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# Commentaries

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## Beyond words: Phonological short-term memory and syntactic impairment in specific language impairment

The assessment of nonword repetition in children goes back at least to 1974, when the Goldman–Fristoe–Woodcock Auditory Skills Battery was published, including a subtest (Sound Mimicry) assessing nonword repetition (Goldman, Fristoe, & Woodcock, 1974). Nevertheless, it was not until 20 years later, when Gathercole and Baddeley (1990) reported a study of short-term memory in children with specific language impairment (SLI), that a theoretical framework was developed linking deficits in nonword repetition to impaired language acquisition. Gathercole's Keynote in this issue (2006) tells the story of how this initial study revealed a striking nonword repetition deficit in children with SLI, complementing work on typically developing children showing a major role of phonological short-term memory (STM) in word learning. As she points out, the story is a complex one: phonological STM is not the only skill tapped by the nonword repetition task, and children may do poorly for different reasons. Furthermore, relationships between nonword repetition and word learning may be reciprocal, with vocabulary level affecting children's ability to segment nonwords efficiently and retain them in memory. However, the original finding, that deficient nonword repetition is a strong correlate of SLI, has stood the test of time, to the extent that poor performance on this test has been used successfully as a marker of a heritable phenotype in molecular genetic studies of SLI (Newbury, Monaco, & Bishop, 2005).

According to the theoretical framework presented by Gathercole (2006), word learning should proceed slowly in SLI, and this is indeed usually the case. Nevertheless, for most children, vocabulary is less impaired than syntax (see Leonard, 1998, for review). This raises the question of whether phonological STM is implicated in acquisition of syntax as well as vocabulary.

This issue was raised in 1998 by Baddeley, Gathercole, and Papagno, who presented a theory of the phonological loop as a language learning device, arguing that the ability to retain small amounts of phonological information in STM evolved as a human characteristic that had selection advantage because it facilitated language acquisition. In that paper they reviewed evidence that, in typically developing children, nonword repetition, a measure of phonological loop capacity, was related not only to vocabulary learning but also to acquisition of syntax.

This theoretical account was attractive to those working on SLI, because it suggested that a deficit in a single specialized memory system could potentially account for the whole gamut of linguistic deficits seen in language-impaired children, without needing to invoke domain-specific impairment of specialized

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syntactic mechanisms (Joanisse & Seidenberg, 1998). It is possible to formulate at least two hypotheses that predict a link between weak nonword repetition and poor syntax in SLI. The first corresponds to a storage account, and maintains that incoming speech needs to be held in a temporary buffer while syntactic analysis is carried out. This operation will be hampered if there is rapid decay of phonological material in the short-term store. The second hypothesis predicts that poor syntactic abilities will follow if the child persists in analyzing incoming speech at the level of the syllable, rather than identifying individual phonemic segments. As Gathercole (2006) notes in her Keynote, this could lead to poor nonword repetition; however, in addition, the child may not recognize that words such as "walked," "hopped," and "laughed" all end with the same sound, and thus fail to extract a morphosyntactic rule of past tense formation.

Although both hypotheses seem plausible, more recent work suggests that they are almost certainly wrong. The first indication of this came from simple correlations between measures of nonword repetition and syntax in children with SLI, which were far weaker than would be predicted if phonological STM were a major factor in syntax acquisition. For instance, Norbury, Bishop, and Briscoe (2001) found no significant correlation between nonword repetition and a measure of production of verb inflections in 14 children with SLI aged from 7 to 10 years. More powerful evidence for independence of phonological STM and syntax comes from Bishop, Adams, and Norbury (2006), who studied a sample of 173 6-year-old twin pairs, selected to include a high proportion of children with language impairments. Twins provide a means of disentangling genetic and environmental influences on language ability. Monozygotic (MZ) twins are genetically identical, whereas dizygotic (DZ) twins share on average 50% of alleles from segregating genes (i.e., genes that have different allelic forms in different people). If genes are implicated in causing a disorder, we expect cases of concordance (i.e., both twins have the disorder) to be more numerous in MZ than in DZ twins. More complex methods of analysis can be used to study quantitative scores on language measures, to estimate the extent to which deficits are under genetic influence. Furthermore, by looking at cross-concordance across language measures, one can test whether two different deficits are influenced by the same genetic factors. Bishop et al. (2006) first looked at nonword repetition. Heritability of poor nonword repetition was not as high in this 6-year-old sample as in previous samples of older twins. However, it was noted that in 6-year-olds, nonword repetition was correlated with articulation skills, and the pattern of errors suggested that some children did poorly because they could not produce the sounds correctly even in very short nonwords (see also Sahlén, Reuterskiöld-Wagner, Nettelbladt, & Radeborg, 1999). To obtain a purer index of phonological STM, a derived measure was computed, reflecting the score on longer nonwords, after adjusting for level of performance on the shortest nonwords. This measure was more sensitive to language impairment and gave higher estimates of heritability than the raw unadjusted measure, incidentally supporting Gathercole's (2006) claim that articulatory limitations do not explain the link between SLI and nonword repetition. The next step was to look at heritability of other language measures, including tests of syntactic ability. These, too, were highly heritable. However, the correlation between syntactic measures and phonological STM, although significant, was weak ($<.3$), and bivariate genetic analysis suggested that different genes were implicated in causing risk for weak phonological STM and poor syntactic skill. This result throws into question theoretical accounts that aim to explain all the linguistic deficits in SLI in terms of an underlying limitation of phonological STM capacity.

A remaining puzzle is why there should be any correlation between phonological STM and syntax if they have independent origins. A hint comes from the finding by Gathercole, Tiffany, Briscoe, Thorn, and The ALSPAC Team (2005) that one can have children who have poor nonword repetition skills but normal scores on language tests. This is surprising, given that deficient nonword repetition is a strong correlate of language impairment. One possible explanation raised by Gathercole (2006) is that weak phonological STM may lead to SLI only if it is accompanied by other cognitive risk factors. Our data on syntax fit well with that interpretation, and suggest that the child who just has weak phonological STM or just has slow mastery of syntax may show few overt language difficulties, but if both these deficits occur in combination, the impact on everyday language skills is much more severe.

The field has shown considerable advances based on the initial insights of Gathercole and colleagues, who recognized that the deceptively simple task of repeating nonwords taps a fundamental building block of language learning. However, the more we learn, the clearer it becomes that any single factor explanation of SLI is inadequate to explain the phenomenon.

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## Clarifying the phonological processing account of nonword repetition

Individual differences in nonword repetition (NWR) show a particularly strong association with vocabulary acquisition for both first- (L1) and second-language (L2) learners, and they serve as a behavioral marker for specific language impairment (SLI) in children (Gathercole, 2006). However, this association is susceptible to alternative explanations.

Proponents of the so-called *phonological processing account* (PPA; e.g., Bowey, 1996, 1997, 2001; Chiat, 2001; Snowling, Chiat, & Hulme, 1991; Snowling, Goulandris, Bowlby, & Howell, 1986) view NWR as a complex task involving several components, most involving phonological processing. These include speech perception, the construction, and encoding of a phonological representation in the phonological store, maintenance of this representation, retrieval of the representation from the phonological store, assembly of articulatory instructions, and articulation itself. Difficulties in one or more of these components may impair NWR. Findings that manipulations that increase phonological complexity adversely affect NWR support the PPA. Nevertheless, because these manipulations sometimes place additional demands on phonological store capacity, some require further investigation (Gathercole, 2006).

There is considerable overlap between Gathercole's (2006) position and the PPA. Advocates of the PPA acknowledge that NWR is constrained by phonological store capacity (e.g., Bowey, 1996, 1997). Although phonological store capacity can impair new word learning (e.g., Gathercole, Hitch, Service, & Martin, 1997), Gathercole concedes that NWR is not a pure measure of the capacity of the phonological store, and that poor phonological storage may not itself be sufficient to produce the severe NWR and language deficits associated with SLI.

Although they differ concerning the relative centrality of the role ascribed to phonological store capacity per se in constraining NWR and language learning, the PPA and a *phonological store capacity account* (PSCA) represent complementary rather than incompatible accounts of NWR. The extent to which NWR reflects phonological processing efficiency or phonological store capacity varies not only between individuals but also with nonword characteristics. Moderately long nonwords with high phonotactic probabilities and familiar prosody are efficiently encoded, maintained, retrieved, and articulated by individuals with a mature and efficient phonological processing system. Thus, NWR is more likely to reflect phonological store capacity when such individuals repeat this type of nonword than when children with immature or inefficient phonological processing systems recall nonwords with unfamiliar phonotactics and prosody.

Several findings support the PPA over the PSCA. For instance, findings that NWR is more predictive of early L1 and L2 vocabulary acquisition (see Gathercole, 2006), where the phonology of the language is less familiar, are consistent with the PPA. However, if NWR primarily reflects phonological store capacity, and if this largely constrains vocabulary acquisition, then NWR should predict vocabulary acquisition just as well beyond the earliest stages, especially in adult L2 learners.

Similarly, the findings of Archibald and Gathercole (2005) pose difficulties for the PSCA but not the PPA. When nonverbal ability effects were covaried, children with SLI differed from language controls in NWR but were no worse in recalling the same syllables presented as a series one-syllable items. Gathercole (2006) views this finding as puzzling, given her view that the phonological content is equivalent in the NWR and serial recall tasks. However, although Archibald and Gathercole claim that all syllables contained tense vowels, nonwords presented as isolated consonant–vowel (CV) syllables are more likely to have fully stressed vowels that are longer in duration, and consonants in isolated CV syllables also contain clearer and more invariant acoustic–phonetic information (see Cole & Jakimik, 1978). These features would make it easier for SLI children to construct higher quality phonological representations of CV nonwords presented as isolated syllables than as a single multisyllabic nonword, and thus reduce the overall reliance of the serial recall task on phonological processing efficiency per se. The serial recall items were presented at rate of 1 per 750 ms, leading to decay of material in the phonological store (Baddeley, 1986; Brown & Hulme, 1995). Although these items could be rehearsed, redintegration of nonwords is minimal (Gathercole, 2006). Because the recall of isolated CV syllables thus comprises a purer test of phonological store capacity, the PSCA wrongly predicts that, relative to language controls, SLI children should show greater deficits in repeating a series of nonword syllables than multisyllabic nonwords.

Gathercole (2006) notes that accounts of SLI must explain the finding that, relative to controls, SLI children show more marked deficits with longer nonwords than shorter nonwords. This finding is readily explicable by the PPA. Item length effects in NWR are unlikely to reflect rehearsal (see Gathercole, Willis, Baddeley, & Emslie, 1994, p. 122). NWR length effects per se can be explained in probabilistic terms, in addition to phonological store capacity, and may also reflect trace decay and possibly interference during retrieval and recall (Brown & Hulme, 1995). If SLI children initially encode lower quality phonological representations of nonwords, which are even more prone to decay and interference, then they will show a more marked length effect (Brown & Hulme, 1995).

Following the early work of Gathercole, Willis, and Baddeley (1991), Bowey (1996, 2001) investigated the extent to which NWR and phonological sensitivity (or phonological awareness[1]) account for largely shared or independent variance in vocabulary in 5-year-olds. NWR and phonological sensitivity (operationalized by phonological identity and rhyme oddity performance) were hypothesized to be alternative surface manifestations of an underlying phonological processing ability. Thus, findings that, with performance IQ effects first controlled, phonological sensitivity and NWR accounted for largely common variance in vocabulary (Bowey, 1996, 2001; see also Metsala, 1999) were interpreted as most consistent with the PPA. However, some aspects of Bowey's (2001) findings suggested that phonological store capacity independently contributes to children's vocabulary acquisition.

Gathercole (2006) suggests that findings that phonological sensitivity and NWR explain largely overlapping variance in vocabulary may reflect the incorporation of a substantial phonological memory component within the phonological sensitivity tasks. A rhyme oddity task, in which children name one of three simple spoken words that does not rhyme with the other two, requires three words to be held in memory while the phonological judgment is made, and thus includes a phonological memory component (see Baddeley, 1986; Bowey, 1994). However, to reduce the memory demands of Bowey's (1996) rhyme oddity task, all spoken words were represented by pictures that remained visible throughout each trial. Furthermore, Bowey (1996, 2001) observed parallel findings from a highly explicit phoneme identity task that minimizes memory requirements (see Bowey, 1994). Here, for each item, children see a series of three pictures, two sharing a final phoneme (e.g., *knife, mop, leaf*). Children are told the name of the top picture (*knife*) and the last sound of that word (/f/), and are then asked which of the two spoken words (*mop* and *leaf*), whose referents are pictured below, end with /f/. This task is similar to that used to investigate rhyme sensitivity in PV, a patient with an auditory span of only two or three words or digits (Vallar & Badddley, 1984).

Gathercole (2006) distinguishes a *phonological sensitivity hypothesis* from the more general PPA. Nowhere in Bowey's (1996, 1997, 2001) work is there any proposal that phonological sensitivity per se directly contributes to NWR, vocabulary, or language acquisition.[2] Bowey's (1996, 1997) theoretical discussions were framed entirely in terms of the phonological processing demands of the NWR task, with NWR and phonological sensitivity viewed as alternative indicators of a latent phonological processing ability. Bowey (2001) linked the PPA to what may be termed the *protracted lexical restructuring hypothesis*, according to which the process of establishing fine-grained segmental representations of vocabulary items extends into middle childhood, driven largely by the need to distinguish similar-sounding words (see Charles-Luce & Luce, 1990; Walley, 1993). What Gathercole (2006) refers to as *phonological sensitivity* should be termed *lexical restructuring*; thus, the phonological sensitivity hypothesis should be termed the *lexical restructuring hypothesis*. Researchers who argue that detailed segmental representations are established virtually from the outset (e.g., Ballem & Plunkett, 2005; Fennell & Werker, 2003; Swingley, 2003) challenge this view. Much of the work pertaining to the lexical restructuring hypothesis cannot be definitively interpreted (see Bowey & Hirakis, in press). However, the PPA is not inherently tied to the lexical restructuring hypothesis.

NWR constitutes a behavioral marker for SLI (Gathercole, 2006). However, the extent to which NWR deficits in SLI reflect underlying phonological processing difficulties or deficits in phonological store capacity is not clear. Gathercole and Baddeley (1990) did attempt to eliminate phonological processing deficits as a more basic cause of SLI, although more demanding phonological processing tasks may have revealed differences. SLI children performed as well as controls in articulation speed and in discriminating between minimally contrasting pairs of CVC words and nonwords, although the SLI children appeared to be worse at discriminating between nonword than word pairs. Phonological processing difficulties are common in SLI (see Chiat, 2001; Joanisse & Seidenberg, 1998). Chiat argued that underlying phonological processing difficulties selectively impair the acquisition of aspects of vocabulary and grammar depending on the accurate perception and representation of phonological information, including words whose meaning is underdetermined within any one particular context, phonologically conditioned morphemes (e.g., -*ed*), and syntactic constructions involving long-term dependencies, particularly when signaled by unstressed morphemes.

Clearly much work remains in testing rival accounts of SLI (Chiat, 2001; Joanisse & Seidenberg, 1998). Given the robustness of NWR as a marker of SLI, further research investigating the processes involved in NWR may assist in understanding not only processes limiting vocabulary acquisition, but also developmental disorders of language acquisition, and possibly in determining subtypes of SLI (Gathercole, 2006).

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## NOTES

1. Following Stanovich's (1992) recommendation, Bowey (e.g., 1996, p. 52) used the term phonological sensitivity rather than phonological awareness.
2. This confusion may stem from Bowey's use of phonological sensitivity (see note 1). Bowey (1996, 1997, 2001) used phonological sensitivity only when contrasting phonological sensitivity and NWR tasks.

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## The developmental trajectory of nonword repetition

In line with the original presentation of nonword repetition as a measure of phonological short-term memory (Gathercole & Baddeley, 1989), the theoretical account Gathercole (2006) puts forward in her Keynote Article focuses on phonological storage as the key capacity common to nonword repetition and vocabulary acquisition. However, evidence that nonword repetition is influenced by a variety of factors other than item length has led Gathercole to qualify this account. In line with arguments put forward by Snowling, Chiat, and Hulme (1991), one of Gathercole's current claims is that nonword repetition and word learning are constrained by "the quality of temporary storage of phonological representations, and this quality is multiply determined." Phonological storage is not just a quantity-limited capacity.

In this Commentary, I take Gathercole's (2006) account a step further. I propose that the factors contributing to the quality of temporary storage and their relative contribution change in the course of development. After making the case for a developmental trajectory of nonword repetition, I argue that this leads to a more convincing explanation for findings that are challenging for the storage-based account.

## EARLY PHONOLOGICAL SENSITIVITY

Long before children produce words, and can be asked to repeat nonwords or to perform phonological awareness tasks, they deploy skills in recognizing and storing details of phonological input. In the first year of life they show acute sensitivity to the properties and frequency of rhythmic patterns and segmental combinations in phonological input, and use these as cues to segmenting words for storage (see, e.g., Gerken, 2001; Jusczyk, 1997; Jusczyk, Cutler, & Redanz, 1993; Jusczyk, Houston, & Newsome, 1999; Mattys & Jusczyk, 2001; Morgan & Saffran, 1995; Saffran, Aslin, & Newport, 1996; Saffran & Thiessen, 2003; Thiessen & Saffran, 2003). The implication is that children come to nonword repetition with previously established phonological representations and the phonological processing skills that underpin these. This gives rise to what I call the "early phonological sensitivity hypothesis." According to this hypothesis, variations in children's early sensitivity to phonology and their resulting phonological representations will influence their ability to repeat nonwords. Children with significantly reduced sensitivity to phonological details will have deficits in nonword repetition. They will also have deficits in lexical segmentation and recognition, and may ultimately present with language impairments (see Chiat, 2001, for elaboration of this claim).

Direct evaluation of these predictions requires longitudinal studies investigating relations between infants' responses to speech input at age 6–12 months and their performance on nonword repetition at age 2–3 years. Such studies are in their early stages, but initial results reported by researchers at the University of Wales, Bangor, are promising (Bywater, 2004; Vihman, Keren-Portnoy, & Armstrong, personal communication; see also Friedrich & Friederici, 2005). A different source of evidence for the early phonological sensitivity hypothesis is the finding that factors influential in early phonological development are also influential in nonword repetition. As pointed out above, infant studies have revealed very early sensitivity to prosodic structure, and use of prosodic structure to segment the stream of speech. In our studies of word and nonword repetition in typically developing children at age 2–4, and children referred with concerns about language development at age 2.5–4 (Chiat & Roy, in press; Roy & Chiat, 2004), we controlled for prosodic structure of items and included analysis of prosodic effects. We found that the overall performance of the clinically referred group was very much poorer than that of the typically developing group. Errors of syllable omission were also significantly more frequent in the clinically referred group. However, both groups of children showed effects of prosodic structure on syllable omission that could override effects of length. They were many times more likely to omit unstressed syllables that precede the stress than those that follow the stress in two-syllable items. Furthermore, loss of prestress syllables in two-syllable items was nearly double that of poststress syllables in longer, three-syllable items. In line with our results, a study of Swedish 5-year-olds with language impairment (Sahlén, Reuterskiöld-Wagner, Nettelbladt, & Radeborg, 1999) found that these children omitted six times more prestress syllables than poststress syllables. These findings show that differential sensitivity to elements of prosodic structure is robust in typically and atypically developing children, and plays a role in their nonword repetition. It is certain weak syllables and segmental details within prosodic structures that are most vulnerable, and that give rise to variation in performance.

## GROWING CONTRIBUTIONS OF VOCABULARY

It is now generally accepted that children's growing vocabulary is an emergent source of support for nonword repetition, supplementing the support of earlier emerging phonological representations discussed above. In her paper, Gathercole points out that the relationship between nonword repetition and vocabulary changes with age. Previous studies have also indicated that the direction of influence changes, with abilities tapped by nonword repetition only predicting vocabulary in the early stages of development (Gathercole, Willis, Emslie, & Baddeley, 1992; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004). The nature of relations between vocabulary, nonword repetition, and phonological awareness at later stages of development is the subject of considerable debate, which Gathercole addresses. However, little attention has been paid to other influences on vocabulary development that will indirectly influence nonword repetition. Vocabulary acquisition relies not only on the establishment of phonological forms. Word forms must be attached to word meanings. Hence, strengths in identifying meanings and connecting these to phonology will influence vocabulary growth. So will exposure to vocabulary. These child internal and external influences on vocabulary growth will indirectly influence the potential facilitatory effects of vocabulary on nonword repetition. This increasingly complex interplay of influences on nonword repetition opens up the possibility of increasingly divergent trajectories and outcomes.

## INSIGHTS FROM A DEVELOPMENTAL PERSPECTIVE

This analysis of the developmental trajectory may account better for the two findings that are puzzling for the storage-based account of nonword repetition and that lead Gathercole (2006) to supplement this account. The first is the finding that children with specific language impairment (SLI) are considerably more impaired on nonword repetition than serial recall tasks, even when stimuli in the two tasks contain identical syllables. The finding of differential effects on items of the same length cannot be explained by a purely quantitative constraint on storage. Gathercole suggests that the selective deficit in nonword repetition may be due to fast rates of transmission of the acoustic signal, but does not elaborate on this possibility. What distinguishes the stimuli in the two tasks is prosodic structure: a nonword, unlike a string of syllables, forms a rhythmic unit. According to the early phonological sensitivity account, children with SLI have reduced ability to register weak syllables and segmental details within a prosodic structure. This is in keeping with the disproportionate difficulty they show repeating polysyllabic nonwords, whose constituent syllables vary in stress, compared with strings of monosyllabic nonwords whose constituent syllables are all stressed.

The second troubling finding for the storage-based account is that some children with marked impairments in nonword repetition and serial recall at 5 years present with age-appropriate vocabulary and language abilities at 8 years. If nonword repetition and vocabulary acquisition crucially depend on the same phonological storage capacity, this mismatch between an early measure of phonological memory and later vocabulary is puzzling. In her Keynote (2006), Gathercole infers that a phonological storage deficit may not be sufficient to disrupt language development, and suggests that there must be a further deficit, proposing "working memory" as a candidate.

Analysis of the developmental trajectory may yield alternative accounts of the observed differences in outcome. The above analysis leads to at least three reasons why some children with poor nonword repetition at age 5 may have intact vocabulary and language at age 8. First, even though they attained comparable scores to children with SLI on a nonword repetition test at 5 years, they may have differed in the severity and/or pervasiveness of their phonological deficit. Second, these children may differ in relevant nonverbal abilities. Strengths in nonverbal development could help children discover word meanings and thereby support their vocabulary development. Third, they may differ in their capacity to register links between phonology and semantics: stronger connections between phonology and semantics may mitigate the effects of weak phonological processing on vocabulary and syntax.

These reinterpretations illustrate why it is important to recognize that nonword repetition has a developmental trajectory, and to identify the forces operating at different stages in that trajectory. Unusual patterns of performance will then lead us to explore which hypothesized skills and resulting representations are out of step with each other relative to their typical trajectory.

Furthermore, a developmental perspective opens up the possibility that nonword repetition may be "the most effective predictor of language learning ability" (Gathercole, 2006) at some but not all stages in the trajectory. Other measures, such as sentence repetition, may become better predictors. However, that is another story.

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## The role of phonological storage deficits in specific language impairment: A reconsideration

In her Keynote Article, Gathercole (2006) presents a theoretical framework intended to account for evidence regarding the relation between nonword repetition and word learning. This framework stems from an impressive amount and breadth of research on this topic, including findings from adults and children with typical language abilities as well as language learning disorders. In this commentary we focus on claims relative to the interpretation of nonword repetition deficits in children with specific language impairment (SLI). One issue we address pertains to the nature of the proposed model of nonword processing and word learning, particularly with respect to phonological sensitivity and storage. The second issue we address relates to the assumption that a phonological storage deficit, although not sufficient, is necessary for SLI.

Gathercole (2006) asserts that phonological storage is central to both nonword repetition and word learning, and that both of these abilities are additionally constrained by auditory, phonological, and speech–motor output processes. She systematically lays out the evidence to demonstrate that problems with nonword repetition in SLI are not primarily attributable to each of these additional constraining processes. In doing so, the overall impression is one of a relatively simple serial information processing mechanism, especially with respect to the dichotomy of the debate about phonological storage versus phonological sensitivity. Her figure 4 shows unidirectional arrows from auditory processing to phonological analysis to phonological storage to both speech–motor planning/output and phonological learning. However, there are alternative models supported by empirical data indicating that these cognitive processes are, in fact, interactive (e.g., Christiansen & Chater, 2001; Elman, Hare, & McRae, 2005; Plaut & Kello, 1999; Seidenberg & MacDonald, 1999).

Given that Gathercole (2006) acknowledges that deficits in cognitive processes besides phonological storage may be necessary to account for SLI, it seems curious to take such a strong position on minimizing the role of phonological analysis and representation. Although studies conducted by Gathercole and colleagues support the claim that the source of the difficulty is with phonological storage rather than with earlier aspects of phonological analysis, other evidence, as discussed below, is more consistent with the phonological sensitivity explanation.

Gathercole (2006) argues that the *phonological storage hypothesis* (namely, that children with SLI have a deficit in phonological storage) best accounts for empirical data regarding nonword repetition in children with SLI relative to age peers. Gathercole contrasts the phonological storage hypothesis with the *phonological sensitivity hypothesis*, a term she uses to describe the theoretical framework of Beckman, Edwards, and Munson (Beckman & Edwards, 2000a; Edwards, Beckman, & Munson, 2004; Munson, 2001; Munson, Edwards, & Beckman, 2005; Munson, Kurtz, & Windsor, 2005). These authors argue for an account of phonological acquisition in which phonological representations are highly tied to words the child knows in early language learning and gradually become more independent of context as vocabulary size increases. In this view, difficulties with nonword repetition in SLI are more readily interpreted as a consequence of small vocabulary size rather than as a causal factor (Beckman & Edwards, 2000b).

In particular, Gathercole (2006) argues that the phonological storage hypothesis better explains the finding that the accuracy differences in nonword repetition between children with SLI and their age peers increase as word length increases because of decay. However, there are also findings that are better explained by the phonological sensitivity hypothesis. Edwards et al. (2004) examined 104 typically developing children aged 3 through 9 years, and found that accuracy differences between children with smaller vocabularies and those with larger vocabularies were greater for low-frequency phoneme sequences compared to high-frequency sequences. Furthermore, in a similar experiment with different stimuli, Munson, Kurz, et al. (2005) found that accuracy differences in nonword repetition between children with SLI and their typically developing age peers were greater for low-frequency phoneme sequences compared to high-frequency sequences. Moreover, children with SLI performed similarly to younger typically developing peers, matched for vocabulary size. Given that the words containing the low-frequency and high-frequency phoneme sequences were of the same length, this finding is difficult for the phonological storage hypothesis to explain. The phonological sensitivity hypothesis can readily explain this result: namely, as the size of the lexicon increases, phonological representations become less context sensitive so that nonword repetition accuracy is less dependent on whether the child has encountered a similar sequence in a known word. The fact that an interaction between vocabulary size and phonotactic probability was not observed in Gathercole, Frankish, Pickering, and Peaker (1999) may be due to the different nature of the task (serial recall) or to the more limited age range tested (7- and 8-year-olds only).

Another concern with Gathercole's (2006) account is that it appears to conflate wordlikeness and phonotactic probability. Bailey and Hahn (2001) found that adult wordlikeness judgments consist of two independent components: neighborhood density and phonotactic probability. In a study of monosyllabic nonwords, neighborhood density and phonotactic probability both contributed independently to adults' wordlikeness judgments. Adults rated a nonword as more wordlike as its neighborhood density and its phonotactic probability increased.

This finding is relevant in that longer nonwords differ from shorter nonwords in neighborhood density. Neighborhood density is inversely correlated with word length: the longer the word, the fewer lexical neighbors it will have (Storkel, 2004). For example, two-syllable words on the Children's Test of Nonword Repetition (CNRep; Gathercole, Willis, Baddeley, & Emslie, 1994) have a number of lexical neighbors. For example, *ballop* rhymes with *gallop*, *sladding* is a lexical neighbor of both *sliding* and *sledding*, and so on. However, none of the five-syllable words on the CNRep have any lexical neighbors. Thus, longer words on the CNRep differ from shorter words in two respects: they contain more syllables and they have fewer lexical neighbors. Just as low phonotactic probability resulted in a greater decrement in performance for children with SLI relative to peers, it may be that low neighborhood density also results in a greater decrement in performance for children with SLI. Perhaps the finding of Gathercole and Baddeley (1990) that there is a greater decrement in performance for children with SLI relative to age peers on longer nonwords is more related to neighborhood density rather than to word length per se. This is an empirical question that can be answered only by contrasting nonwords of the same length with different neighborhood densities.

As suggested above, the framework represented in Gathercole's (2006) figure 4 does not adequately represent the highly interactive and multidimensional nature of phonological representations and phonological processing. Within a more complex model, one might assume that different levels of processing (or representation) are influencing each other such that phonological analysis and storage would interact in a dynamic fashion. According to this type of model, one would expect that it would be more difficult to analyze phonological representations that are poorly stored and that it also would be more difficult to store poorly specified phonological representations. As noted by Gathercole (2006), it typically takes multiple passes (exposures) to learn a word. If a child has a deficit in phonological analysis, then getting the word stored might be difficult. The child may not arrive at the same phonological analysis each time, thereby amassing conflicting information such that he/she must suppress or override prior representations that were stored incorrectly.

Given such a complex system, it may be that some children with SLI have a primary deficit in phonological storage, other children have a primary deficit in phonological analysis, and some children have neither. Although some research supports the phonological storage hypothesis (e.g., Gathercole & Baddeley, 1990) and some research supports the phonological sensitivity hypothesis (e.g., Edwards et al., 2004; Munson, Kurtz et al., 2005), most studies of nonword repetition in children with SLI relative to typically developing peers have found much variability in performance, especially among the children with SLI. Many of these studies (e.g., Edwards & Lahey, 1998; Ellis Weismer et al., 2000) have found overlap in performance between children with SLI and their age peers.

Ellis Weismer et al. (2000) investigated nonword repetition in second grade children as measured by the task developed by Dollaghan and Campbell (1998). Using an odds ratio analysis, they found that nonword repetition performance, although helpful, was not sufficient by itself to classify children on the basis of language diagnosis or intervention status. This large ($N = 581$) population-based sample of children had been diagnosed according to the EpiSLI criteria established by Tomblin, Records, and Zhang (1996). Although it was the case that the SLI group and nonspecific language impairment groups both performed significantly worse than the normal language and low cognitive (normal language) groups, there was considerable overlap across the groups. The total percentage phonemes correct (PPC) for the children diagnosed as having normal language ranged from 48 to 99%, and the PPC for the longest nonwords (four syllables) ranged from 8 to 99%. A substantial minority of children with SLI performed at or above the mean for the control group on total PPC and four-syllable PPC (33 and 25% of the SLI group, respectively).

Gathercole (2006) explicitly states that limitations in phonological storage may not be sufficient to cause substantial language deficits. This explains how some children with poor nonword repetition skills can still have normal range word learning/vocabulary skills. Within Gathercole's framework, it is poor phonological storage plus restrictions in supporting cognitive resources, most notably working memory, that are posited to lead to language learning difficulties. As she notes, there is empirical support for the notion that children with SLI display deficits in verbal working memory compared to normal language peers, as measured by a variety of tasks (e.g., Ellis Weismer, Evans, & Hesketh, 1999; Montgomery, 2000). Ellis Weismer and Thordardottir (2002) reported that nonword repetition and listening span (working memory task) were significant unique predictors of language abilities (as measured by a standardized language test) in a group of second graders who had a wide range of nonverbal cognitive and language abilities. It is noteworthy that the listening span measure accounted for substantially more variance in language scores than nonword repetition performance in this sample. Despite the fact that children with SLI, as a group, demonstrate both phonological storage and working memory difficulties, not all children with SLI display poor nonword repetition (Ellis Weismer et al., 2000), nor do all children with SLI exhibit verbal working memory deficits on other measures (Ellis Weismer et al., 1999; Ellis Weismer & Thordardottir, 2002).

Several investigators have discussed the heterogeneity of SLI and hypothesized that there may be different underlying causal factors for various subgroups of children (Bishop, Carlyon, Deeks, & Bishop, 1999; Ellis Weismer, 2004, 2005; Tomblin, Zhang, Weiss, Catts, & Ellis Weismer, 2004). For instance, research suggests speech perception deficits (Stark & Heinz, 1996) and slowed processing speed (Miller, Kail, Leonard, & Tomblin, 2001; Windsor & Hwang, 1999) are primarily linked to receptive–expressive SLI rather than expressive-only SLI. In a recent longitudinal investigation, Catts, Adolf, Hogan, and Ellis Weismer (2005) examined the relationship between SLI and dyslexia in a population-based sample of school-age children. Findings from that study suggest that comorbidity with dyslexia may account in large part for the poor nonword repetition performance displayed by most children with SLI. Children diagnosed with SLI who did not also meet the criteria for dyslexia displayed only mild problems with nonword repetition. Rather than attempting to identify one primary cognitive process that is believed to be implicated in language learning deficits, it may be important to consider the possibility that there are different underlying factors for different subgroups.

In conclusion, this seminal paper by Gathercole (2006) brings together many different strands of research on nonword repetition. It points the way to further empirical work, as well as to the need for more explicit and complex models of the processes involved in both nonword repetition and word learning, particularly in relation to SLI.

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Commentary on Keynote

Our understanding of the relationship between verbal short-term memory as indexed by nonword repetition and word learning must now incorporate myriad factors that were not as apparent 17 years ago when Gathercole and Baddeley (1989) proposed that "the phonological memory skills tapped by nonword repetition play a causal role in vocabulary development" (p. 211). In particular, successful nonword repetition involves more than the phonological loop, word learning happens by degrees and is influenced by many factors other than phonology, and children with specific language impairment (SLI), who have served as test cases by virtue of consistently demonstrating phonological memory deficits, often exhibit other deficits with the potential to negatively impact word learning. Gathercole (2006) still makes the case for temporary phonological storage playing an important role in word learning, but with several caveats. I would like to add two.

First, when assessing the relationship between the ability to repeat nonwords and vocabulary acquisition, it is important to distinguish between studies using extant vocabulary and those teaching new words to children. Our research examining the initial stage of word learning, known as fast mapping, has generally not found a significant relationship between nonword repetition and fast mapping in young children with SLI. Gray (2004) assessed fast mapping comprehension and production in 20 preschoolers with SLI who were age and gender matched to children with typical development (TD). On the nonword repetition task (Dollaghan & Campbell, 1998) the TD group repeated significantly more nonwords than the SLI group, and comprehended significantly more words on the fast mapping task, but receptive vocabulary and expressive phonology predicted fast mapping comprehension. Similarly, Gray (in press) studied fast mapping in 53 young children (3–6 years) diagnosed with SLI and 53 children with TD matched for age and gender to the SLI group. The TD group scored significantly higher than the SLI group on nonword repetition at ages 3, 4, 5, and 6; but only the 5-year-old TD group outperformed the SLI group on fast mapping comprehension and production. Age and nonword repetition predicted fast mapping production *for the TD group*, but no variable predicted a significant amount of fast mapping variance for the SLI group.

Gray (2004) also assessed word learning beyond the fast mapping stage as children were taught words in a 1 : 1 play context. The TD group learned to comprehend and to produce more words than the SLI group, and did so in fewer trials. As in the previous study, receptive vocabulary predicted the number of words comprehended. Expressive language and a measure of semantic knowledge were the only significant predictors for the *number of words* children learned to produce. In contrast, nonword repetition *was* a significant predictor of the number of trials children required to learn to produce a word. Gathercole (2006) states that poor phonological learning ability will not prevent word learning; rather, learning is slowed because children require more exposures to words before they can produce them. Our results illustrate this, and suggest that nonword repetition may index phonological storage *efficiency*, which affects word learning efficiency, and this is impacted by a number of other variables.

Second, different nonword repetition tasks may yield different outcomes because of the properties of the nonwords, scoring, and task instructions. For example, because children can use stored lexical representations to help produce nonwords, the more "wordlike" the nonwords are, the easier they are to repeat (Dollaghan, Biber, & Campbell, 1999; Gathercole & Baddeley, 1990). There is also evidence that nonword repetition can improve with practice (Edwards & Lahey, 1998; Gray, 2003). Gray found that preschoolers with SLI and age- and gender-matched peers with TD significantly improved their nonword repetition performance when provided two opportunities to repeat the list of nonwords 1 day apart. Further, SLI group scores improved more than TD group scores with a medium effect size for the SLI group and a small effect size for the TD group. It is also interesting to note that scores for the first and second administrations were significantly correlated for the SLI group ($R = .72$) but not the TD group ($R = .40$). These findings suggest the need for a standardized, norm-referenced nonword repetition task with good psychometric properties that will allow research findings to converge on the relationship between phonological short-term memory and word learning.

Consistent with the observation of many language researchers, Gathercole (2006) has broadened her view to consider a phonological storage deficit as just one of the core problems that may prevent normal language development. This fits well with research investigating the neurobiology of SLI that reports a number of brain differences in these children (see Webster & Shevell, 2005, for a review) including atypical patterns of brain development (Gauger, Lombardino, & Leonard, 1997), atypical coordination of activation across brain regions during encoding and recognition tasks (Ellis Weismer, Plante, Jones, & Tomblin, 2005), and differences in auditory processing (Uwer, Albrecht, & von Suchodeletz, 2002). Given these findings and the complexity of brain–behavior relationships, it is not surprising that we cannot easily define subtypes of SLI (e.g., Conti-Ramsden, Crutchley, & Botting, 1997) or prescribe differential treatments. However, it remains important to accurately quantify the skills of individual children, thereby paving the way for more precise participant descriptions and more individualized treatment. In this respect, nonword repetition continues to serve as a valuable tool for researchers and clinicians interested in SLI.

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## Nonword repetition, phonological storage, and multiple determination

The proposals that (a) nonword repetition and word learning both rely on phonological storage and (b) both are multiply determined are two of the major foci of Gathercole's (2006) Keynote Article, which marshals considerable evidence in support of each. In my view, the importance of these proposals cannot be overstated: these two notions go to the heart of the relationship between nonword repetition and word learning. Indeed, they figure prominently in the approach that my colleagues and I have taken to studying that relationship (e.g., Gupta, 2006;

Gupta, Lipinski, Abbs, & Lin, 2005; Gupta & MacWhinney, 1997). An important aspect of our approach has been the attempt to construct a computational model that can simulate performance in a nonword repetition task and in a word learning task, the rationale being that a computational model that achieved this would constitute a proposal about the *processing mechanisms* that may underlie the relationship. In this Commentary, I describe how our computational work offers a concrete way of thinking about *how* nonword repetition and word learning may rely on phonological storage, and about *how* these abilities may be multiply determined. Such computational work is, I suggest, a valuable tool in further investigating the important relationship that has been revealed by Gathercole's influential work, and that is analyzed in the Keynote Article.

The question of how nonword repetition might rely on phonological storage leads directly, as in Gathercole's discussion (2006), to the question of how performance in a nonword repetition task might be related to performance in immediate serial recall, the canonical phonological storage task. In addressing this question, my colleagues and I have pointed out (Gupta et al., 2005) that the functional requirement for performance of either task is the immediate encoding and retrieval of the *serial order of a novel phonological sequence*, which in immediate serial recall is a novel sequence of words or digits, and in nonword repetition is a novel sequence of sublexical units such as phonemes and/or syllables. The mechanism(s) of phonological storage underlying performance in these tasks must therefore necessarily be concerned with computing serial order. In the one case, however, the serial ordering is at the level of lexical representations (lists of word forms, in immediate serial recall). In the other case (nonword repetition), the serial ordering is at the level of sublexical constituents. Phonological serial ordering must therefore be capable of operating at both levels of representation: lexical and sublexical.

This means that a computationally specified account that simulates performance in both tasks must provide some basis for *representation* of both lexical and sublexical information (in addition to specifying the basis for serial ordering for both types of information). That is, the account must incorporate the kinds of representational distinctions that are the stuff of (psycho)linguistics. One approach here might be to propose a bufferlike phonological storage device into which sequences of representations are copied, no matter whether they be sequences of words, or syllables, or phonemes. In our own work, we have adopted a different approach. As shown in Figure 1, our model incorporates word form and semantic levels of lexical representation, and syllabic and phonemic levels of sublexical representation, and thus encompasses much of what is typically included in psycholinguistic models of lexical processing. In keeping with this, the connection weights between units at these various levels of representation instantiate what is, in effect, long-term linguistic knowledge in the system, both phonological and semantic.

The presentation of a word form to the model (depicted by the "speech input" arrows in Figure 1) results in sequences of representations being activated at the various levels of representation. For instance, presentation of the word form *zitricaymus* is manifested in the model as activation of the relevant sequence of phoneme representations at the phoneme level, activation of the relevant sequence of syllable representations at the syllable level, and activation of the relevant word

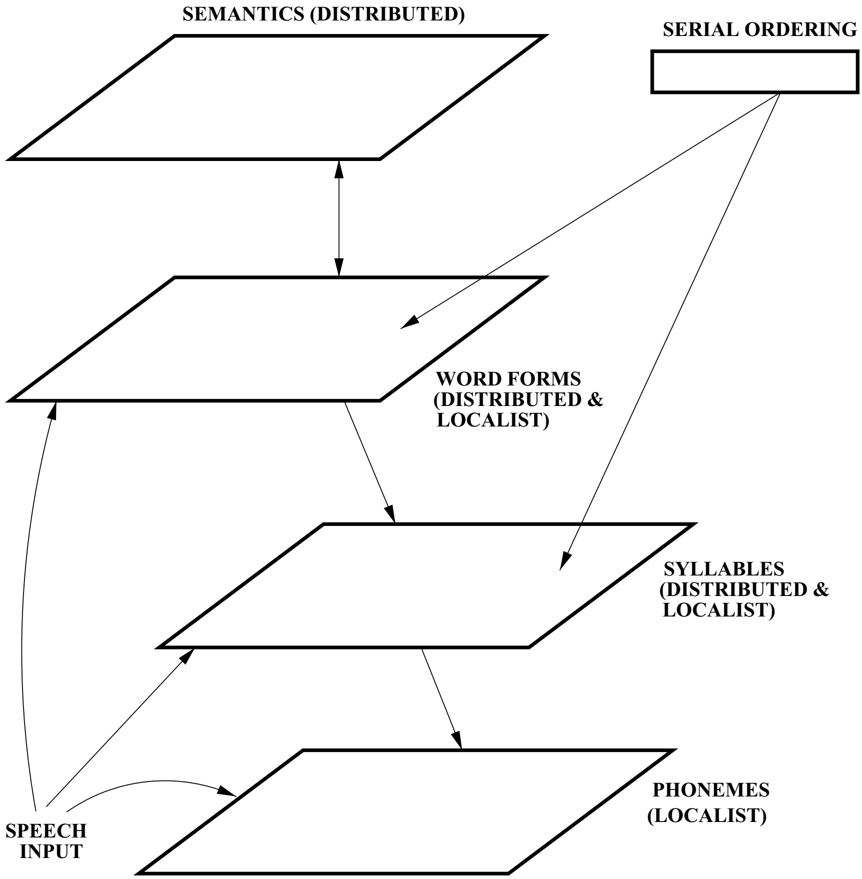


Figure 1. A model of nonword repetition and immediate serial recall (Gupta, 2006).

form representation at the word form level. New representations are created on the fly as necessary at each of these levels. Presentation of either a known word form or a novel word form thus gives rise to sequences of activations at the phoneme and syllable levels, and of a single activation at the word form level. A "list" is simply a sequence of these sequences. For instance, presentation of the list {*cat dog ball chair*} leads to activation of the sequences of phonemes and syllables constituting each word in the list, and additionally, gives rise to a sequence of activations at the word form level (the representations of the word forms cat, dog, ball, and chair). Thus, in a real sense, a word form is just a list of length one.[1] The model also incorporates a serial ordering mechanism that encodes and retrieves the serial order of a sequence of activations, at any level of representation it is connected to. Details of its operation are provided elsewhere (Gupta, 2006; Gupta & MacWhinney, 1997); for present purposes, the main points to note are as follows. First, the encoding does not involve making a copy of the elements of the sequence; rather, it consists of a connection weight-based encoding, in the connections from the serial ordering mechanism to the word form and syllable levels of representation. Second, because these connection weights decay, the encoding is strictly short term. Third, following presentation and encoding of a sequence in this manner, recall takes the form of "replaying" the previously encoded sequence at the same level of representation where it occurred, that is, in the linguistic system, via the short-term connection weights; thus, it is important that encoding and retrieval engage not only the serial ordering device but also the linguistic system as well. As shown in Figure 1, the serial ordering mechanism has connections to both the word form and syllable levels of representation, and can thus encode and retrieve the serial order of sequences of activation that occur at either of these levels. Thus, the model provides for serial ordering at both lexical and sublexical levels of representation; that is, it can perform both immediate serial recall and nonword repetition. In response to presentation of a list, or a word, or a nonword, it can repeat the list/word/nonword, with the output being serially ordered sequences of phonemes within (if appropriate) a serially ordered sequence of syllables within (if appropriate) a serially ordered sequence of words.

In simulations, this model exhibits several key characteristics of immediate serial recall and nonword repetition (Gupta, 2006). For immediate serial recall, these include serial position effects, list length effects and positional gradients for movement errors. For nonword repetition, they include a decrease in accuracy with nonword length, and the syllable-wise serial position effects that have recently been documented in repetition of individual polysyllabic nonwords (Gupta, 2005; Gupta et al., 2005). Furthermore, the model's nonword repetition performance is correlated with its immediate serial recall performance (Gupta, 2006). Thus, as gauged by its correspondence with human behavior, the model as thus far developed appears plausible.

How does this computational model relate to Gathercole's (2006) two proposals? The dependence of nonword repetition on phonological storage is very directly realized in this model: the serial ordering mechanism, which provides for phonological storage, is crucial for nonword repetition, as well as for the canonical phonological storage task of immediate serial recall. This has been confirmed in the model by disrupting operation of the serial ordering mechanism, which grossly impairs immediate serial recall and nonword repetition performance, but, as in "pure short-term memory" patients (Vallar & Baddeley, 1984), leaves intact the repetition of known words (which in the model are encoded by long-term connection weights between the semantic/word form/syllable layers). The dependence of word form learning on phonological storage arises because what *gets* encoded in the long-term connection weights over multiple exposures depends on the accuracy with which that sequence is encoded in the first place, as a nonword, and that depends on phonological storage.

Nonword repetition performance, is also, however, critically dependent on many other components of the model. Nonword repetition performance will depend, for instance, on the effectiveness of the long-term knowledge of syllables, incorporated in the model's connection weights from the syllable to the phoneme level. The efficiency of word form *learning* will also depend on the effectiveness of those connection weights, and additionally on the effectiveness of long-term knowledge of word forms as a whole, incorporated in the model's connection weights from the word form to the syllable level. In addition, *word learning*, comprising learning of not only a word form, but also an association between the word form and a semantic representation, is clearly dependent on learning in the connections between the semantic and word form levels of representation. The model thus offers a concrete realization of the notion that nonword repetition and word learning are both multiply determined. Of interest, the model's instantiation of multiple determinations also offers a resolution of the debate between the phonological sensitivity and phonological storage hypotheses described in the target article. In the model, there is no opposition: *both* have a role to play. The role of phonological storage has already been discussed. The role of phonological sensitivity (or more generally, linguistic experience) arises because the development of long-term linguistic knowledge itself increases the effectiveness of the long-term connection weights between the various linguistic levels, facilitating additional learning that is possible between those levels of representation, and thus facilitating both nonword repetition and word learning. The model's concretizaton of the notion of multiple determinations thus suggests that the controversy over phonological storage versus phonological sensitivity may be misplaced.

This last point serves as an appropriate place to conclude this Commentary. I believe it nicely illustrates the theoretical importance of Gathercole's (2006) proposals; it also illustrates the value of computational work in further investigation of these important phenomena.

## NOTES

1. For a list or a single word form, the activated representation(s) at the word form level will lead to activations at the semantic level of representation. For known word forms, these will be the specific semantic representation that is associated with that word form, whereas for nonwords the evoked semantic representation will tend to be an indeterminate semantic representation that is a blend of those corresponding to known word forms that are similar to the nonword.

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## Do nonword repetition errors in children with specific language impairment reflect a weakness in an unidentified skill specific to nonword repetition or a deficit in simultaneous processing?

This Commentary supports Gathercole's (2006) proposal on a double deficit in children with specific language impairment (SLI). The author suggests that these children have a limited phonological storage combined with a particular problem of processing novel speech stimuli. According to Gathercole, there are three areas of skill contributing to memory for nonwords: general cognitive abilities, phonological storage, and an unidentified skill specific to nonword repetition. The focus of this Commentary is to examine whether these children's nonword repetition performance is influenced by an unidentified skill or some other processes. An alternative hypothesis is that the nonword repetition errors observed in children with SLI are related to one of their main weaknesses, to their difficulties in simultaneous processing of information. Evidence for this argument comes from our recent studies: from error analyses data and from findings on nonword repetition with stimuli that included meaningful parts (monosyllabic real words).

Our earlier findings showed a deficit in simultaneous processing across verbal and nonverbal working memory tasks in children with SLI (linguistic span task, list recall, space visualization, etc.; Marton & Schwartz, 2003; Marton, Schwartz, Farkas, & Katsnelson, in press; Marton, Schwartz, Phinkasova, Roth, & Kelmenson, 2006). These children showed diminished primacy and recency effects in list recall tasks; they were not able to process the new incoming stimuli and rehearse the old information simultaneously. In the linguistic span task, children with SLI either repeated the sentence-final words/nonwords or answered the questions that targeted the sentence content. Again, they were not able to perform both operations concurrently. Their difficulties were not simply related to limitations in storage. Although these children remembered relatively few of the sentence-final words during testing, if testing was stopped and they were asked whether they could repeat the stimuli they were presented with, most children repeated entire sentences correctly. Thus, their difficulty was not in remembering long stimuli, but performing various tasks concurrently.

In this Commentary, I suggest that nonword repetition is a task that requires simultaneous processing, a skill with which children with SLI have difficulty. The following findings from our studies are of relevance to this argument. According to a theory of phonological encoding in word retrieval, the phonemes of a word and the word's metrical frame are processed separately. The "segment-to-frame association" theory (Biran & Friedmann, 2004; Levelt, 1992) suggests that segments/phonemes are inserted into the metrical frame of a word during phonological encoding. The metrical frame includes the number of syllables and information on the words' stress pattern; the segmental part consists of information on the phonemes (consonants, vowels, clusters). In word retrieval, these two types of information are integrated by the mechanism of segment-to-frame association.

Evidence comes from various speech errors in different populations, for example, stress exchange, anticipatory and perseveratory phoneme substitutions, and changes in syllabification (Biran & Friedmann, 2004; Meyer, 1992).

Detailed analyses of nonword repetition errors of children with SLI and their typically developing (TLD) peers indicate that the majority of their errors are segment substitutions with notable assimilation errors (when the production of one part of the nonword influences the production of another part of the same nonword) in the former group. In contrast to the many segmental errors, the metrical frames of these nonwords are produced correctly; the number of syllables and the stress patterns are correct. In one of our earlier studies (Marton & Schwartz, 2003), we found that about 80% of all errors produced by the children with SLI were segmental errors: vowel and consonant substitutions with no syllable structure changes. These children repeated nonwords that consisted of the same number of syllables and stress patterns than the target stimuli. In our recent study (Marton et al., 2006), the percentage of nonwords produced with segment substitutions and segment order errors was 90% for the children with SLI and 92% for the children with TLD. Thus, the majority of the error nonwords resembled the metrical frame of the original stimulus.

An increase in word length influenced nonword repetition in all groups; all children made more errors in repeating four-syllable nonwords than in repeating three-syllable nonwords (this result is in agreement with previous findings; e.g., Gathercole, Willis, & Baddeley; 1991; Montgomery, 1995). In addition to a group effect (children with SLI made significantly more errors than the children with TLD), the children also differed in the proportion of single versus multiple errors per nonword. If a child produced only one segmental error in a nonword, that was considered as a single error. If they produced several errors within the same nonword, those errors were categorized as multiple errors. Children with SLI not only produced more multiple errors than their age-matched and language-matched peers, but the proportion of multiple errors compared to the total number of errors increased with the increase in the number of syllables. The proportion of single versus multiple errors did not change with an increase in word length for the children with TLD (see Figure 1). Both control groups produced more single than multiple errors at each word length. Thus, children with SLI showed a different performance pattern in nonword repetition than the typically developing children as the amount of information that had to be processed concurrently increased.

However, even with this decline in performance accuracy in the children with SLI, the distribution of error types remained the same. Children with SLI produced many multiple errors that consisted of segment substitutions, assimilations, and of a change in the original phonemic order. The number of syllables was in most cases the same as that in the target stimulus. The percentage of changes in the stress pattern was below 1% of all errors. Thus, the repetition of nonwords showed that the children with SLI were able to produce the correct metrical frame, but experienced difficulty when they had to integrate the segments with the frame. These data support the idea that metrical and segmental information are represented separately and accessed in parallel (Levelt, Roelofs, & Meyer, 1999.

The following part of this Commentary provides further evidence to the argument that nonword repetition requires simultaneous processing, and therefore, it is highly demanding on language-impaired children's working memory. In our recent

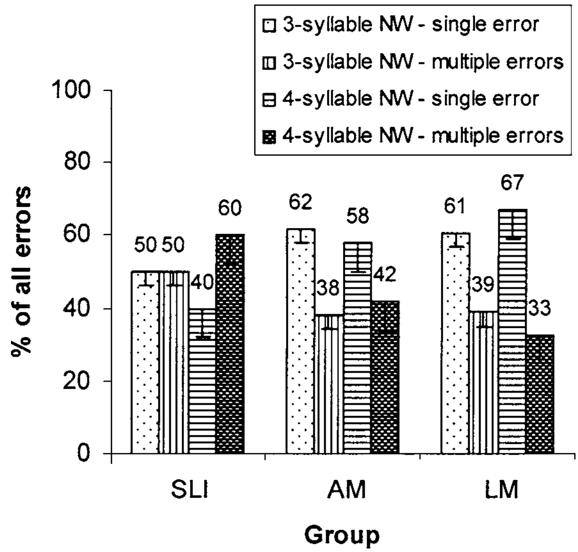


Figure 1. The proportion of single and multiple errors in nonword repetition.

study (Marton et al., 2006), we compared nonword repetition accuracy of stimuli with no meaningful syllables to nonwords that consisted of one monosyllabic real word and two to three syllables that had no meaning. Previous research showed that children's nonword repetition accuracy improves if the nonwords include meaningful syllables (Dollaghan, Biber, & Campbell, 1995). Our results showed a similar pattern for the age-matched and the language-matched groups. The children with SLI, however, did not show a difference in performance accuracy across the nonword lists (see Figure 2). Their performance did not improve, even when we ensured that they knew the words that were inserted in the nonwords. The children with TLD did benefit from their permanent knowledge, whereas the children with SLI did not take advantage of their long-term knowledge.

One explanation for these findings is that the simultaneous processing of different phonological structures (metrical frame and segments) was so demanding for the children with SLI that they were not able to process the semantic information of the inserted monosyllabic words. There may be alternative interpretations of these data that focus on the access of long-term knowledge during working memory performance in children with SLI, but the current findings strongly support the idea that these children have extreme difficulty in tasks that require concurrent processing of information. In these situations, children with SLI are often not able to use even their existing knowledge to support their working memory performance. The results have further theoretical implications regarding the relations between working memory and the long-term lexicon; however, that discussion is outside the scope of the present paper. There are various functions that influence the simultaneous processing of information; one candidate for the difficulties observed in children with SLI is a weakness in attention switching. Complex tasks that involve the concurrent processing of information require continuous attention

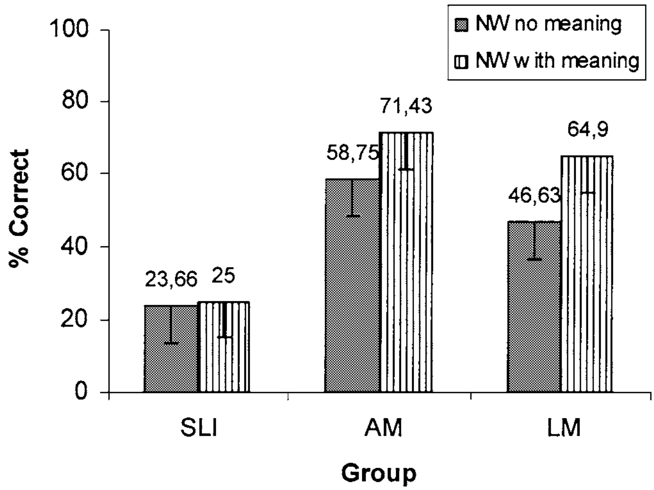


Figure 2. Nonword repetition across lists.

switching. Further research is needed to decide whether a deficit in this function influences these children's performance in working memory tasks.

In summary, this commentary provides an alternative explanation to the role of an unidentified skill for language-impaired children's difficulty in nonword repetition. I argue that nonword repetition is a task that requires simultaneous processing of information, and that children with SLI show poor performance in situations where they have to perform concurrent tasks. In these tasks, they cannot even use their existing knowledge efficiently to support their working memory performance. Evidence comes from a number of studies and the pattern of performance is consistent across various experiments.

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Commentary on Keynote

In her Keynote, Gathercole (2006) provides a comprehensive review regarding the nature of the nonword repetition (NWR) task and a compelling argument for the utility of the task as a robust index of children's phonological short-term storage capacity. She further argues that temporary phonological storage acts as a primitive learning mechanism that plays an instrumental role in the lexical learning of young children, including children with specific language impairment (SLI). In this Commentary, we focus our remarks on two related themes concerning the relation of NWR and SLI: (a) performance on NWR tasks provides a window into these children's more general cognitive (dis)abilities and (b) the robustness of NWR as a predictor of these children's lexical knowledge and learning abilities.

Gathercole and Baddeley's (1990) paper has become a seminal work for those who investigate the cognitive and language characteristics/associations in children with SLI. Children with SLI are those who are generally developing in a typical manner in all respects except for demonstrable receptive and/or expressive language impairments. These children exhibit language difficulties across the different domains, including lexical, morphological, and syntactic. However, they exhibit particular weakness in the areas of grammatical morphology and syntax (for a review, see Leonard, 1998. Gathercole and Baddeley (1990) were the first investigators to propose that children with SLI have a marked deficit in phonological short-term memory (PSTM) capacity (as indexed by their poor repetition of three-, four-, and five-syllable nonwords). They further argued that this deficit may well be causal to their language impairments.

Gathercole (2006) points out that NWR tasks involve various language-related factors (e.g., knowledge of phonotactic probabilities in the language, knowledge of canonical stress patterns of words) and a range of more general cognitive and memory-related processes (e.g., perceptual and encoding processes, redintegration processes, retrieval, articulatory planning, and execution processes), but argues that it is an especially sensitive index of children's *phonological storage capacity*. She argues this to be the case for both typically developing (TD) children and children with SLI. Although this may well be true for TD children, we urge caution in making the same claim about children with SLI.

With respect to language-related factors, the data for TD children are consistent in demonstrating that knowledge of constituent syllable structure (Dollaghan, Biber, & Campbell, 1993) and the phonotactic probably of phoneme sequences (Coady & Aslin, 2004; Munson, 2001; Munson, Edwards, & Beckman, 2005) supports NWR. The same also appears to generally hold for children with SLI. For instance, NWR of children with SLI also appears to be affected by the degree of similarity between nonword items and real words (Bishop, North, & Donlan, 1996; Briscoe, Bishop, & Norbury, 2001; Montgomery, 1995; Munson, Kurtz, & Windsor, 2005). Nonwords that more closely approximate the features of real words are repeated more accurately than those that diverge from the properties of real words. Such findings indicate that children with SLI are sensitive to the same lexical properties as TD children and use this knowledge to facilitate NWR. At the same time, however, many children with SLI exhibit lower vocabulary and a reduced network of lexical knowledge (e.g., Kail & Leonard, 1986) compared with their age peers. Such differences would likely lead to lower lexical and phonological neighborhood densities and phonotactic probabilities in the lexicons of children with SLI. These limitations may well make NWR somewhat less a language-related task for children with SLI, at least when compared with many of their TD age peers. However, as the lexicons of children with SLI grow and become more richly and densely connected the same language-related knowledge sources will likely play a greater facilitative role in their NWR.

Comparing the NWR of children with SLI with that of younger, language-matched TD children suggests that the poor NWR of children with SLI is constrained not by poorer language-related knowledge but by a variety of nonlanguage-related factors. Both Gathercole and Baddeley (1990) and Montgomery (1995) reported that, relative to a group of younger, language-matched children, children with SLI showed significantly poorer NWR performance. Because receptive vocabulary was accounted for in both of these studies, the poorer NWR of the children with SLI cannot be easily attributed to differences in receptive language-related knowledge. However, in a more recent study by Munson et al. (2005) no difference in NWR was found between a group of children with phonological disorder and a younger, language-matched group of TD children. These findings notwithstanding, it is safe to assume that at least some of the NWR difficulties of children with SLI are attributable to nonlanguage-related abilities.

Although it is true that various cognitive and memory-related processes mediate TD children's NWR, it may well be that it is these factors that most strongly distinguish children with SLI and TD children in NWR ability. Unlike most TD children, many children with SLI exhibit deficits in one or more of the processes assumed to underlie NWR, including poorer rapid rate acoustic–phonetic processing (Bishop, Bishop, Bright, Delaney, & Tallal, 1999; Tallal, Stark, & Mellits, 1985), perhaps inferior phonological encoding leading to the creation of less precise and/or stable phonological representations (e.g., Edwards & Lahey, 1998; Evans, Viele, Kass, &

Tang, 2002), inefficient lexical retrieval operations (Kail & Leonard, 1986), and/or problems with complex articulatory production (e.g., Bishop et al., 1996; Briscoe et al., 2001). It is because NWR entails such a wide range of input and output processing requirements that we suggest that NWR performance represents a more complex psycholinguistic exercise for children with SLI than TD children. That is, the poor NWR by children with SLI reflects more than just reduced PSTM capacity (or a PSTM deficit coupled with weak auditory processing abilities; Bishop et al., 1999). It also reflects these children's broader cognitive deficits. It is precisely because NWR taps so many different cognitive and memory-related skills that it has proved to be a highly reliable discriminator of TD children and children with SLI (Bishop et al., 1996; Conti-Ramsden, Botting, & Farragher, 2001; Dollaghan, & Campbell, 1998; Ellis Weismer et al., 2000). Thus, any conclusion ascribing the poor NWR performance of children with SLI to *primarily* a phonological storage deficit is premature.

Our second point relates to the robustness of NWR performance in predicting level of vocabulary knowledge and novel lexical learning in SLI. As indicated by Gathercole (2006), the association between NWR and word learning in TD children is far from straightforward. It is important, though, that NWR tends to be a good/stable predictor of TD children's level of vocabulary knowledge and novel word learning. The relation in children with SLI appears to be even less straightforward, especially given the mixed findings reported in several recent studies. Munson et al. (2005), for instance, found NWR and existing receptive vocabulary knowledge to be significantly correlated. Other researchers, however, have failed to report a similar positive correlation (e.g., Botting & Conti-Ramsden, 2001; Edwards & Lahey, 1998). The evidence documenting the relation between NWR and novel word learning (as indexed by receptive measures) in SLI is likewise mixed. Gray (2004), for example, showed a positive association between NWR accuracy and novel receptive word learning in a group of preschoolers with SLI. Ellis Weismer (1996) also reported a similar positive relation in a group of young school-age children with SLI. However, Horohov and Oetting (2004) failed to find a correlation between NWR and receptive word learning in a group of school age children with SLI. The picture regarding an association between NWR and vocabulary in SLI becomes even less clear when one looks for an association with expressive vocabulary. Results from studies by Briscoe et al. (2001) and Ellis Weismer (1996) showed no positive correlation between NWR and level of expressive vocabulary (Briscoe et al.) or between NWR and novel lexical learning as measured by novel word production (Ellis Weismer, 2006).

The lack of consistent correlations between NWR and vocabulary knowledge and lexical learning in SLI may relate to the possibility that NWR tasks do not adequately capture the nature and scope of the complexity of the relation. Gathercole (2006) alludes to this possibility, and we would echo this notion. The SLI literature is clear in demonstrating that children with SLI have verbal memory deficits that extend well beyond phonological storage. They also show difficulty performing a variety of tasks requiring simultaneous verbal processing and storage (e.g., Ellis Weismer, Evans, & Hesketh, 1999; Marton & Schwartz, 2003; Montgomery, 2000). It is far more likely that a greater portion of the variance in SLI vocabulary and word learning would be explained by a matrix of memory measures that captures the simultaneous verbal processing and storage abilities of these children (e.g., Ellis Weismer & Thordardottir, 2002).

There is no debate that children with SLI demonstrate inferior NWR relative to most age-matched TD children and even many younger, language-matched TD children. There is, however, debate as to how best to explain these children's NWR deficit. We argue that the evidence thus far appears to favor a more multicausal explanation than it does a *primarily* phonological storage deficit account or even a phonological storage deficit plus auditory processing impairment account (Bishop et al., 1999). With respect to the association between NWR and word learning in these children, our understanding is complicated by the fact that (a) the significant correlations between NWR and measures of word knowledge and/or learning are not consistent across studies, and (b) NWR appears to be more predictive of receptive vocabulary than of expressive vocabulary. The NWR task has proven to be a valuable theoretical and clinical heuristic for those researchers investigating the nature of SLI. Future investigations will certainly continue to explore the linguistic and cognitive underpinnings of the NWR task, as well as the ability of the task to explain a meaningful portion of the variance in the language learning and performance of children with SLI. The theoretical and clinical utility of the task as it relates to SLI depends on it.

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## Nonword repetition and levels of abstraction in phonological knowledge

Susan Gathercole's Keynote Article (2006) is an impressive summary of the literature on nonword repetition and its relationship to word learning and vocabulary size. When considering research by Mary Beckman, Jan Edwards, and myself, Gathercole speculates that our finding of a stronger relationship between vocabulary measures and repetition accuracy for low-frequency sequences than for high-frequency sequences is due to differences in the range of the two measures. In our work on diphone repetition (e.g., Edwards, Beckman, & Munson, 2004; Munson, Edwards, & Beckman, 2005) we tried to increase the range in our dependent measures by coding errors on a finer grained scale than simple correct/incorrect scoring would allow. Moreover, restriction of range does not appear to be the driving factor in the relationship between vocabulary size and the difference between high- and low-frequency sequence repetition accuracy (what we call the *frequency effect*) in at least one of our studies (Munson et al., 2005). When the children with the 50 lowest mean accuracy scores for high-frequency sequences were examined, vocabulary size accounted for 10.5% of the variance in the frequency effect beyond what was accounted for by chronological age. When the 50 children with the highest mean accuracy scores for high-frequency sequences were examined (a group in which the range of high-frequency accuracy scores was more compressed, arguably reflecting ceiling effects), an estimate of vocabulary size accounted for only 6.9% of the frequency effect beyond chronological age. The associated $\beta$ coefficient was significant only at the $\alpha < 0.08$ level. This is the opposite pattern than Gathercole's argument would predict.

Nonetheless, I concede that ceiling effects may be a complicating factor in any study of nonword repetition accuracy. One could argue that the Length × Group (specific language impairment [SLI] vs. typically developing) interactions that are observed in many studies (although not in Munson, Kurtz, & Windsor, 2005) themselves may be due to restrictions in the range of performance on shorter items. One collective challenge that we face as a community of scientists is to construct nonword repetition tasks and dependent measures that elicit a range of performance, so that no group is at ceiling- or floor-level performance. In the meantime, one manipulation that we should all be using to increase the range of performance is rationalized arcsine transformations of our dependent measures, a transformation that we should be making to meet the normality assumptions required to calculate parametric statistics. For example, rationalized arcsine transformation diphone repetition scores on the Munson et al. (2005) data exhibit an appreciably larger range of data than nontransformed scores.

Although there are many different perspectives on the factors that drive nonword repetition performance, we can all agree that the relationship between nonword repetition and word learning is due to the association of these constructs with phonological representations. The relevant question to ask, then, concerns the nature of phonological representations themselves. What are they? Textbook descriptions of these generally posit that they look something like the strings of symbols that we are taught to transcribe in phonetics classes. However, phonetic transcriptions, even narrow ones, are abstractions of the signals that are being transcribed. The level of detail that they code is ultimately related more to the perceptual abilities of the listener, the degrees of freedom in the symbol system, and a priori assumptions about the quantity of detail that is relevant for transcription than to the signal being transcribed and its associated phonological representation.

What, then, do "real" phonological representations encompass? What is being represented? The answer to that is anyone's best guess. Representations themselves are latent variables. We can never see them, we can only posit them as explanations for the sensitivity that people have to variation and consistency in the speech signal in different tasks. To what aspects of the speech signal, then, are people sensitive? Classic research showed that speech perception appears sometimes to reference a relatively coarse-grained signal, suggesting that representations were themselves rather coarse-grained, abstract, symbolic entities, analogous to phonemic transcriptions of words. In contrast, a growing body of literature suggests that people encode, remember, and use a great deal of fine phonetic detail in speech (e.g., Johnson, 1997). We refer to these as *specific* speech encodings. Evidence for the existence of specific encodings comes from a variety of sources. Work in the emerging field of sociophonetics shows that individuals have acute sensitivity to fine phonetic detail when making judgments about a range of social categories like talker gender and sexual orientation, among others. Moreover, individuals' knowledge of systematic fine phonetic detail in speech influences their performance on phonological processing tasks that do not explicitly draw their attention to this variation (e.g., Goldinger & Azuma, 2004; Strand, 2000). These findings suggest that representations in memory consist of far more detail, perhaps in the form of detailed memories of individual perceptual "episodes," than classic models would suggest. At the same time, there is clear motivation to posit abstract units. These are needed, for example, to explain individuals' sensitivity to type frequency in the lexicon, such as the phonotactic probability effects noted Frisch, Large, and Pisoni (2000). The net result is that phonological representations in memory likely consist of two parallel representations: a specific encoding and an abstract encoding.

How do dual-level phonological representations arise? Are they learned simultaneously, or is one learned advance of another? Pierrehumbert (2003) argues that abstract representations are learned in development as progressive abstractions over specific perceptual episodes held in long-term memory. At the outset, language learners encode as much acoustic–perceptual detail in the speech signal as their perceptual mechanism will allow. These specific encodings will not be random, but they will reflect the phonological category structure of the ambient language. Learners then use domain-general statistical learning processes to infer the abstract phonological categories of the ambient language, based on the distribution of observed values along different acoustic–perceptual parameters.

Put simply, phonological category learning involves encoding the input and inferring the underlying structure. As Fisher, Hunt, Chambers and Church (2001) put it, "representations must be abstract enough to encompass variability due to voice, intonation, and linguistic context [but] also include enough phonetically relevant detail . . . to permit the child to learn about the various systematic sources of variability." Although this learning process has been studied exclusively as it relates to phonological categories (e.g., Maye, Werker, & Gerken, 2002), one can imagine that learners also make progressive generalizations over specific encodings to infer the abstract social–indexical categories that are invoked in sociophonetics experiments.

If phonological representations are comprised of both abstract and specific encodings, and development involves learning each of these levels of abstraction, we must ask ourselves whether nonword repetition is indeed the best tool measure a child's ability to create phonological representations. The wealth of published evidence suggests that it has considerable potential. The level of phonological knowledge tapped in nonword repetition experiments appears to be coarse grained and abstract, as shown, for example, by the influence of type frequency on repetition accuracy and latency.

How, then, do we measure a child's ability to create specific representations? In my laboratory, we have been examining an alternative method for assessing the ability to create *both* abstract and specific phonological representations using a single task. The task is long-term repetition priming, which we sometimes abbreviate *implicit phonological priming*. This task is comprised of two phases. In the *study* phase, children are presented with a string of nonwords without a referent. After a distracter task, children engage in a *test* phase that measures some aspect of their implicit "learning" of the nonwords that they were presented in the study phase. In the simplest version of this paradigm, this knowledge is gauged by measuring repetition accuracy. Previous research by Fisher et al. (2001) found that children repeat "studied" nonwords (stimuli identical to those played in the study phase) less accurately than completely novel stimuli.

Crucially, the implicit phonological priming paradigm allows for the systematic examination of the level of abstraction of the representations learned in the study phase. This can be accomplished by creating test-phase nonwords that have some characteristics in common with stimuli from the study phase but differ in other ways. For example, a study-phase stimulus might be a nonword like [mæfnaʊb], which contains the heterosyllabic sequence [aʊb]; this sequence is not attested in any monomorphemic words of English. In the test phase, the child might be asked to repeat nonwords like [maʊbfɪt]. A finding that the child repeated the [aʊb] sequence more accurately than another unstudied, unattested sequence (such as [aɪtʃ]) would be evidence that exposure to this sequence was sufficient to create a robust enough perceptual representation to support its repetition in an unstudied phonetic frame. The same paradigm can be used to examine specific encodings. For example, the study phase and test phase stimuli might vary in their fine phonetic detail, allowing for the systematic examination of the level of specific encoding that occurs during exposure to speech in the study phase.

My students and I believe that this paradigm holds significant promise in measuring the abilities of children with different speech and language impairments to learn both specific and abstract phonological representations. We are particularly enthusiastic about this methodology because it melds the established, well-supported nonword repetition task with an implicit learning task. We feel that study phase of the implicit learning task has a measure of ecological validity beyond traditional nonword repetition, in that it mirrors the way that children are exposed to new lexical items in real-world language development.

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## Phonological networks and new word learning

The first report of a connection between vocabulary learning and phonological short-term memory was published in 1988 (Baddeley, Papagno, & Vallar, 1988). At that time, both Susan Gathercole and I were involved in longitudinal studies, investigating the relation between nonword repetition and language learning. We both found a connection. Now, almost 20 years later, in her Keynote Gathercole (2006) reviews a multitude of data bearing on the interpretation of this often replicated connection. Her main conclusions are three. First, both nonword repetition and word learning are constrained by the quality of temporary storage. She sees this storage as multiply determined, that is, affected by factors like perceptual analysis, phonological awareness (ability to identify and reflect on the speech sounds that make up words). Second, both nonword repetition and word learning are also affected by sensory, cognitive, and motor processes. Third, an impairment of phonological storage is typically associated with specific language impairment (SLI) but this may not be a sole causal factor.

The conclusions are closely related to the hypothesis of the phonological store in the Baddeley and Hitch framework as a language-learning device (Baddeley, Gathercole, & Papagno, 1998). According to this hypothesis, temporary storage in the phonological loop determines how well new material can be permanently presented in long-term memory (LTM). Two alternative explanations for the relation have been put forward. According to one, proposed by Snowling, Chiat, and Hulme (1991), nonword repetition reflects already existing language knowledge. Children with greater vocabularies are more likely to find similarities between the words they already know and the nonwords they are asked to repeat, which is likely to help them in the repetition task. Thus, nonword repetition is sensitive to past language acquisition speed, which is likely to be a good predictor of future word learning. A second major competitor to the temporal phonological storage hypothesis is that nonword repetition performance reflects a general phonological processing factor, affecting temporary phonological storage but also phonological awareness and the ability to rapidly name objects and symbols (Wagner & Torgesen, 1987). This view has been promoted by, for instance, Metsala (1999) and Bowey (1996). Various phonological processing tasks have also been found to be correlated with word learning in typically developing populations, children with SLI, and second-language learners (Gajar, 1987).

Teasing out causal relations between highly intercorrelated variables, like phonological awareness, phonological memory, and vocabulary, in correlational studies has proved difficult. None of our measures seem to be pure. Moreover, they may measure different cognitive processes in different populations. For instance, digit span may be a measure of learning of digit names in 3-year-olds, phonological memory without rehearsal in 5-year-olds, working memory capacity for rehearsal in 7-year-olds, phonological memory for efficiently rehearsed material, but also for skill with elaborative strategies, in university students. However, we may not need to select between the temporary phonological storage, the language knowledge, and the general phonological processing hypotheses, described above. I would like to propose a variant of the temporal storage view that incorporates both the competing hypotheses as well.

The main proposition is that what Baddeley has termed *the phonological store* and Gathercole calls *temporary storage of phonological representations* gives us a snapshot of a phonological learning device. What we see in nonword repetition, or other short-term storage tasks, is a measure of the efficiency of this learning device. I propose that this device is a phonological network that primarily creates representations as the result of top-down influences on incoming speech material. The quality of the representations is multiply determined, both by the signal to noise ratio of the perceptual signal and by the top-down mapping processes that associate it with knowledge in LTM. Unlike Gathercole (2006), I do not think that the top-down effects seen at encoding and/or storage (Luotoniemi, Service, & Maury, in press; Thorn, Gathercole, & Frankish, 2005) as well as redintegration are irrelevant to learning. On the contrary, more wordlike material is both easier to represent in this network and to remember later (Service & Craik, 1993). Top-down effects may, however, not be a source of significant variation between individuals with vocabularies of by and large similar sizes, for instance, children of the same age. Moreover, top-down effects may compensate for a generally noisier network, which would be why repetition of wordlike items is not predictive of individual differences in word learning.

The feature that makes temporary storage tasks so sensitive to the quality of representations in this learning network may be their requirement for simultaneous representation. For instance, in nonword repetition, stimuli with unpredictable syllabic structures, consisting of multiple phonemes, are presented at the rate of normal adult speech. The more phonological material needs to be active at the same time, the more competing information is there for each feature of the stimulus (e.g., each phoneme, each phonetic feature, each stress value). Noise can be controlled by top-down means (association to preexisting units with strong representations). In the case of common real words, such associations are well established; so well established that single-word repetition to a healthy person is a trivial task and says little about the efficiency of phonological storage. The same demand for discriminability between representations is also critical for their later recall. Noisier representations will be harder to retrieve among similar neighbors and more prone to proactive interference from material encountered earlier. It is also possible that noisy representations in short-term memory are a sign of inadequate top-down mapping of some of the individual phonemes. In this case, the representations will not necessarily add to the strength of previous representations for the same item, for instance at the second encounter of a new word. Instead a new, competing, representation will be created, which will add noise to the top-down process when the item is heard a third time. This type of mechanism would lead to a double problem in a noisy system. The system would be inadequate in representing an incoming item and top-down help would be hampered with competition between several imperfect candidates.

We have not studied SLI, but our studies of adults with developmental dyslexia suggest that they have a phonological memory deficit, detectable with digit span, nonword span, and nonword repetition (Laasonen et al., 2006; Laasonen, Service, & Virsu, 2001, 2002). Their short-term recognition memory deficit extends to binary sequences of tones (two frequencies), light flashes (in two locations), and touch stimuli (pricks of two fingers). They also have separate problems with tasks that require fine time discrimination between two streams of stimuli. We found sensory memory to be correlated with phonological memory in both our control group and the dyslexic group (although their performance on individual measures of a single construct was more variable). We interpret our findings to mean that developmental dyslexia, in at least a subgroup of individuals, is related to the ability to simultaneously represent multiple stimuli that are encoded with respect to a limited set of stimulus features. This problem is accentuated in the language domain where repeated exposure *does* lead to learning of phonological categories and patterns, however, at a clearly impaired rate.

We believe that noisy traces in representational networks lead to slower processing, which is at the core of the difficulties our dyslexic group had with temporal acuity tasks. This could also explain why the SLI group in the studies by Gathercole and her colleagues were more impaired in nonword repetition than temporal storage of the same syllables in a paced sequence. The syllables in nonword repetition tasks are delivered fast, and little time is available for a noisy network to settle and clean up a representation. Single syllables, one at a time, allow for compensatory time between items. At least, this hypothesis would be worth testing.

To summarize, a learning device for phonological material is sketched. Its efficiency can best be seen in tasks requiring the simultaneous storage of multiple phonological units. The quality of the created phonological representations can also be seen in long-term learning as well as in various tasks of phonological processing.

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## Precautions regarding nonword repetition tasks

Using nonword repetition tasks as an experimental approach with both adults and children has become quite common in the past 10 to 15 years for studying lexical learning and phonological processing (e.g., Bailey & Hahn, 2001; Gathercole, Frankish, Pickering & Peaker, 1998; Munson, Edwards, & Beckman, 2005; Storkel, 2001; Vitevich & Luce, 2005). In her Keynote, Gathercole (2006) indicates that "The ability to repeat multisyllabic nonwords . . . probably represents the most effective predictor of language learning ability that is currently known" and that "nonword repetition . . . may also hold the key to understanding developmental disorders of language learning." Her Keynote reviews many of the findings from a variety of nonword repetition studies with typically developing children and children with specific language impairment (SLI) or other language-related disorders. Despite the substantial benefits and interesting findings that nonword test paradigms have provided in addressing different issues, a number of questions and precautions should be kept in mind regarding such approaches. Researchers who routinely employ these procedures are likely to be well aware of these issues, and in fact, Gathercole points out some of the limitations. For those less familiar with nonword repetition tasks, it seems advisable to reinforce the need for a certain amount of caution in evaluating the results of such approaches.

The presumed benefit of using nonwords as stimuli in various types of experiments is that they involve limited linguistic processing (i.e., not to the same extent or possibly in the same manner that repeating real words does). However, it is often not clear *specifically* what differences are associated with nonword repetitions versus real words. Semantic processing is assumed to be largely lacking in nonword repetition, but certain stimuli are somewhat more similar to real words than others are in their phonotactic structure and/or other phonological characteristics, which is an important variable in many nonword studies. Although nonwords that are more wordlike may invoke some amount of lexical–semantic processing, it is difficult to quantify precisely the degree of wordlikeness of various stimuli (Bailey & Hahn, 2001), especially across individual subjects; and utilizing adult evaluations of wordlikeness when studying children is also a potential concern. A nonword such as "cloyper," for example, could be judged to be somewhat similar to words such as "clover" and "clobber," and perhaps "cloister" or other words for some subjects. Depending on the specific phonological characteristics of the nonwords and the lexical experience and sophistication of the subjects in a study (e.g., children with different lexicon sizes or typically developing vs. SLI children), varying and relatively unquantifiable amounts of lexical–semantic processing are likely to occur for different subjects and across different stimuli.

In addition, despite many well-designed experiments that have been conducted, it is not clear when utilizing nonword repetition procedures how accurately input, memory, and output factors can be distinguished in attempting to understand the findings of such studies. That is, in very general terms, nonword repetition tasks involve some amount of auditory, cognitive, phonological, and motoric processing, in that stimuli must be heard, remembered, and repeated. Given that speech output always constitutes the "end product" of this process, it is difficult to know with certainty if output errors that subjects make in an imitation task reflect whether they may have misheard the production of a stimulus to be repeated, it was heard correctly but then stored in short-term memory inaccurately, it was mispronounced for reasons unrelated to hearing or memory factors, or it was potentially due to some combination of these factors. For example, a child with a hearing loss (or possibly a child with normal hearing who was presented stimuli with a low signal to noise ratio) might produce output errors due to input problems, but also potentially because of memory and/or articulation limitations unrelated to his/her hearing status. Gathercole (2006) attempts to clarify some of these uncertainties, as have others, regarding the sequence of receiving input through producing output, but conclusive evidence indicating where in the imitation process malfunctions occur is difficult to obtain. One approach that seems to be somewhat helpful in this regard is to carefully examine the specific types of errors made at the output level utilizing various phonological analyses (e.g., Edwards, Beckman, & Munson, 2004), rather than only classifying a response as correct or incorrect, as has been done in some investigations. Particularly when studies involve relatively young children or children with SLI, evaluating their speech to determine what individual articulation errors they may manifest is important, so that such patterns can be factored into conclusions about their nonword repetition errors. That is, some output inaccuracies might not be a consequence of the test procedures, but may simply reflect a young child's individual speech patterns (e.g., Edwards & Lahey, 1998).

Another precaution concerning interpretation of data from nonword studies is that whatever adults or children do in the context of an experimental task may not reflect what they actually do in their normal lexical learning. For instance, the fact that a group of subjects shows evidence of statistical sensitivities/preferences for certain phonotactic patterns compared to others does not ensure that they typically utilize such propensities in their routine lexical–phonological processing. An analogous situation to consider is that in assessing speech production patterns and capabilities in children and adults over the past several decades, researchers have sometimes had subjects talk at faster than normal rates in different experiments. In fact, both children and adults have demonstrated that when required to do so, they can talk faster than they generally do (e.g., Smith, Sugarman, & Long, 1984). Nevertheless, under normal circumstances, they do not speak at those faster rates. Thus, there is a difference between the rates at which subjects *typically* speak compared to rates at which they are *able* to speak. Similarly, demonstrating that subjects show sensitivities to phonotactic patterns in nonword repetition tasks should be viewed cautiously, as they may not routinely utilize these abilities in the process of lexical or phonological learning. They may, of course; but in the absence of any conclusive evidence of this nature, it seems appropriate to be quite conservative when interpreting findings from such tasks.

One must also be careful about generalizing too broadly on the basis of group averages and statistical tendencies, especially in terms of how they might relate to the performance of *individual* subjects. Gathercole (2006) notes (as do others who utilize such procedures) that there is "substantial individual variation and developmental change," but this awareness among investigators sometimes seems to be overlooked when conclusions are reached and models are developed. Some children may indeed have phonotactic sensitivities similar to those determined from group statistical results; however, others may not, or they may vary at different times in their development. In addition, given that some studies report statistically significant but nonetheless reasonably modest differences (e.g., 10–15%) between SLI and typically developing children or between high and low phonotactic probability, for example, one must be careful not to assume that such results are necessarily representative of each individual subject's performance. There is often considerable overlap in performance among subjects from different groups (e.g., Edwards & Lahey, 1998). To the extent a particular model assumes that certain phonotactic probabilities exist or that a particular processing sequence occurs, for instance, investigators must be careful not to conclude that all subjects possess the same abilities or demonstrate the same patterns. Thus, among a group of subjects, it is important to know how many of them show performance patterns consistent with group averages and for those who do not, how and to what extent they differ. When describing general findings or modeling a particular process, accounting for those subjects who do not reflect "average" or typical patterns is important.

In conclusion, research utilizing nonword repetition procedures has provided many new insights in recent years into the nature of word learning. It is likely that future investigations will continue to report additional intriguing findings that will further our understanding of this complicated process, particularly as data collection and analysis techniques continue to be refined. Further attempts to identify and clarify the nature of individual differences in response to such testing procedures will be one important direction to consider in greater depth, as will more fully understanding interactions among the specific perceptual, cognitive, and motor processes involved in such tasks.

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# Nonword repetition and language learning disorders: A developmental contingency framework

In 1990 Gathercole and Baddeley proposed a strong hypothesis that has generated a wealth of research in the field of language development and disorder. The hypothesis was that phonological memory, as indexed by nonword repetition, is causally related to vocabulary development. Support for the hypothesis came from an impressive range of longitudinal, correlational, and laboratory training studies, and from studies of specific language impairment (SLI). However, more recently, Gathercole, Tiffany, Briscoe, Thorn, and The ALSPAC Team (2005), directly tested the causal hypothesis by following a cohort of children from age 5 to 8 years. Contrary to prediction, children with poor nonword repetition abilities at age 5 had normal vocabulary at the age of 8.

Gathercole (2006) presents a revised version of the hypothesis cast in a framework comprising the key phonological processes contributing to nonword repetition, including input and output processes, the quality of phonological representations, and phonological storage, with a range of factors affecting each stage of the process. Gathercole distinguishes two hypotheses regarding vocabulary growth. According to the phonological storage hypothesis that she favors, the capacity of phonological storage underpins and places constraints on behavioral measures of vocabulary, nonword repetition, and phonological awareness. Within this view, an increase in phonological storage with age leads to increases in nonword repetition, new word learning, and phonological awareness skills.

The phonological sensitivity hypothesis is more explicitly developmental. Within this model, vocabulary growth drives the development of lexical representations, causing progressive segmentalization (Walley, 1993). In turn, the development of segmental representations is a precursor of phoneme awareness, and leads to improvements in a range of phonological processes including nonword repetition and new word learning. Neither hypothesis emphasizes reciprocal causation yet such influences need to be accommodated to fully understand the developmental changes observed in normal and atypical development (e.g., Castro-Caldas, Petersson, Reis, Stone-Elander, & Ingvar 1998).

In our view it is premature to reject the phonological sensitivity hypothesis because there is insufficient evidence to distinguish it from the phonological storage hypothesis. We suggest that future research should be guided by a developmental framework in which phonological representations undergo a continual process of modification as the consequence of lexical development and the constraints that operate on it, and which are critical both to phonological storage and word learning. We contend that the framework should be capable of accounting for the established finding that poor nonword repetition is a risk factor for SLI, but that language learning disorders (including SLI) are unlikely to be caused by a unitary deficit.

An adaptation of the developmental contingency modeling approach of Morton and Frith (1995) is used here to consider the role of different factors in driving nonword repetition, as well as the causation of language disorders. This approach separates cognitive and behavioral levels of explanation, and is a useful way of thinking about contingencies between different processes during development. It also allows for a consideration of the role of the environment, both as a cause of behavior and a mediator of reciprocal influences. The approach does not make any commitment to the model or mechanism that mediates brain–behavior relationships at the cognitive level (Morton, 2004).

The first step in the causal modeling process is to separate processes at the cognitive and behavioral levels. The present concern is with the predictors of two behaviors, nonword repetition, and new word learning, and their relationship to vocabulary knowledge. Gathercole (2006) focuses primarily on nonword repetition that she considers the behavioral marker of a primitive learning mechanism that is impaired in SLI, highly heritable, and relatively impervious to environmental influence. We agree with Gathercole that an exclusive focus on nonword repetition is not adequate to fully explain the impairments of children with language learning disorders. We propose that it is productive to consider the role of semantic representations in vocabulary learning, and to allow for the reciprocal influence of vocabulary growth on the status of both semantic and phonological representations. The proposed causal hypothesis is depicted in Figure 1. At the cognitive level, there is a neural network with bidirectional connections between semantic and phonological representations. The development of segmental phonological representations is fuelled by vocabulary growth, the impetus for which is semantic development (as specified by the phonological sensitivity hypothesis). In addition, input and output processes (not depicted in the framework) influence phonological development, the pacemaker of phonological learning.

Within this view, the constraints on nonword repetition that Gathercole (2006) discusses have their impact on the development of the representations that underpin nonword repetition, new word learning, vocabulary growth, and other skills such as phoneme awareness. In turn, these behaviors feedback and influence the further development of semantic and phonological representations. One of the strengths of this model is that it can accommodate the dissociations between nonword repetition and vocabulary seen in developmental disorders. Thus, dyslexia is associated with a deficit in phonological representations, whereas semantic representations are unimpaired (Swan & Goswami, 1997); the typical behavioral manifestation is therefore of a phonological learning deficit in the absence of vocabulary impairments (e.g., Aguiar & Brady, 1991). The deficit in phonological representation observed in dyslexia is shared with children with SLI who have decoding deficits in reading (Bishop & Snowling, 2004). However, it is important to emphasize that the deficit in phonological representation (and it follows in nonword repetition) is not seen in all cases of SLI (Catts, Adlof, Hogan, & Ellis Weismer, in press), and it is not sufficient to explain the language or reading profile of others (Bishop, 2006; Nation, Clarke, Marshall, & Durand, 2004). The model leads to the hypothesis that deficits in semantic representation contribute to, and in some cases may be a primary cause of, specific language impairment; furthermore, such deficits may be the sequelae of environmental factors, such as language deprivation that either predates or is a consequence of language difficulties.

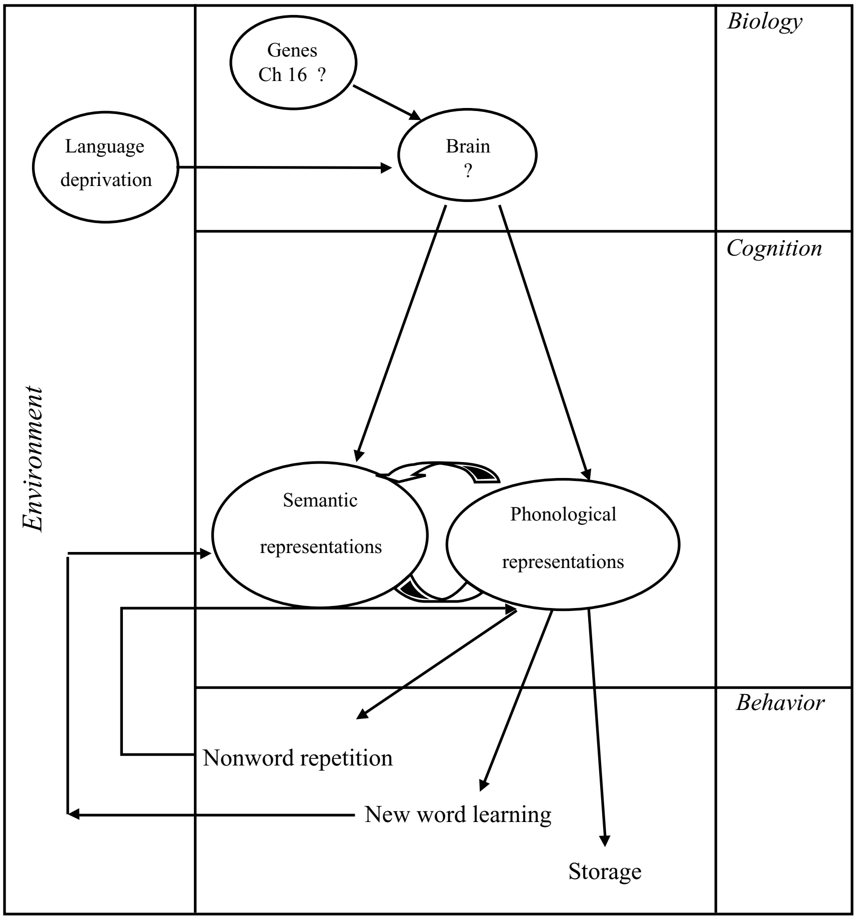


Figure 1. The developmental contingency model for the consideration of language learning disorders.

In summary, Gathercole's (2006) revision of the nonword repetition hypothesis is to be welcomed. Further research directed at the development of an interactive model of vocabulary growth would be a fruitful next step in understanding the causes of language learning impairments.

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## Exploring the impact of higher level linguistic representations on nonword repetition performance

Gathercole's (2006) comprehensive and interesting Keynote Article on the nature of the relations between nonword repetition and word learning highlights the complex number of interacting factors that affect this relation through development. In this Commentary we focus on the impact of higher level cognition, particularly linguistic representations on lower level functions such as attention and processing, as well as higher level functions such as memory. In addition, we note the importance of distinguishing children with specific language impairment (SLI) who do and do not have phonological deficit when testing for memory impairments. We argue that further detailed investigations are warranted at the linguistic levels of cognitive processing *alongside* memory tasks that tap different components of language and nonlinguistic memory. Such studies would help tease apart the complex, and probably bidirectional relations between attention, memory, and linguistic representations. Moreover, we propose that this investigative strategy crucially needs to take a longitudinal developmental perspective if we are to understand the developmental trajectory.

Gathercole (2006) pertinently notes the effect of phonological representation on nonword repetition, that is, "the capacity to store nonwords is influenced by (among other things) prior factors affecting the initial construction of the phonological representation." Yet, the precise nature of this relationship has yet to be fully explored. To do this, a theoretical framework of phonology as well as memory (the latter Gathercole provides) is needed. One such phonological framework within the generative phonology tradition is "prosodic theory" (Harris, 1994). Prosodic theory can be used to understand both normal acquisition and the nature of the phonological deficits found in children with SLI. We argue that such a framework is needed if we are going to elucidate the relations between memory, phonological representations (in typical and atypical development), dependent relations between them, and their effect on nonword repetition. Empirical support for such dependency between memory and phonology and other levels of linguistic representation are evident in the literature.

The impact of higher level cognitive functions (e.g., phonology, morphology, and syntax) on memory as well as on lower level perception and attention is illustrated by the many EEG event-related potential (ERP) studies investigating the neural correlates elicited in nonattended auditory odd-ball paradigms (Näätänen et al., 1997; Pulvermuller, Shtyrov, Kujala, & Näätänen, 2004). Such tasks elicit a component known as the "mismatch-negativity" (MMN), which is a negatively going wave at around 200–250 ms after a rare (odd-ball) event. This component is considered to reflect memory traces of auditory events, and is clearly affected by the nature of the phonological, syntactic, morphological, and semantic materials. Surprisingly, in the developmental literature, relatively little attention has been paid to these findings, which illustrate the complex nature of memory.

However, more than a decade ago, van der Lely and Howard (1993), raised the possibility that the prosodic structure of the nonword could have an effect on nonword repetition in children. Van der Lely and Howard (1993) found that not all children with SLI have short-term memory problems. Investigating a group of typically developing children and children with grammatical (G-)SLI we found that when the phonological structure of the to be remembered nonwords was simple, children were able to remember as many words as their language matched peers. Thus, the prosodic structure of certain words could make them difficult to repeat.

The prosodic structure of a word has two aspects. One governs how individual consonants and vowels are grouped into syllables (syllabic structures). The other governs relations of stress prominence between neighboring syllables (metrical structure). In an attempt to understand the phonological deficit in children with SLI, we set about devising a nonword repetition procedure that would take into account the prosodic complexity of a nonword, rather than the amount or length of the to be repeated nonword. Complexity was determined through the number of "marked parameters" (syllable and/or metrical). So-called "marked parameters" are not attested in all languages, and are acquired later than unmarked parameters. This allowed us to investigate how phonological complexity influences performance using a nonword repetition task. The resulting Test of Phonological Structure (van der Lely & Harris, 1999), allows a thorough examination of phonological abilities by systematically varying the prosodic complexity of a word. The procedure consists of 96 nonwords that have been constructed using five binary phonological parameters, chosen because they establish the major typological outlines of syllable and metrical structure in English.

In a recent study (Gallon, Harris, & van der Lely, 2006) a group of participants with G-SLI (ages 12–20 years) and two groups of typically developing children (ages 4–8 years) were studied. Our results revealed a significant difference in the pattern of performance for children with G-SLI compared to typically developing younger children. We also found that the prosodic complexity of a word impacts on performance: the greater the number of marked prosodic structures, the greater the decrease in performance. This effect was apparent even on monosyllabic and disyllabic nonwords. Of particular note is that unfooted (unstressed) syllables at the metrical level cause problems for the children at the syllable level of the prosodic hierarchy, even in these short disyllabic words (Gallon et al., 2006; Gallon et al., 2006; Marshall, Ebbels, Harris, & van der Lely, 2002).

Our finding reveal that although short-term memory is likely to affect nonword repetition accuracy it cannot provide a full account of the performance we saw in these one and two syllable nonwords. These nonwords should not present a problem in terms of repetition accuracy but yet when we increased the prosodic complexity either through the marked syllabic structure or metrical stress pattern, performance for the participants with G-SLI deteriorated.

In addition to the impact of phonological structure, morphology can also be seen to impact on the repetition of nonwords in the tasks carried out by Gathercole and colleagues. Archibald and Gathercole (2006) report performance on nonword repetition in comparison to that of serial recall using the same phonological segments. In the nonword repetition task the nonword, for example, *feimoychee* has to be repeated, although in the serial recall task the nonword is broken into monosyllabic nonwords, and these have to be repeated: *fei*... *moy*... *chee*. Note that each syllable was stressed in both tasks. Archibald and Gathercole found a difference in performance between the two tasks with the nonword repetition task being harder. This led the authors to conclude that an "unidentified skill" specific to nonword repetition is involved. We propose that rather than their being an "unidentified skill" involved, the prosodic nature of the two tasks differ and can perhaps explain their results. Phonologically, such words could have a prosodic hierarchical structure with three, footed syllables, all with strong stress within one word. Whereas stressed monosyllabic (one footed syllable) words are frequently found in English (*dog, cat, bee)*, stressed three-syllable words would be highly unusual and, indeed, rare. Thus, repeating such a nonword would be more akin to repeating a morphological compound such as, "*nap*" *kin*-"*ring*," "*wal*" *nut*-"*tree*," or "*pho*" *to*-"*frame*." Thus, based on a typology of SLI, whereby different deficits in the components of language (e.g., syntax, morphology, phonology, lexicon) in different children determine the nature of the deficit (van der Lely, 2005), this leads to the prediction that for those children with morphological deficit, such nonwords would be particularly problematic to repeat. It is of note also that nonwords in the Children's Test of Nonword Repetition also contain derivational and morphological forms (-er, -ity, -ic, -ing). Once again, we would predict that nonwords containing such morphological forms would disadvantage any child with morphological deficit in comparison to typically developing children.

In sum, we consider that it is vitally important to take into account, control, and/or manipulate the prosodic complexity, as well as other levels of linguistic representations, that might be tapped when designing materials in nonword repetition tasks. Incorporating these factors into nonword repetition procedures would facilitate our understanding of memory and the acquisition of language components and their interrelations through development. Furthermore, it would help us identify and distinguish children with memory deficits from those with deficits in language components. Such differential diagnosis is crucial to further our understanding of SLI and provide appropriate remediation for their deficits.

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## Manipulating the characteristics of words and nonwords to better understand word learning

The work of Susan Gathercole and others on nonword repetition has increased general interest in the relationship between memory and language, and has provided a fertile theoretical framework for researchers to explore how the language system makes use of the phonological loop, a component in Baddeley's (1986) working memory model. Gathercole (2006) integrated a number of findings from a variety of research methodologies and populations to support this theoretical framework. She also discussed how this framework might be applied to increase our understanding of language disorders characterized by word learning problems. Synthesizing the findings from many and diverse areas of study to formulate a coherent theory is a challenge, but this challenge must be undertaken if we hope to significantly advance our understanding of human behavior, including the differences in processing that are found across the life span and across individuals. I admire Gathercole for undertaking this challenge (and the additional challenge of applying the theory to language disorders) in the area of word learning.

I also wholeheartedly agree with Gathercole (2006) regarding the value of using a variety of research methodologies to identify phenomena that are worthy of further exploration, and the strength of experimental manipulation to determine the underlying causal relationships among relevant variables. Future research involving the manipulation of several key variables, such as phonotactic probability and neighborhood density, could significantly advance our understanding of word learning, as well as provide insight into the relationship between word learning and other linguistic processes, such as the production and recognition of spoken words.

*Phonotactic probability* refers to the frequency with which phonological segments or sequences of segments occur in the language (Vitevitch, Luce, Charles-Luce, & Kemmerer, 1997). Certain segments, such as word initial /s/, and sequences of segments, such as /s^/, are more common than other segments, such as word initial /j/, and sequences of segments, such as /ji/. See Vitevitch and Luce (2004) for information on how to obtain phonotactic probability values based on American English pronunciations. *Neighborhood density* refers to the number of words that sound like a given word; these similar sounding words are called neighbors. One way to estimate the number of neighbors a word has is to add, subtract, or substitute a single phoneme in that word (Landauer & Streeter, 1973; Luce & Pisoni, 1998). For example, adding, subtracting, or substituting a single phoneme in the word *cat* yields as neighbors the words *scat, at, hat, kit*, and *cab* (note, *cat* has other neighbors, but only a few were listed for illustration). Words that have many neighbors are said to have a dense neighborhood, whereas words that have few neighbors are said to have a sparse neighborhood.

A number of studies have examined the influence of phonotactic probability and neighborhood density on spoken word recognition in adults, and have yielded important insights about the use of lexical and sublexical representations in spoken word recognition (Vitevitch & Luce, 1998, 1999, 2005; see also Pitt & Samuel, 1995). Lexical representations correspond to whole word forms, whereas sublexical representations correspond to parts of words, such as phonological segments or sequences of segments. When lexical representations are used to process spoken stimuli, effects of neighborhood density are observed such that sparse items are responded to more quickly than dense items. When sublexical representations are used to process spoken stimuli, effects of phonotactic probability are observed, such that high probability items are responded to more quickly than low probability items.

In tasks that do not require lexical representations to be accessed for accurate performance, such as auditory shadowing (also called nonword repetition) and same–different matching, sublexical representations can be used to process spoken stimuli. For example, Vitevitch and Luce (1998, 1999, 2005) found that high probability/dense nonwords were responded to more quickly than low probability/sparse nonwords in auditory shadowing and same–different matching tasks, suggesting the use of sublexical representations in processing. Although lexical representations are typically used to process real words (see the results of the real words in Vitevitch & Luce, 1998, 1999, in those same tasks), sublexical representations can be used in certain circumstances to process real words in English, resulting in high probability/dense words being responded to more quickly than low probability/sparse words (Vitevitch, 2003).

In tasks that require lexical representations to be accessed for accurate performance, such as lexical decision, lexical representations are used to process spoken stimuli. As is typical for real words, but interestingly, for nonwords as well, in a lexical decision task, high probability/dense items were responded to more slowly than low probability/sparse items (Vitevitch & Luce, 1999; see also Luce & Pisoni, 1998). The manipulation of phonotactic probability/neighborhood density, lexicality, and task demand in these experiments show that there are two types of representation with different processes operating on them being used to recognize spoken items.

However, spoken word recognition is not the only linguistic process influenced by phonotactic probability and neighborhood density. Storkel (2001, 2003; Storkel & Rogers, 2000) found that these variables also influence word learning in children. After multiple presentations of a novel referent and a novel word form, children in these studies demonstrated in a number of tasks (and even after a delay of 1 week) that they had learned high probability/dense novel words more rapidly than low probability/sparse novel words, suggesting that phonotactic probability influenced the formation of semantic representations and the association between semantic and lexical representations, key components of word learning.

Using a similar task with nonwords varying in phonotactic probability, Storkel (2004) found that normal children were able to capitalize on the phonological similarity of some novel words to known words by learning high probability/dense novel words more rapidly than low probability/sparse novel words, whereas children with phonological delays tended to learn novel words that were dissimilar to other words, suggesting that children with phonological delays may have difficulty processing or resolving among phonologically similar words. Testing children that are normally developing or that have language delays in experiments that manipulate phonotactic probability/neighborhood density may help us better understand the process of word learning as well as the nature of various language disorders.

It is important to note, however, that there is a positive correlation between neighborhood density and phonotactic probability (Vitevitch, Luce, Pisoni, & Auer, 1999). Although most studies compared stimuli that were high in phonotactic probability *and* had dense neighborhoods to stimuli that were low in phonotactic probability *and* had sparse neighborhoods (e.g., Vitevitch & Luce, 1998), it is possible to manipulate one variable while controlling the other, or to orthogonally manipulate both variables (e.g., Luce & Large, 2001; Vitevitch, Armbruster, & Chu, 2004). Studies of spoken word recognition and production that have separated the influence of neighborhood density and phonotactic probability have helped us better understand the unique contribution of lexical and sublexical representations to various language processes. By manipulating both of these variables, future studies of word learning might better determine the unique role that each variable plays in learning novel word forms (e.g., Gathercole, Frankish, Pickering, & Peaker, 1999; Roodenrys & Hinton, 2002; Storkel, Armbruster, & Hogan, in press; Thorn & Frankish, 2005). Furthermore, such studies might help us better understand what contributes to poor word learning in children with language impairments, and may lead to improved tools for diagnostics and treatment.

The work of Gathercole and others has done much to advance our understanding of word learning, but there is still much about the process of word learning in normal and clinical populations that we do not understand. As Gathercole (2006) suggests, the experimental manipulation of certain variables can further advance our understanding of the word learning process. Future work that capitalizes on the manipulation of tasks and key variables has the potential to not only increase our understanding of the word learning process, but to greatly improve our models and theories of word learning and related language processes.

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