The Influence of Vocabulary Size, Phonotactic Probability, and Wordlikeness on Nonword Repetitions of Children With and Without Specific Language Impairment

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Research has shown that children repeat high-probability phoneme sequences more accurately than low-probability ones. This effect attenuates with age, and its decrease is predicted by developmental changes in the size of the lexicon (J. Edwards, M. E. Beckman, & B. Munson, 2004; B. Munson, 2001; B. Munson, J. Edwards, & M. Beckman, 2005). This study expands on these findings by examining relationships between vocabulary size and repetition accuracy of nonwords varying in phonotactic probability by 16 children with specific language impairment (SLI), 16 chronological-age-matched (CA) peers with typical speech and language development, and 16 younger children matched with the children with SLI on vocabulary size (VS). As in previous research, children with SLI repeated nonwords less accurately than did CA children. The children with SLI and the VS children showed similar levels of nonword repetition accuracy. Phonotactic probability affected repetition accuracy more for children with SLI and VS children than for CA children. Regression analyses showed that measures of vocabulary size were the best predictor of the difference in repetition accuracy between high- and low-probability sequences. Analyses by items showed that measures of phonotactic probability were stronger predictors of repetition accuracy than judgments of wordlikeness. Taken together, the results support research demonstrating that vocabulary size mediates the influence of phonotactic probability on nonword repetition, perhaps due to its influence on the ongoing refinement of phonological categories.

KEY WORDS: language impairment, school-age children, nonword repetition, phonotactic probability, vocabulary size

In a nonword repetition task, a person listens to an unfamiliar string of phonemes and repeats it. While superficially a simple task, nonword repetition relies on a number of cognitive processes, such as perceiving and discriminating the acoustic signal, matching the signal with phonological representations in memory, planning the articulatory movements required to replicate the nonword, and executing the response. Nonword repetition accuracy increases during typical development. A number of studies by Gathercole and colleagues have shown that younger children repeat nonwords less accurately than do older children and adults (e.g., Gathercole & Baddeley, 1989a, 1989b). Munson (2001) extended this work by showing that younger children repeat nonwords less accurately and with longer and more variable durations than older children or adults. More recently, Edwards, Beckman, and Munson (2004) replicated Munson's finding with a large (n = 126) cohort of children between the ages of 3 and 8 years and adults. The purpose of the current study is to extend this line of research by examining factors that influence nonword repetition in older, school-age children with typical language development and with specific language impairment (SLI).

Phonotactic Probability and Vocabulary Size in Children and Adults

A parallel line of research has investigated developmental changes in the influence of phonotactic probability on the accuracy and duration of repetition of sequences of phonemes embedded in nonwords. Phonotactic probability is a measure of the frequency with which a sequence of phonemes occurs in the lexicon of a language; it is typically expressed as the probability that a word in the language contains a particular sequence of phonemes. High-probability sequences of phonemes are sequences that occur in many real words. For example, the sequence /ft/ occurs in many real words, including *after, fifty,* and *fifteen*. The phonetically very similar sequence /fk/ occurs in no monomorphemic words of English, with the exception of some foreign names (i.e., *Kafka, Zifko*). Phonotactic probability affects the extent to which participants are able to use lexical knowledge during nonword repetition. Consider the task of repeating a four-syllable nonword containing only high-probability phoneme sequences, such as /hɪsəsanət/. When repeating this nonword, a child can use subparts of phonological representations of lexical items in memory: The sequence /hɪ/ occurs in *hit, his,* and *him*; the sequence /ɪs/ occurs in *hiss, miss,* and *kiss*; the sequence /sə/ occurs in *suppose and support*; and so on. Compare this with the processes used to repeat the low-probability four-syllable nonword /gujæðəʃ/. The sequences that make up that nonword occur in considerably fewer real words of English (i.e., /jæ/, which occurs in some low-frequency words like *yak*); consequently, children are able to apply considerably less lexical knowledge when repeating this item. Instead, they must combine representations of phonemes to repeat this item accurately.

The impact of phonotactic probability on phonological processing has been shown in a variety of studies using different tasks and participants of different ages. Vitevitch and Luce (1999) showed that adults repeat high-probability nonwords more quickly and more accurately than low-probability nonwords. Frisch, Large, and Pisoni (2000) showed that adults rate high-probability nonwords as more like real English words than low-probability nonwords. Moreover, Frisch et al. (2000) showed that adults have better recognition memory for high-probability nonwords than for low-probability ones.

The results of these studies have been used to argue for a model of phonological development and adult phonological competence in which abstract phonological knowledge arises from generalizations made over the lexicon (for a full discussion of these models, see Beckman, Munson, & Edwards, in press, and Pierrehumbert, 2003). In particular, these models posit that children's ability to represent phonological units separately from the words in which they occur emerges as a consequence of word learning: As children's vocabularies grow, their representations of phonemes become increasing more autonomous from their lexical representations. Children with more robustly abstracted phonological units are better able to combine them into novel sequences than children with less robustly abstracted units. The relationship between phonology and the lexicon continues to hold in adults, as shown by the lasting influence of phonotactic probability on adults' processing of nonwords.

Previous investigations showed that the influence of phonotactic probability on nonword repetition accuracy decreases with age. Munson (2001) studied the effects of phonotactic probability on nonword repetition in adults and in two groups of typically developing (TD) children, age 3–4 and 7–8 years. Stimuli were CVCCVC nonwords containing either high-probability CC sequences (e.g., /ft/, /kt/, and /sp/) or low-probability CC sequences (e.g., the phonetically similar sequences /fk/, /pt/, and /ʃp/). While adults were able to repeat both high- and low-probability sequences equally accurately and fluently (where fluency was operationalized as sequence duration), both groups of children repeated low-probability sequences less accurately and less fluently than high-probability sequences. A larger effect size was noted in the younger group of children. All three groups of participants produced low-probability sequences with more variable durations than the high-probability sequences.

Munson (2001) hypothesized that developmental changes in vocabulary size caused the developmental decline in the effect of phonotactic probability on nonword repetition. The relationship between vocabulary size and performance on the nonword repetition task was examined directly by Edwards et al. (2004). Edwards et al. (2004) examined nonword repetition by three groups of children (3-4-year-olds, 5–6-year-olds, and 7–8-year-olds) and adults. Participants repeated 44 nonwords. The nonwords were grouped into 22 pairs of nonwords that contrasted in the phonotactic probability of a target two-phoneme CV, CC, or VC sequence. For example, the high-probability sequence /ik/ (which occurs in words like *week, Greek,* and *seek*) in the nonword [ikbəni] was matched with the low-probability sequence /aʊk/ (which occurs in no words of English) in the nonword /aʊkpəder/. Accuracy of repetition of the target two-phoneme sequences was measured. As in Munson, analyses of variance (ANOVAs) found that the effect of phonotactic probability on nonword repetition declined with age. A second set of analyses used hierarchical multiple regression to examine predictors of overall nonword repetition accuracy, as well as predictors of the difference in accuracy between high- and low-probability sequences, which Edwards et al. termed the *frequency* effect. The independent variables in these regressions were two measures of vocabulary size (raw scores on the Peabody Picture Vocabulary Test—III [PPVT–III]; Dunn & Dunn, 1997, and the Expressive Vocabulary Test [EVT]; Williams, 1997) and age. These analyses found that vocabulary size accounted for a significant proportion of variance in the frequency effect. This was true even when the effects of age were controlled by forcing it as the first variable in the regression. Raw score on the PPVT accounted for 9.9% of the variance beyond what was accounted for by age, and EVT accounted for 10.1% of the variance beyond that accounted for by age.

The conjecture that phonological development involves a series of progressive generalizations over known lexical items is supported by other studies using a variety of different experimental methodologies. For example, Storkel (2002) examined a similar question in a study in which children provided metalinguistic judgments of the similarity of pairs of words. She found that children showed better sensitivity to fine phonetic structure for words that were phonetically similar to many other real words in the lexicon. This finding suggested that children's knowledge of the phonological structure of words is related to the structure and growth of the lexicon itself. Gathercole, Frankish, Pickering, and Peaker (1998) showed that children's serial recall of high-probability nonwords exceeded that of low-probability nonwords. This finding showed that phonotactic probability affects children's ability to encode and recall nonwords in online memory tasks. Metsala and Walley (1998) reviewed findings from a variety of studies providing support for the notion that phonological development was related to a developmental restructuring of the mental lexicon along lines of phonological similarity.

Phonotactic Probability and Vocabulary Size in Atypical Language Development

Recently, Munson, Edwards, and Beckman (2005) examined the relationship between the frequency effect and a wide range of predictor measures in a group of 40 children between the ages of 3 and 6 years with phonological disorder (PD; i.e., children who make many speech-sound errors in the absence of any obvious medical etiology) and 40 chronological-age-matched (CA) children with typical phonological development. Munson et al. hypothesized that the speech-production deficit in children with PD might be related to a particular difficulty in abstracting phonological units from lexical items. If this were the case, then children with PD should show a larger effect of phonotactic probability on nonword repetition than CA peers with typical phonological development and similar-size lexicons. That is, it was hypothesized that the more poorly specified phonological representations of children with PD would hinder their ability to combine sounds into sequences unattested in the lexicon. The children with PD in Munson et al. did not demonstrate broader language impairment: All of them received a standard score of at least 85 on the PPVT–III and the EVT. Munson et al.'s hypothesis was not supported: The children with PD did not show a larger frequency effect on nonword repetition than their CA peers.

As in earlier research, multiple regression analyses were used to examine predictors of the frequency effect. Predictor measures included the PPVT–III, the EVT, two measures of phoneme-production accuracy in real words (raw scores on the Goldman Fristoe Test of Articulation—Second Edition [GFTA–2]; Goldman & Fristoe, 2000, and raw scores on a nonstandardized phonetic inventory probe); a measure of speech perception (raw scores on a discrimination task described in Edwards, Fox, & Rogers, 2002); a measure of nonverbal IQ (standard scores on the Columbia Mental Maturity Scale [CMMS]; Burgemeister, Blum, & Lorge, 1972); and age. Average nonword repetition accuracy was predicted by almost all of the dependent measures. However, the frequency effect was predicted only by the measures of vocabulary size and by age. As in Edwards et al., vocabulary-size predictors were significant even when age was forced first in the regression, with EVT raw scores accounting for 22.1% of the variance in the TD children, and 9.8% of the variance in the children with PD. Thus, Munson et al. demonstrated that the influence of phonotactic probability on the nonword repetitions of children with PD was similar to its influence on children with TD. Moreover, the same measures predicted the magnitude of the phonotactic probability effect in both groups.

Nonword Repetition in Children With Specific Language Impairment

The purpose of the present study is to extend this line of research further by examining the influence of phonotactic probability on nonword repetition in children with SLI. Children with SLI are diagnosed with a battery of tests that typically includes one or more measures of vocabulary size; thus, it is common for children with SLI to have smaller lexicons than TD same-age peers. It is for this reason that this population can provide potentially interesting data on the role of vocabulary size in mediating the effect of phonotactic probability on nonword repetition.

Measures of nonword repetition accuracy have been found to distinguish between TD children and children with SLI. Edwards and Lahey (1998) examined nonword repetition in children with SLI and in TD children. A detailed analysis of error patterns suggested that the nonword repetition deficits of children with SLI stemmed from difficulties creating phonological representations rather than deficits in speech perception or production. Dollaghan and Campbell (1998) found that children receiving services for language impairment repeated nonwords less accurately than TD children only when the words were three syllables or longer. Ellis Weismer et al. (2000) replicated Dollaghan and Campbell's finding with a much larger group of children. More recently, Botting and Conti-Ramsden (2001) showed that nonword repetition was related to measures of more complex grammatical abilities in school-age children with SLI. Nonword repetition abilities have significant diagnostic potential. Conti-Ramsden, Botting, and Faragher (2001) found that nonword repetition accuracy discriminated between school-age children with SLI and age-matched peers with normal language. Conti-Ramsden (2003) replicated this result with younger children and showed that this measure had diagnostic sensitivity that was comparable to a measure of grammatical ability, past-tense production. Bishop, North, and Donlan (1996) showed that nonword repetition continues to be impaired in children with SLI even after they have received successful intervention services.

The reasons for the poor nonword repetition seen in children with SLI are the subject of much debate. Some researchers (e.g., Gathercole & Baddeley, 1990) argue that they indicate a primary deficit in phonological working memory that underlies language impairment. Others (e.g., Edwards & Lahey, 1998, Snowling, Chiat, & Hulme, 1991) have argued that nonword repetition deficits are related to a deficit in specifically linguistic skills. That is, the nonword repetition difficulties may be due to the poorer ability of children with SLI to create sufficiently rich, abstract, and context-neutral phonological representations to support repetition of an unfamiliar string.

Phonotactic Probability and Wordlikeness

Some studies on the relationships between lexical knowledge and nonword repetition have used stimuli that vary in wordlikeness. Broadly defined, wordlikeness is a measure of how much a nonword stimulus is like a real word. There are two general methodologies for creating stimuli that vary in wordlikeness. One is to elicit metaphonological judgments of the wordlikeness of novel forms and to use average judgments as an index of the proximity of a nonword stimulus to the lexicon. Another method is to create stimuli that vary in whether the subparts constituting them are attested real words. Nonwords whose subparts constitute real words are presumed to be more wordlike that those whose subparts are unattested in the lexicon. Studies have found that more wordlike nonwords are repeated more accurately than less wordlike ones (Dollaghan, Biber, & Campbell, 1995; Gathercole, 1995).

Numerous investigations have shown that wordlikeness is related to phonotactic probability (Bailey & Hahn, 2001; Frisch et al., 2000; Hay, Pierrehumbert, & Beckman, 2004; Munson, 2001): Nonwords whose subparts are attested in more lexical items are rated as more wordlike than those with sequences that are infrequent or unattested. That is, people's metaphonological judgments draw on their knowledge of distributional properties of sounds in the lexicon. To date, no study has examined the relative power of phonotactic probability and wordlikeness to predict nonword repetition accuracy. An ancillary goal of this study is to use regression analyses by items to examine predictors of average nonword repetition accuracy to determine whether phonotactic probability influences nonword repetition beyond the influence of wordlikeness on nonword repetition.

Experimental Questions

This article examines the repetition of high- and low-probability nonwords in three groups of children to further understand relationships among vocabulary size, phonotactic probability, and nonword repetition. The first group consists of children with SLI between the ages of 8 and 13 years. The second group is CA children with typical language achievement. The children with SLI that we examine in this article were identified by means of a standardized language test (the Clinical Evaluation of Language Fundamentals—Third Edition [CELF–3]; Semel, Wiig, & Secord, 1997) that correlates highly with measures of vocabulary size. For example, the technical manual for the

Expressive One-Word Picture Vocabulary Test ([EOWPVT]; Gardiner, 2000) reports that there are modest, statistically significant correlations between CLEF–3 and EOWPVT standard scores. Consequently, the children with SLI in this study were expected to have smaller vocabularies than CA children. The comparison between these two groups allows us to examine the influence of vocabulary size on phonotactic probability effects in nonword repetition while controlling for age. The third group of participants consists of younger, typically achieving children who are matched in vocabulary size to the older children with SLI (VS children). These children are between the ages of 6 and 10 years. Comparison between this group and the children with SLI allows us to examine the influence of age on phonotactic probability effects controlling for vocabulary size.

Comparison of the CA and VS groups allows us to compare the results of this experiment with the work of Edwards et al. (2004) and Munson et al. (2005) on younger children. Previous studies have examined children between the ages of 3 and 8 years. It may be that the role of vocabulary size in mediating the relationship between phonotactic probability and nonword repetition is seen only in early development. That is, there may be an asymptotic relationship between vocabulary development and the development of phonological units. Once phonological units have been robustly abstracted from the words in which they occur, the statistical relationship between vocabulary size and phonotactic-probability effects disappears. Alternatively, this effect may persist later in development. That is, the vocabulary expansion that happens in the age range we examine in this study (6–13 years) may continue to influence the robustness with which children's phonological representations are abstracted from the words in which they occur. This continuing refinement would be reflected in the difference in repetition accuracy between high- and low-probability nonwords.

This study makes two predictions. First, we hypothesize that the children with SLI will show a larger frequency effect on nonword repetition than the CA children. That is, we hypothesize that the children with SLI, like the younger, TD children examined by Edwards et al. (2004) and Munson et al. (2005), will show evidence of less robustly abstracted phonological representations than their CA peers. Moreover, we predict that the best predictor of the size of the frequency effect in children with SLI and CA children will be measures of vocabulary size.

The second prediction concerns the size of the frequency effect in the SLI and VS groups. Based on the findings of Edwards et al. (2004) and Munson et al. (2005), we would predict that children with SLI should not differ from VS children in the size of the frequency effect, because they have similar-size vocabularies. However, there is an alternative prediction, namely, that the children with SLI will show a larger frequency effect than VS children. This prediction would follow if we assumed that SLI were associated with a particular difficulty in making generalizations over lexical items. That is, if one of the problems with SLI were a unique difficulty in making phonological generalizations, then we expect that children with SLI would have less robust phonological representations than a younger, TD child with an equivalent-size lexicon. This difficulty in making generalizations would lead to a reduced ability to reproduce low-probability sequences of phonemes and, consequently, a bigger difference in repetition accuracy between high- and low-probability sequences than VS children.

In addition to these two predictions, this study has an exploratory component. The stimuli used in this study varied in both phonotactic probability and wordlikeness. As in other studies, these variables were correlated, so it was impossible to create a set of stimuli that varied orthogonally in wordlikeness and phonotactic probability. Because of this, any group differences as a function of phonotactic probability may be attributable to the influence of that variable on wordlikeness. However, we are able to exploit the imperfect correlation between wordlikeness and phonotactic probability in an analysis by items. This analysis allows us to determine the relative contribution of wordlikeness and phonotactic probability on nonword repetition accuracy.

Method

Participants

Forty-eight children (16 children with SLI, 16 CA peers, and 16 younger, VS peers) participated in this study. The CA children and the children with SLI participated in a larger study on cognitive–linguistic processing. They are a subset of the children described in greater detail in Kohnert and Windsor (2004) and Windsor and Kohnert (2004).[1] In those publications,

[1]Other research on this cohort of children (Kohnert & Windsor, 2004; Windsor & Kohnert, 2004) referred to them as having *primary language impairment (PLI)* because their observed language difficulties were not secondary to more general cognitive, psychosocial, or medical problems. We use the term *SLI* in this article to facilitate comparison with previous research on this topic. However, we believe that the term *PLI* is more descriptively adequate, given the robust finding that children identified with SLI show deficits in a variety of nonverbal cognitive and perceptual–motor tasks that do not tap linguistic knowledge (e.g., Windsor, Milbrath, Carney, & Rakowski, 2001).

Table 1. Demographic data for SLI, CA, and VS children.

	SLI		CA		VS	
	M	*SD*	*M*	*SD*	*M*	*SD*
% girls	50		38		63	
Age (months)	135	17	134	18	90	16
CELF–3[a] standard score	75	10	109	11	114	17
IQ standard score[b]	95	7	106	9	109	14
EOWPVT[c] raw score	92	15	115	15	95	13
PPVT–III[d] raw score	128	18	153	19	118	18

Note. SLI = specific language impairment; CA = chronological age matched; VS = vocabulary-size matched. Standard scores have a mean of 100 and a standard deviation of 15.

[a]Clinical Evaluation of Language Fundamentals, Third Edition (Semel, Wiig, & Secord, 1997). [b]Either the Test of Nonverbal Intelligence, Third Edition (Brown, Sherbenou, & Johnsen, 1997) or the Matrices portion of the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 1990). [c]Expressive One-Word Picture Vocabulary Test (Gardiner, 2000), [d]Peabody Picture Vocabulary Test—III (Dunn & Dunn, 1997).

the children referred to as *CA* in this study were called *EO* because they were monolingual, English-only speakers. Demographic information for the participants can be found in Table 1. Children with SLI (mean age = 11 years 3 months) were identified by having scored at least 1 standard deviation or below on either the Receptive or Expressive subtests of the CELF–3 and scores on a measure of nonverbal IQ, the Test of Nonverbal Intelligence—3 (TONI–3; Brown, Sherbenou, & Johnsen, 1997), at or above 85. All of the SLI children had a history of receiving special education services. Children also completed two measures of vocabulary knowledge, the PPVT–III and the EOWPVT. The 16 CA children (mean age = 11 years 2 months) were matched individually by chronological age with the children with SLI within 3 months. The CA children all scored within normal limits on the EOWPVT, PPVT–III, TONI–3, and CELF–3. SLI and CA children produced no phoneme errors on the GFTA–2.

The 16 younger, VS-matched children (mean age = 7 years 6 months) were matched to the children with SLI based on raw scores on the EOWPVT. We chose the EOWPVT (rather than the PPVT–III) because of previous research showing that expressive vocabulary is a stronger predictor of developmental changes in linguistic abilities than receptive vocabulary (i.e., Marchman & Bates, 1994). These children were matched individually with children with SLI based on raw scores on the EOWPVT, within 7 points. The average difference was 3 points. One of the children in the VS group had received speech–language services for a derhotacized /r/ pronunciation. This child was included because of research demonstrating that children with residual articulation errors (i.e., distortions of /s/ and /r/) do not differ in their long-term academic and social outcomes from children without a history of such errors (Lewis & Freebairn, 1992). The Matrices section of the Kaufman Brief Intelligence Test (K–BIT; Kaufman & Kaufman, 1990) was used to measure nonverbal IQ in the VS children. Results from the CELF–3, the PPVT–III, the EOWPVT, and the K–BIT confirmed that none of the VS children included in the study presented with a language impairment or broader cognitive impairment, as defined by performance at or below 1 standard deviation below the mean on any of these tests. Children in all three groups passed a hearing screening.

A single-factor multivariate analysis of variance (MANOVA) was used to examine group differences in the demographic measures in Table 1, with group (SLI vs. CA vs. VS) as the between-subjects factor. As expected, significant post hoc differences between children with CA and SLI, and between children with SLI and VS, were found for all standardized language measures. No significant post hoc differences were found between CA and VS children for any of these measures. Significant post hoc differences were found between CA and SLI children, and between VS and CA children, for the two raw measures of vocabulary size.

Stimuli

A nonword repetition task was administered in which children repeated 20 nonwords taken from Frisch et al. (2000). These are shown in Table 2. The stimuli that were chosen were either three or four syllables long, because of Dollaghan and Campbell's (1998) finding that the greatest difference in repetition accuracy between children with SLI and CA peers was for nonwords of that length. All of the three-syllable words had a CVCVCVC word shape; all of the four-syllable words had a CVCVCVCVC word shape. The three-syllable words had stress on the first syllable; the four-syllable nonwords had primary stress on the third syllable and secondary stress on the first syllable. An additional 10 filler items were included in this experiment. These included both high- and low-probability nonwords.

The nonwords contained either high- or low-probability diphone sequences, as determined by their frequency in an online dictionary of English, the *Hoosier Mental Lexicon* (*HML;* Pisoni, Nusbaum, Luce, & Slowiacek, 1985). Ten of the nonwords consisted of high-probability phoneme sequences, and the other 10 consisted of low-probability phoneme sequences. Note that the nonwords in this study differed from those in our earlier work on phonotactic probability and

Table 2. Nonword stimuli.

Three syllable						Four syllable					
High probability			Low probability			High probability			Low probability		
Stimulus	EP	WL	Stimulus	EP	WL	Stimulus	EP	WL	Stimulus	EP	WL
hesɚləm	−7.7	3.50	zʊweðʊs	−16.7	1.88	hesəsanət	−9.5	3.13	zʊfetʃoʊθɛd	−19.4	1.63
mesɚʃem	−7.5	3.25	gufegɛd	−13.4	2.00	kisɚtaləm	−9.9	2.92	vufætʃɝʒəʃ	−17.2	1.83
sæsənəm	−6.8	4.42	jɔɪfegʊʃ	−14.9	1.92	sisɚtaləp	−11.0	3.21	jɔɪwɛʃɝʒɔɪl	−20.1	1.46
hæsələp	−8.0	3.58	vufɛgəɪl	−13.1	1.96	kɪsəsaʃəm	−9.2	1.63	gufɛʃɝgʊs	−16.8	1.67
kesənən	−6.2	4.71	gujæðəʃ	−14.0	1.88	mæsɚtalən	−8.8	4.75	zɔɪwætʃɝʒɛð	−20.5	1.42

Note. EP = expected probability; WL = wordlikeness on a 7-point scale, where 7 represents *highly wordlike*. See Frisch et al. (2000) for a discussion of EP and WL measures.

nonword repetition in one key way. Earlier studies used pairs of nonwords contrasting in the phonotactic probability of a single diphone sequence within the stimulus (i.e., [mofkən] and [kiften], which contrast the low-probability sequence /fk/ with the high-probability sequence /ft/). The remaining diphones in those stimuli were uniformly high in phonotactic probability. Consequently, the low-probability stimuli in the earlier experiments were less difficult to repeat than those used in the current experiment, in which all of the diphone sequences in a stimulus were low in probability. The choice to use stimuli with overall high- and low-probability sequences in this study was motivated by our desire to avoid ceiling performance on both sequence types. That is, the task of repeating a single low-probability sequence embedded in a nonword may not be sufficiently taxing to reveal an effect of phonotactic probability on performance in the age range examined in this study. The task of repeating a nonword containing 8 low-probability sequences (as with our four-syllable low-probability nonwords) is considerably more taxing, and performance on such a task is not as likely to be subject to ceiling effects as would be accuracy in repeating a single low-probability sequence.

Detailed information about the calculations of phonotactic probability for the stimuli used in this study can be found in Frisch et al. (2000). Briefly, Frisch et al. counted the number of words in the *HML* that contained each of the diphone sequences constituting the nonword in the same prosodic position. Each of these diphones was then expressed as a probability that a word would contain that sequence. The phonotactic probability of the entire nonword was expressed as the sum of the log-transformed diphone probabilities. Frisch et al. called these the *expected probabilities* (EP) of the nonwords; they are presented in Table 2. Frisch et al. gathered wordlikeness judgments for these stimuli from adults with normal speech, language, and hearing. Full details about the collection procedures can be found in Frisch et al. (2000). Frisch et al. found strong nonlinear relationships between EP and wordlikeness. This nonlinear relationship held for the 20 stimuli in this study. A polynomial regression equation of the form Wordlikeness = $(-1.4 * \text{EP}^2) + (11.91 * \text{EP}) - 32.57$ had an R^2 value of 0.78; the regression was highly significant, $F(2, 17) = 29.8$, $p < .01$.

Prerecorded production prompts were used to elicit nonword repetitions. A phonetically trained female speaker of English recorded the words using their narrow phonetic transcription and prompts from the first author as a guide. These were recorded at a sampling rate of 44.1 kHz, with 16-bit quantization. During the experiment, the stimuli were played at a comfortable listening level from the hard drive of a portable laptop computer or from a CD player, through headphones. The children's responses were recorded for later analysis. Stimulus order was pseudorandomized and maintained across participants.

Children's nonword repetitions were transcribed phonetically from their recorded productions using a careful, broad phonetic transcription. A second coder retranscribed 5 of the 20 nonwords from each participant (16.6% of the productions) for reliability; there was 92.4% agreement, measured as the quotient of the number of phonemes transcribed similarly divided by the total number of phonemes transcribed. Each child's average nonword repetition accuracy, measured by percentage phonemes correctly repeated (PPC), was calculated separately in high- and low-probability three- and four-syllable words. These percentages were then arcsine-transformed before completing statistical analyses, to control the error variance.

Results

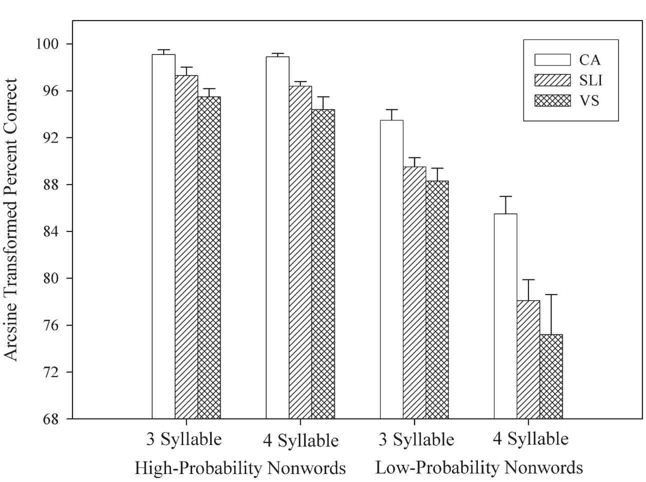
Two sets of analyses were done. The first set used ANOVA to examine group differences in nonword repetition accuracy. In the second set of analyses, regression was used to examine predictors of the frequency effect. As in Edwards et al. (2004) and Munson et al. (2005), the frequency effect was measured as the difference in repetition accuracy between the high- and low-probability nonwords. This section also examined the relative strength of phonotactic probability and wordlikeness in predicting nonword repetition accuracy.

Analysis of Variance

Figure 1 shows average arcsine-transformed PPC scores for the three groups of children in the four conditions. Average performance differed as a function of group, length, and probability. Multiple Kolmogorov–Smirnoff tests of normality were used to determine whether the data met the normality assumptions required to use fully factorial ANOVA. None of the 12 tests (2 lengths × 2 probability × 3 groups) achieved significance, even for the condition in which the highest mean performance was noted (CA children's repetition of three-syllable high-probability nonwords).

Fully factorial ANOVA was used to examine the influence of group, stimulus length, and phonotactic probability on nonword repetition. A three-factor mixed-model ANOVA was used, with group as the between-subjects factor and length and probability as the within-subjects factors. A significant main effect of length was found, $F(1, 45) = 65.9$, $p < .001$, partial $\eta^2 = .59$. Averaged across groups, four-syllable nonwords were repeated less accurately than three-syllable nonwords. A main effect of probability was also found, $F(1, 45) = 281.8$, $p < .001$, partial $\eta^2 = .86$. Averaged across groups, the nonwords containing high-frequency phoneme sequences were repeated more accurately than those containing low-frequency sequences. Finally, a significant main effect of group was found, $F(2, 45) = 10.1$, $p < .001$, partial $\eta^2 = .31$. Averaged across stimulus types, the CA children performed better than the VS and SLI children on the nonword repetition task. Post hoc Scheffé tests indicated that the SLI and VS groups did not differ in overall repetition accuracy.

Figure 1. Average nonword repetition accuracy (+ 1 *SEM*). SLI = participant with specific language impairment; CA = participant with typical development, matched to a child with SLI in chronological age; VS = participant with typical development, matched to a child with SLI for estimated receptive vocabulary size.



There were two significant interactions. First, there was a significant Length × Probability interaction, $F(1, 45) = 71.5$, $p < .001$, partial $\eta^2 = .61$. This arose because there was a greater difference between high- and low-probability four-syllable nonwords than three-syllable nonwords. Finally, the interaction between group and probability did not achieve statistical significance at the conventionally used $\alpha < .05$ level but did approach significance, $F(1, 45) = 2.9$, $p < .07$, partial $\eta^2 = .11$. The association between group and probability was explored in two ways. First, tests of significant effects examined the influence of probability separately in the three groups. A significant effect of probability was found for all three groups, $F(1, 15) = 84.1$, $p < .001$, partial $\eta^2 = .85$ for CA; $F(1, 15) = 354.8$, $p < 0.001$, partial $\eta^2 = .96$ for SLI; $F(1, 15) = 58.2$, $p < .001$, partial $\eta^2 = .80$ for VS. Three pairwise Group × Probability comparisons were calculated to examine the relative size of this effect. When the CA and SLI groups were compared, a significant interaction between group and probability was found, $F(1, 30) = 8.2$, $p < .01$, partial $\eta^2 = .21$. The children with SLI showed a larger effect of probability on nonword repetition accuracy than their CA peers. The interaction between group and probability did not achieve statistical significance at the $\alpha < .05$ level when the CA and VS children were examined, but it did approach significance, $F(1, 30) = 3.2$, $p = .08$, partial $\eta^2 = .10$. There was a trend for there to be a larger difference in repetition accuracy between high- and low-probability nonwords in the younger, VS children than in the older, CA children. Finally, no significant Group × Probability interaction was found between the VS and SLI children, $F(1, 30) < 1$, $p > .05$: Phonotactic probability affected repetition accuracy similarly in these two groups. The VS and SLI children differed in age; however, the interaction between group and probability continued not to be significant even when age was used as a covariate in an analysis of covariance, $F(1, 29) = 1.4$, $p > .05$.

The Group × Probability interaction was also examined through a test of significant main effects in which the effect of group was examined separately

Table 3. Correlations[a] among measures for the entire group of participants.

	Average nonword repetition	Frequency effect, 4-syllable nonwords	IQ[b] standard score	CELF–3[c] standard scores	PPVT–III[d] raw score
Frequency effect, 4-syllable nonwords	−.77***				
IQ standard score	.26*	−.22			
CELF–3 standard scores	.42***	−.32*	.58***		
PPVT–III raw score	.40**	−.41***	.42***	.70***	
EOWPVT[e] raw score	.36*	−.33*	.32*	.71***	.74***

[a]Partial correlations controlling for the effect of age. [b]Either the Test of Nonverbal Intelligence, Third Edition (Brown, Sherbenou, & Johnsen, 1997) or the Matrices portion of the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 1990). [c]Clinical Evaluation of Language Fundamentals, Third Edition (Semel, Wiig, & Secord, 1997). [d]Peabody Picture Vocabulary Test—III (Dunn & Dunn, 1997). [e]Expressive One-Word Picture Vocabulary Test (Gardiner, 2000).

*$p < .05$. **$p < .01$. ***$p < .003$.

for high- and low-probability nonwords. The effect of group was significant both for high-probability, $F(2, 45) = 12.8$, $p < .001$, partial $\eta^2 = .36$, and low-probability, $F(2, 45) = 7.3$, $p < .01$, partial $\eta^2 = .24$, nonwords. Post hoc Scheffé tests showed all pairwise group differences in repetition accuracy for high-probability nonwords to be significant at the $\alpha < .05$ level. For the low-probability nonwords, post hoc pairwise differences between CA and SLI children and the pairwise differences between CA and VS children were significant. No significant difference between SLI and VS children was found.

Together, these findings support the hypothesis that children with SLI have a larger influence of phonotactic probability on nonword repetition than CA-matched children. Moreover, the children with SLI did not show a larger frequency effect than the younger, VS group. Finally, comparisons of the two groups of typically developing (CA and VS) children showed a pattern similar to that found in previous research, in which younger children demonstrated a larger effect of phonotactic probability on nonword repetition than older children.

Regression

This section reports the results of two sets of regression analyses. The first analysis examined predictors of the frequency effect (i.e., the difference in repetition accuracy between high- and low-probability nonwords). We calculated the frequency effect for the four-syllable nonwords only, rather than for all stimuli. That is, the frequency effect was calculated as repetition accuracy for high-probability four-syllable nonwords minus repetition accuracy for low-probability four-syllable nonwords. This was motivated by our observation that performance for most of the three-syllable items was at or close to ceiling. When the frequency effect was calculated with these items taken into account, a much smaller range of performance was noted than when only the four-syllable nonwords were used.

Predictors in this analysis were age, a measure of overall language ability (CELF–3 standard score), two measures of vocabulary size (raw scores on the PPVT–III and the EOWPVT), and nonverbal IQ. The choice of raw measures of vocabulary size, rather than standard scores, is consistent with earlier analyses by Edwards et al. (2004) and Munson et al. (2005). Together, these two analyses are designed to examine whether the earlier finding that vocabulary-size measures are the best predictors of the frequency effect in younger, 3–8-year-old children is also true for this population of older, school-age children.

The second set of regression analyses examines predictors of repetition accuracy of each individual nonword, averaged across groups. These analyses allow us to examine whether phonotactic probability and wordlikeness affect nonword repetition accuracy independently.

Partial correlations between nonword repetition accuracy and predictor measures, controlling for the effect of age, are shown in Table 3. This table also shows correlations between predictor measures and average nonword repetition across the four stimulus types. Raw scores on the PPVT–III and EOWPVT were log-transformed, so that the distribution of scores more closely approximated a normal distribution. Three significance levels ($\alpha < .05$, $\alpha < .01$, and $\alpha < .003$) are shown. The $\alpha < .003$ level is the $\alpha < .05$ level Bonferroni-corrected for the number of correlations being computed (15). As these correlations show, all four standardized test measures predicted overall nonword repetition accuracy, with CELF–3 scores showing the strongest correlation. In contrast, only the three language measures

Table 4. Results of regression analyses predicting the four-syllable frequency effect.

Dependent measure	Step	Variable	ΔR^{2a}	B^b	$SE\ B^b$	β^b
Four-syllable frequency	1	Age	.081*	.03	0.06	.05
Effect[c]	2	PPVT–III raw score[d]	.148**	−25.6	8.7	.53**

[a]Increase in R^2 over the model containing all previous steps. [b]Coefficients for the full model. [c]$F(2, 42) = 4.4$, $p < .05$, for the full regression model. [d]Log-transformed.

*$p < .05$. **$p < .01$.

were related to the frequency effect, with PPVT–III raw scores showing the strongest correlation.

Frequency Effect

In the first regression analysis, age was forced as the first variable. In the second step, the other variables (CELF–3 standard score, IQ standard score, and standard scores and log-transformed raw scores on the PPVT–III and EOWPVT) were entered stepwise if they accounted for a significant additional proportion of variance ($\alpha < .05$) in the dependent measure. Results of a regression including all 48 participants are also shown in Table 4. Age predicted 8.1% of the variance in the frequency effect. In addition, an estimate of vocabulary size, log-transformed PPVT–III raw score, predicted 14.8% of the variance in the frequency effect beyond what was predicted by age. The negative β weight indicates that participants with larger lexicons showed less of an effect of phonotactic probability on nonword repetition than those with smaller lexicons.

The results of this regression are broadly consistent with earlier findings and suggest that vocabulary size continues to play a role in mediating the frequency effect in nonword repetition beyond the age range that had been examined in previous studies. One possibility that might limit this interpretation is that the 48 children examined in this study included children with SLI, who had both smaller vocabularies and larger frequency effects than the children with typical development. That is, the predictive relationship between vocabulary size and the frequency effect in nonword repetition in this study may have been due to the inclusion of children with SLI. A second regression was run examining only the 32 CA and VS children. In that regression, age predicted 14.6% of the variance in the frequency effect, and log-transformed raw scores on the PPVT-III predicted an additional 8.2% of the frequency effect beyond what was accounted for by age. The hypothesis that vocabulary-size measures predicted the frequency effect only because SLI children were included was thus not supported.

An additional factor potentially limiting the interpretation of these data is that the predictor measures included a mix of log-transformed raw PPVT–III and EOWPVT scores and standard CELF–3 scores. A second regression was conducted in which standard scores only were entered into the regression. In the regression for all 48 participants, PPVT–III standard scores continued to predict a significant proportion of variance in the frequency effect beyond what was accounted for by age, although the actual percentage of variance accounted for (7.2%) was lower than in the original regression. A third regression, in which only log-transformed raw test scores were entered, was similar to the original regression: PPVT–III raw scores, rather than CELF–3 raw scores, accounted for a significant proportion of variance beyond that accounted for by age.

Figures 2 and 3 plot the relationship between the average repetition accuracy for high- and low-probability four-syllable stimuli and log-transformed PPVT–III raw score (Figure 2) or age (Figure 3) for the entire group of 48 participants. As these figures show, the difference in accuracy between high- and low-probability sequences was smaller for participants with larger vocabularies than for those with smaller vocabularies: The difference between the regression lines attenuates as vocabulary increases. In contrast, the slopes of the regression lines predicting repetition accuracy from age are more similar: Age predicts repetition accuracy, but it predicts the frequency effect more weakly than PPVT–III raw scores.

Analysis by Items

The final set of regression analyses examined predictors of accuracy for the 20 individual nonwords. As stated above, the stimuli used in this study varied in both wordlikeness and phonotactic probability. The focus of this analysis was to examine whether the apparent main effect of phonotactic probability seen in the ANOVA on accuracy scores, and in the regression analyses examining predictors of phonotactic-probability effects, was due to the influence of phonotactic probability or the influence of wordlikeness on repetition accuracy. This was assessed by calculating the average performance on each item and then examining whether measures of phonotactic probability predicted

Figure 2. Linear relationships between average nonword repetition accuracy and natural-log scaled raw scores on the Peabody Picture Vocabulary Test—III for high- (HP) and low-probability (LP) four-syllable (syll) words, plotted separately. SLI = participant with language impairment; CA = participant with typical development, matched to a child with SLI in chronological age; VS = participant with typical development, matched to a child with SLI for estimated receptive vocabulary size.

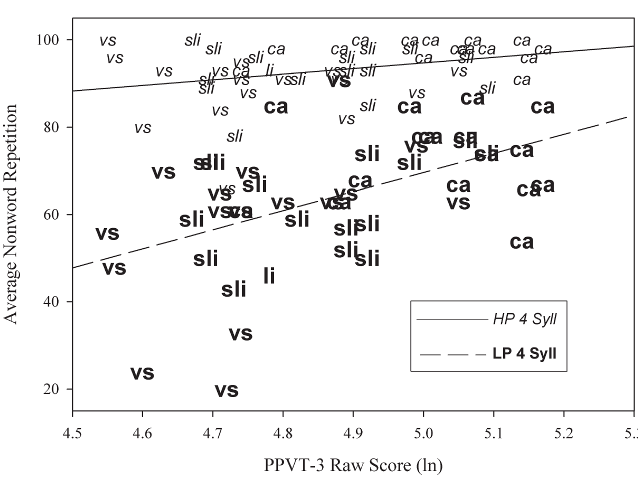
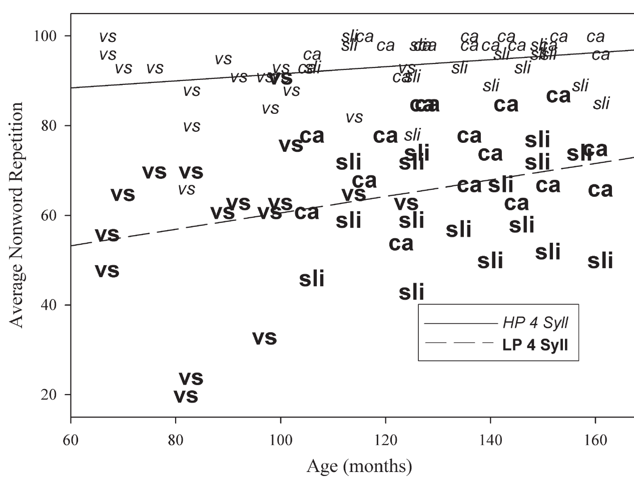


Figure 3. Linear relationships between average nonword repetition accuracy and age in months for high- (HP) and low-probability (LP) four-syllable (syll) words, plotted separately. SLI = participant with language impairment; CA = participant with typical development, matched to a child with SLI in chronological age; VS = participant with typical development, matched to a child with SLI for estimated receptive vocabulary size.



a significant proportion of variance in these measures beyond what was predicted by wordlikeness. Word length was also entered as a factor in these regressions, as it was shown to have a significant effect on repetition accuracy.

The results of the regression analyses are shown in Table 5. The dependent measure for the regressions in Table 5 is average nonword repetition across the three groups for each item. In each regression, stimulus length was forced as the first independent measure, wordlikeness as the second independent measure, and expected probability as the third independent measure. As Table 5 shows, word length did not predict a significant proportion of variance in this analysis by items. Wordlikeness accounted for 39% of the variance in scores. Expected probabilities accounted for an additional 26% of the variance in scores beyond what was accounted for by wordlikeness. In the final regression model containing all three independent measures, expected probability was the only variable whose β weight was significantly different from zero. The standardized β weight was .97, indicating that more probable nonwords were repeated more accurately than less probable nonwords.

Discussion

Phonotactic Probability and Nonword Repetition in Normal Language Development

This study examined repetition of high- and low-probability nonwords by children with SLI, CA-matched

Table 5. Regression analyses predicting average nonword repetition from length, wordlikeness, and expected probability for all 20 stimuli.

Step	Variable	ΔR^{2a}	B^b	$SE\ B^b$	β^b
1	Word length	0.12	−0.38	3.50	−.01
2	Wordlikeness	0.39**	−1.51	2.70	−.12
3	Expected probability	0.26**	2.86	0.67	.97**

Note. $F(3,16) = 17.9$, $p < .01$, for the full regression model.

[a]Increase in R^2 over the model containing all previous steps. [b]Coefficients for the full model.

**$p < .01$.

peers with typical language achievement, and younger, typically developing, VS-matched children. In all three groups, phonotactic probability affected nonword repetition accuracy: High-probability nonwords were repeated more accurately than low-probability nonwords. However, the size of this effect differed in the three groups. Children with SLI showed a larger effect of phonotactic probability on nonword repetition accuracy than CA peers. The effect of phonotactic probability was similar in the children with SLI and the VS children. As in earlier work, there was a tendency for the effect of phonotactic probability to be larger for the younger, typically developing VS children than for the older, typically developing CA children; however, this difference did not achieve statistical significance at the $\alpha < .05$ level. Regression analyses showed that a measure of vocabulary size predicted the accuracy differences between high- and low-probability nonwords, even when the effects of age were controlled. Moreover, an analysis by items showed that phonotactic probability influenced nonword repetition accuracy independently from wordlikeness. Previous research (Frisch et al., 2000) demonstrated that phonotactic probability and wordlikeness are correlated. Other research (Dollaghan et al., 1995) showed that wordlikeness influences nonword repetition accuracy. These findings leave open the possibility that the apparent influence of phonotactic probability on nonword repetition might be due to the influence of wordlikeness on repetition accuracy. Our analysis by items showed that both phonotactic probability and wordlikeness have independent influences on nonword repetition accuracy.

This study differed from earlier work on the relationships among vocabulary size, phonotactic probability, and nonword repetition two ways. First, it examined an older group of typically developing children than had been examined previously. The participants in the current study ranged from 6 to 13 years of age. In contrast, those examined by Munson et al. (2005) ranged from 3 to 6 years of age. The findings (a) that nonword repetition accuracy continues to improve in this age range, (b) that the frequency effect continues to decline in this age range, and (c) that vocabulary size predicts developmental decreases in the frequency effect all suggest that individuals' representations of phonological units as separate from lexical items continue to be refined throughout later phonological development.

Along with the earlier findings of Edwards et al. (2004) and Munson et al. (2005), the results of the current investigation can be interpreted as evidence that lexical development influences individuals' knowledge of categorical representations of phonological units that are separate from lexical items in which those sounds occur. These representations are subject to continued elaboration and refinement in the age range we studied in this investigation. This is illustrated by children's gradually increasing ability to repeat nonwords accurately, particularly those that contain low-probability sequences of phonemes. These results in turn support more general probabilistic models of phonology and suggest that the cognitive architecture that underlies individuals' knowledge of sound structure is tightly linked to the lexicon, rather than standing as a separate module of the cognitive system. Note, however, that the developmental decrease in the frequency effect did not achieve statistical significance at the conventional $\alpha < .05$ level. There are two reasons why this may be so. One may simply relate to statistical power, as only 32 TD children were examined in this study. Indeed, the interaction between frequency and group did achieve statistical significance in a post hoc examination of the influence of frequency on nonword repetition on a larger group of children with typical language achievement, including children whose data were not used in the current analysis, $F(1, 32) = 5.3$, $p < .05$, partial $\eta^2 = .14$. This group included children who participated in the study but whose data were not included, so that the three groups could be equal in size. A second, related possibility is that nonword repetition does not have the sensitivity to robustly detect developmental changes in phonological knowledge in older children. Other measures, such as the wordlikeness judgments that Frisch, Large, Zawaydeh, and Pisoni (2001) found to be related to adults' vocabulary sizes, might be needed to measure these changes in older children.

One possible response to the predictive relationship between vocabulary size and nonword repetition is to postulate that they reflect children's increased motor abilities: Children with larger vocabularies have had more opportunities to produce low-frequency sequences in real words, and this may facilitate their ability to say the same sequences in nonwords. This hypothesis was considered by Edwards et al. (2004) and Munson et al. (2005). Edwards et al. found that the influence of vocabulary size on phonotactic-probability effects was present in comparisons of both high- versus low-probability and high- vs. zero-probability real words. If motor development were driving the phonotactic-probability effect in nonword repetition, then it would not be present for zero-probability sequences. Munson et al. found that a measure of speech-motor development did not predict the effect of phonotactic probability on nonword repetition accuracy. Given these previous findings, it seems unlikely that motor development mediated the effect observed in this study.

Phonotactic Probability and Nonword Repetition in Children With SLI

This investigation showed that children with SLI demonstrate a larger effect of phonotactic probability on nonword repetition than their CA peers with typical language development, as hypothesized. Regression analyses suggest that this difference may be due to group differences in vocabulary size. Two findings support this. First, the frequency effect (the accuracy difference between high- and low-probability nonwords) of children with SLI was statistically indistinguishable from that of a younger, typically developing, VS-matched sample. Second, the magnitude of the frequency effect was predicted best by measures of vocabulary size. This was true both when transformed raw scores only were used and when standard scores only were used.

The finding that children with SLI do not show a larger effect of phonotactic probability on nonword repetition than VS-matched children can be interpreted a number of ways. One potential interpretation of these findings is that SLI is not associated with a difficulty in abstracting phonological representations from lexical items. However, this interpretation should be made with caution. As suggested by Fisher and Church (2001) and Beckman et al. (in press), phonological abstractions over lexical items are both a *consequence* and a *cause* of word learning. They are a consequence in that they arise only after the child has acquired enough holistic lexical-level representations to make the generalization that phonological units exist separately from the words that constitute them. However, these newly abstracted phonological units may facilitate future word learning. That is, a child who possesses representations of the phonological categories of a language is better able to recognize the units of an unfamiliar word as members of known categories than a child without such phonological representations. Children with robust phonological representations can then make a more efficient indexical association between an unfamiliar string and its semantic representation than the child with impoverished or absent knowledge of phonological categories. In this way, learning phonological categories facilitates the rapid and efficient learning of lexical items.

In this framework, the difficulties in word learning experienced by children with SLI might themselves be both a cause and a consequence of difficulties in abstracting phonological representations. That is, the difficulties that children with SLI experience in learning new words (Dollaghan, 1987; Oetting, Rice, & Swank, 1995) might prevent them from amassing enough lexical items to make the generalizations needed to develop phonological representations. Consequently, the children with SLI would experience more difficulty learning new words than typically developing children, because they would lack the phonological representations needed to efficiently recognize novel strings during word-learning tasks. This predicts that the difference in the size of the frequency effect between young children with SLI and their typically developing CA-matched peers would be smaller than the difference between older SLI children and their CA-matched peers. The difference between the groups in the frequency effect would widen as the typically developing children developed and refined their phonological representations and increased the size of their lexicons and the children with SLI continued to have poorly specified phonological representations. Future research should examine the relationships among vocabulary size and phonotactic-probability effects in typically developing children and children with SLI longitudinally.

One cautionary note must be made regarding the interpretation of the finding that vocabulary-size measures are the best predictors of the frequency effect. One reasonable response to this finding is to point out that measures of language ability are highly correlated. Omnibus measures of language (such as the CELF–3) are often highly correlated with measures of vocabulary size, such as the PPVT–III and the EOWPVT. The predictive relationships between VS measures and the frequency effect in nonword repetition may have reflected that language abilities predict the frequency effect, rather than vocabulary size. We respond to this conjecture two ways. First, measures of vocabulary size always predicted a larger proportion of variance in the frequency effect in the analyses presented in this investigation. Second, the hypothesis that vocabulary size predicts the frequency effect is consistent with research on younger children (i.e., Bates, Bretherton, & Snyder, 1988; Bates & Goodman, 1997) demonstrating that vocabulary size, rather than broader language ability, predicts developmental changes in other language abilities, like morphology and syntax.

However, we concede that these data do not provide definitive evidence that vocabulary size, rather than general language ability, is the single best predictor of the frequency effect. Future research should examine this question more directly by including groups of children with SLI whose language abilities are selectively impaired in different structural domains. A finding that the frequency effect is more closely related to vocabulary size in a group of children with dissociations in impairments in syntax and word learning could provide powerful support for the hypothesis that vocabulary growth drives the development and refinement of phonological categories.

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References

Bailey, T., & Hahn, U. (2001). Determinants of wordlikeness: Phonotactics or lexical neighborhoods. *Journal of Memory and Language, 44,* 568–591.

Bates, E., Bretherton, E., & Snyder, L. (1988). *From first words to grammar: Individual differences and dissociable mechanisms*. New York: Cambridge University Press.

Bates, E., & Goodman, J. C. (1997). On the inseparability of grammar and the lexicon: Evidence from acquisition, aphasia and real time processing. *Language and Cognitive Processes, 12,* 507–586.

Beckman, M., Munson, B., & Edwards, J. (in press). The influence of vocabulary growth on developmental changes in types of phonological knowledge. In J. S. Cole & J. I. Hualde (Eds.), *Papers in laboratory phonology* (Vol. 9). New York: Mouton de Gruyter.

Bishop, D., North, T., & Donlan, C. (1996). Nonword repetition as a behavioural marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Psychiatry, 37,* 391–403.

Botting, N., & Conti-Ramsden, G. (2001). Nonword repetition and language development in children with specific language impairment (SLI). *International Journal of Language and Communication Disorders, 36,* 421–432.

Brown, L., Sherbenou, R., & Johnsen, S. (1997). *Test of Nonverbal Intelligence, Third Edition.* Austin, TX: Pro-Ed.

Burgemeister, B. B., Blum, L. H., & Lorge, I. (1972). *Columbia Mental Maturity Scale*. New York: Harcourt Brace Jovanovich.

Conti-Ramsden, G. (2003). Processing and linguistic markers in young children with specific language impairment (SLI). *Journal of Speech, Language, and Hearing Research, 46,* 1029–1037.

Conti-Ramsden, G., Botting, N., & Faragher, B. (2001). Psycholinguistic markers for specific language impairment (SLI). *Journal of Child Psychology and Psychiatry, 42,* 741–748.

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

Dollaghan, C. A., Biber, M. E., & Campbell, T. E. (1995). Lexical influences on nonword repetition. *Applied Psycholinguistics, 16,* 211–222.

Dollaghan, C. A., & Campbell, T. E. (1998). Nonword repetition and child language impairment. *Journal of Speech, Language, and Hearing Research, 41,* 1136–1146.

Dunn, L., & Dunn, L. (1997). *Peabody Picture Vocabulary Test—III*. Circle Pines, MN: AGS.

Edwards, J., Beckman, M. E., & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in novel word repetition. *Journal of Speech, Language, and Hearing Research, 47,* 421–436.

Edwards, J., Fox, R. A., & Rogers, C. (2002). Final consonant discrimination in children: Effects of phonological disorder, vocabulary size, and articulatory accuracy. *Journal of Speech, Language, and Hearing Research, 45,* 231–242.

Edwards, J., & Lahey, M. (1998). Nonword repetitions of children with specific language impairment: Exploration of some explanations for their inaccuracies. *Applied Psycholinguistics, 19,* 279–309.

Ellis Weismer, S., Tomblin, J. B., Zhang, X., Buckwalter, P., Chynoweth, J. G., & Jones, M. (2000). Nonword repetition performance in school-aged children with and without language impairment. *Journal of Speech, Language, and Hearing Research, 43,* 865–878.

Fisher, C., & Church, B. A. (2001). Implicit memory support for language acquisition. In J. Weissenborn & B. Höhle (Eds.), *Approaches to bootstrapping: Phonological, lexical, syntactic and neurophysiological aspects of early language acquisition* (Vol. 1, pp. 47–69). Amsterdam: John Benjamins.

Frisch, S. A., Large, N. R., & Pisoni, D. B. (2000). Perception of wordlikeness: Effects of segment probability and length on processing of non-word sound patterns. *Journal of Memory and Language, 42,* 481–496.

Gardiner, M. (2000). *Expressive One-Word Picture Vocabulary Test*. San Antonio, TX: Psychological Corporation.

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

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

Gathercole, S. E., & Baddeley, A. D. (1989b). The role of phonological memory in vocabulary acquisition: A study of young children learning new names. *British Journal of Psychology, 81,* 439–454.

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

Gathercole, S. E., Frankish, C., Pickering, S. J., & Peaker, S. (1998). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 84–95.

Goldman, R., & Fristoe, M. (2000). *The Goldman Fristoe Test of Articulation—2*. Circle Pines, MN: American Guidance Service.

Hay, J., Pierrehumbert, J., & Beckman, M. (2004). Speech perception, well-formedness, and the statistics of the lexicon. In J. Local, R. Ogden, & R. Temple (Eds.), *Papers in laboratory phonology VI* (pp. 58–74). Cambridge, U.K.: Cambridge University Press.

Kaufman, A., & Kaufman, N. (1990). *The Kaufman Brief Intelligence Test*. Circle Pines, MN: American Guidance Service.

Kohnert, K., & Windsor, J. (2004). The search for common ground: Part II. Nonlinguistic performance by linguistically diverse learners. *Journal of Speech, Language, and Hearing Research, 47,* 891–903.

Lewis, B. A., & Freebairn, L. (1992). Residual effects of preschool phonology disorders in grade school, adolescence, and adulthood. *Journal of Speech and Hearing Research, 35,* 819–831.

Marchman, V., & Bates, E. (1994). Continuity in lexical and morphological development: A test of the critical mass hypothesis. *Journal of Child Language, 21,* 331–366.

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 89–120). New York: Erlbaum.

Munson, B. (2001). Phonological pattern frequency and speech production in adults and children. *Journal of Speech, Language, and Hearing Research, 44,* 778–792.

Munson, B., Edwards, J., & Beckman, M. (2005). Relationships between nonword repetition accuracy and other measures of linguistic development in children with phonological disorders. *Journal of Speech, Language, and Hearing Research, 48,* 61–78.

Oetting, J., Rice, M., & Swank, L. (1995). Quick incidental learning (QUIL) of words by school-aged children with and without SLI. *Journal of Speech and Hearing Research, 28,* 434–445.

Pierrehumbert, J. B. (2003). Probabilistic phonology: Discrimination and robustness. In R. Bod, J. Hay, & S. Jannedy (Eds.), *Probabilistic linguistics* (pp. 177–228). Cambridge, MA: MIT Press.

Pisoni, D., Nusbaum, H., Luce, P., & Slowiacek, L. (1985). Speech perception, word recognition, and the structure of the lexicon. *Speech Communication, 4,* 75–95.

Semel, A., Wiig, E., & Secord, W. (1997). *Clinical Evaluation of Language Fundamentals, Third Edition*. San Antonio, TX: Psychological Corporation.

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

Storkel, H. (2002). Restructuring of similarity neighborhoods in the developing mental lexicon. *Journal of Child Language, 29,* 251–274.

Vitevitch, M., & Luce, P. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language, 40,* 374–408.

Williams, K. (1997). *Expressive Vocabulary Test*. Circle Pines, MN: American Guidance Service.

Windsor, J., & Kohnert, K. (2004). The search for common ground: Part 1. Lexical performance by linguistically diverse learners. *Journal of Speech, Language, and Hearing Research, 47,* 877–890.

Windsor, J., Milbrath, R., Carney, E., & Rakowski, S. (2001). Generalized slowing in language impairment: Methodological considerations in testing the hypothesis. *Journal of Speech, Language, and Hearing Research, 44,* 446–461.

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