is even greater than that of the characteristic delayed vocabulary development and reading development which are typically used as the criteria of developmental language disorders (e.g., Stark & Tallal, 1981). This pattern of findings rules out the possibility that repetition abilities are a function of general language skills, as the verbal controls and disordered group had equivalent vocabulary and reading knowledge. Instead, the results are consistent with the view that the memory skills tapped by repetition play a central role in language development, and that it is impairment in these skills which is, in part at least, instrumental to the developmental language problems encountered by the disordered group.

The results of Experiment 1B also show that the repetition deficit of the disordered
children is greatest for the three- and four-syllable nonwords, although the data from Experiment 1A showed an impairment in the repetition of one-syllable nonwords, too. The reason why the language-disordered and control groups were not distinguished for the one-syllable items in 1B also is not clear, although it should be noted that almost three times as many one-syllable stimuli were employed in 1A as in 1B. The failure to detect a repetition deficit for the language-disordered children for the one-syllable items in Experiment 1A may therefore just reflect the relative insensitivity of a test including a small number of trials. On this basis, it seems appropriate to conclude that the disordered children are deficient in repeating even the shortest nonwords, but that this deficit becomes increasingly robust as the length of the nonwords increases. This finding fits well with the view that the repetition difficulties of the language-disordered children reflect a capacity limitation of the phonological component of working memory. If the language-disordered children did have a reduced capacity for storing phonological material, the impairment would be expected to be most striking for the most lengthy phonological events.

The repetition skills of the groups were not distinguished, though, by whether the nonwords contained single or clustered consonants. The failure to find an increased sensitivity of this group to complexity suggests that articulatory output problems are probably not the basis of the poor repetition abilities of these children. Clustered consonants clearly require more complex articulatory output procedures than single consonants, so an articulatory output deficit should lead to more severe problems in repeating nonwords containing clustered rather than single consonants.

Relevant to this, the results from our study of repetition skills in young children of normal language abilities suggest that a disruptive effect of clustered consonants on repetition is restricted only to young children (aged 4) of low vocabulary skills (Gathercole & Baddeley, 1989a). The 4-year-olds with good vocabulary skills, and 5-year-olds in general, were not impaired at repetition when the nonwords contained consonant clusters. These results converge on the view that although more complex articulatory procedures are required in repeating items containing clustered rather than single consonants, by the age of 5, most children have mastered the necessary articulatory skills required to accurately reproduce these complex phonological specifications. Given this, as the disordered children have the general language skills of an average 6-year-old child, they would not be expected to have problems in articulating the more complex items.

In summary, nonword repetition abilities were powerful discriminators of the language-disordered children from the control children in this study. The disordered group was much poorer at repeating nonwords, particularly three- or four-syllable nonwords, than even the younger control children of matched vocabulary and reading skills. This pattern of results lends strong support for the view that a central deficit of language-disordered children resides in their abilities to represent material in phonological form in working memory.

**Serial Recall**

In the second part of the study, the phonological memory characteristics of the language-disordered group were further investigated by employing experimental techniques developed specifically in the context of the working memory model (Baddeley, 1986; Baddeley & Hitch, 1974). The principal question being addressed in these experiments concerns whether the phonological memory deficit of the disordered group reflects problems in the initial phonological encoding and storage of the verbal material within the working memory system, or in
the maintenance of this material via rehearsal.

The current view is that the phonological loop consists of a phonological store which represents verbal information in a phonological form, and a subvocal articulatory rehearsal process which maintains the material in the phonological store. Immediate memory for sequences of unconnected items is limited both by the storage capacity of the phonological store, and the rate of rehearsal. Thus items that are phonologically similar to one another will lead to poorer performance because of the problem of trace discrimination at retrieval (Baddeley, 1966). Furthermore, shorter items will lead to faster rehearsal, allowing more items to be maintained. Both of these short-term memory phenomena—poorer recall of phonologically similar rather than dissimilar lists of memory items, and impaired recall of long (i.e., multisyllabic) relative to short words—have been well-documented both for adults (e.g., Baddeley, 1966; Baddeley et al., 1975) and for children aged 5 and above (e.g., Conrad, 1972; Hulme, Thomson, Muir, & Lawrence, 1984; Nicolson, 1981).

In the present series of experiments, we assessed the phonological encoding skills and rehearsal abilities of the language-disordered children, by comparing the effects of phonological similarity (Experiment 2) and word length (Experiment 3) on serial recall of memory lists in the groups of language-disordered and control children. The presence of a phonological similarity effect in the disordered group would indicate that they were representing information in the phonological store, while the presence of the word length effect would suggest that they can subvocally rehearse.

Deficits in either process—representation of items in the phonological store or subvocal rehearsal—could plausibly account for the impaired recall demonstrated in previous studies of language-disordered children (e.g., Graham, 1980). Kirchner and Klatzky (1985) found that one feature which distinguished between disordered and normal children concerned the amount of rehearsal of novel memory items. Although this rehearsal failure could also reflect failure to originally encode memory items, this result does raise the possibility that poor rehearsal processes might provide the basis for the impaired short-term memory performance of language-disordered children. If this is the case, we would expect the disordered group to show normal sensitivity to phonological similarity, but not to word length.

On the other hand, it appears from studies of the working memory of poor readers that their memory deficits are best characterized by a phonological store of reduced capacity. Although some investigations have found reduced effects of phonological similarity of poor compared to good readers (e.g., Mann & Liberman, 1984), it now appears that this interaction may be an artifact of using fixed list lengths which exceed the short spans of poor readers. When list lengths are used which approximate span for each group, effects of phonological similarity are found with good and poor readers (Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983; Johnston, Rugg, & Scott, 1987). So it seems that poor readers do encode verbal material in a phonological form, but that the capacity of the phonological store may be less than that of children with better reading skills. Thus one of the aims of the present studies is to assess whether language-disordered children show the same profile of memory deficits as do poor readers, or if they show a qualitatively different profile.

In Experiment 2, the influence of phonological similarity on recall was compared across groups, using a procedure in which lists of two to six items in length were presented to each child. The lists were either composed of items which were phonologically dissimilar or phonologically similar to one another. A comparable design was fol-
followed in Experiment 3, except that lists were comprised of either one-syllable words or three-syllable words. For both of the list types employed in Experiment 3, memory items were phonologically dissimilar.

**Experiment 2**

**Method**

*Subjects.* The six language-disordered children, and each of their verbal and non-verbal matched controls, participated in this experiment.

*Design.* Recall of phonologically dissimilar and phonologically similar words was tested in each of the three groups. One set of six dissimilar words, and one set of similar words, was used. From each of these sets, four lists were generated at each length from two to six words. Thus 20 lists in all were constructed by sampling randomly and without replacement from each six-word set. All subjects were tested on all 20 lists in each set.

The experimenter read aloud the words in each list. Presentation of the dissimilar and similar lists was blocked and, within a word set, the same sequence of lists was given to each subject. The first list presented in each set contained two words, and the list length was increased by one across successive trials up to Trial 5, when a six-word list was given. The procedure of presenting lists of increasing length from two to six items was repeated three more times for each word set, making a total of 20 experimental trials for each of the dissimilar and similar sets. Three of the language-disordered children received the dissimilar word set first, and the remaining three were tested first on the similar word set. The control children received the same order of list set as the language-disordered child with whom they were individually matched.

*Materials.* Two sets of six concrete nouns used by Conrad (1972) were employed. The phonologically dissimilar words were *bus, clock, hand, horse, girl,* and *spoon,* and the phonologically similar words were *bat, cap, cat, pan, pram,* and *tap.* For each of these sets, a response card was constructed which consisted of a $3 \times 2$ array of readily-identifiable line drawings which corresponded to the words in the stimulus set.

*Procedure.* Each child was tested individually. A training session was given at the beginning of each experimental session, in which the child was shown the array of line drawings corresponding to the first set of words to be used in the experiment. The child was asked to name each picture. On the majority of occasions the label generated by the child corresponded to the appropriate word in the memory set. When a different word was elicited, the experimenter provided the experimental label, and asked the child to repeat it. The child was then retested on each picture following this procedure, until all of the experimental names were generated as the first response to a drawing.

The experimenter then said aloud two words from the set, and asked the child first to point to the picture corresponding to the first word and then to the second one. This procedure was repeated once, and then twice more with the array of drawings removed from the child’s sight during presentation of the two words. The response card was placed in front of the child immediately after the second word. None of the children had any apparent difficulty in understanding or performing this training task. The experimental trials then commenced.

The following events took place on each trial of the experiment. The experimenter said “*Ready,*” and then read aloud the memory list at a rate of one word per s. List lengths of two to six words were used, and the length of the list was increased by one item over successive trials. At the end of each list, the array of drawings was placed in front of the child, who then attempted to
point to the pictures in the same order in which the picture labels had been presented by the experimenter. The sequence produced by the child on each trial was recorded by the experimenter.

Results

Accuracy of recall was examined separately for each of the five list lengths used in the experiment. The results are shown in Fig. 2. It appears that the effect of phonological similarity on the recall of each group is highly dependent on list length. Recall of two-item lists is virtually 100% for all groups on both similar and dissimilar lists. For three-item lists, recall is 100% for the dissimilar word lists in the case of the two control groups, who nonetheless appear to show a greater effect of similarity on performance than the disordered group. For lists of four items, all groups show poorer recall of lists of similar than dissimilar words. At list length five, the language-disordered group show a lesser sensitivity to similarity than the two control groups, but their recall level for the dissimilar lists is considerably lower than for either of those two groups. Finally, for the six-item lists, the disordered group showed a reduced sensitivity to similarity relative to the control groups due to their apparently better recall of similar lists.

Analyses of variance were performed on the mean recall scores at each length, as a function of the materials and group. Given the large numbers of analyses to be reported here, the full terms for nonsignificant factors will not be reported. For the two-word lists, there was a main effect of similarity, $F(1,5) = 11.364, Mse = .245, p < .05$, reflecting poorer recall of similar rather than dissimilar lists. No group terms reached significance. No significant terms were obtained in the analysis of the three-item lists. For the four-word lists, there was a significant effect only of similarity, $F(1,5) = 80.645, Mse = 3.444, p < .001$, but no interaction between group and similarity.

Significant group by similarity interactions were, however, found for both the five- and six-item lists. For the five-word lists, an analysis of simple main effects...
based on the interaction term, $F(2,10) = 7.534, Mse = 6.994, p < .05$, showed that this reflected significant effects of similarity for both control groups ($p < .001$, both cases), but not for the language-disordered children ($p < .05$). There was, in addition, a main effect of similarity in this analysis, $F(1,5) = 76.216, Mse = 5.161, p < .001$.

For the six-item lists, the interaction between similarity and group was also significant, $F(2,10) = 4.107, Mse = 11.878, p < .05$. Simple main effects analysis showed that this once again reflected the effects of similarity on recall for the two control groups ($p < .05$, both cases), but not for the language-disordered group ($p > .05$). There was also a main effect of similarity in this analysis, $F(1,5) = 58.419, Mse = 7.311, p < .001$.

Discussion

The first important feature of these results is that they confirm that the language-disordered children have an immediate memory deficit for lists of words; their overall recall was poorer than that of either the nonverbal controls or the younger verbal controls of matched verbal skills. This result establishes that for words as well as nonwords, the language-disordered children have a memory impairment which does not simply arise from their delayed level of vocabulary and reading development.

Second, all groups were sensitive to the phonological similarity of list items; recall of lists of similar items was poorer than that of dissimilar items. In particular, for lists of four items, the disordered group showed a disruptive effect of similarity on recall which was comparable in magnitude to that experienced by the two control groups, despite having lower overall recall accuracy than those two groups.

Equivalent sensitivity to phonological similarity across the three groups was not observed for all list lengths, though. The disordered group showed no influence of similarity on recall of lists of five and six items, whereas the verbal and nonverbal control children did show poorer recall of lists of similar rather than dissimilar items for these list lengths also. Given the evidence from recall at shorter lists that the language-disordered children can encode the list items in phonological form, it is clearly inappropriate to interpret this lack of sensitivity to similarity in long lists as an inability to encode phonologically. One possibility is that the language-disordered children abandoned the use of the phonological store for the longest lists where their storage capacity was drastically exceeded, and switched to an alternative, nonphonological strategy. Perhaps the language-disordered children shifted strategy because they have a phonological store of reduced capacity, and this capacity was far exceeded by the five- and six-item lists. Certainly for the five-item list, the phonological stores of the control children do not appear have been as overloaded as the language-disordered children, as they remembered considerably more phonologically distinct sequences. This account of the absence of a similarity effect at longest list lengths with the language-disordered children is clearly very speculative in nature, and depends on indirect evidence for support. In its favor, though, an apparently similar abandonment of a phonological strategy at list lengths which greatly exceeded span was also observed by Salame and Baddeley (1986) in a study of adult subjects.

More importantly, these results suggest that the basis for the poor immediate memory of the disordered group is not a failure to encode phonologically. It remains a possibility, though, that the capacity of the phonological store is reduced, and that this is the basis for poorer recall of the disordered group. Another possibility is that the language-disordered children are less able to use the subvocal rehearsal process effectively (c.f. Kirchner & Klatzky, 1985). This hypothesis is investigated in the next experiment, where the task is to recall lists of
short and long words. If impaired rehearsal processes provide the basis for the memory deficits of the language-disordered children, we would expect a change in the magnitude of the word length effect for this group.

Experiment 3

Method

Subjects. The six language-disordered children and their matched verbal and non-verbal controls participated in this experiment.

Design. The design corresponded to that employed in Experiment 2, except that the two list types were one-syllable and three-syllable words. Six words of each type were used.

Materials. The one-syllable word set was bed, boat, cat, egg, pig, and sun. The three-syllable set was banana, elephant, lady-bird, piano, pineapple, and telephone. The words were taken from the sets constructed by Hitch and Halliday (1983), which were matched across set for age of acquisition (Gilhooly & Logie, 1980) and frequency of occurrence (Carroll, Davies, & Richman, 1971).

Procedure. The same procedure was adopted as in Experiment 2. The two experiments were carried out on different days of the same week, for each child.

Results

Recall was scored according to the number of words correctly recalled in each list position at each length. These data are summarized in Fig. 3, where they are shown in terms of mean percentage recall for each list type, for each group, at each list length.

Although recall performance is generally lower for the language-disordered group than for the two sets of controls, there is no indication of a reduced effect of word length on the disordered children. For the two-item lists, performance is virtually 100% for all groups with both short and long words. The data from the three-, four-, and five-word lists show that recall of all three groups is lower for the three-syllable than

![Mean percent recall in Experiment 3 as a function of group, word length, and list strength.](image-url)
for the one-syllable words, and of about equivalent magnitude for the groups of language-disordered and control children. For six-item lists, the two control groups show once again a reduction with long words, whereas the recall of the disordered children is not influenced by length. But in this case, the disordered children show better recall of the long words than the control children.

Separate analyses of variance were carried out at each of the five list lengths. In each case, the analysis was performed on the number of words correctly recalled by each subject in each of the two list conditions for that length. Only terms with significant probability values will be fully reported here.

For the two-word lists, none of the terms in the analysis was significant. For the three-word lists, there was a significant main effect of length, $F(1,5) = 6.667$, $Mse = 2.400$, $p < .05$, reflecting the better recall of one-syllable rather than three-syllable lists. A significant effect of length was also found for four-word lists, $F(1,5) = 33.255$, $Mse = 6.178$, $p < .01$. There was no significant main effect of group for this set, $F(2,10) = 3.616$, $Mse = 19.594$, $p > .05$, but planned comparisons of the group means showed that the mean score for the disordered group was lower than that of either the verbal or nonverbal groups ($p < .05$, both cases). There was no significant interaction between group and length.

For the five-word lists, there were significant main effects of length, $F(1,5) = 54.930$, $Mse = 7.161$, $p < .001$, and group, $F(2,10) = 5.128$, $Mse = 22.594$, $p < .01$. Planned comparisons showed that the means for the language-disordered group here were significantly lower than those of the nonverbal controls ($p < .05$) but not the verbal controls. The interaction between group and similarity was not significant. Finally, there was a significant interaction between these two terms for the six-word lists, $F(2,10) = 5.079$, $Mse = 9.128$, $p < .05$. An analysis of simple main effects for this term showed only a significant effect of length for the nonverbal group, $F(1,5) = 14.36$, $Mse = 11.750$, $p < .05$.

Discussion

As in Experiment 2, the language-disordered children in this experiment were poorer at recalling the word lists than were either sets of controls. So once again, these results confirm that the immediate memory skills of this group cannot readily be explained by their poor level of vocabulary and reading skills, since the disordered group have a selective deficit in immediate memory which exceeds their vocabulary and reading impairments.

There was no evidence from this experiment that the language-disordered children had impaired rehearsal processes. They were disrupted by increasing the word length of the memory items to the same extent as the two sets of control children, except at the longest list lengths. A similar insensitivity to the phonological characteristics of the list items was observed in Experiment 2, where it was suggested that the language-disordered children may abandon the phonological loop as a mnemonic device for list lengths which greatly exceed the capacity of their phonological memory. Once again, though, it should be acknowledged that this evidence is indirect in nature.

The principal finding of this experiment is that it provides no indication that the rehearsal processes of the language-disordered children are inadequate. The presence of a word-length effect suggests that they are using subvocal rehearsal to maintain items within verbal memory in the same way that the control children with normal language development are, at least up to list lengths of about five items.

In conjunction with the findings from Experiment 2, the present results fit well with the view that the language-disordered children are impaired in the processes involved in phonological coding in immediate memory, although not to the extent that phono-
logical coding cannot be used. Reduced phonological capacity would be expected to give rise to reduced memory span, but with preserved phonological similarity and word-length effects. The failure to distinguish the language-disordered children from their controls on the basis of subvocal rehearsal processes, though, appears to stand in contrast with Kirchner and Klatzky's (1985) findings that language-disordered children rehearse less than children with normal language skills. In fact, though, the procedures employed across the two sets of studies differed in many respects. Kirchner and Klatzky used a procedure in which memory items were presented at the rate of one every 25 s, and subjects were instructed to rehearse aloud during the inter-item period. Overt rehearsal processes were examined by analysis of the spoken protocols of subjects during list presentation. In our experiments a word was presented every 2 s, representing a more typical immediate memory procedure, and the contribution of covert rehearsal was evaluated indirectly by assessing the extent of the recall advantage of short over long words (Baddeley, 1986). Clearly, the differences in experimental procedure alone make direct comparisons across studies problematic. Furthermore, the results are not necessarily incompatible with one another, since Kirchner and Klatzky's observation that the disordered children were deficient at overtly maintaining and rehearsing the memory items may possibly reflect problems in the initial registration of these items in the phonological store. Such a failure would indeed be expected to lead to reduced availability for rehearsal of to-be-remembered items.

**Phonological Processing and Articulation Rate**

We have suggested that the dramatic deficits in repetition and serial recall abilities of the language-disordered children may reflect impaired phonological storage in working memory. The sensitivity of the disordered children to the phonological similarity and syllabic length of lists of to-be-remembered words indicates that they do both encode material phonologically and use subvocal rehearsal to maintain the phonological representations. Our proposal is that the poor repetition and level of recall of the children is due to impaired efficiency of the processes involved in phonological representation.

Before elaborating our ideas about the speculated memory deficit associated with developmental language disorder, though, it is necessary first to consider possible "nonmemory" accounts of the deficits in repetition and recall. One such possibility is that the language-disordered children fail in immediate memory tasks because initial perceptual analysis of the acoustic events to be remembered is impaired. And indeed, there is already evidence that some children with language problems do have deficits in the perceptual processing of acoustic stimuli. Detailed investigations by Tallal and collaborators (e.g., Tallal & Piercy, 1975; Tallal, Stark, & Mellitts, 1985) have demonstrated that certain language-disordered children are deficient in detecting rapid transitions in synthetic acoustic and visual stimuli. Similarly, Elliott, Hammer, and Scholl (1989) have described children with language-learning problems who have deficits in fine-grained auditory discrimination of synthesized phonological contrasts, and Brady, Shankweiler, and Mann (1983) have shown that children who are poor readers also have selective problems in discriminating degraded speech.

The perceptual discrimination problems associated with disordered language development have been demonstrated primarily for synthetic acoustic stimuli containing rapid transitional information, or for speech stimuli in acoustically degraded environments. If the perceptual deficits are restricted to such stimuli, they seem unlikely to be the basis of the dramatic phonological memory impairments shown by the language-disordered children in the present
study, as the items were not presented in degraded conditions at input. However, the possibility remains that the language-disordered children are also impaired in the perception of normal speech events, and that it is this problem which underpins their poor repetition and recall of spoken events, rather than deficits in phonological representation in memory as we have suggested.

We investigated this hypothesis in Experiment 4 by comparing the abilities of the disordered children and the control children to discriminate speech stimuli of the type used in our experiments. The children heard pairs of either words or nonwords, spoken by the experimenter in undegraded acoustic conditions. The task was to judge whether the two stimuli were identical (“yes”) or different (“no”); the stimulus pairs that were different differed by one critical feature only. If the poor immediate memory skills of the language-disordered children do reflect impaired perceptual analysis, they should perform more poorly than controls at this task of phonological discrimination.

Experiment 4

Method

Subjects. Five children from the language disordered group, verbal control group, and nonverbal control group participated in this experiment.

Design. Each child made a “same/different” judgment to 72 spoken pairs of CVC stimuli. Half of the stimulus pairs contained words, and the other half contained nonwords. Three of the subjects in each group received the word pairs first, with the other two receiving the nonword pairs first. Subjects in the control groups received the same order of materials as the language-disordered child with whom they were matched. Within each set, the order of pairs containing the various features was randomized, with each subject receiving the same sequence of stimuli.

Materials. The stimuli used in this study were 36 pairs of CVC words and 36 pairs of CVC nonwords constructed by Bishop (1985). One third of the pairs in each set were identical, one third differed in fricative/affricative feature, and one third differed in nasal/plosive feature. For each of the 24 different pairs within each set, there were two pairs of stimuli differing on each of 12 phoneme contrasts. In each pair, the initial phoneme of one pair was different, and the final phoneme of the other pair was different.

A cassette recording was made of the experimenter saying aloud each of the sets of 36 pairs, and was replayed to subjects.

Procedure. All of the children were tested individually. They were told that they would hear two sounds, and to say “yes” if they were the same, and “no” if they were different. Before each of the word and nonword sets of stimuli, the experimenter gave the child two appropriate examples, one of which was the same and one of which was different. Prior to the nonwords pairs, it was explained that the sounds did not make real words, but were “funny made-up ones.”

The stimuli were presented on a cassette recording. The two stimuli were spoken aloud by the experimenter with a 2-s interval between them. A 6-s pause separated successive trials. A rest period was given between the two sets of materials, and the experiment lasted approximately 15 min.

Results and Discussion

The number of correct discriminations made by each child was calculated for words and nonwords. The mean number of correct discriminations of word and nonword pairs for each of the three groups is shown in Table 3. Correct discrimination of the word pairs did not differ across groups, although the language-disordered children did show a slight reduction in performance for the nonword pairs. Separate analyses of variance were performed on the discrimination scores for the words and nonwords for each subject. The effect of group on dis-
crimination performance was nonsignificant for both the analysis of the word scores, $F(2,8) < 1$, and the nonword scores, $F(2,8) = 2.073, Mse = 5.050, p > .05$. In each case planned comparisons were made of the differences between the scores of the language disordered group and each of the control groups. For the words, the comparisons between the disordered group and each of the verbal and nonverbal controls were nonsignificant, $F(1,4) < 1$, in both cases. For the nonwords, too, no significant differences were found between the disordered children and the verbal or nonverbal controls, $F(1,8) = 3.347, Mse = 5.050, p > .05$, and $F(1,8) = 2.851, Mse = 5.050, p > .05$, respectively.

In statistical terms, the language-disordered children do not appear to be significantly impaired in the perceptual discrimination of the kind of speech stimuli used in the four memory experiments reported in this paper, although they were slightly less accurate at discriminating nonword pairs than the two control groups. There was no indication of impaired discrimination of word pairs. As we have found large deficits in recall of word stimuli in Experiments 2 and 3, the results of this perceptual study make an account of the memory deficits of the language-disordered children in terms of problems in the perceptual discrimination of speech stimuli seem unlikely. This issue will be discussed further at a later point in the paper.

Experiment 5

An alternative nonmemory account of the poor immediate memory performance of the language-disordered children is that they have slow rates of articulation which leads to slow subvocal rehearsal and hence impaired memory span. Variations in articulation rate have been found to have important consequences for immediate memory performance. In both children and adults of normal language skills, there is a close positive association between speech output rate and memory span (e.g., Baddeley et al., 1975; Hulme et al., 1984). This relationship has been interpreted as showing that immediate memory capacity is limited by articulation rate, with the increase in rate in children during early school years forming the basis of the developmental increase in memory span observed during this period (Hitch & Halliday, 1983; Hulme et al., 1984; Nicolson, 1981).

It is clearly possible that the poor memory performance of language-disordered children is simply a consequence of their slow articulation rate and hence the reduced amount of phonological information they can maintain in working memory. To test this explanation of the memory deficits of the language-disordered children, the articulation rates of the children in each group were measured. In addition, a measure of articulation latency—the time taken to initiate an utterance from a signal to do so—was taken for each child, in order to determine whether the language-disordered children were slower at executing a planned speech act than the controls.

Method

Subjects. The same subjects were tested as in Experiment 4: five subjects from each of the language disordered, verbal control, and nonverbal control groups.

Design and materials. Two sets of familiar words were constructed—six one-syllable words, and six three-syllable

### TABLE 3

<table>
<thead>
<tr>
<th>Lexical class</th>
<th>Words</th>
<th>Nonwords</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDG*</td>
<td>29.9 (2.1)</td>
<td>27.4 (2.6)</td>
</tr>
<tr>
<td>Verbal controls</td>
<td>30.2 (4.0)</td>
<td>30 (2.1)</td>
</tr>
<tr>
<td>Nonverbal controls</td>
<td>29.0 (2.6)</td>
<td>29.8 (1.9)</td>
</tr>
</tbody>
</table>

Standard deviations are shown in parentheses.

* Language-disordered group.
words. The one-syllable words were bed, cat, egg, lamb, pig and tap, and the three-syllable words were banana, catapult, elephant, ladybird, pineapple and telephone. Thus words were matched across the set for initial phoneme.

Measures of articulation rate and articulation latency were obtained for each subject for each of these words. For each word the speech latency was tested first, followed by 10 articulation latency trials for that word. The first two articulation latency trials were practice, and the remaining eight were experimental trials. The order of testing words was randomized across subjects, with the constraint that successive trials alternated from short to long words. The control subjects received the same sequence of words as the language-disordered children with whom they were matched.

Apparatus. A cassette recorder was used to record the articulation rate trials. For the articulation latency measure, a digital timer was linked to a switch and a small lightbulb. When the switch was depressed by the experimenter, the timer was initiated and the bulb flashed. The timer was stopped when the voice onset was detected by a stand microphone which was linked to the timer via a voice key.

Procedure. The following procedure was used for each of the 12 words employed in this experiment. The experimenter said the word aloud to the child, and instructed the child to repeat it aloud three times. The experimenter then switched on the cassette recorder, and said “Now.” This was the child’s cue to repeat the word aloud 10 times as quickly as possible. The child was told not to count the repetitions, but simply to repeat the word until the experimenter said “Stop.” The recorder was then switched off. The articulation rate for each word was later calculated from the cassette recording of the child’s repetition.

The articulation latency trials for each word immediately followed the articulation rate procedure. A microphone and a small bulb were placed on the table in front of the child. The experimenter flashed the light by pressing a switch which was located underneath the table, hidden from the subject’s view. The switch depression also initiated a millisecond timer which was stopped when the subject’s voice was detected by a voice key. The child was instructed to say the word as quickly as possible into the microphone when the light flashed, which it did at unpredictable intervals while the subject was attending. Three practice trials for each word were given, during which the experimenter adjusted the sensitivity of the voice key for the child’s voice. Ten experimental trials followed in which the articulation latency displayed by the timer was recorder.

The experiment lasted approximately 15 min.

Results

Articulation rates. The mean articulation rate for each of the 12 words was calculated for each subject from the cassette recording of the experimental session. A stop watch with a maximum accuracy of one-fifth of a second was used for timing. These data are summarized in Table 4, which shows the mean number of words of each length articulated per second by children in the three groups.

The articulation rates of the language-disordered children were slower than those of the nonverbal controls for both short and long words, but about the same as those for the verbal control children. An analysis of variance was performed on the mean articulation rate of each child, as a function of group and word length. There was a highly significant effect of word length, $F(1,5) = 87.790, Mse = .074, p < .001$, reflecting the slower articulation rate for long than short words. The main effect of group was non-significant, $F(2,10) = 2.832, Mse = .270, p > .05$. Planned $t$-tests that compared the means for the language-disordered group and each of the verbal and nonverbal con-
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Table 4
Mean Articulation Rate (Number of Words/Sec) and Articulation Latency (ms) as a Function of Group and Number of Syllables in Experiment 5

<table>
<thead>
<tr>
<th>Group and no. of syllables</th>
<th>Measure</th>
<th>Articulation rate</th>
<th>Articulation latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDG*</td>
<td>Articulation rate</td>
<td>2.18 (.32)</td>
<td>240 (69)</td>
</tr>
<tr>
<td>1-syllable</td>
<td>Articulation rate</td>
<td>1.42 (.16)</td>
<td>243 (57)</td>
</tr>
<tr>
<td>3-syllable</td>
<td>Articulation rate</td>
<td>2.13 (.52)</td>
<td>317 (31)</td>
</tr>
<tr>
<td>Verbal controls</td>
<td>Articulation rate</td>
<td>1.38 (.27)</td>
<td>286 (11)</td>
</tr>
<tr>
<td>1-syllable</td>
<td>Articulation rate</td>
<td>2.89 (.65)</td>
<td>299 (82)</td>
</tr>
<tr>
<td>3-syllable</td>
<td>Articulation rate</td>
<td>1.62 (.21)</td>
<td>294 (65)</td>
</tr>
<tr>
<td>Nonverbal controls</td>
<td>Articulation rate</td>
<td>2.69 (.56)</td>
<td>299 (82)</td>
</tr>
<tr>
<td>1-syllable</td>
<td>Articulation rate</td>
<td>1.62 (.21)</td>
<td>294 (65)</td>
</tr>
</tbody>
</table>

Standard deviations are shown in parentheses.
* Language-disordered group.

trol groups were also nonsignificant; t(4) < 1, and t(4) = 1.813, p > .05, respectively. The interaction between group and word length was nonsignificant, F(2,8) = 3.976, Mse = .056, p > .05.

**Articulation latencies.** For each child, the mean articulation latency was calculated for the one- and three-syllable words, using the last eight experimental trials for each word. The mean latencies are shown in Table 4. There was no evidence that the language-disordered children had slower latencies than the two control groups; their response times were slightly faster. In the analysis of variance of the mean latencies for each subject as a function of group and word length, no terms were significant: group, F(2,8) = 1.636, Mse = 6716.442, p > .05, word length, F(1,4) = 1.463, Mse = 643.133, p > .05, and group by word length, F(2,8) = 1.012, Mse = 784.308, p > .05.

Discussion

These results indicate that differences in speed of articulation and thus presumably rehearsal rate do not offer a good explanation of the poor immediate memory performance of the language-disordered children. The articulation rates for the disordered group and the verbal controls were very similar, while the verbal control children performed consistently better in the immediate memory experiments. No group differences were found in articulation latency. So although the speed of speech output may be associated with general language skills such as vocabulary and reading abilities, it does not appear to provide the basis for the memory deficits of our group of language-disordered children.

General Discussion

The language-disordered children were found to have dramatic impairments of immediate phonological memory. In both the repetition of single spoken nonwords and the serial recall of lists of spoken words, the disordered group performed more poorly than an even younger group of normal children with equivalent vocabulary and reading skills. This pattern of results establishes that the memory deficits of the disordered children do not simply arise from their poor level of vocabulary and reading achievement; if this was the case, the memory characteristics of the verbal controls and the language-disordered children would be equivalent. Instead, the results indicate that the disordered group has a selective deficit of phonological memory skills. Whereas the vocabulary and reading skills of the language-disordered children were delayed by about 20 months, their repetition skills were by our estimates delayed by about four years. The magnitude of the phonological memory deficit is further illustrated by the fact that the language-disordered children performed worse on the nonword repetition test than any of the control children.

The language-disordered children and controls tested in this project therefore appear to be most powerfully distinguished by their phonological coding skills. These findings both replicate and extend previous reports of phonological memory deficits in children with specific language difficulties...
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(Graham, 1980; Kirchner & Klatzky, 1985; Wiig & Semel, 1976). Moreover, in our studies recall involved pointing to pictures in sequence, rather than by spoken output. This aspect of the design ensures that the low estimate of immediate memory of the language-disordered children did not reflect problems in output rather than encoding or maintenance of the memory sequence.

All groups of children, normal and disordered, showed sensitivity in serial recall to both the phonological similarity and word length of the memory items, providing that the list lengths were not too short (leading to ceiling effects) and did not grossly exceed memory span. This similarity in the memory characteristics of the three groups suggests that the poor immediate memory performance of the disordered group does not reflect the absence of either phonological storage or subvocal rehearsal processes.

Explanations of the poor immediate memory abilities of the language-disordered children in terms of nonmemory mechanisms were also addressed in this project. One such hypothesis is that problems in the perceptual discrimination of the spoken words and nonwords used in our memory experiments, rather than in the phonological encoding or storage of the perceived items, led to the apparent memory deficits found in our studies. The data here were slightly ambiguous, as the language-disordered children appeared to make more errors in discriminating between nonwords that the two groups of control children. The difference was not, however, statistically significant, and there was no hint of a corresponding deficit for the word pairs. In the memory experiments, though, the nonword repetition deficits of the disordered group were consistent, large and significant, as were their impairments in serial recall of word lists. Thus any perceptual deficits there might be in the language-disordered group just do not appear to match the magnitude of the memory impairments, particularly when it is considered that the memory items were highly discriminable, and taken from a familiar and restricted set. An alternative position is that simple perceptual discriminations may place less demands on the adequacy of phonological are presentations than do the processes of maintenance and production involved in memory tasks. It is not, however, clear that such a position is testable, or indeed that it is incompatible with the view being put forward here. Our point is simply that an explanation of the memory deficits of the language-disordered children in terms of the phonological information that does not gain access to working memory as a result of perceptual failure seems unlikely.

We do not wish to deny that more subtle perceptual discrimination deficits in language-disordered groups arise when synthetic stimuli containing rapid transitional information or highly degraded speech stimuli are used (e.g., Brady et al., 1983; Elliott et al. 1989; Tallal et al., 1985). Indeed, these deficits may themselves stem from the reliance of the testing procedure on phonological memory representations. A same–different acoustic discrimination requires the initial stimulus to be stored until comparison with the second stimulus is complete. Retaining a single item may make substantial demands on memory, producing clear evidence of forgetting over a 3-s delay, providing that the task of discriminating the presentation and test tones is made sufficiently demanding (Wickelgren, 1968, 1969).

It is apparent from this discussion that the distinction between processes classed as perceptual and those classed as mnemonic is not well-specified by current models. The issues are nonetheless important, and merit further direct empirical and theoretical consideration. Such issues are, however, beyond the scope of the present project.

An account of the phonological memory deficits of the language-disordered children in terms of slow articulation rates was also
ruled out in the present project. There was no indication that the onset or rate of articulation of the disordered children was any slower than that of the verbal control children who had superior memory abilities. In addition, the language-disordered children had no selective impairment in the repetition of nonwords containing clustered rather than single consonants, even though the articulatory output procedures required for the clusters are considerably more complex. For these reasons, disturbance of articulatory output procedures and associated subvocal rehearsal processes can be discounted as a likely basis for the poor memory performance of the language-disordered children observed in our series of experiments.

Why, then, are the language-disordered children so much poorer than even the younger control children of matched vocabulary and reading skills at repeating nonwords and recalling lists of spoken words? Our proposal is that their memory deficit reflects an impairment in the specialized storage of phonological information in working memory. At present the working memory model in general and the formulation of the phonological loop in particular are not sufficiently well-specified to permit detailed analysis of the individual components, although work is in progress to develop more computationally explicit models (e.g., Brown, 1989). For the moment, we can only speculate on the nature of the proposed functional impairment of the phonological store. One possibility is that the processes of acoustic and segmental analysis of phonological events may be noisy, so that the resulting phonological representations are less discriminable at retrieval. An alternative account is that the capacity of the phonological store is less, leading to either fewer items being stored, or to the same number being stored less richly and redundantly, leading to a less adequate memory trace. Another possibility is that the phonological trace decays faster in these particular children. Note that by any of these possibilities, the deficit could lie generally in the phonological representations, rather than in the rehearsal loop component of working memory. In either case, the consequences would be impaired phonological memory skills.

Although all of the memory measures taken during the course of the project were expected to reflect the contribution of phonological storage to distinguish the language-disordered children from their controls, the greatest deficits of the language-disordered children were shown in nonword repetition, particularly of multisyllabic items. There are good reasons why nonword repetition should provide an even better discriminator of the disordered children than measures of recall of word sequences. If phonological storage processes are impaired in these children, we would expect that storage of stimuli which depend most on phonological representations to be maximally sensitive to this phonological deficit. Because of their nonlexical status, nonwords presumably are critically dependent on short-term phonological representations. For words, on the other hand, alternative levels of representation are available if stored lexical knowledge is accessed. Thus we may expect nonword repetition to be even more sensitive to impaired phonological storage skills than memory span for words or digits.

Our proposal is that phonological storage skills play an important role in the development of a range of complex higher level linguistic abilities such as reading, vocabulary, and comprehension all at which language-disordered children are typically very poor. There is now evidence from both normal and disordered populations that phonological memory plays an important role in acquiring new vocabulary items (Baddeley et al., 1988; Gathercole & Baddeley, 1989a, 1989b, 1989c). The contribution of phonological memory to learning a new word seems likely to be located in the processes of achieving a stable representation of the initially novel sound sequence in
long-term memory. Perhaps the sound is temporarily represented in the phonological loop prior to the long-term memory representation being established, so that the success of the consolidation process will interact with the adequacy of the temporary memory representation. By this account, poor phonological memory skills would indeed be expected to impair the acquisition of sounds of new words.

The nature of the contribution of phonological memory to the acquisition of reading skills appears to be complex and highly dependent on level of reading expertise. Phonological memory appears to make a critical contribution to reading development at the point at which relationships between letter groups and sounds are being acquired. Within the majority of Western educational systems, this stage typically occurs at around 6 years of age (e.g., Ellis & Large, 1988). Results we have recently obtained suggest that it is at this stage that repetition skills in children without language problems are most closely related to their reading achievement (Gathercole & Baddeley, 1990a). These data suggest that phonological memory may be particularly important in establishing simple letter-sound correspondence rules, possibly in much the same way as in learning the sounds of new words. Further evidence for this relationship between memory and success at reading is provided by Snowling’s (1981) report that poor readers are also poor at repeating nonwords.

Although our characterizations of the learning procedures involved in the acquisition of vocabulary and reading skills have been focused on phonological coding skills, many other factors are clearly important. For example, acquisition of vocabulary will also be influenced by global intellectual abilities and the richness of the verbal environment, as well as by the rate at which the child can learn new phonological sequences. Similarly, reading skill is likely to be a joint function of basic cognitive capacities and the amount and quality of instruction. Indeed the educational experience of our language-disordered group may explain why their vocabulary and reading abilities are apparently superior to their phonological memory skills. The extra two years of schooling and experience plus intensive remedial tuition that the disordered children had experienced may have allowed them to be equal to their 6-year-old verbal controls in these measures of language achievement, while continuing to be notably inferior in their underlying phonological memory performance.

In conclusion, the present project has established that children selected as being developmentally language-disordered have a selective impairment in immediate phonological memory, whether tested by recall of word lists or by repetition of nonwords. This deficit was present not only when such children were compared with age-matched controls of equivalent nonverbal intelligence, but also when compared with younger children whose reading and vocabulary performance was equivalent to that of the language-disordered group. Detailed experimental analysis indicated that the deficit could not readily be attributed to impairments in auditory perceptual processes, articulation rate, failure to encode material phonologically in memory, or failure to use subvocal rehearsal. The most likely root of the memory deficit therefore appears to be in phonological storage. Our proposal is that phonological memory makes an important contribution to the development of many complex linguistic abilities in children, and that disordered language development may be a relatively direct consequence of phonological memory impairments.

REFERENCES


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