The Phonological Loop as a Language Learning Device

Article *in* Psychological Review · February 1998

DOI: 10.1037/0033-295X.105.1.158 · Source: PubMed

Susan Gathercole
Medical Research Council (UK)

Costanza Papagno
Università degli Studi di Milano-Bicocca

Psychological Review
1998, Vol. 105, No. 1, 158-173

0033-295X/98/$3.00

The Phonological Loop as a Language Learning Device

Alan Baddeley and Susan Gathercole
University of Bristol

Costanza Papagno
Università Degli Studi di Milano

A relatively simple model of the phonological loop (A. D. Baddeley, 1986), a component of working memory, has proved capable of accommodating a great deal of experimental evidence from normal adult participants, children, and neuropsychological patients. Until recently, however, the role of this subsystem in everyday cognitive activities was unclear. In this article the authors review studies of word learning by normal adults and children, neuropsychological patients, and special developmental populations, which provide evidence that the phonological loop plays a crucial role in learning the novel phonological forms of new words. The authors propose that the primary purpose for which the phonological loop evolved is to store unfamiliar sound patterns while more permanent memory records are being constructed. Its use in retaining sequences of familiar words is, it is argued, secondary.

Baddeley and Hitch (1974) considered the possibility that short-term memory (STM) may serve as a general working memory designed to support complex cognitive activities. This suggestion led to the development of a specific multicomponent model of working memory and has subsequently contributed to an enduring interest in the specific cognitive functions that are fulfilled by the separate subcomponents of working memory. The aspect of working memory for which the fullest theoretical account is now available is the phonological loop (Baddeley, 1986). The loop is specialized for the retention of verbal information over short periods of time; it comprises both a phonological store, which holds information in phonological form, and a rehearsal process, which serves to maintain decaying representations in the phonological store. This relatively simple model has proved capable of accommodating a great deal of experimental evidence from normal adult participants, children, and neuropsychological patients (see Baddeley, 1997, and Gathercole & Baddeley, 1993, for reviews).

Although the evidence for the existence of such a short-term system is strong, it is not obvious why the phonological loop should be a feature of human cognition at all. People have a remarkable capacity to repeat what they hear, a capacity that has extensively been investigated by using lists of digits or unrelated words. When looking for a function that this capacity serves, Baddeley and Hitch (1974) concentrated on asking why it should be useful for people to remember sequences of words, and this led them to study comprehension and verbal reasoning. However, the evidence of a major role for the phonological loop was far from compelling (see Baddeley, 1986, for review). Indeed, much of the neuropsychological evidence that has led to the development of the current model of the phonological loop (e.g., Vallar & Baddeley, 1984) itself raises questions about its function. Many individuals with specific deficits in short-term phonological memory appear to have few problems in coping with everyday cognition: Despite dramatic reductions in the capacity of the phonological loop, such individuals typically have normal abilities to produce spontaneous speech (Shallice & Butterworth, 1977) and encounter few significant difficulties in language comprehension (Vallar & Shallice, 1990). Does this mean that the loop is of little practical significance and that at least this aspect of STM does not serve as a working memory? Some authors have argued that this is indeed the case (Butterworth, Campbell, & Howard, 1986).

The purpose of the present article is to propose that the phonological loop does indeed have a very important function to fulfill, but that it is one that is not readily uncovered by experimental studies of adult participants. We suggest that the function of the phonological loop is not to remember familiar words but to help learn new words. According to this view, the ability to repeat a string of digits is simply a beneficiary of a more fundamental human capacity to generate a longer lasting representation of a brief and novel speech event—a new word. For an experimental psychologist working exclusively with adults, this might at first seem a singularly arcane and useless skill for humans to possess. For a developmentalist, though, the point of such a skill is all too evident because the task of forming long-term representations of novel phonological material is a key component of language development. At a conservative estimate, the average 5-year-old child will have learned more than 2,000 words (Smith, 1926) and will learn up to 3,000 more per year in the coming school years (Nagy & Herman, 1987). Indeed, successful vocabulary

Alan Baddeley and Susan Gathercole, Department of Psychology, Centre for Study of Memory and Learning, University of Bristol, Bristol, England; Costanza Papagno, Clinica Neurologica III, Università Degli Studi di Milano, Milano, Italy.

Much of the work reported in this article was supported by the Medical Research Council (MRC) of Great Britain and the Economic and Social Research Council. The support of MRC Grant G9423916 during the writing of the final draft is gratefully acknowledged. Finally, we are very grateful to Dorothy Bishop of the MRC Applied Psychology Unit Cambridge for stimulating discussion and making many constructive suggestions.

Correspondence concerning this article should be addressed to Alan Baddeley, Department of Psychology, Centre for Study of Memory and Learning, University of Bristol, 8 Woodland Road, Bristol BS8 1TN, England. Electronic mail may be sent via Internet to alan.baddeley@bristol.ac.uk.

acquisition has been claimed to be the single most important determinant of a child's eventual intellectual and educational attainments (Sternberg, 1987). Learning new words is clearly an important task facing the child's developing cognitive system.

Studies of language acquisition have highlighted numerous domains of skill that the young child has to command in order to become a competent speaker of the native language. There are well-established research traditions concerned with identifying, for example, the ways in which the phonological system develops during infancy and early childhood so that the child can start producing language that is comprehensible to others (e.g., Fowler, 1991; Ingram, 1974): how a child learns the concepts associated with words and their usage (Clark, 1983; Keil, 1979; Markman, 1994), and how the syntactic structure of a language is acquired (e.g., Brown, 1973; Gleitman, 1993; Pinker, 1984). However, little systematic attention has been directed at the processes and mechanisms by which the sound patterns of the words of the native language are learned by the child. This, we propose, is the function for which the phonological loop has evolved.

In the next section, we review evidence that the function of the phonological loop is to provide temporary storage of unfamiliar phonological forms while more permanent memory representations are being constructed (Gathercole & Baddeley, 1993). The contribution of this system to the short-term retention of familiar verbal material in conventional memory-span-type tasks is, we argue, merely an incidental by-product of the primary function of the phonological loop, which is to mediate language learning.

Table 1
Simple and Partial Correlations Between Phonological Memory and Vocabulary Measures Across Different Studies

		Nonword repetition		Digit span	
Age	*n*	Simple	Partial	Simple	Partial
3.00[a]	54	**.34**	**.31**	.15	.16
4.01[b,c]	70	**.49**	**.47**	**.28**	**.22**
4.07[d]	80	**.56**	**.46**	—	—
4.09[e]	57	**.41**	**.41**	**.28**	**.29**
5.03[b]	70	**.34**	**.36**	.20	.18
5.06[f]	48	**.48**	—	—	—
5.07[d]	80	**.52**	**.50**	—	—
5.09[e]	51	**.41**	**.31**	**.38**	**.28**
5.09[g,h]	65	**.61**	**.53**	**.44**	**.38**
6.07[d]	80	**.56**	**.48**	**.44**	**.33**
8.07[d]	80	**.28**	.22	**.36**	.23
13.10[g]	60	—	—	**.49**	**.46**

Note. Dashes indicate partial correlations are not available. Coefficients printed in bold are significant at the 5% level. In the partial correlations, the nonverbal ability measure (Raven's Coloured Progressive Matrices; Raven, 1986) was partialed out. Unless indicated otherwise (by Footnote c or h), vocabulary composite scores are based on the British Vocabulary Scale (Dunn & Dunn, 1982).
[a] Data are from Gathercole and Adams (1993). [b] Data are from Gathercole and Adams (1994). [c] Composite vocabulary score is based on British Picture Vocabulary Scales (Long Form; Dunn & Dunn, 1982) and the Oral Vocabulary subtest of the McCarthy Scales for Children (McCarthy, 1970). [d] Data are from Gathercole, Willis, Emslie, and Baddeley (1992). [e] Data are from Gathercole, Willis, and Baddeley (1991). [f] Data are from Michas and Henry (1994). [g] Data are from Gathercole, Hitch, Service, and Martin (1997). [h] Composite vocabulary score is based on the measures indicated in Footnote c and the Expressive One-Word Picture Vocabulary Scale (Gardner, 1990).

Vocabulary Acquisition and the Phonological Loop in Children

Childhood represents the most intensive period of new-word learning for most people, and it is during this period that a natural relationship between the phonological loop and word learning has proved easiest to observe. During childhood, large individual differences are found in STM capacity, even for samples of unselected children of the same age. For example, in a 3-year longitudinal study of children, we found that 10% of children aged between 2 years 10 months and 3 years 1 month could already achieve a digit span of four, whereas 36% of the same cohort did not reach this level until 2 years later (Gathercole & Adams, 1993).

Similar degrees of individual variation are found in children's knowledge of native vocabulary; furthermore individual differences in children's STM performance prove to be related to their vocabulary knowledge, with children who perform well on tests of verbal STM typically also having good vocabulary knowledge. Table 1 summarizes the correlation coefficients between two measures of verbal STM (auditory digit span and nonword repetition) and of vocabulary knowledge found in a range of studies (Gathercole & Adams, 1993, 1994; Gathercole & Baddeley, 1989; Gathercole, Hitch, Service, & Martin, 1997; Gathercole, Willis, & Baddeley, 1991; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994).

Before considering the results in detail, it is worth commenting on these two tasks. Digit span (a measure of the maximum length of sequence of digits that an individual can correctly recall) is the most widely used measure of verbal STM ability and is present as a subtest in most major standardized ability test batteries such as the Wechsler Intelligence Scale for Children (Wechsler, 1974), Wechsler Adult Intelligence Scale (Wechsler, 1981), and the British Abilities Scales (Elliott, 1983). The digit span measure provides a useful indication of the capacity of an individual's phonological loop. Nonword repetition provides a measure of the accuracy with which a child can accurately repeat unfamiliar spoken forms such as *woogalamic* or *loddernaypish.* We originally became interested in this task because it appeared to provide a relatively pure measure of phonological loop capacity. Our reasoning was that owing to the absence of lexical support for these by unfamiliar sound patterns, the child would have to rely very heavily on the representation of the nonword in the phonological loop as a means of supporting its repetition (Gathercole & Baddeley, 1989, 1990a). Thus, nonword repetition may in fact turn out to be more sensitive to phonological loop function than the more conventional digit span measure.

Table 1 shows that across the early and middle childhood years, vocabulary knowledge is strongly associated with both digit span and nonword repetition scores. The significant values of the partial correlation coefficients shown in Table 1 (where available), in which the variance in vocabulary knowledge associated with general nonverbal ability was partialed out, establish that this relationship does not simply reflect a shared contribution to both STM performance and vocabulary knowledge of a general intelligence factor. It should be noted that the STM–vocabulary association is particularly high for measures of nonword repetition, in which coefficients typically fall in the range .4–.6; for digit span, the coefficients are consistently lower, in the range .25–.45. Possible reasons for this especially close link between vocabulary and nonword repetition are discussed later.

Of course, correlation does not imply causation. It is in principle as plausible that good vocabulary knowledge supports accurate nonword repetition as the reverse. One way of collecting further evidence on the direction of causality is to carry out a cross-lagged correlational analysis of longitudinal data. Such an analysis compares the correlation between two measures across a particular time period in the two possible causal directions (i.e., the correlations are calculated and compared between early x and later y and early y and later x). According to the logic of cross-lagged correlations (e.g., Crano & Mellon, 1978), the correlation should be stronger in the causal than in the noncausal direction. In other words, if verbal STM ability is the causal factor in the developmental relationship between nonword repetition and vocabulary, one would expect a stronger prediction from nonword repetition at the first assessment to vocabulary 1 year later than the reverse pattern. Gathercole, Willis, Emslie, and Baddeley (1992) applied a cross-lagged correlational analysis to data obtained in a longitudinal study of 80 children tested on three occasions between 4 and 8 years of age (see also Gathercole & Baddeley, 1989) and yielded results that were consistent with the phonological loop hypothesis. Nonword repetition at age 4 was found to be significantly associated with vocabulary test scores 1 year later (partial $r = .38$, $p < .001$, with variance associated with age and nonverbal ability controlled), whereas the vocabulary measure at age 4 was not a significant predictor of nonword repetition scores at age 5 (partial $r = .14$, $p > .05$). Although such a pattern does not provide watertight evidence for causation, it certainly lends further support to the view that ability to repeat nonwords influences learning of new words.

Research carried out by Service and colleagues on Finnish children learning English at school has extended the link between ability to repeat nonwords and word learning to the acquisition of foreign language vocabulary. The original group of children studied by Service (1992) started to learn English at school at 9 or 10 years. Before commencing the English course, the children were given a series of cognitive tests, one of which involved repeating pseudo-English nonwords. The measure of nonword repetition accuracy proved to a very strong predictor of English language learning when it was tested 2 years later. Further longitudinal analysis of Finnish children learning English as a foreign language has provided more direct evidence that the children's later success at acquiring English is principally mediated by a direct link between repetition ability and vocabulary acquisition (Service & Kohonen, 1995). Similar results have recently been reported in a study of 12-year-old children learning English as a second language (Cheung, 1996).

The data reviewed so far have established a close, natural association between children's phonological loop abilities and their knowledge of native vocabulary. Correlational studies of this kind are inevitably prey, however, to a number of important limitations. One such limitation is that studies of natural vocabulary learning do not permit close control of the word-learning opportunities of individual children. Could it therefore be the case that individuals with both good phonological loop skills and vocabulary knowledge are simply exposed to richer linguistic environments at home and that the greater variety of linguistic forms experienced will boost any language-related ability?

Another limitation concerns the specificity of the hypothesized causal relationship between the phonological loop and word learning. Although we have assumed that the loop serves to support the immediate retention and eventual learning of the novel phonological form of new words, the data from studies of children reviewed so far merely establish a link between loop function and ability to demonstrate knowledge of the meaning of a spoken word. Is it really the case that learning the *sound* of a new word taxes the phonological loop, or is it linked with all aspects of word learning, phonological and nonphonological? If so, the theoretical account of the relationship, which is that the temporary representation of the novel phonological form provided by the phonological loop provides the basis for the construction of a more enduring phonological specification, would clearly require substantial modification.

At least some of these concerns have been laid to rest by experimental studies of word learning in children. In an initial study, Gathercole and Baddeley (1990a) tested the abilities of 5-year-old children of either high or low nonword repetition ability (matched on a measure of nonverbal ability) to learn new names of toy animals. Across 15 trials, the experimenter named four toys and tested the children's memory for these names. The toys were either given familiar names such as Peter and Michael or phonologically unfamiliar names such as Pyemass and Meeton (constructed from the same phonological pool as the familiar names). The findings were clear: The children with the low nonword repetition scores were significantly poorer at learning the phonologically unfamiliar names than the high-repetition children. In contrast, there was no reliable difference in the rates at which the two groups of children learned the familiar names.

These results provide some reassurance that new-word learning is indeed linked to phonological memory skills, even when environmental exposure to new words is controlled across subjects. Furthermore, the specific pattern of findings, in which phonological loop function is significantly related to children's abilities to learn nonwords but not words, has turned out to be highly characteristic of studies of STM and long-term learning and is the signature of many of the studies discussed elsewhere in this article. Similar findings were obtained in a recent study of phonological memory and word learning in 65 5-year-old children (Gathercole, Hitch, Service, & Martin, 1997). The principal concern in this study was to investigate the specificity of the association between phonological loop function and the learning of the phonological form of new words. The children were tested, in separate sessions, on their abilities to learn either pairs of familiar words such as *table–rabbit* or word–nonword pairs such as *fairy–bleximus.* The main finding was that phonological loop ability in this sample of children, as indexed by their scores on nonword repetition and digit span tasks, was highly associated with rate of learning the word–nonword pairs ($r = .63$, $p < .001$) but not with word pair learning ($r = .23$, $p > .05$). Even after variance attributable to differences in age, nonverbal ability, and vocabulary knowledge were taken into account, the partial correlation between phonological memory and word–nonword learning remained strong (partial $r = .49$, $p < .001$); the corresponding partial correlation between memory and word pair learning diminished further to .07, $p > .05$. Thus, ability to learn to associate pairs of familiar words was quite independent of phonological loop function. In contrast, the children's ease of learning new words was strongly constrained by their phonological loop capacity.

A similar finding emerged from a recent study of experimental word learning by Michas and Henry (1994), in which young children were taught the names of three new words, such as *gondola, platypus,* and *minstrel.* An important degree of specificity to the memory–vocabulary association established by Michas and Henry was that it was independent of spatial memory skill.

Further explorations of the developmental relationship between nonword repetition in particular and vocabulary acquisition indicate that it is oversimplistic to claim that the phonological loop mediates long-term phonological learning in a unidirectional manner. Instead, vocabulary knowledge, phonological loop capacity, and nonword learning share a highly interactive relationship. There is accumulating evidence that, for at least some nonwords, the task of nonword repetition taps both the phonological loop and knowledge about the structure of the native language. This fact is demonstrated most simply by the finding that children are reliably more accurate at repeating nonwords that are high in degree of rated wordlikeness (Gathercole, 1995a; Gathercole, Willis, Emslie, & Baddeley, 1991). So even though the stimuli are by definition nonlexical, it appears that children are drawing on their knowledge of either specific familiar words in the language or generalized knowledge of the statistical properties of the language to support the repetition of the novel sound pattern.

The sensitivity of nonword repetition to word likeness provides an important clue as to the relationship between phonological loop function and vocabulary knowledge. It explains why nonword repetition is more highly correlated with vocabulary knowledge than digit span (see Table 1); the reason is that the repetition task itself draws to some degree on the child's vocabulary knowledge and on reflecting phonological loop constraints. For wordlike nonwords, the contribution of long-term knowledge will probably reduce the phonological loop contribution to repetition and hence the sensitivity of the task to phonological loop constraints.

Other evidence also points to a highly interactive relationship between the phonological loop, language knowledge, and long-term learning of the sounds of new words. In the study discussed earlier by Gathercole, Hitch, Service, and Martin (1997), in which experimental word-learning tasks were used as a means of assessing the cognitive components in vocabulary acquisition, speed of learning was correlated to a highly significant extent with children's vocabulary knowledge, even after shared variance with phonological STM had been partialed out. Thus, learning the sounds of new words appears to be mediated by both the phonological loop and long-term knowledge of the native language. The combination of these two types of learning support yields a highly flexible word-learning system in which, where possible, the capacity constraints of the phonological loop are offset by the use of stored knowledge about the language (Gathercole & Martin, 1996).

In summary, evidence from studies of children indicates that the phonological loop mediates the long-term phonological learning involved in acquiring new vocabulary items. This role appears to be particularly significant when the novel phonological forms to be learned have highly unfamiliar sound structures.

Experimental Word Learning and the Phonological Loop in Adults

If the phonological loop is important for acquiring new vocabulary, it should be possible to hinder such acquisition by interfering with the operation of the loop. Any given manipulation may of course be regarded as affecting several underlying variables, and it could be one of these rather than phonological storage that plays a crucial role in vocabulary acquisition. It is at this point that a coherent model of the phonological loop, which is tied to well-explored experimental phenomena, becomes particularly valuable. Several quite distinct variables share a known impact on the phonological loop; if each of these has a corresponding influence on the learning of unfamiliar phonologically novel vocabulary items, it becomes much harder to provide an alternative account of the results. Accordingly, the three sets of experiments described later study the influence on vocabulary acquisition of variables that are known to influence the operation of the phonological loop in clearly specified ways. Detailed accounts of these empirical phenomena in terms of the phonological loop model are provided elsewhere (e.g., Baddeley, 1986, 1997). Briefly, the effective capacity of the phonological loop is diminished when list items have long names rather than short names, the *word length effect* (Baddeley, Thomson, & Buchanan, 1975), have names that are phonologically similar to one another, the *phonological similarity effect* (Conrad & Hull, 1964), and when participants are required to engage in irrelevant articulation during presentation of the memory list, the *articulatory suppression effect* (Murray, 1967). Although the word length and articulatory suppression effects appear to be located in the rehearsal process, the source of the phonological similarity effect is believed to be the phonological store (e.g., Baddeley, 1986). The important question for the hypothesis that the phonological loop mediates the long-term learning of the sounds of new words is the following: Do these three variables also influence phonological learning?

In an initial series of experiments, Papagno, Valentine, and Baddeley (1991) studied the effect of articulatory suppression on the acquisition rate of pairs of familiar words and items of a foreign language vocabulary by normal participants. It is important to note here that articulatory suppression places minimal demands on executive processes but has a precise effect on the capacity for phonologically encoding visually presented material and for actively maintaining it by rehearsal. It thus has no effect on performance for patients such as P.V. who do not use this mode of encoding (Baddeley, Papagno, & Vallar, 1988), but it does remove the phonological similarity effect with visual though not auditory presentation, in line with the phonological loop model (Murray, 1967). The participants in the initial experiments reported by Papagno et al. were native Italian speakers, and they were asked to learn two types of material. The first comprised pairs of unrelated Italian words such as *cavallo–libro,* whereas the second involved learning Italian–Russian pairs (e.g., *rosa–svieti*). Both visual and auditory presentation were used because articulatory suppression is likely to interfere with the two in slightly different ways; with visual presentation, the phonological recording of the material should be prevented (Baddeley et al., 1975), but on the other hand a visual code will be provided, and this may be helpful in vocabulary learning. With auditory presentation, the supplementary visual code will be absent, but the obligatory auditory access to the phonological store will allow a phonological representation to be set up, though not rehearsed (Vallar & Baddeley, 1984). Hence, suppression should impair performance under either mode of presentation. This is in fact what occurred, with suppression having a clearly deleterious effect on the acquisition of foreign language vocabulary. Suppression had little effect, though, on meaningful paired-associate learning in the participants' native language.

This pattern of findings has consistently emerged in experimental studies of paired-associate learning: Although the learning of phonological unfamiliar material is highly sensitive to variables known to influence the phonological loop, the learning of associations between already familiar phonological lexical forms proceeds more or less independently of these variables. The pattern is also notably similar to the one found in studies of children's word learning, in which learning of unfamiliar phonological forms is constrained by phonological memory skills, whereas learning of familiar names is not (Gathercole & Baddeley, 1990a; Gathercole, Hitch, Service, & Martin, 1997). The clear implication is that, when possible, people use existing language knowledge to mediate their attempts at verbal learning. When unfamiliar phonological forms are presented so that no such knowledge is available to support learning, participants are forced to rely solely on the more fragile phonological loop system to provide the necessary temporary storage of the phonological material while more stable long-term phonological representations are being constructed.

In line with this interpretation, an initial attempt to replicate the Papagno et al. (1991) findings described earlier by using English participants ran into difficulties because the participants found it too easy to form semantic associations to the forms of the Russian words. However, once the association values of the material were reduced (initially by using nonsense material and subsequently by using the more unfamiliar phonological structures provided by Finnish vocabulary), the initial results obtained with Italian participants were replicated (Papagno et al., 1991). A second way of exploiting the phonological loop model is to vary the degree of acoustic similarity among the items to be learned. There is abundant evidence to suggest that the long-term acquisition of pairs of items in one's native language depends on semantic rather than on acoustic coding (Baddeley, 1966). However if the unfamiliar new vocabulary items depend on the phonological loop for their initial acquisition, then one would expect an acoustic similarity effect to occur.

In a further series of experiments, Papagno and Vallar (1992) therefore manipulated the degree of phonological similarity among the items to be learned. The predictions are again straightforward. When learning meaningful paired associates, the principal mode of coding should be lexical–semantic, with the result that phonological similarity will have little impact. On the other hand, when participants are learning unfamiliar vocabulary from a foreign language, the phonological loop system should be crucial, hence phonologically similar items should be confusable and lead to slower learning. In a series of experiments using both auditory and visual presentation, Papagno and Vallar demonstrated that this was indeed the case.

A final variable that would be expected to specifically impair the operation of the phonological loop is item length, with immediate memory for long nonwords impairing immediate recall because of the impact of length both on rehearsal and on output delay. Papagno and Vallar (1992) therefore manipulated the number of syllables in the native and foreign response items to be learned in their paired-associate tasks. Once again, the prediction for lists containing familiar words is that length should not be an important variable because items will be acquired principally on the basis of semantic coding. In contrast, learning foreign language vocabulary (i.e., word–nonword pairs) should be impaired if the participant uses subvocal rehearsal as a crucial part of the phonological loop-based learning process. The data were consistent with this prediction: Word length had no influence on the participants' acquisition of pairs of items in their native language, but it had a substantial effect on the acquisition of unfamiliar Russian vocabulary.

In interpreting the influence of articulatory suppression, phonological similarity, and word length on the acquisition of foreign language vocabulary, three points are of particular importance. First, in each case the observed effect was predicted on the basis of specific well-established characteristics of the operation of the phonological loop. Second, the specific nature of the interaction between the type of material and each of the variables is important; in all cases, the relevant variable has no effect on the acquisition of words, coupled with a very clear effect on nonword learning. Finally, any possibility that we are simply picking up effects of added difficulty is ruled out by the absence of an influence of each of these variables, not only on word learning in normal participants but also in the absence of any effect on the performance of patients who do not utilize the phonological loop in the normal way (Baddeley et al., 1988).

Further evidence in favor of the phonological loop hypothesis comes from a series of studies concerned with optimizing foreign language learning. Ellis and Beaton (1993) investigated the role of visual imagery and rote verbal rehearsal in the acquisition of German vocabulary by English speakers. Imagery proved to be the most effective strategy for learning to produce the English equivalent of German words, but when the requirement was to generate the German translation of an English word, rote rehearsal proved more effective, again implicating the phonological loop in that aspect of the task that involves learning to produce novel phonological forms.

Indeed, it is an interesting possibility that imitating the sounds of new words may be a natural strategy that serves to boost vocabulary acquisition by enhancing phonological loop representations of the novel phonological structures. There is certainly considerable evidence that imitation does play a significant role in vocabulary learning, with many observations that some infants spontaneously imitate the language of others (Bloom, Hood, & Lightbown, 1974; Coggins & Morrison, 1981). Masur (1995) has recently provided a detailed quantitative evaluation of the links between imitation of words and later vocabulary development on the basis of longitudinal laboratory observations of 20 children between the ages of 10 months and 2 years. Children with larger vocabularies were found to imitate words spoken by the caregiver more than children with more restricted early vocabularies. Furthermore, Masur found that spontaneous imitations of words that were not in the children's current vocabulary significantly predicted their later vocabulary growth during the second year, even after the size of the children's vocabulary at the time of imitation had been taken into account. Whatever lies at the root of these differences in spontaneous imitation, these findings suggest that imitation of novel phonological forms may indeed serve to promote the long-term phonological learning of new words, possibly by increasing the period over which they are held in the phonological loop.

These various experimental studies converge on a simple model of new-word learning. According to this model, the long-term learning of the sound structures of novel, phonologically unfamiliar words depends on the availability of adequate representations of the sound pattern in the phonological loop. Thus, the phonological loop appears to provide a critical input to the construction of the more permanent phonological structures that are stored in the mental lexicon. Learning of associations that require the production of familiar lexical items, on the other hand, is achieved typically either without any reliance on the phonological loop or with reduced loop support and is presumably mediated instead by the use of existing knowledge of the native language.

In the sections that follow we summarize further evidence from a variety of participant populations and research laboratories that is consistent with the model of the function of the phonological loop as a word-learning device outlined earlier. In these sections, we chart the consistently close relationships between phonological loop capacity and abilities to learn new words, either in natural vocabulary acquisition or in experimental simulations of vocabulary learning in individuals with STM deficits arising from brain damage, developmental disorders, and specific mental handicaps. The weight of this converging evidence lends considerable force to the view that the primary function of the phonological loop is to support the long-term learning of the phonological forms of words in one's own language.

Cases of Cognitive Deficit

Following early studies by Shallice and Warrington (1970), the accepted view was that STM patients have a normal capacity for long-term learning. It is notable, though, that most long-term memory (LTM) tests give ample scope for semantic coding. Participants are usually required to learn arbitrary sequences of familiar words, not phonologically novel material. Baddeley et al. (1988) therefore decided to test the capacity of the STM patient P.V. for learning the vocabulary of an unfamiliar language, Russian.

P.V. and a group of 14 matched control participants were asked to learn the two types of paired associates used subsequently in the Papagno et al. (1991) study with normal adult participants. The pairs consisted of either unrelated Italian words (P.V.'s native language was Italian) or Italian–Russian equivalents. Because P.V. had difficulty repeating back polysyllabic Russian words, we restricted our list to comparatively short items. In each case, lists of eight pairs were presented by using either the auditory mode, which should place the maximum load on her phonological store, or the visual presentation of the transliterated stimuli. The results were clear. P.V. was perfectly normal at learning to associate pairs or words in her native language, but her capacity for learning Russian vocabulary was severely impaired. With auditory presentation, the control participants had learned the whole list before P.V. had mastered a single item, despite the fact that they were short enough for her to be able to hear and repeat back accurately. With visual presentation her performance was somewhat better, but it was still markedly worse than that of the control participants.

It appears then that P.V.'s short-term phonological deficit was indeed associated with a specific impairment in long-term learning of phonologically unfamiliar material. She showed a dissociation between her normal general long-term and learning capacity and her very marked deficit in long-term phonological learning. A similar pattern of immediate memory and long-term learning deficit was also reported by Trojano and Grossi (1995), in a study of a patient, S.C., with very poor phonological function who showed no evidence of rehearsal. Characteristically, S.C. was completely unable to learn auditorily presented word–nonword pairs, despite showing evidence of adequate learning ability in other tasks that did not share such a heavy phonological learning component.

Evidence that a long-term phonological learning deficit arises from impairments in the phonological loop has also been provided in a study of an individual who appears to have a developmental impairment of the loop. In attempting to collect control participants for an experiment, Baddeley (1993) identified a graduate student, S.R., with an unusual STM profile. Although highly intelligent and sophisticated in cognitive psychology, S.R. was not reliably able to repeat sequences of more than four digits and performed very poorly on a task involving the immediate repetition of multisyllabic nonwords. When compared with a group of six fellow students on a wide range of short-term phonological memory tests, S.R. invariably performed more poorly. On the other hand, his capacity for short-term visual memory was normal while his long-term visual recognition score on the Doors and People Test (Baddeley, Emslie, & Nimmo-Smith, 1994) was excellent.

The crucial question was how he would perform on phonological LTM. On two companion tests to the Doors Test, which involved the recognition and recall of names, S.R. performed more poorly than any of the control participants. Finally, he was tested by using a paradigm based on that developed with P.V., in which he learned pairs of meaningful English words and English–Finnish foreign language vocabulary. S.R. showed excellent use of mnemonics and was quite normal in his learning of meaningful paired associates. His capacity to learn Finnish vocabulary, though, was grossly impaired when compared with control participants. It is perhaps worth noting that S.R. had previously tried unsuccessfully to learn two languages, being eventually excused on a language qualification for admission to university on the grounds of his incapacity for such learning. His vocabulary was excellent as was his reading, but his spelling performance was very poor, despite the considerable energy and ingenuity he had invested in developing spelling mnemonics. In short, S.R.'s low nonword repetition and digit span were associated with very poor performance on name and foreign language learning and on English spelling.

The profiles presented by these three individuals with severely limited phonological loop function, due in two cases to acquired neurological damage (Baddeley et al., 1988; Trojano & Grossi, 1995) and in the other case to an unidentified developmental deficit (Baddeley, 1993), are very similar. Despite their STM limitations, both individuals were able to function adequately and indeed at a high level across a range of intellectual tasks. They did share, though, a highly specific deficit in learning verbal material that was phonologically unfamiliar, despite their normal long-term verbal learning of arbitrary pairs of familiar words.

Notably, neither individual had poor vocabulary knowledge in their native tongue. For P.V. this is unsurprising, as the vast majority of natural vocabulary acquisition takes place before adulthood, at a time before she suffered the neurological insult that resulted in her STM deficit. On the other hand, S.R.'s memory problems do seem likely to be part of a developmental disorder that extended back to early childhood. Although we did not have access to school or clinic records, he reported having been referred to a remedial program in connection with his spelling and language learning problems. Nevertheless, his vocabulary acquisition problems appear to have been restricted to foreign language learning.

There is no doubt that S.R. represents an important paradox for our hypothesis; if he has an impaired phonological loop, how has he acquired a good vocabulary? To resolve this paradox, the process of vocabulary acquisition needs to be considered. During the early years, the words that are first acquired are likely to be highly frequent and often relate to concrete objects. Vocabulary in children is typically assessed by requiring them to either name or point to pictures, and in the early years these are likely to represent objects that most children would be likely to encounter. Under these circumstances, the rate of learning is likely to be set by the child's capacity to master the new phonological forms and to attach them to their referents rather than to the likelihood that the word has been encountered. The probable importance of phonological factors is indicated by the data on age of acquisition, in which for an equivalent level of word frequency, long words tend to be acquired later than short words (Brown & Hulme, 1996). As vocabulary develops, it is likely to depend increasingly on acquiring low-frequency words. These in turn will often be abstract in nature and relatively unlikely to be encountered with any frequency in day-to-day conversation. Testing tends to be by synonym matching, allowing the participant to use sophisticated guessing strategies to rule out at least some of the alternatives. General intelligence is likely to be important in this context and to be even more important in determining whether the listener or reader is able to gain some idea as to the meaning of a novel word when it is encountered in context. Hence, a phrase such as "the lawyer was searching sedulously through his papers" may give some idea as to the meaning of "sedulous" even though the word is never specifically looked up in a dictionary or defined.

We now return to S.R. who is highly intelligent, well motivated, and well educated but with poor phonological loop capacity: His rate of acquisition of new words is initially likely to be relatively slow, but over 20 years he is likely to have plenty of opportunity to acquire the type of word that occurs frequently within the language. His performance on relatively frequent words is thus likely to approach a similar plateau to other participants, although more slowly. In the case of those rarer words that it is necessary to know in order to score more highly on vocabulary tests, he is favored by his general intelligence, his education, and his motivation. Hence, while he might not have as high a vocabulary as he would have done had he been phonologically well endowed, his cognitive and educational advantages are likely in the long run to substantially outweigh the limitations set by the slower rate of acquisition of new phonological forms.

To uncover a direct relationship between verbal STM and natural vocabulary acquisition, it is therefore necessary to study either children still in the process of acquiring their first language or individuals without exceptional cognitive abilities to compensate for specific memory problems in vocabulary learning. It is to these participant populations that we turn to in the next two sections.

Learning Disabilities

There is increasing awareness of the diverse patterns of cognitive ability that may be seen in genetic syndromes associated with mental handicap. Bellugi and her colleagues have conducted a series of studies contrasting the phenotypic profiles of individuals with Williams syndrome and those with Down's syndrome, and they noted that while both are associated with mental handicap, the profile of abilities is very different (e.g., Bellugi, Marks, Bihrle, & Sabo, 1988). Individuals with Williams syndrome demonstrate relatively good language skills in relation to their mental ages and are more likely to produce unusual and low-frequency words both in spontaneous speech and in a verbal fluency task, whereas Down's syndrome is usually associated with poor communicative skills. Wang and Bellugi (1994) explicitly compared memory span in individuals with Williams and Down's syndromes, using groups who were matched on overall IQ. Those with Williams syndrome had a mean digit span of 4.6, whereas the Down's group had a significantly lower mean span of 2.9. Wang and Bellugi found a contrasting pattern of differences between the two groups on a measure of nonverbal span, the Corsi Blocks Test (DeRenzi & Nichelli, 1975), with superior performance by those with Down's syndrome.

Although the innovative research by Bellugi and her colleagues (Bellugi et al., 1988) clearly demonstrated different patterns of performance in Down's and Williams syndromes, the absence of appropriate control groups makes it difficult to be sure whether the pattern represents a particular weakness in Down's syndrome or a particular strength in Williams. A tendency for Down's syndrome to be associated with hearing problems presents a further complication. Recent studies by Jarrold and Baddeley (1997) and Jarrold, Baddeley, and Hewes (in press) suggested that Down's syndrome is indeed associated with impaired digit span when compared not only with Williams syndrome but also with younger mainstream children and participants with minimal learning difficulties when the groups were matched for verbal mental age. Furthermore, hearing problems were ruled out as a possible explanation of the deficit. It is of interest to note that even when the Down's group was matched with the comparison groups on current vocabulary, their digit span was significantly lower. When matched for vocabulary, however, the Down's group tended to be significantly older, suggesting that their impaired phonological loop performance may have resulted in their taking longer to acquire the same amount of vocabulary as the comparison groups.

Recent work on Williams syndrome has made it clear that although language development in this group is better preserved than nonverbal skills, nonetheless, the verbal IQ scores are typically in the delayed range (Arnold, Yule, & Martin, 1985; Karmiloff-Smith, Grant, Berthoud, Davies, Howlin, & Udwin, in press). A recent study by Grant et al. (1997) has specifically looked at nonword repetition in Williams syndrome, finding that repetition performance was not correlated with chronological age, presumably because the degree of learning disability was varied across participants but finding that it was associated with digit span ($r = .59$, $p = .12$), Raven's Matrices (Raven, 1986; $r = .50$, $p = .039$), Bishop's Test for the Reception of Grammar ($r = .68$, $p = .003$), and vocabulary ($r = .77$, $p < .001$). The mean test age of the group was 107 months on the vocabulary measure, compared with test ages in the region of 80 months on the other tests. This presumably reflects the fact that vocabulary represents a "crystallized" measure that accumulates over time, whereas the other measures are based on current capacity. Finally, Grant et al. found a higher correlation between repetition of low wordlike items and vocabulary than occurred with high wordlike items—a pattern that resembled Gathercole's (1995a) observations on 4-year-old normally developing children rather than on her results for 5-year-olds. They interpreted this pattern as indicating that repetition performance in this group relies principally on phonological memory and is less influenced by existing vocabulary, concluding that "the good vocabulary scores of older children and adults with WS [Williams syndrome] may be simply due to their relatively good phonological short-term memory" (Grant et al., 1997, p. 82).

Although these authors did not directly explore the relationship between the phonological loop and vocabulary knowledge in the groups of individuals with Down's and Williams syndromes, unusually good vocabulary knowledge is a characteristic of Williams syndrome (Bellugi et al., 1988). The profile of superior phonological STM skills and precocious vocabulary knowledge in this syndrome, accompanied by very depressed levels of more general cognitive function, is therefore entirely consistent with the notion that the phonological loop serves a word-learning function.

A notable feature of Down's syndrome is the wide degree of variability in the cognitive abilities of different cases. In fact, a small proportion of individuals with Down's syndrome has achieved near-normal language abilities by adulthood (Rondal, 1994). Vallar and Papagno (1993) investigated the word-learning capabilities of one such case, a young woman with Down's syndrome who had a full scale IQ of 71 but a digit span of 5.7, well within the normal range. She was Italian but had lived abroad with her parents and could speak good English and reasonable French. When given the same paired-associate tests as P.V., she proved to be normal in her capacity for learning Russian vocabulary but impaired when compared with control participants in learning pairs of words in her native language, showing the converse deficit to P.V. Thus, as has been reported with Williams syndrome, this woman's intact phonological memory skills appear to have been sufficient to mediate normal levels of vocabulary learning, despite her substantial cognitive deficits in other areas.

Children With Specific Language Impairment (SLI)

The developmental studies reviewed earlier in this article focused on the consequences of individual variation in phonological loop function in normal children for their capacity to acquire new vocabulary. In the present section, a brief overview is provided of the memory and word-learning profiles of children with specific language impairment (SLI). This condition is diagnosed when a child fails to develop language at a normal rate for no obvious reason and despite adequate progress in other areas. The particular profile of language problems varies from child to child, but problems with syntax and morphology are particularly common, with expressive language usually more severely impaired than receptive language (Bishop, 1992). In line with the general profile of impaired language skills, SLI children typically lag behind their peers in terms of vocabulary development (Stark & Tallal, 1981). Could a phonological loop deficit lie at the root of their word-learning problems?

Phonological memory problems have certainly been implicated in SLI (Kirchner & Klatzsky, 1985; Menyuk & Looney, 1976). When compared with age-matched controls, children with SLI perform poorly on both conventional verbal memory span tests (Locke & Scott, 1979, Raine, Hulme, Chadderton, & Bailey, 1991) and on tests of nonword repetition (Kamhi & Catts, 1986; Taylor, Lean, & Schwartz, 1989). Studies of incidental word learning have shown that SLI children are poorer at recalling phonologically novel names for new concepts than age-matched controls, although nonphonological aspects of their acquisition of new words are unimpaired (Dollaghan, 1987; Rice, Buhr, & Nemeth, 1990).

Although abundant evidence exists for patterns of association between cognitive processes in SLI children, it is difficult to tease apart cause and effect. Poor memory in children with SLI is consistent with the hypothesis that memory limitations are the root cause of the language impairment. However, the opposite is also possible; poor verbal memory could result from weak language skills. One approach to this dilemma is to compare language-impaired children with younger control children matched on language level. If their memory is poor even in relation to this language-matched younger control group, then it can be assured that the problem is not just a secondary consequence of the language limitations. However, a finding of no difference is difficult to interpret; it does not rule out the possibility that memory deficits are holding the child's language development back, but it is also compatible with the view that the memory deficits are secondary (Bishop, 1992).

Studies using the language-matched control design have obtained mixed results. Leonard and Schwartz (1985) found that young SLI children at the one-word stage of language development tended to imitate adult's speech, just like normal young children at this language level, and in an experimental task they showed facility at learning nonsense names for novel items equal to that of younger language-matched controls. However, Haynes (1982) conducted an intentional word-learning study and found that her group of SLI children was far poorer than younger language-matched controls at identifying the target nonwords to which they had earlier been exposed. It is possible that the different results reflect the fact that the children studied by Haynes were older with more severe problems.

In a study of a group of SLI children, Gathercole and Baddeley (1990b) found evidence of a phonological loop deficit that was even more severe than the generalized language delay of the children. In terms of vocabulary knowledge, sentence comprehension and reading achievement, the SLI participants (who had a mean age of 8 years) were lagging, on average, between 18 and 24 months behind their chronological age peers. The SLI group showed normal evidence of rehearsal in their immediate serial recall. However, on tests of immediate nonword repetition, the SLI children performed significantly more poorly than even their 6-year-old language controls; on a 40-item nonword repetition test, all of the SLI children performed more poorly than any of the control children. The nonword repetition abilities of the SLI children were equivalent to those of the average 4-year-old, a full 4 years behind the mean chronological age of this group. Van der Lely and Howard (1993) reported no difference in nonword recall between an SLI group and age-matched controls. Their conclusions are, however, open to dispute (Gathercole & Baddeley, 1995), and subsequent studies from other laboratories report substantial phonological memory deficits in SLI children (Jones, von Stienbrugge, & Chicralis, 1994; Montgomery, 1995).

Intriguingly, Bishop, North, and Donlan (1996) found severe limitations of nonword repetition in children with a history of SLI, whose language problems had been resolved as well as in those who still had measurable language deficits. Because the resolved group no longer had significant impairments on standardized language tests, their memory failures could not be regarded as a secondary consequence of generally weak verbal skills. However, if poor phonological memory causes language delay, how can a child have a major impairment of nonword repetition without showing major limitations of language skills? Bishop et al. argued that children can use good general ability to compensate for early language deficits. As previously suggested in our discussion of the graduate student S.R., weak phonological loop function will delay language development, but it does not necessarily result in lasting deficits, especially if the child is bright and can adopt compensatory strategies.

Gifted Language Learners

So far, the principal focus of this review has been on the poor vocabulary acquisition abilities that are associated with below-average phonological loop function, in both children and adults. Intriguing evidence has recently been presented that the converse is also true and that the source of the "natural talent" that some individuals have for acquiring foreign languages may be the result of exceptional phonological loop skills.

Papagno and Vallar (1995) compared the performance of groups of polyglot and nonpolyglot university students on a range of memory and long-term learning tasks. The polyglots were able to speak at least three languages fluently and were enrolled at the Language Faculty of Milan University. The nonpolyglot students were not studying any languages at an advanced level and had only studied one foreign language at school. The polyglot and nonpolyglot participants performed indistinguishably on tests of nonverbal ability, visuospatial STM span, and visuospatial learning and were equivalent in general intellectual skills.

Interestingly, though, the polyglots performed significantly better on the two phonological memory tests: auditory digit span and nonword repetition. On the span measure, the memory advantage to the polyglot group corresponded to an extra 1.6 digits, a substantial gain. Performance on the two phonological memory measures correlated highly with participants' abilities to learn new word–nonword pairs by using the stimuli and methods developed by Baddeley et al. (1988). Memory scores were, however, independent of word–word paired-associated learning.

Once again, good phonological memory performance shares a highly specific link with fast and efficient learning of unfamiliar phonological material, but it is independent of both nonverbal STM skills and the ability to learn combinations of familiar lexical items. This profile, recurring as it does across children, adults, and several special developmental populations, provides the substantive basis for our claim that the primary function of the phonological loop is to provide a mechanism for the temporary storage of new words while more stable long-term phonological representations are being constructed. The case of gifted language learners suggests that a natural talent for language learning may arise directly as a consequence of excellent phonological loop function.

A Device for the Acquisition of Syntax?

Learning the vocabulary of one's native language is one of the most important aspects of language acquisition. Words represent the basic building blocks of language, and vocabulary knowledge limits both the speaker's production of spoken language and the comprehension of language produced by others. The role we ascribe here to the phonological loop, of supporting the learning of new words, is therefore by no means trivial.

This view may nonetheless represent an underestimation of the contribution of the phonological loop in language acquisition. A further possibility is that the loop system mediates the acquisition of syntactic knowledge, as well as the learning of individual words. The preschool years are characterized by children's rapid learning of syntactic rules, and this syntactic knowledge is itself the source of very considerable individual variation. Many researchers in the area of child language have argued that one of the ways in which this syntactic development is achieved is by the child learning a storehouse of multiword language patterns that are used both as models for his or her own utterances and for the abstraction of the rules governing connected language (e.g., Brown & Fraser, 1963; Nelson, 1987; Pinker, 1984; Plunkett & Marchman, 1993). Speidel (1993) has proposed that the multiword utterances to be learned must first be held in phonological working memory. By this account, the integrity of the temporary phonological representations of the utterances will constrain the speed and accuracy with which more permanent LTM representations will be constructed.

Speidel (1989, 1993) based this suggestion on a detailed longitudinal analysis of the developing language abilities of two bilingual siblings, Mark and Sally. Both children had excellent and comparable general intellectual abilities and had no problems in understanding either language. However, although Sally's language production was as good as her comprehension, Mark had difficulties in speaking both languages. His parents reported that he was slow to start producing single words, and articulatory and word order problems were apparent by the time he started producing multiword utterances. By 5 years of age, his speech was intelligible but marked by syntactic errors and difficulties in retrieving the precise phonological forms of familiar words. Notably, Mark performed much more poorly than Sally on phonological memory tests such as auditory digit span and serial recall. Speidel (1989, 1993) suggested that as a consequence of Mark's relatively poor abilities to hold phonological material temporarily, he failed to develop adequate long-term representations of the words and phrases that are used to build syntactic patterns in speech. Thus, he had a much more limited repertoire of templates to guide the construction of his own utterances and also to provide the basis for his abstraction of the syntactic rules governing the two languages.

Correlational studies of normally developing children also support a link between phonological memory ability in young children and speech output. A study by Daneman and Case (1981) showed that word span was better than chronological age at predicting performance of 2- to 6-year-old children in an artificial grammar-learning task, and Blake, Austin, Cannon, Lisus, and Vaughan (1994) reported that word span predicted mean length of utterance in 2- to 3-year-olds better than either chronological age or mental age. Similar findings have emerged from a study by Adams and Gathercole (1995) who contrasted the spontaneous speech of two groups of 3-year-old children: one group with good scores on the phonological memory tests of digit span and nonword repetition and one group with relatively poor performance on these measures. Clear differences emerged in both the quantity and quality of their utterances. The high-memory-performance children produced lengthier utterances (see also Adams & Gathercole, 1996) and used a wider vocabulary than the low-memory children. Furthermore, a significantly wider range of syntactic structures was also present in the speech of the high- than the low-memory-performance group. Again, there is evidence of a relationship between phonological loop function during language acquisition and syntactic as well vocabulary development.

In summary, the phonological loop may play a crucial role in syntactic learning and in the acquisition of the phonological form of lexical items. This line of inquiry is very much in its early stages at present. The results so far, though, are certainly consistent with recent views developed on the basis of computational models of language acquisition that a single mechanism underpins the learning of single words and of the morphological properties of the language (e.g., Plunkett & Marchman, 1993). According to this position, there is no functional distinction between the way that words and, for example, inflectional morphology are learned. Our suggestion here is that the operation of this single system is significantly constrained by the phonological loop.

What Part of the Phonological Loop Supports Language Learning?

We have as yet said little about the more detailed aspects of how the loop system mediates learning. A full account of the mechanisms by which the sounds of new words are learned has still to be developed, but some advances in the direction of a fuller understanding have been made. Some of the major issues concerning the microstructure of the phonological loop and how it supports language learning are considered in the next two sections.

Phonological Storage or Rehearsal?

The current model of the phonological loop consists of two components: the phonological short-term store and a subvocal rehearsal process that serves to preserve decaying representations in the phonological store (Baddeley, 1986). The body of evidence reviewed earlier indicates a close association between the phonological loop and long-term phonological learning. An obvious question to ask is the following: What aspect of the phonological loop is critical to this learning function?

The answer seems to be that the fundamental mechanism linking phonological memory and vocabulary acquisition is the phonological store. It is now widely believed that although the phonological store is in place in children as soon as language abilities begin developing, their use of subvocal rehearsal as a means of silently maintaining the contents of the phonological store does not emerge until around 7 years of age (see Cowan & Kail, 1996, and Gathercole & Hitch, 1993, for reviews). There is a variety of evidence supporting this claim, including the emergence of overt signs of articulatory activity in immediate memory tasks at around this age (Flavell, Beach, & Chinsky, 1966) and in the absence of significant correlations between articulation rate (which appears to provide an index of rate of subvocal and overt articulation) and memory span in children below this age (Gathercole & Adams, 1994).

However, as Table 1 illustrates, there is ample evidence of close links between phonological memory performance and vocabulary learning under 7 years of age and, indeed, from children as young as 3 years (Gathercole & Adams, 1993). This makes it unlikely that it is the subvocal rehearsal process that mediates long-term phonological learning in young children, although rehearsal does appear to play a role in second-language learning in adults, as evidenced by both the negative effects of articulatory suppression (Papagno et al., 1991) and the positive effects of a rehearsal strategy (Ellis & Beaton, 1993).

The importance of storage rather than rehearsal processes is reinforced by consideration of the demands of the nonword repetition task. The task involves the child attempting the immediate repetition of a single unfamiliar item. Repetition attempts typically commence within 1 s of the end of the nonword, and the nonwords in the test we have developed typically have spoken durations of considerably less than 1 s (Gathercole, Willis, Baddeley, & Emslie, 1994). Given the usual estimate of the temporal capacity of the phonological store of about 2 s (Baddeley et al., 1975), and the fact that the child is allowed to repeat the item aloud as soon as he or she wishes, the likelihood that the rehearsal process significantly contributes to individual differences in nonword repetition ability seems remote. Rather, we suggest, performance on the task is constrained by the quality of the phonological representation of the just-spoken unfamiliar item. In other words, nonword repetition provides a measure of the phonological store, not phonological rehearsal.

There is, however, at least one other possible account of the memory–vocabulary association that merits consideration. It has been suggested by Snowling, Chiat, and Hulme (1991) that the association is mediated by articulatory output skills (see also Wells, 1995). The argument is that children with poor articulatory function will perform at a low level on verbal tasks that require speech output and that these output difficulties will be particularly manifest in tasks such as nonword repetition in which output of the spoken form is unpracticed by the child, and absolute phonological accuracy is required.

At one level, this account must be true: Children with impaired articulation such as J.B. (Snowling & Hulme, 1989) will necessarily be poor at repeating nonwords, and it would clearly be inappropriate to interpret low nonword repetition scores in individuals with articulatory deficits as reflecting a phonological loop impairment. A more important issue for the present purposes is whether the link between phonological memory function and word learning in the populations that have been studied (normal children and adults, gifted language users, neuropsychological cases, and cases of developmental disorder) is entirely mediated by individual differences in speed of articulation (Gathercole, 1995b). This seems unlikely as such an interpretation was explicitly ruled out by the observation of impaired phonological long-term learning despite normal articulation rate in studies involving both SLI children (Gathercole & Baddeley, 1989) and the STM deficit patient P.V. (Baddeley et al., 1988).

In the case of normal 4-year-old children, it has been shown that a speech output requirement in immediate memory performance is not crucial to the link between memory and vocabulary (Gathercole, Hitch, Service, Adams, & Martin, 1997). A nonword matching span task was used in which the children heard sequences of nonwords repeated in either the same or transposed order. The sequences increased in length over successive trials, and the child's task was simply to identify the two sequences as either the same (e.g., *guk, dar, lus . . . guk, dar, lus*) or different (e.g., *pes, vip, mel . . . pes, mel, vip*), thereby removing any significant output component to the task. Nonword matching span measured in this way was found to be significantly related to vocabulary knowledge ($r = .56, p < .05$), as was both digit span ($r = .59, p < .05$) and nonword repetition ($r = .39, p < .05$). There was therefore no evidence that the link between immediate memory performance and vocabulary was critically mediated by differences in the abilities of these children to accurately output nonwords. Rather, the data suggest that a common phonological loop constraint underpins the relationship between all three memory measures and vocabulary knowledge.

Finally, the relationship between phonological memory and long-term phonological learning of new words is not simply restricted to cases in which the individual has to recall the new word form. Gathercole, Hitch, Service, and Martin (1997) found significant links between young children's performance on tests of phonological memory and experimental word learning even in a task in which the child was required not to recall the phonological form of a new word but simply to recognize it and to supply its associated semantic attributes.

In summary, the broad sweep of available evidence indicates that it is the phonological store that plays a critical role in the learning of the phonological forms of new words. Although rehearsal may be important for maintaining the quality of its representations, it is the store that is the primary language learning device.

What Is the Phonological Store?

We have so far depended on an extremely simple model of the phonological loop as some form of store supplemented by an articulatory rehearsal process. It is far from obvious how such a store might operate or why indeed it would be helpful in the acquisition of novel long-term phonological representations. In particular, the relationships between short- and long-term aspects of the phonological loop are clearly close, but quite unspecified.

One popular way of conceptualizing working memory is in terms of the activation of some aspect of LTM (for a discussion see Gathercole & Martin, 1996). This simple generalization does indeed capture one important feature of the operation of the phonological loop; namely its capacity to exploit prior learning. The evidence for this capacity is now extensive. (a) Nonwords that closely resemble the phonological structure of English are more readily repeated than less wordlike items (Gathercole, 1995a) and are better recalled in a serial recall paradigm (Gathercole, Frankish, Pickering, & Peaker, 1997). (b) We have found that English children's abilities to repeat unfamiliar nonwords constructed to conform to the phonotactic rules of the French language are directly related to their knowledge of French vocabulary (Gathercole & Thorn, 1997; Thorn & Gathercole, in press). (c) Memory span for sequences of nonwords increases when the items are familiarized through a training procedure, whereas the use of already familiar words further enhances performance (Hulme, Maughan, & Brown, 1991). (d) Span increases dramatically from about 5 words to 16 or more when sequences of unrelated words are replaced by text. Although this clearly reflects the importance of syntactic and semantic factors in text recall, performance still appears to have a phonological basis, as a similar sentential advantage is also found in patients with a phonological loop deficit who might have a span of 1 or possibly 2 unrelated words, but who will have a sentence span of 6 or 7 (Baddeley, Vallar, & Wilson, 1987).

Under these circumstances, it is tempting to argue that the phonological loop simply represents the activation of those systems necessary for the perception of language (Allport, 1984; Brown & Hulme, 1996; Gathercole & Martin, 1996). There are, however, three problems with this interpretation. First of all, it predicts that patients with marked phonological loop deficits should have equivalent problems in speech perception, production, or both. Although Allport has argued for the presence of subtle deficits in one of the classic cases of a STM patient, Shallice (1988) has argued that the evidence for such a view is extremely weak, particularly because patient P.V. (Vallar & Baddeley, 1984) has shown no evidence of speech perception or production problems.

The second reason for doubting a simple association between phonological processing and memory comes from the study of articulatory suppression. Suppression has a very marked effect on memory span performance while having little or no effect on the capacity to perform a phonological judgment such as assessing whether two items are homophonous (Baddeley & Lewis, 1981; Besner, Davies, & Daniels, 1981).

A third reason for dissatisfaction with interpretations of STM processes, purely in terms of structures within the LTM, comes from considering the development of vocabulary. It is clear that in the case of an adult or older child, vocabulary growth is associated with a range of variables that probably involves both phonological and lexical development. A relevant model is that proposed by Brown and Hulme (1996), shown in Figure 1. The problem with this model is that it provides no explanation for why some children develop vocabulary more rapidly than others. Furthermore, each component of the model implicitly depends on prior learning, but no mechanism for such learning is provided. Our own evidence suggests that while such a multiply interactive model may well apply to older children, the earlier stages of development are better characterized by a model in which differences in the capacity to repeat back unfamiliar items will lead to differences in vocabulary, which only subsequently begin to have a reciprocal influence on nonword repetition performance (Gathercole et al., 1992).

Despite the absence of a primary function for phonological STM in their own model, Brown and Hulme (1996) have proposed an important role for a separate STM system in vocabulary acquisition. They emphasized the computational advantage of having such a temporary system by using as an analogy the case made by McClelland, McNaughton, and O'Reilly (1994) for the role of the hippocampus. McClelland et al. argued that efficient LTM involves representing the underlying structure of the environment in the neocortex, which in turn requires the assignment of similar patterns to similar representations by a slow incremental process. However, to allow the rapid encoding and representation of novel experiences, a more temporary registration is necessary, a process that is dependent on the operation of the hippocampus. Brown and Hulme suggested that a phonological short-term store, although operating over a much briefer time scale, could serve a similar function to that of the hippocampus, in allowing the precise registration of phonological sequences while they are recoded into a more durable form in phonological and lexical LTM.

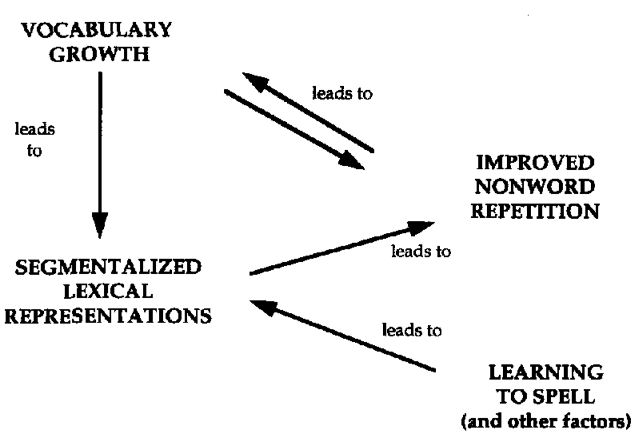

Figure 1. Causal relationships between vocabulary size, nonword repetition, and other factors as proposed by Brown and Hulme (1996).

Note that it is important for such a system to make use of prior phonological and lexical knowledge but not to allow that knowledge to override the short-term representation of novel stimuli. A system that simply reflects existing knowledge will be inherently conservative and insensitive to novel inputs and as such will represent a poor learning system. Conversely, a system that attempts to learn all novel events will run the risk of unnecessarily committing valuable storage resources. Consider the case of spoken language. Many of the utterances people hear are spoken in a range of different voices, accents, or are partially masked by ambient noise. Permanent storage of the novel tokens in each of these cases would be premature and of little value. However, a system in which learning occurs incrementally over time, on the basis of the detection of repeated features of temporary memory representations, would allow a long-term record of new words to be based on abstractions of sound patterns consistent over several exposures. In this way learning of mispronounced stimuli or strangely accented forms is minimized, allowing effective use of limited learning resources to be focused on real new words. What is required therefore is some form of temporary representation that can both provide an accurate if brief record of specific potentially novel input while relating that input to the long-term system that represents the prior knowledge of the structure of language. The system thus needs some form of temporary activation, which might in connectionist terms be represented as "fast weights," which in turn may gradually influence some more durable representation, "slow weights" (Hinton & Plaut, 1987).

The association between the phonological loop and long-term phonological learning does not, however, appear to run only in one direction. Earlier, we reviewed a range of evidence showing that more permanent knowledge about the structure of individual words and of language more generally influences immediate memory performance (Gathercole, Frankish, et al., 1997; Hulme et al., 1991; Gathercole & Thorn, 1997). The implication of such findings is that long-term knowledge is used to "fill in" representations in the phonological loop that are incomplete, as a consequence of either decay or interference, by using a process of "redintegration" (Brown & Hulme, 1995), whereby partial traces resulting from familiar words or highly wordlike novel words have a greater likelihood of being correctly reinstated than nonwords with unusual sound patterns such as words in a foreign language. This application of stored knowledge about the sound structure of the language to the phonological loop will, of course, result in a temporary memory system, which is effectively tailored for storing words in one's native language. Given the role played by the phonological loop in long-term learning, this will also mean that such words are relatively easy to learn.

Our broad overview of the phonological loop is summarized in Figure 2. Auditory information is analyzed and fed through to a phonological store, where the input is represented by means of a STM trace. The trace involves the temporary activation of a structure or network that reflects the influence, though not

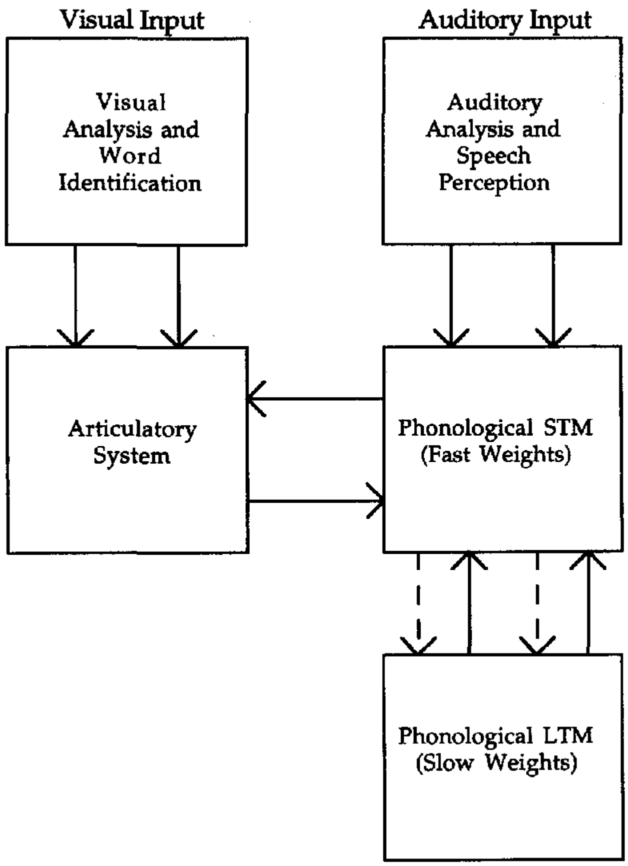

Figure 2. A simple model of the proposed components involved in short-term storage and long-term phonological learning. STM = short-term memory; LTM = long-term memory.

dominance, of a phonological long-term system. The activation is short lived but has the capacity, in turn, to influence the long-term representation. However, although the short-term system depends on fast weights, the capacity to modify the long-term system depends on slow weights and is likely to require substantial learning, particularly in the case of the acquisition of very novel material by an already mature phonological system. It is important to note that the phonological LTM is not an episodic memory system but rather represents the residue of accumulated long-term phonological knowledge. Immediate serial recall can of course be influenced by both semantic and episodic memory. However, these influences are beyond the scope of the present discussion.

In the case of written input of verbal material, the visual analysis will be fed into the phonological store by means of subvocal speech by using the articulatory system. This system is also used for verbal output, which in the case of overt speech will lead to an auditory input that in turn will enter the phonological store. This process can be operated in the absence of overt output, as in the case of silent rehearsal, in which case the phonological store is activated in the absence of auditory input.

Neuropsychological evidence is broadly supportive of this structure, with recent neuroradiological imaging studies supporting earlier findings based on the location of brain lesions. In particular, the phonological store appears to be located in the perisylvian region of the left hemisphere, whereas the articulatory rehearsal component appears to be associated with Broca's area (Paulesu, Frith, & Frackowiak, 1993). A review of this and subsequent evidence is provided by Smith and Jonides (1995).

In recent years, much more detailed and specific models of the phonological store have begun to be developed. Examples include that of Burgess and Hitch (1992, 1996); Hartley and Houghton (1994); and by Page, Norris, and collaborators (e.g., Henson, Norris, Page, & Baddeley, 1996). Although these models differ in detail, they have many features in common, including a tendency to separate the storage of order and item information. In all three cases, however, the models so far concentrate on short-term retention and have not yet tackled the question of how short-term storage leads to long-term phonological learning.

Conclusions

We have suggested in this article that the phonological loop component of working memory has evolved as a system for supporting language learning. The evidence reviewed points to direct links between phonological loop function and word learning in a variety of participant populations and also identifies significant contributions of existing knowledge of the structure of the spoken language to both immediate memory performance and to vocabulary acquisition. The general model we advocate is of a highly flexible language learning system in which the valuable but limited-capacity resource of the phonological loop is available to support the construction of more permanent representations of the phonological structure of new words, but in which established knowledge of the language is used to offset this fragile temporary storage component whenever possible. Many of the details of this model have yet to be fully fleshed out, and this process of theoretical development represents a major goal of our current program. The general structure of the model characterized in this article, however, appears to us to be grounded securely in empirical evidence.

Given the overwhelming importance of language learning to cognitive development, this position attributes considerable significance to a component of memory, the phonological loop, in which its practical significance has in the past been attributed principally to dealing with telephone numbers. It seems likely that one reason for underestimating the developmental significance of the phonological loop is precisely because of the traditional emphasis on indexes of verbal STM based on recall of unrelated words, and especially digit span. We propose that the primary function of the phonological loop is the processing of novel speech input. Participants who are asked to memorize familiar words will make use of the phonological loop, but in so doing they exploit a supplementary function of a device that evolved for other, more important, purposes.

References

Adams, A.-M., & Gathercole, S. E. (1995). Phonological working memory and speech production in preschool children. *Journal of Speech and Hearing Research, 38,* 403–414.

Adams, A.-M., & Gathercole, S. E. (1996). Phonological working memory and spoken language development in young children. *Quarterly Journal of Experimental Psychology, 49A,* 216–233.

Allport, D. A. (1984). Auditory–verbal short-term memory and conduction aphasia. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 313–325). Hillsdale, NJ: Erlbaum.

Arnold, R., Yule, W., & Martin, N. (1985). The psychological characteristics of infantile hypercalcaemia: A preliminary investigation. *Developmental Medicine and Child Neurology, 27,* 49–59.

Baddeley, A. D. (1966). The influence of acoustic and semantic similarity on long-term memory for word sequences. *Quarterly Journal of Experimental Psychology, 18,* 302–309.

Baddeley, A. D. (1986). *Working memory.* Oxford, England: Oxford University Press.

Baddeley, A. D. (1993). Short-term phonological memory and long-term learning: A single case study. *European Journal of Cognitive Psychology, 5,* 129–148.

Baddeley, A. D. (1997). *Human memory: Theory and practice* (2nd ed.). Boston: Allyn & Bacon.

Baddeley, A. D., Emslie, H., & Nimmo-Smith, I. (1994). *Doors and People: A test of visual and verbal recall and recognition.* Flempton, Bury St. Edmunds, England: Thames Valley Test Co.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.

Baddeley, A. D., & Lewis, V. J. (1981). Inner active processes in reading: The inner voice, the inner ear and the inner eye. In A. M. Lesgold & C. A. Perfetti (Eds.), *Interactive processes in reading* (pp. 107–129). Hillsdale, NJ: Erlbaum.

Baddeley, A. D., Papagno, C., & Vallar, G. (1988). When long term learning depends on short-term storage. *Journal of Memory and Language, 27,* 586–595.

Baddeley, A. D., Thomson, N., & Buchanan, M. (1975). Word length and the structure of short-term memory. *Journal of Verbal Learning and Verbal Behavior, 14,* 575–589.

Baddeley, A. D., Vallar, G., & Wilson, B. A. (1987). Sentence comprehension and phonological memory: Some neuropsychological evidence. In M. Coltheart (Ed.), *Attention and performance XII: The psychology of reading* (pp. 509–529). Hillsdale, NJ: Erlbaum.

Bellugi, U., Marks, S., Bihrle, A., & Sabo, H. (1988). Dissociation between language and cognitive functions in Williams syndrome. In D. V. M. Bishop & K. Mogford (Eds.), *Language development in exceptional circumstances* (pp. 177–189). Edinburgh, Scotland: Churchill Livingstone.

Besner, D., Davies, J., & Daniels, S. (1981). Phonological processes in reading: The effects of concurrent articulation. *Quarterly Journal of Experimental Psychology, 33,* 415–438.

Bishop, D. V. M. (1992). The underlying nature of specific language impairment. *Journal of Child Psychology and Child Psychiatry, 33,* 1–64.

Bishop, D. V. M., North, T., & Donlan, C. (1996). Nonword repetition as a phenotypic marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Child Psychiatry, 37,* 391–404.

Blake, J., Austin, W., Cannon, M., Lisus, A., & Vaughan, A. (1994). The relationship between memory span and measures of imitative and spontaneous language complexity in preschool children. *International Journal of Behavioral Development, 17,* 91–107.

Bloom, L., Hood, L., & Lightbown, P. (1974). Imitation in language development: If, when and why. *Cognitive Psychology, 6,* 380–420.

Brown, R. A. (1973). *A first language: The early stages.* Cambridge, MA: Harvard University Press.

Brown, R., & Fraser, C. (1963). The acquisition of syntax. In C. N. Cofer & A. Musgrave (Eds.), *Verbal behavior and learning: Problems and processes* (pp. 158–210). New York: McGraw-Hill.

Brown, G. D. A., & Hulme, C. (1995). Modelling item length effects in memory span: No rehearsal needed? *Journal of Memory and Language, 34,* 594–621.

Brown, G. D. A., & Hulme, C. (1996). Non-word repetition, STM, and word age-of-acquisition: A computational model. In S. E. Gathercole (Ed.), *Models of short-term memory* (pp. 129–148). Hove, England: Psychology Press.

Burgess, N., & Hitch, G. J. (1992). Toward a network model of the articulatory loop. *Journal of Memory and Language, 31,* 429–460.

Burgess, N., & Hitch, G. J. (1996). A connectionist model of STM for serial order. In S. E. Gathercole (Ed.), *Models of short-term memory* (pp. 51–72). Hove, England: Psychology Press.

Butterworth, B., Campbell, R., & Howard, D. (1986). The uses of short-term memory: A case study. *Quarterly Journal of Experimental Psychology, 38,* 705–737.

Cheung, H. (1996). Nonword span as a unique predictor of second-language vocabulary learning. *Developmental Psychology, 32,* 867–873.

Clark, E. V. (1983). Meanings and concepts. In J. H. Flavell & E. M. Markman (Eds.), *Handbook of child psychology. Vol. 3: Cognitive development* (pp. 787–840). New York: Wiley.

Coggins, T. E., & Morrison, J. A. (1981). Spontaneous imitations of Down's syndrome children: A lexical analysis. *Journal of Speech and Hearing Research, 24,* 303–307.

Conrad, R., & Hull, A. J. (1964). Information, acoustic confusion and memory span. *British Journal of Psychology, 55,* 429–432.

Cowan, N., & Kail, R. (1996). Covert processes and their development in short-term memory. In S. E. Gathercole (Ed.), *Models of short-term memory* (pp. 29–50). Hove, England: Psychology Press.

Crano, W. D., & Mellon, P. M. (1978). Causal influence of teachers' expectations of children's academic performance: A cross-lagged panel analysis. *Journal of Educational Psychology, 70,* 39–49.

Daneman, M., & Case, R. (1981). Syntactic form, semantic complexity, and short-term memory: Influences on children's acquisition of new linguistic structures. *Developmental Psychology, 17,* 367–378.

DeRenzi, E., & Nichelli, P. (1975). Verbal and nonverbal short-term memory impairment following hemispheric damage. *Cortex, 11,* 341–353.

Dollaghan, C. (1987). Fast mapping in normal and language-impaired children. *Journal of Speech and Hearing Disorders, 52,* 218–222.

Dunn, L. M., & Dunn, L. M. (1982). *The British Picture Vocabulary Scale.* Windsor, England: NFER-Nelson.

Elliott, C. D. (1983). *British Abilities Scales.* Windsor, England: NFER-Nelson.

Ellis, N., & Beaton, A. (1993). Factors affecting the learning of foreign-language vocabulary: Imagery keyword mediators and phonological short-term memory. *Quarterly Journal of Experimental Psychology, 46A,* 533–558.

Flavell, J. H., Beach, D. R., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development, 37,* 283–299.

Fowler, A. E. (1991). How early phonological development might set the stage for phoneme awareness. In S. Brady & D. Shankweiler (Eds.), *Phonological processes in literacy.* Hillsdale, NJ: Erlbaum.

Gardner, F. M. (1990). *The Expressive One-Word Picture Vocabulary Scale* (Rev. ed.). Novato, CA: Academic Therapy Publications.

Gathercole, S. E. (1995a). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory & Cognition, 23,* 83–94.

Gathercole, S. E. (1995b). Nonword repetition: More than just a phonological output task. *Cognitive Neuropsychology, 12,* 857–861.

Gathercole, S. E., & Adams, A. (1993). Phonological working memory in very young children. *Developmental Psychology, 29,* 770–778.

Gathercole, S. E., & Adams, A. (1994). Children's phonological working memory: Contributions of long-term knowledge and rehearsal. *Journal of Memory and Language, 33,* 672–688.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28,* 200–213.

Gathercole, S. E., & Baddeley, A. D. (1990a). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology, 81,* 439–454.

Gathercole, S. E., & Baddeley, A. D. (1990b). Phonological memory deficits in language-disordered children: Is there a causal connection? *Journal of Memory and Language, 29,* 336–360.

Gathercole, S. E., & Baddeley, A. D. (1993). *Working memory and language.* Hillsdale, NJ: Erlbaum.

Gathercole, S. E., & Baddeley, A. D. (1995). Short-term memory may yet be deficient in language-impaired children: A comment on van der Lely & Howard. *Journal of Speech and Hearing Research, 38,* 463–472.

Gathercole, S. E., Frankish, C., Pickering, S. J., & Peaker, S. (1997). *Influences of nonword frequency and lexicality on children's serial recall.* Manuscript submitted for publication.

Gathercole, S. E., & Hitch, G. J. (1993). Developmental changes in short-term memory: A revised working memory perspective. In A. Collins, S. E. Gathercole, M. A. Conway, & P. E. Morris (Eds.), *Theories of memory* (pp. 189–210). Hillsdale, NJ: Erlbaum.

Gathercole, S. E., Hitch, G. J., Service, E., Adams, A. -M., & Martin, A. J. (1997). *Phonological short-term memory and vocabulary acquisition: Further evidence on the nature of the relationship.* Manuscript submitted for publication.

Gathercole, S. E., Hitch, G. J., Service, E., & Martin, A. J. (1997). Phonological short-term memory and new word learning in children. *Developmental Psychology, 33,* 966–979.

Gathercole, S. E., & Martin, A. J. (1996). Interactive processes in phonological memory. In S. E. Gathercole (Ed.), *Models of short-term memory* (pp. 73–100). Hove, England: Psychology Press.

Gathercole, S. E., & Thorn, A. S. C. (1997). Phonological short-term memory and foreign language learning. In A. F. Healy & L. E. Bourne (Eds.), *Foreign language and learning: Psycholinguistic experiments on training and retention.* Hillsdale, NJ: Erlbaum.

Gathercole, S. E., Willis, C., & Baddeley, A. D. (1991). Differentiating phonological memory and awareness of rhyme: Reading and vocabulary development in children. *British Journal of Psychology, 82,* 387–406.

Gathercole, S. E., Willis, C., Baddeley, A. D., & Emslie, H. (1994). The Children's Test of Nonword Repetition: A test of phonological working memory. *Memory, 2,* 103–127.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1991). The influences of syllables and wordlikeness on children's repetition of nonwords. *Applied Psycholinguistics, 12,* 349–367.

Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28,* 887–898.

Gleitman, L. (1993). The structural sources of verb meanings. In P. Bloom (Ed.), *Core readings in language acquisition* (pp. 174–221). Cambridge, England: Harvester Wheatsheaf.

Grant, J., Karmiloff-Smith, A., Gathercole, S. E., Paterson, S., Howlin, P., Davies, M., & Udwin, O. (1997). Phonological short-term memory and its relationship to language in Williams Syndrome. *Cognitive Neuropsychiatry, 2,* 81–99.

Hartley, T., & Houghton, G. (1994). A linguistically-constrained model of short-term memory for nonwords. *Journal of Memory and Language, 35,* 1–31.

Haynes, C. (1982). *Vocabulary acquisition problems in language-impaired children.* Unpublished master's thesis, Guy's Hospital Medical School, University of London, London, England.

Henson, R. N. A., Norris, D. G., Page, M. P. A., & Baddeley, A. D. (1996). Unchained memory: Error patterns rule out chaining models of immediate serial recall. *Quarterly Journal of Experimental Psychology, 49A,* 80–115.

Hinton, G. E., & Plaut, D. C. (1987). Using fast weights to deblur old memories. In *Proceedings of the Ninth Annual Conference of the Cognitive Science Society* (pp. 177–186). Hillsdale, NJ: Erlbaum.

Hulme, C., Maughan, S., & Brown, G. D. A. (1991). Memory for familiar and unfamiliar words: Evidence for a longer term memory contribution to short-term memory span. *Journal of Memory and Language, 30,* 685–701.

Ingram, D. (1974). Phonological rules in young children. *Journal of Child Language, 1,* 97–106.

Jarrold, C., & Baddeley, A. D. (1997). Short-term memory for verbal and visuo-spatial information in Down's Syndrome. *Cognitive Neuropsychiatry, 2,* 102–122.

Jarrold, C., Baddeley, A. D., & Hewes, A. K. (in press). Verbal and non-verbal abilities in the Williams Syndrome phenotype: Evidence for diverging developmental trajectories. *Journal of Child Psychology and Psychiatry.*

Jones, D., von Stienbrugge, W., & Chicralis, K. (1994). Underlying deficits in language-disordered children with central auditory processing difficulties. *Applied Psycholinguistics, 15,* 311–328.

Kamhi, A. G., & Catts, H. W. (1986). Toward an understanding of developmental language and reading disorders. *Journal of Speech and Hearing Research, 51,* 337–347.

Karmiloff-Smith, A., Grant, J., Berthoud, I., Davies, M., Howlin, P., & Udwin, D. (in press). Language and Williams Syndrome: How intact is "intact"? *Child Development.*

Keil, F. C. (1979). *Semantic and conceptual development.* Cambridge, MA: Harvard University Press.

Kirchner, D., & Klatzky, R. L. (1985). Verbal memory and rehearsal in language-disordered children. *Journal of Speech and Hearing Disorders, 28,* 556–565.

Leonard, L. B., & Schwartz, R. G. (1985). Early linguistic development of children with specific language impairment. In K. E. Nelson (Ed.), *Children's language* (Vol. 5, pp. 291–318). Hillsdale, NJ: Erlbaum.

Locke, J. L., & Scott, K. K. (1979). Phonetically mediated recall in the phonetically disordered child. *Journal of Communication Disorders, 12,* 125–131.

Markman, E. M. (1994). Constraints on word meaning in early language acquisition. *Lingua,* 199–227.

Masur, E. F. (1995). Infants' early verbal imitation and their later lexical development. *Merrill-Palmer Quarterly, 41,* 286–306.

McCarthy, D. (1970). *McCarthy Scales of Childrens' Abilities.* New York: Psychological Corporation.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1994). *Why are there complementary learning systems in the hippocampus and neocortex?* (Tech. Rep. No. PDP.CNS.94.1). Pittsburgh, PA: Carnegie Mellon University.

Menyuk, P., & Looney, P. L. (1976). A problem of language disorder: Length versus structure. In D. M. Morehead & A. E. Morehead (Eds.), *Normal and deficient child language* (pp. 259–279). Baltimore, MD: University Park Press.

Michas, I. C., & Henry, L. A. (1994). The link between phonological memory and vocabulary acquisition. *British Journal of Developmental Psychology, 12,* 147–163.

Montgomery, J. (1995). Examination of phonological working memory in specifically language-impaired children. *Applied Psycholinguistics, 16,* 355–378.

Murray, D. J. (1967). The role of speech responses in short-term memory. *Canadian Journal of Psychology, 21,* 263–276.

Nagy, W. E., & Herman, P. A. (1987). Breadth and depth of vocabulary knowledge: Implications for acquisition and instruction. In M. G. McKeown & M. E. Curtis (Eds.), *The nature of vocabulary acquisition* (pp. 19–35). Hillsdale, NJ: Erlbaum.

Nelson, K. E. (1987). Some observations from the perspective of the rare event cognitive comparison theory of language acquisition. In K. E. Nelson & A. van Kleeck (Eds.), *Children's language* (Vol. 6, pp. 229–331). Hillsdale, NJ: Erlbaum.

Papagno, C., Valentine, T., & Baddeley, A. D. (1991). Phonological short-term memory and foreign-language vocabulary learning. *Journal of Memory and Language, 30,* 331–347.

Papagno, C., & Vallar, G. (1992). Phonological short-term memory and the learning of novel words: The effect of phonological similarity and item length. *Quarterly Journal of Experimental Psychology, 44A,* 47–67.

Papagno, C., & Vallar, G. (1995). Verbal short-term memory and vocabulary learning in polyglots. *Quarterly Journal of Experimental Psychology, 38A,* 98–107.

Paulesu, E., Frith, C. D., & Frackowiak, R. S. J. (1993). The neural correlates of the verbal component of working memory. *Nature, 362,* 342–345.

Pinker, S. (1984). *Language learnability and language development.* Cambridge, MA: Harvard University Press.

Plunkett, K., & Marchman, V. (1993). From rote learning to system-building—Acquiring verbal morphology in children and connectionist models. *Cognition, 48,* 21–69.

Raine, A., Hulme, C., Chadderton, H., & Bailey, P. (1991). Verbal short-term memory span in speech-disordered children. *Child Development, 62,* 415–423.

Raven, J. (1986). *Coloured progressive matrices.* Oxford, England: Oxford Psycholinguistic Press.

Rice, M. L., Buhr, J. C., & Nemeth, M. (1990). Fast mapping word learning abilities of language-delayed preschoolers. *Journal of Speech and Hearing Disorders, 55,* 33–42.

Rondal, J. A. (1994). *Exceptional language development in Down's syndrome: Implications for the cognition–language relationship.* New York: Cambridge University Press.

Service, E. (1992). Phonology, working memory, and foreign-language learning. *Quarterly Journal of Experimental Psychology, 45A,* 21–50.

Service, E., & Kohonen, V. (1995). Is the relationship between phonological memory and foreign language learning accounted for by vocabulary acquisition? *Applied Psycholinguistics, 16,* 155–172.

Shallice, T. (1988). *From neuropsychology to mental structure.* Cambridge, England: Cambridge University Press.

Shallice, T., & Butterworth, B. (1977). Short-term memory impairment and spontaneous speech. *Neuropsychologia, 15,* 729–735.

Shallice, T., & Warrington, E. K. (1970). Independent functioning of verbal memory stores: A neuropsychological study. *Quarterly Journal of Experimental Psychology, 22,* 261–273.

Smith, M. E. (1926). An investigation of the development of the sentence and the extent of vocabulary in young children. *University of Iowa Studies in Child Welfare, 3*(5).

Smith, E. E., & Jonides, J. (1995). Working memory in humans: Neuropsychological evidence. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 1009–1020). Cambridge, MA: MIT Press.

Snowling, M., Chiat, S., & Hulme, C. (1991). Words, nonwords and phonological processes: Some comments on Gathercole, Willis, Emslie, & Baddeley (1991). *Applied Psycholinguistics, 12,* 369–373.

Snowling, M., & Hulme, C. (1989). A longitudinal case study of developmental phonological dyslexia. *Cognitive Neuropsychology, 6,* 379–401.

Speidel, G. E. (1989). A biological basis for individual differences in learning to speak. In G. E. Speidel & K. E. Nelson (Eds.), *The many faces of imitation in language learning* (pp. 199–229). New York: Springer-Verlag.

Speidel, G. E. (1993). Phonological short-term memory and individual differences in learning to speak: A bilingual case study. *First Language, 13,* 69–91.

Stark, R., & Tallal, P. (1981). Selection of children with specific language deficits. *Journal of Speech and Hearing Disorders, 46,* 114–122.

Sternberg, R. (1987). Most vocabulary is learned from context. In M. McKeown & M. Curtis (Eds.), *The nature of vocabulary acquisition* (pp. 89–106). Hillsdale, NJ: Erlbaum.

Taylor, H. G., Lean, D., & Schwartz, S. (1989). Pseudoword repetition ability in learning-disabled children. *Applied Psycholinguistics, 10,* 203–219.

Thorn, A. S. C., & Gathercole, S. E. (in press). Language-specific knowledge and short-term memory in bilingual and non-bilingual children. *Quarterly Journal of Experimental Psychology.*

Trojano, L., & Grossi, D. (1995). Phonological and lexical coding in verbal short-term memory and learning. *Brain & Cognition, 21,* 336–354.

Vallar, G., & Baddeley, A. D. (1984). Phonological short-term store, phonological processing and sentence comprehension: A neuropsychological case study. *Cognitive Neuropsychology, 1,* 121–141.

Vallar, G., & Papagno, C. (1993). Preserved vocabulary acquisition in Down's syndrome: The role of phonological short-term memory. *Cortex, 29,* 467–483.

Vallar, G., & Shallice, T. (Eds.). (1990). *Neuropsychological impairments of short-term memory.* Cambridge, England: Cambridge University Press.

van der Lely, H. K. J., & Howard, D. (1993). Children with specific language impairment: Linguistic impairment or short-term memory deficit? *Journal of Speech and Hearing Research, 36,* 1193–1207.

Wang, P. P., & Bellugi, U. (1994). Evidence from two genetic syndromes for a dissociation between verbal and visual–spatial short-term memory. *Journal of Clinical and Experimental Neuropsychology, 16,* 317–322.

Wechsler, D. (1974). *Wechsler Intelligence Scale for Children: Revised.* New York: Psychological Corporation.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale.* New York: Psychological Corporation.

Wells, B. (1995). Phonological considerations in repetition tests. *Cognitive Neuropsychology, 12,* 847–855.

Received October 5, 1994
Revision received July 15, 1997
Accepted July 15, 1997 ■