The role of phonotactic frequency in sentence repetition by children with specific language impairments

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Abstract

Purpose: Recent work suggests that SLI results from a primary deficit in phonological processing. This deficit is perhaps most striking in nonword repetition tasks, where semantic and syntactic demands are eliminated. Children with SLI repeat nonwords less accurately than unimpaired peers, which may reflect difficulty extracting phonological regularities from their lexicons. However, recent evidence suggests that having children with SLI respond to meaningless syllables such as nonwords underestimates their language abilities. Therefore, sensitivity to phonological regularities was measured by having children repeat meaningful sentences containing target words differing in phonotactic pattern frequency (PPF).

Method: 18 children with SLI, mean age 9;0, and 18 age-matched controls repeated acoustically-degraded sentences containing consonant-vowel-consonant (CVC) target words differing in PPF, occurring in either subject or sentence-final position.

Results: Accuracy results revealed significant main effects due to group, PPF, and sentence position (sentence final > subject). However, the nonsignificant group by PPF interaction revealed that both groups of children were similarly affected by PPF.

Conclusion: Children with SLI repeated CVC target words less accurately overall, but showed similar sensitivity to PPF as typical controls, suggesting that they can extract and use phonological and phonotactic regularities from their lexicons as successfully as their typically developing peers.

Key words: SLI, phonotactics, sentence repetition, vocabulary, phonological development

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by children with specific language impairments

Children with specific language impairments, or SLI, have difficulty acquiring and using language despite of having all of the apparent requisite cognitive abilities. These children are measured to have normal hearing, oral-motor skills, and nonverbal intelligence, with no history or social/emotional disturbance or significant neurological impairment. Even so, all available evidence suggests that they experience deficits in all aspects of language (see e.g. Leonard, 1998). While researchers have considered a number of potential underlying causes, some recent work has focused on explaining SLI in terms of a primary phonological deficit (see, e.g. Chiat, 2001). According to this theory, children with SLI have difficulty establishing robust phonological representations of words in their lexicons, which in turn affects their ability to identify word boundaries (Evans & Saffran, 2005) and to extract grammatical morphemes with low perceptual salience, which are typically coronal (unmarked) consonants with shorter duration and lower pitch and amplitude (Leonard, 1989).

"Phonological representation" as a developmental construct

The construct of "phonological representation" is difficult to operationalize in spite of its widespread use. Boada and Pennington (2006) defined it in developmental terms as "the emerging property of the brain that represents, in an increasingly fine-grained and robust manner, the linguistic construct of the phoneme" (pg. 155). This definition assumes a holistic-to-segmental progression, and has received a great deal of experimental support in the literature. For children developing language typically, phonological representations of the earliest words are assumed to be holistic (Fowler, 1991; Jusczyk, 1986; Metsala & Walley, 1998; Treiman &

Baron, 1981). That is, the acoustic forms of words might be stored in terms of their prosodic structure and/or overall acoustic shape, or perhaps in terms of coarsely defined phonetic features. This organizational structure is presumably possible because young children's lexicons contain fewer words that are likely to overlap phonologically (Charles-Luce & Luce, 1990, 1995; *cf.* Coady & Aslin, 2003). Therefore, they don't need to attend to the same level of phonological detail that adults do in order to be able to accurately distinguish lexical alternatives. Over development as the lexicon grows in size, it becomes increasingly likely that children will acquire words that are similar to words already contained in their lexicons. Children must then begin to attend to phonological detail in order to successfully perceive spoken language.

Models of phonological/lexical development consistent with this definition have been described to account for developmental changes in the precision with which lexical entries are stored. Metsala and Walley (1998) have proposed the Lexical Restructuring Hypothesis (LRH), which posits that children's earliest words are learned as unanalyzed wholes. Over development, words in the lexicon undergo a restructuring in which segmental detail is incorporated into holistic lexical representations. Eventually, all words come to be stored as in the adult lexicon, as sequences of individual phonemes. There are two primary drivers for lexical restructuring. The first is neighborhood density, or the degree of phonological overlap among words in the lexicon (Luce & Pisoni, 1998). Words that share phonological overlap with many other words, i.e., those from dense neighborhoods, will be "restructured" first in order to decrease confusability, increasing the likelihood of successful word identification. A second factor that leads to restructuring is word familiarity which depends on two different factors—word frequency and age of acquisition. That is, the earlier a given word is added to the lexicon and the more often it is used (heard or spoken), the earlier it will be restructured. Similarly, Werker and

Curtin's PRIMIR framework (Processing Rich Information from Multidimensional Interactive Representations, 2005) also considers lexical growth as a driver for the acquisition of robust phonological knowledge, specifically at the phoneme level. The PRIMIR framework contains a Phoneme plane that emerges through phonological generalizations drawn from over the entire lexicon. However unlike the LRH, PRIMIR makes no claims about the specificity of children's earliest phonological representations, nor any putative restructuring from holistic to segmental representations. This pattern of restructuring is consistent with Boada and Pennington's (2006) definition of phonological representations, in which organization in terms of the phoneme is crucial.

An alternative account that suggests an expanded definition of "phonological representation" has been proposed by Edwards, Beckman and Munson (2004). As with both the LRH and PRIMIR, they argue that robust phonological knowledge emerges as a consequence of lexical growth. Like PRIMIR, their theory makes no claims about the level of detail in children's early lexical representations. An important distinction is that Edwards and colleagues' theory assumes that children gain knowledge not just at the phonemic level, but rather at multiple levels of phonological detail. As children gain experience hearing and speaking many different words, symbolic knowledge emerges at all hierarchical phonological levels. That is, children gradually gain knowledge at the phoneme level, at sub-syllabic levels (onset and rime levels), at the syllable level, and at the whole word level. This hypothesized end-state requires that the Boada and Pennington definition (2006) of phonological representation be expanded beyond just the phoneme level to include multiple levels of phonological knowledge. Edwards and colleagues also suggest that the relationship between a child's vocabulary and developing phonological knowledge is reciprocal. Phonological knowledge is extracted in terms of phonological generalizations across the corpus of speech that a child hears and says. That same phonological knowledge is used in turn to acquire more words, providing an even larger corpus of speech, thereby increasing the robustness of the phonological knowledge.

Difficulty establishing robust phonological representations in SLI

Children with SLI experience a number of lexical deficits, so it is reasonable to conclude that they will experience difficulty gaining such phonological knowledge. Retrospective studies suggest that children with SLI acquire their first words later than children without language impairments (e.g., Trauner, Wulfeck, Tallal & Hesselink, 1995). They learn new words more slowly (Alt & Plante, 2006; Dollaghan, 1987; Gray, 2004, 2005, 2006; Leonard, Schwartz, Chapman, Rowan, Prelock, Terrell, Weiss & Messick, 1982; Rice, Buhr & Oetting, 1992; Rice, Oetting, Marquis, Bode & Pae, 1994), and tend to be more vulnerable to input perturbations (Ellis Weismer & Hesketh, 1993; 1996; Horohov & Oetting, 2004). For words that they have acquired, children with SLI still exhibit word-finding deficits in a variety of tasks. In gating tasks, they identify familiar words with as little acoustic information as age-matched controls, but they need more acoustic information to identify less frequent words (Dollaghan, 1998; Mainela-Arnold, Evans & Coady, 2008; Montgomery, 1999). They are slower than age-matched typically developing children to recognize words (Edwards & Lahey, 1996), and slower to name pictures (Lahey & Edwards, 1996; Leonard, Nippold, Kail & Hale, 1983). Further, when naming pictures, they tend to make both phonological and semantic errors at higher rates than unimpaired peers (Lahey & Edwards, 1996, 1999). Finally, their performance in definition and drawing tasks suggests that their semantic representations of known words are less robustly specified (Marinellie & Johnson, 2002; McGregor & Appel, 2002; McGregor, Newman, Reilly & Capone, 2002). All of this evidence suggests that children with SLI have smaller vocabularies than typically developing children at any point in development, more difficulty adding new words to their lexicons, and inefficient access to less robustly specified words that they do know. Consequently, it is reasonable to expect that phonological knowledge extracted from their lexicons is also less robustly specified.

In spite of all of these lexical difficulties, some recent work has questioned whether children with SLI truly experience phonological deficits. Catts, Adlof, Hogan and Ellis Weismer (2005) examined phonological processing in four groups of children—(1) children with SLI only; (2) children with dyslexia only; (3) children with both SLI and dyslexia, and (4) children with normal language and reading development. They reported that children with dyslexia, both with and without SLI, scored lower than children with just SLI on phonological processing measures. They suggested that children with SLI only experience phonological deficits in cases of concomitant dyslexia. However, these findings contradict previous work showing a more pronounced phonological deficit in SLI than in dyslexia. For example, Kamhi and Catts (1986) reported that children with SLI scored lower than children with dyslexia on a nonword repetition task. Catts and colleagues (2005) suggested that previous findings such as these were based on groups of children with co-morbid dyslexia and SLI. However, the children with SLI that Kamhi and Catts (1986) included actually scored higher than children with dyslexia on two of three reading measures, but lower on nonword repetition. For that sample of children, at least, poor nonword repetition abilities did not seem to correspond with poor reading abilities. These findings also contradict other studies reporting a phonological deficit in SLI. Joanisse, Manis, Keating and Seidenberg (2000) also broke their group of children down into groups with and without concomitant language impairment. Like Catts and colleagues (2005), they reported significant phonological processing difficulty for children with co-morbid dyslexia and SLI.

However, their results differed in that they found the source of the problem to be SLI. They found no evidence of a phonological processing deficit in children with dyslexia but without SLI. These findings raise the possibility that children with SLI do in fact suffer a phonological processing deficit.

Nonword repetition as a window to phonological representations

Directly examining the robustness of phonological representations has proven quite difficult because of the close link between phonological processing and representation. Performance on any phonological processing task (e.g., perception, encoding, storage, or retrieval) depends on the nature of the underlying phonological representations being stored. Further, as Edwards and colleagues pointed out (2004), the relationship is reciprocal, with phonological representations being used to support phonological processing. As a consequence, the underlying representations themselves cannot be examined independent of processing. This is often discussed in terms of the relationship between phonological memory and representation. Speakers with greater facility with the sound structure of language tend to perform better in phonological memory tasks (Bowey, 1996; Edwards & Lahey, 1998; Metsala, 1999; see also Macdonald & Christiansen, 2001).

Researchers have attempted to circumvent this confound by examining phonological processing independent of representation. Specifically, the nonword repetition task has gained wide acceptance for examining phonological memory independent of language knowledge. Any phonological processing tasks using real words will be influenced by word frequency and familiarity. Because nonwords are non-occurring (zero-frequency) and unfamiliar, it has been suggested that speakers should not use any language knowledge to support accurate repetition (e.g., Marton & Schwartz, 2003). Therefore, any variance in repetition accuracy putatively corresponds to variance in phonological memory. However, we know that speakers can and do use any source of available language knowledge (e.g., lexical, sublexical, prosodic) to support nonword repetition (Snowling, Chiat & Hulme, 1991). Repetition accuracy is better for all speakers for nonwords containing easily discriminable consonants (Kamhi & Catts, 1986), single consonants vs. consonant clusters (Gathercole & Baddeley, 1989), higher subjective wordlikeness ratings (Gathercole, Willis, Emslie & Baddeley, 1991), embedded real words (Dollaghan, Biber & Campbell, 1993), frequently occurring phonotactic patterns (Vitevitch, Luce, Charles-Luce & Kemmerer, 1997), and attested vs. unattested consonant sequences (Beckman & Edwards, 2000). These findings have led researchers to flip this argument on its head, and to investigate whether nonword repetition tasks can be used to examine the robustness of underlying phonological knowledge.

The logic behind such a claim is that a speaker's ability to repeat novel phonological strings depends at least in part on the speaker's facility with the phonological structure of their language. If robust phonological knowledge emerges as a consequence of lexical growth, then phonemes that occur in many different words and in many different phonetic contexts should be more robustly specified simply by virtue of their frequency of occurrence. Because of this robustness, speakers should be able to repeat nonwords containing frequently occurring phonemes more accurately than those containing less frequent phonemes, a finding consistently reported in the literature (Coady & Aslin, 2004; Edwards et al., 2004; Munson, Kurtz & Windsor, 2005; Vitevitch et al., 1997; Zamuner, Gerken & Hammond, 2004). There are of course a number of explanations for this phenomenon. Phonological memory may be more accurate for frequently occurring phonemes than for infrequent phonemes, as may speech perception, phonological segmentation, phonological encoding, or articulation. However, all of these phonological processes depend on the robustness of the representations themselves. Therefore, differences in accuracy between nonwords containing frequent phonemes and those containing infrequent phonemes reflect differences in the robustness of the underlying phonological knowledge.

Using nonword repetition to examine phonological representations in children with SLI

Attempts to use the nonword repetition task to examine the robustness of phonological knowledge in children with SLI have provided mixed results. Munson and colleagues (2005) had children with SLI and two groups of typically developing controls, one group of age-matched children and a second group of younger, vocabulary-matched children, repeat nonwords differing in phonotactic frequency. When they compared children with SLI and age-matched controls, they found significant main effects of group, length and phonotactic probability, along with a significant interaction between group and phonotactic probability, indicating that children with SLI had a larger effect due to phonological pattern frequency. When they compared children with SLI to younger vocabulary-matched children, they found no significant differences in the two groups' nonword repetition accuracy, suggesting that differences in vocabulary mediated the aforementioned differences in phonotactic sensitivity. They concluded that children with SLI have difficulty extracting phonological knowledge from their lexicons, and that this effect is due to their smaller lexicons. However, one aspect of their nonwords bears mentioning.

Their nonwords came from Frisch, Large and Pisoni (2000), and differed globally in consonant, vowel, and diphone (phoneme co-occurrence) frequencies. However, eight of ten low-PPF nonwords contained phoneme combinations that may be unattested in children's lexicons. As an example, consider a pair of nonwords, high frequency /si·sɚ·ta·ləp/ and low frequency /zo^{I}·wæ·tʃɝ·žɛð/. The high-frequency nonword contains frequently occurring consonants and reduced vowels in frequently occurring combinations. In contrast, the low frequency nonword contains the very infrequent combination /zo^{I}-/, the unattested combination /žɛ-/, and the combination /-ɛð/, which does occur, but never at the end of a word. While children most certainly do know words containing these individual segments, the combinations may be unattested in their lexicons. Accordingly, only limited conclusions can be drawn from this nonword repetition task. Finding a significant group by PPF interaction does indeed suggest that children with SLI have not developed representations of the individual phonemes robust enough to support repetition in unfamiliar contexts. This conclusion is consistent with a deficit establishing phonological representations as Boada and Pennington (2006) defined them. However, Edwards and colleagues (2004) suggested that phonological representations entail knowledge at multiple levels of representation, not just the phoneme. Including unattested phoneme combinations in the nonwords limits conclusions that can be drawn about other levels of phonological representation. If phoneme sequences are not even present in children's lexicons, then there is no reason to expect that they would have even fragile knowledge of these phonological units.

Coady, Evans, and Kluender (2008) also presented a study examining the role of phonotactic frequency in nonword repetition by children with SLI. They used two different sets of nonwords—one differing in only consonant frequency, with vowel and diphone frequency held constant, and another differing in only diphone frequency, with consonant and vowel frequency held constant. They reported significant main effects of group, length, and phonotactic frequency, but no group by phonotactic frequency interaction. This lack of an interaction suggests that children with SLI have extracted phonotactic regularities across their lexicons that they can use to support nonword repetition. Children with SLI may be slower to complete this process, but they have extracted knowledge about the relative frequencies of occurrence and co-occurrence, at least by the age tested there, 9;2.

The importance of using real words to test phonological processing in children with SLI

Findings from the Munson et al. study (2005) suggest that children with SLI may have difficulty establishing robust representations of individual phonemes as measured by repetition in potentially unattested contexts. However, findings from the Coady et al. study (2008) suggest that children have established robust phonological representations at multiple levels as measured by repetition in attested contexts. However, any potential deficits may have been exaggerated by the use of meaningless test items. Recent findings suggest that testing children with SLI using meaningless test items such as nonwords does not give a true picture of their language abilities. Coady and colleagues (Coady, Evans, Mainela-Arnold & Kluender, 2007; Coady, Kluender & Evans, 2005) reported results from speech perception tasks employing either real words or meaningless syllables. Overall, children with SLI perceived naturally-spoken real words comparably to age-matched peers, but showed impaired perception of abstract nonword syllables. These findings present a conundrum, as nonword repetition tasks were originally developed to test language processing independent of language knowledge. While knowledge-based, standardized language measures tend to over-identify children from non-standard language backgrounds, processing-based measures such as the nonword repetition task avoid this problem by assessing children's language abilities independent of prior language knowledge (Ellis Weismer, Tomblin, Zhang, Buckwalter, Chynoweth & Jones, 2000). However, children with SLI have difficulty responding to meaningless test items precisely because they cannot exploit established lexical knowledge to facilitate processing. With regard to the use of nonwords, group differences in sensitivity to phonotactic probability may simply reflect difficulty responding to meaningless test items rather than true differences in phonological processing.

Examining lexical representations using meaningful speech should be preferred over nonwords. However, the use of real words introduces other potential confounds. Generally speaking, the processing of nonwords depends on phonotactic probability while the processing of real words depends on neighborhood density. Vitevitch and Luce (1998, 1999) originally reported these findings, which they interpreted in terms of a lexical competition model. High phonotactic frequency nonwords are easier to process because they receive a boost from the frequently occurring phonotactic patterns. In contrast, high phonotactic frequency words are more difficult to process because the high frequency phonotactic patterns mean that they sound like many other words (they come from dense neighborhoods) and so are more subject to competition. According to this model, phonotactic frequency effects in nonwords are facilitatory, with the locus at the sublexical level, while phonotactic frequency effects in words are inhibitory, with the locus at the lexical level. However, Vitevitch and Luce (1999) argue that word identification depends on the interaction of these two factors. When effects due to lexical competition are reduced, speakers show evidence of facilitation due to phonotactic frequency in the processing of real words (see also Luce & Large, 2001). Subsequent work has shown that speakers are indeed sensitive to phonotactic frequency in real words. For example, Storkel (2001, 2003) has reported that children learn new words containing high frequency phonotactic patterns more quickly than those containing low frequency phonotactic patterns. Also, Roodenrys, Hulme, Lethbridge, Hinton and Nimmo (2002) found that adults were better able to recall words with high frequency phonotactic patterns.

The purpose of the present study was to examine phonotactic sensitivity in children with SLI by using meaningful speech. A sentence repetition task was used to measure how well children with SLI were able to extract and use phonological regularities from their lexicons. Sentence repetition was favored over nonword repetition because it uses meaningful words in realistic combinations, thereby allowing children to exploit established language knowledge to facilitate repetition. Further, because meaningful sentences were used, effects due to lexical competition were reduced, thereby unmasking effects due to phonotactic probability. Previous studies have established that performance on sentence repetition and nonword repetition tasks is highly correlated (Bishop, North & Donlan, 1996; Conti-Ramsden, Botting & Farragher, 2001; Kamhi & Catts, 1986). In order to examine the role of phonotactic pattern frequency on repetition, children repeated sentences containing consonant-vowel-consonant (CVC) target words differing in phonotactic probability and occurring in either subject or sentence-final position. The specific research questions were: (1) In a sentence repetition task, will children repeat real words with frequent phonotactic patterns more accurately than words with less frequent phonotactic patterns? (2) Will children with SLI show a similar or different pattern of sensitivity to phonotactic pattern frequency (PPF) as age-matched typically developing controls?

Method

Participants

Participants included a total of 36 children—18 monolingual English-speaking children (10 females, 8 males) with specific language impairments, mean age 9;0 (range 7;3 to 10;6) and 18 typically developing children (12 females, 6 males), mean age 8;10 (range 7;4 to 10;0), matched for chronological age. The age difference between groups was not significant, $t(34) = 0.72$, *n.s.* Children were drawn from a larger sample of children in local schools. Children with

SLI met exclusion criteria (Leonard, 1998), having no frank neurological impairments, no evidence of oral-motor disabilities, normal hearing sensitivity, and no social or emotional difficulties (based on parent report). Nonverbal IQs were at or above 85 (one s.d. below the mean or higher) as measured by the Leiter International Performance Scale—Revised (Leiter-R; Roid & Miller, 1997) or the Columbia Mental Maturity Scale (CMMS; Burgemeister, Blum & Lorge, 1972). To control for possible confounding effects of articulation impairments, only children without articulation deficits were included. Speech intelligibility, as measured during spontaneous production, was at or above 98 percent for all children. All children also had normal range hearing sensitivity on the day of testing as indexed by audiometric pure tone screening at 25 dB for 500 Hz tones, and at 20 dB for 1000, 2000, and 4000 Hz tones. One typically developing child failed the hearing screen, and was not tested that day. She passed the hearing screen on her next visit, at which time she participated in the full experimental battery.

Language assessment measures included (1) Clinical Evaluation of Language Fundamentals—Revised (CELF-R; Semel, Wiig & Secord, 1989), (2) the Nonword Repetition Task (NRT; Dollaghan & Campbell, 1998), and (3) the Competing Language Processing Task (CLPT; Gaulin & Campbell, 1994). Children with SLI received the full expressive and receptive language batteries of the CELF-R, and composite expressive (ELS) and receptive (RLS) language scores were calculated. Typically developing children received the full expressive language battery of the CELF-R, while their receptive language was screened with the Oral Directions subtest of the receptive language battery.

The group of children with SLI included eight children with only expressive language impairments (E-SLI) and ten with both expressive and receptive language impairments (ER-SLI). The language criteria for E-SLI were ELS at least one standard deviation below the mean

(<85) and RLS greater than one standard deviation below the mean (>85). Criteria for ER-SLI were both ELS and RLS at least one standard deviation below the mean (<85). Language criteria for the age-matched control group were ELS above 85 and standard score on the Oral Directions subtest at or above 8. Group summary statistics are provided in Table 1. Children with SLI scored significantly below typically developing children on all diagnostic measures: CELF-R ELS, $t(34) = 7.50$, $p < .0001$, $\eta^2_p = .623$, power = 1.00; CELF-R Oral Directions subtest, $t(40) = 3.51$, $p = .001$, $\eta^2_p = .266$, power = .93; NRT, $t(34) = 3.93$, $p < .001$, $\eta^2_p = .313$, power = .97; CLPT, $t(34) = 5.43$, $p < .0001$, $\eta^2_p = .464$, power = 1.00. Individual scores for the children with SLI are provided in Appendix A.

Stimuli

Forty sentences appropriate for children were drawn from the Hearing in Noise Test (HINT; Nilsson, Soli & Sullivan, 1994). Of the 130 sentences appropriate for children, 98 contained a total of 144 consonant-vowel-consonant (CVC) words, including nouns, pronouns, verbs, adjectives, adverbs and prepositions. Of these, 33 were excluded because they did not contain CVC target words in one of two prosodically salient positions: subject position or sentence-final position. The remaining 65 sentences contained 48 unique CVC words. Ten of the 65 sentences contained CVC target words in both positions, and so were included as stimulus sentences. Of the remaining 55 sentences, 20 contained a CVC target in subject position, and 35 contained a target word in sentence-final position. Twenty-five of these sentences were eliminated so that each remaining target word occurred only one time in the stimulus set. When a potential target word appeared in more than one sentence, preference was given to the sentence containing the target in subject position. The remaining 40 sentences served as stimulus items—11 with a CVC target in subject position, 19 with a target in sentence-final position, and 10 with a target in both subject and sentence-final positions. Each CVC target word occurred in only one sentence, with two exceptions. The words *girl* and *road* each occurred in two sentences, both containing target words in both sentence positions.

CVC target words were also divided by means of a median split into high- and low-phonotactic pattern frequency (PPF) groups. PPF was calculated from a segmental analysis of the Brown corpus in the CHILDES database (Brown, 1973; MacWhinney, 1991), described previously by Coady and Aslin (2004). PPF calculations incorporated both positional segment frequencies and forward transitional probabilities. As an example, the probability of the CVC target word *hat* was calculated as (1) the probability of [h] given a syllable (or word) boundary multiplied by (2) the probability of [æ] given [h] multiplied by (3) the probability of [t] given [æ] multiplied by (4) the probability of a syllable (or word) boundary given [t]. Of the 21 target words in subject position, 11 were high-PPF and 10 were low-PPF. Of the sentence-final target words, 14 were high-PPF and 15 were low-PPF. Overall, CVC target words differed in log PPF, $t(48) = 11.80$, $p < .001$, $\eta^2_p = .744$, power = 1.00, and in log-frequency-weighted neighborhood density, $t(48) = 2.67$, $p < .01$, $\eta^2_p = .129$, power = .74, but not in log word frequency, $t(48) = 1.51$, *n.s,* $\eta^2_p = .045$, power = .32.

The HINT sentences are simple declaratives, four to seven words in length (6—7 syllables), containing early-acquired words in semantically predictable contexts. For words in subject position, 15 occurred following an article, one occurred after an adjective, and five occurred after both an article and adjective. The distribution was similar for high- and low-PPF words, $\chi^2(2) = 1.76$, *n.s.* For words in sentence-final position, 20 were nouns, five were adjectives, three were adverbs, and one was a verb (from a reduced infinitive). Again, the distributions did not differ for high- and low-PPF words, $\chi^2(3) = 4.97$, *n.s.* Stimulus sentences are listed in Appendix B.

The linguistic forms of the previously recorded stimulus sentences were not altered in any way. However, the acoustic forms of the original sentences were degraded. The acoustic degradation method used was originally described by Shannon and colleagues (Shannon, Zeng, Kamath, Wygonski & Ekelid, 1995). Spoken sentences were divided into eight frequency bands, and the amplitude envelope from each frequency band was then used to modulate speech-shaped noise. Amplitude-modulated noise bands were then recombined into sentences with preserved temporal and amplitude cues, but with severely degraded spectral cues. Previous work using this spectral degradation with these same sentences found that children's repetition accuracy was greatly reduced when sentences were divided into four or six frequency bands, but that performance reached asymptote at approximately 80 percent accuracy when sentences were divided into eight frequency bands (Eisenberg, Shannon, Martinez, Wygonski & Boothroyd, 2000). One potential problem with this type of acoustic degradation is that fricatives may be more effectively masked than sonorants or stop consonants because of their noisy spectrum. Therefore, the number of fricatives was compared for high- and low-PPF words. The 25 high-PPF words contained a total of 11 fricatives, while the 25 low-PPF words contained 14 fricatives, a nonsignificant difference, $t(48) = -0.69$, *n.s,* $\eta^2_p = .010$, power = .10.

The acoustic degradation served two important purposes. First, these sentences are simple declaratives, so children should be able to repeat them at or near 100 percent accuracy. The acoustic degradation should circumvent any potential ceiling effects. Second, the degradation should force participants to use existing language knowledge to support repetition. The HINT sentences do not differ in syntactic or semantic complexity (*cf.* increasing morphosyntactic complexity in the Recalling Sentences subtest of the CELF-R, Semel *et al.*, 1989), and CVC target words did not differ in word frequency. Only two sources of information varied—PPF and neighborhood density. As described above, including words in meaningful sentence contexts should reduce neighborhood effects due to lexical competition. Accordingly, any differences in accuracy can be attributed to knowledge of phonotactic pattern frequency. Acoustically-modified sentences were transferred to a compact disc for presentation.

Procedure

Children participated in the sentence repetition task as a part of a larger experimental battery lasting 75-120 minutes, depending on how well children stayed on-task. For all children, this was the third experimental task, occurring after a psychoacoustic task (Coady, Evans & Kluender, 2004) and a speech perception task (Coady, Kluender & Evans, 2005). After the two previous tasks and requisite breaks, the sentence repetition task occurred approximately 60-75 minutes into the session, and lasted approximately 4-5 minutes.

Children were tested individually in a large sound-proof chamber (Acoustic Systems). Test items were presented over a single speaker (Realistic Minimus 7) at 75 dB SPL. Frequency response (100-10,000 Hz) was measured earlier and found to be acceptably flat. The speaker was positioned approximately two feet in front of the listener, and calibrated at the beginning of each session. Children were told that they would be hearing a man with a scratchy voice saying some sentences, and their job was to repeat the sentences as quickly and accurately as possible. All children then heard two familiarization sentences. They heard the first sentence (*"Mother picked some flowers"*), and were asked if they could repeat it. Most children could not, so the experimenter said "It sounds to me like *'Mother picked some flowers.'* Let's hear that one again." The first sentence was then played a second time and all children agreed with the experimenter's repetition. Children then heard a second familiarization trial (*"School got out early today"*), and all were able to repeat it after a single presentation. The 40 test sentences were then presented in a fixed, random order, and children's repetitions were recorded for subsequent transcription.

The first author transcribed children's responses from recordings of the experimental sessions. Whole sentences were transcribed using English orthography. CVC target words were then scored in a binary fashion as either correct or incorrect (1 or 0). Because the stimulus items were real words, and because none of the children had articulatory difficulties, cases in which a child missed a single segment were counted as errors.

Reliability

Twenty-two percent of the data (four children from each group chosen at random) were re-transcribed by a listener unfamiliar with the task. This transcriber was given the target sentences, but was blind to both children's language status and the purpose of the study. Interscorer reliability for the four children with SLI was $r = .89$ (96% agreement), and for the four age-matched controls was $r = .95$ (99% agreement). In order to correct for the skewed distributions typical of percentage results, raw accuracy scores were arcsine transformed to normalize the resulting distributions. Arcsine transformed accuracy scores were submitted to statistical analysis.

Results

Raw accuracy scores for both groups of children are shown in Figure 1. Transformed accuracy scores were entered into a mixed design ANOVA, with group as the between subjects factor and PPF and sentence position as within subjects factors. All main effects were significant. Children with SLI repeated CVC target words less accurately than age-matched controls, $F(1,34) = 9.44$, $p < .01$, $\eta^2_p = .217$, power = .85. All children repeated CVC target words with frequently occurring phonotactic patterns more accurately than those with less frequent phonotactic patterns, $F(1,34) = 7.424$, $p = .01$, $\eta^2_p = .179$, power = .75. Also, all children repeated CVC target words more accurately in sentence-final position than in subject position, $F(1,34) = 12.036$, $p = .001$, $\eta^2_p = .261$, power = .92. None of the two way interactions was significant. Both groups of children showed similar effects due to PPF, $F(1,136) = .024$, *n.s.*, $\eta^2_p = .001$, power = .05, and due to sentence position, $F(1,136) = .006$, *n.s.*, $\eta^2_p = .001$, power = .05. Also, for the entire group of children, the effects due to PPF did not differ by sentence position, $F(1,136) = .013$, *n.s.*, $\eta^2_p = .001$, power = .05. However, the three-way interaction between group, PPF and sentence position was significant, $F(1,34) = 5.072$, $p = .03$, $\eta^2_p = .130$, power = .59. Exploration of this interaction revealed that children with SLI were not affected by PPF for words in subject position, $F(1,17) = 0.128$, *n.s.*, $\eta^2_p = .007$, power = .06, but they showed a significant effect due to PPF for words in sentence-final position, $F(1,17) = 5.577$, $p = .03$, $\eta^2_p = .247$, power = .61. Age-matched, typically developing children showed the opposite effect. Their accuracy for words in subject position was affected by PPF, $F(1,17) = 6.798$, $p = .02$, $\eta^2_p = .286$, power = .69, but their accuracy for words in sentence-final position was not, $F(1,17) = 0.359$, *n.s.*, $\eta^2_p = .021$, power = .09.

Children's errors could be broadly placed into three categories. Semantic errors occurred when a child produced a meaningful sentence containing real words that did not match the target. As an example, one child heard the sentence *"The jelly jar is full"* and responded *"The jelly roll is full."* Semantic errors accounted for 42.9% of the errors made by children with SLI and 64.8% of the errors made by typically developing children. Nonword errors occurred when a child replaced a real word with a nonword. An example was a child who responded to the same sentence with *"A jerry dar is four."* Nonword errors accounted for 3.4% of the errors of children with SLI and 1.9% of the errors of typically developing children. The final error type occurred when children made no response. For children with SLI, 53.7% of the errors were no-response errors, while for typical controls, 33.3% of the errors were no-response errors. The distribution of errors types was different for the two groups, $\chi^2(11) = 32.16$, $p < .001$. Generally speaking, children with SLI were more likely to make no-response errors while typical controls were more likely to make semantic errors.

Discussion

The purpose of the present study was to examine whether children with SLI experience difficulty extracting phonological and phonotactic regularities across the corpus of speech that they hear and produce. To this end, children with SLI and age-matched typically developing peers repeated acoustically-degraded sentences containing CVC target words differing in the frequency of their constituent phonological patterns. Meaningful sentences were used instead of nonwords because of recent evidence that the language abilities of children with SLI are underestimated when they are tested with meaningless test items such as nonwords. Results replicated previous findings examining phonotactic sensitivity using a nonword repetition task (Coady, Evans & Kluender, 2008). Children with SLI were less accurate overall, but all children repeated high-PPF target words more accurately than they repeated low-PPF targets. Further, the nonsignificant group by PPF interaction revealed that the magnitude of this effect was similar for both groups. This finding suggests that older children with SLI have extracted phonotactic regularities and established phonological knowledge that they can use to support nonword repetition and sentence repetition, at least by the age of 9;0.

While these findings replicate previous findings by Coady and colleagues (2008), they fail to replicate previous findings reported by Munson and colleagues (2005). Munson and colleagues asked children with SLI and age- and vocabulary-matched controls to repeat nonwords differing in PPF. They found significant effects due to language group and PPF, and a significant interaction between the two. They interpreted this as evidence that children with SLI experience difficulty extracting robust phonological knowledge, resulting from differences in vocabulary size. Differences in stimuli are the most reasonable explanation for different results between studies. Munson and colleagues used nonwords differing in PPF. Their high-PPF nonwords contained frequently occurring consonants and vowels in frequent phonotactic contexts while their low-PPF nonwords contained infrequent phonemes in potentially unattested contexts. The current study used real CVC words familiar to children. Even the low-PPF words consistently occur in speech to and by children. Differences in PPF in the familiar CVC target words may have been enough to trigger differences in repetition accuracy (a main effect), but possibly not differences in group sensitivity to PPF (an interaction effect).

Another finding from the present study was that CVC target words in sentence-final position were repeated more accurately than those in subject position. While this effect was not the intended purpose of the experiment, it was not surprising considering that the stimuli were semantically plausible sentences. A reasonable explanation is that the beginnings of these sentences are uncertain, while the endings are more predictable. In that case, children will be more likely to exploit another source of information, PPF in this case, to facilitate recall of earlier items, but that same PPF information will be less useful for recall of later items that are relatively more predictable given preceding context. This predicts that children should show a larger effect due to PPF for words in subject position, but a smaller effect for words in sentence-final position. This prediction was borne out for typically developing children. However, the three-way interaction revealed that this pattern of sensitivity was not the same for the two groups of children. Children with SLI were more affected by PPF in sentence-final position, while age-matched controls were more affected in subject position.

There are three possible explanations for this finding. First, words in the different sentence positions differed in form class. Words in subject position were always nouns, but words in sentence-final position were nouns, adjectives, adverbs, or verbs. This increased uncertainty about form class may also have forced children with SLI to use PPF to facilitate repetition. However, this option seems unlikely as sentence-final CVC words were repeated more accurately than CVC words in subject position by all children in spite of less certainty. The second possibility is that this difference in phonotactic sensitivity simply might reflect group differences in the serial position effect in memory. Groups may have differed in their recall for earlier (subject position) vs. later (sentence-final position) items, or primacy vs. recency. Gillam, Cowan and Marler (1998) reported that children with SLI showed a reduced recency effect, or poorer recall of later occurring items in a serial memory task. A reduced recency effect would increase the likelihood that children with SLI will exploit another source of information, PPF, to facilitate recall of sentence-final words. Age-matched controls, on the other hand, exhibit better recall of later occurring items such as sentence-final words. While typically developing children may be sensitive to PPF, they may not need to use it to recall words at the ends of short sentences. The third possibility is that the two groups differed in their ability to use established language knowledge to aid sentence recall. Typically developing children may have had to rely on PPF for recall of CVC target words in subject position, but they could rely on semantic structure to recall sentence-final targets, rendering PPF unnecessary. Children with SLI on the other hand may have less robust language knowledge, such as that of semantic expectancies, and may be forced to augment semantic information with PPF information to facilitate repetition. All of these explanations can account for why children with SLI show an effect due to PPF when repeating target words in sentence-final position while age-matched controls do not, but they fail to account for why children with SLI show no effect of PPF for words in subject position.

The results of the current experiment provide evidence that phonotactic frequency facilitates processing of real words in meaningful sentences. On the surface, these results are inconsistent with previous findings that PPF hinders the processing of real words, but facilitates the processing of nonwords (Vitevitch & Luce, 1998). PPF effects in words are assumed to result from competition at the lexical level, while PPF effects in nonwords are assumed to result from facilitatory effects at the sublexical level. However, studies reporting inhibition due to neighborhood density have included tasks that identify words in isolation, with no semantic context. For example, Luce and Pisoni (1998) measured word identification in noise, auditory lexical decision, and speeded word repetition to show that adults respond more slowly to words from dense neighborhoods. In a subsequent study, however, Vitevitch and Luce (1999) reported that inhibitory effects from neighborhood density could be attenuated under conditions in which lexical competition was reduced. In the current study, lexical competition was reduced by including words in sentence contexts. When children heard meaningful, semantically plausible sentences, they were able to exploit PPF to facilitate repetition.The results of the current experiment also provide evidence for the utility of processing-based tasks employing meaningful language. Researchers have avoided using real words to examine language processing in children with SLI because of group differences in overall language abilities. The time and accuracy with which a research participant responds to real words will depend on a number of factors, including but not limited to word frequency, neighborhood density, neighborhood frequency, word familiarity, and age of acquisition. Because children with SLI tend to have smaller lexicons and less command over morphosyntax, researchers have advocated for the use of processing-based tasks either instead of or in conjunction with more traditional knowledge-based tasks (Campbell, Dollaghan, Needleman & Janosky, 1997; Tager-Flusberg & Cooper, 1999). Specifically, Campbell and colleagues advocated for measures in which children of different backgrounds and abilities are equally familiar, or equally unfamiliar, with the tasks and stimuli. Researchers initially focused on nonwords, since they are equally unfamiliar to all children. The alternative described here is to use simple words and sentences that are equally familiar to all children. By using phonologically simple, known words in familiar syntactic frames, children could use established language knowledge to support repetition.

This study provides further evidence that older children with SLI have extracted phonological knowledge from across their lexicons that they can use to support nonword repetition and sentence repetition. The results of a nonword repetition task (Coady et al., 2008) provided such evidence from a processing-based task using stimuli with which all children are equally unfamiliar, and the results from the current study provide similar evidence from a processing-based task using stimuli with which all children are equally familiar. While the sentence repetition task avoids the pitfalls of the nonword repetition task by having children respond to meaningful sentences, it presents a different set of shortcomings in as much as children from nonstandard language backgrounds tend to have less language knowledge to apply to the experimental task. In this case, however, because the words and syntactic frames were familiar, the processing-based sentence repetition task provides converging evidence that children with SLI are sensitive to phonotactic frequency, and that they can use it to support repetition.

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Appendix A

Chronological age (years;months.days), Composite Expressive (ELS) and Receptive (RLS) Language Scores on CELF-R[a], percent phonemes correct on NWR[b], percent final words recalled on CLPT[c], and standard scores on nonverbal IQ measure[d] for children with SLI.

CHILD	AGE	ELS[a]	RLS[a]	NRT[b]	CLPT[c]	Nonverbal IQ[d]
SLI-E 1	7;7.24	84	107	66.67	0	110
SLI-E 2	8;3.14	73	93	39.58	29	118
SLI-E 3	8;4.27	82	89	72.92	21	110
SLI-E 4	9;0.25	76	91	77.08	19	110
SLI-E 5	9;5.16	76	101	81.25	42.8	122
SLI-E 6	10;2.8	84	103	73.96	35.7	106
SLI-E 7	10;4.13	72	90	81.25	52.38	102
SLI-E 8	10;6.13	78	89	71.88	38.1	115
SLI-ER 1	7;2.29	59	76	47.92	2.4	94
SLI-ER 2	7;5.2	70	70	0[e]	0	106
SLI-ER 3	7;7.7	82	70	71.88	0	116
SLI-ER 4	8;2.13	84	80	59.38	4.8	100
SLI-ER 5	9;2.4	54	63	59.38	19	99
SLI-ER 6	9;5.13	62	80	69.79	28.6	108
SLI-ER 7	9;8.21	69	53	63.54	30.95	87
SLI-ER 8	9;9.13	62	50	75	2.4	97
SLI-ER 9	9;9.25	62	54	65.63	33.3	100
SLI-ER 10	10;2.29	53	57	65.63	28.57	89

[a]Clinical Evaluation of Language Fundamentals—Revised (Semel *et al*., 1989)

[b]Nonword Repetition Task (Dollaghan & Campbell, 1998)

[c]Competing Language Processing Task (Gaulin & Campbell, 1994)

[d]Leiter International Performance Scale—Revised (Leiter-R; Roid & Miller, 1997) or Columbia Mental Maturity Scale (CMMS; Burgemeister *et al*., 1997)

[e]This child would not repeat any nonwords.

Appendix B

Stimulus sentences used in the repetition task

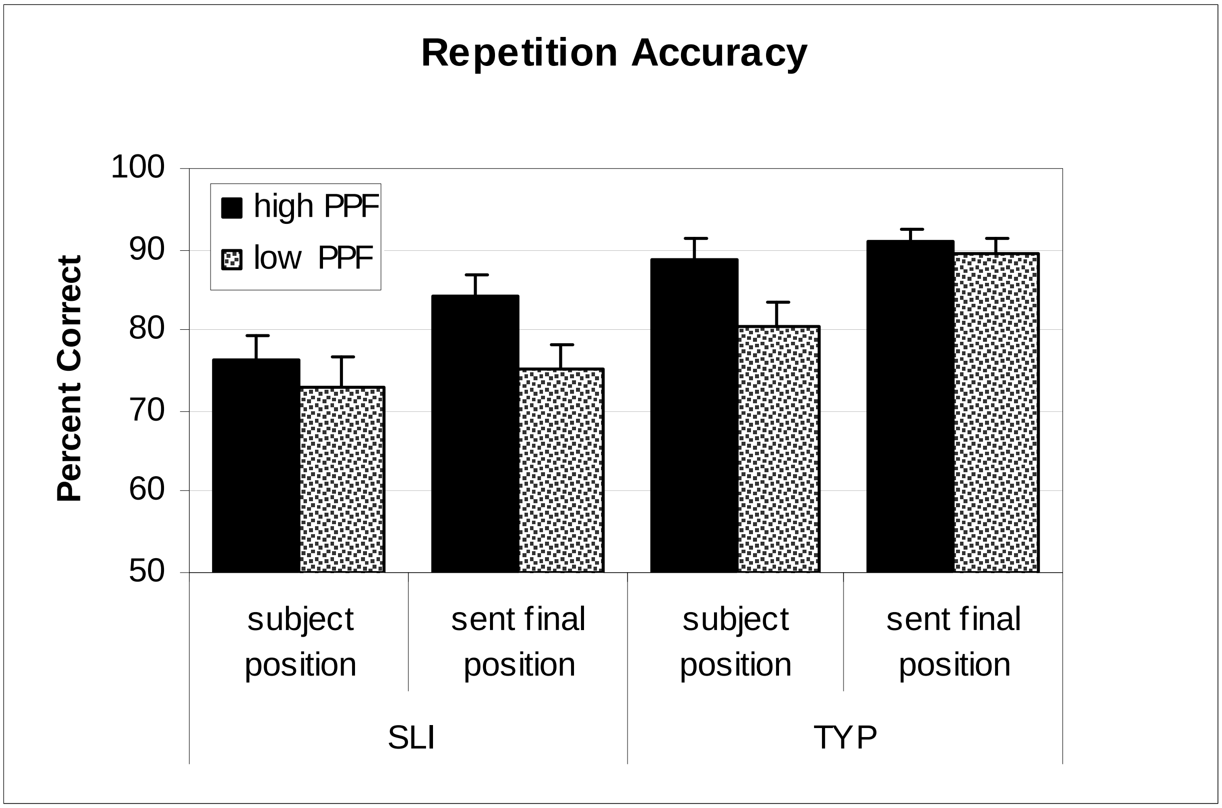
Sentence number		Target Word	Sentence Position	PPF
C007	The fire is very hot.	fire	Subj	low
		hot	Final	high
C008	She's drinking from her own cup.	cup	Final	high
C011	A boy ran down the path.	path	Final	low
C013	Strawberry jam is sweet.	jam	Subj	low
C014	The shop closes for lunch.	shop	Subj	low
C015	The bus leaves before the train.	bus	Subj	high
C017	It's getting cold in here.	here	Final	high
C018	The man called the police.	man	Subj	high
C019	The mailman shut the gate.	gate	Final	low
C021	They heard a funny noise.	noise	Final	high
C024	The book tells a story.	book	Subj	high
C028	The new road is on the map.	road	Subj	low
		map	Final	low
C030	The team is playing well.	team	Subj	low
		well	Final	high
C033	The kitchen clock was wrong.	wrong	Final	low
C035	They finished dinner on time.	time	Final	low
C038	The cat drank from the saucer.	cat	Subj	high
C040	The lady packed her bag.	bag	Final	low
C051	The clown has a funny face.	face	Final	low
C052	The dishcloth is soaking wet.	wet	Final	high
C055	The oven door was open.	door	Subj	high
C069	The ball broke the window.	ball	Subj	high
C072	The rain came pouring down.	rain	Subj	low
		down	Final	high

C080	The road goes up a hill.	road	Subj	low
		hill	Final	high
C083	A sharp knife is dangerous.	knife	Subj	low
C086	She's helping her friend move.	move	Final	low
C089	The sun melted the snow.	sun	Subj	high
C091	The house had nine bedrooms.	house	Subj	high
C094	She took off her fur coat.	coat	Final	low
C097	The baby slept all night.	night	Final	high
C100	There was a bad train wreck.	wreck	Final	low
C104	The old woman is at home.	home	Final	low
C111	A girl came into the room.	girl	Subj	high
		room	Final	low
C112	A field mouse found the cheese.	mouse	Subj	low
		cheese	Final	low
C115	The driver started the car.	car	Final	high
C118	Yesterday he lost his hat.	hat	Final	high
C122	The dog is eating some meat.	dog	Subj	low
		meat	Final	high
C123	The apple pie was good.	good	Final	high
C124	The jelly jar is full.	jar	Subj	high
		full	Final	low
C125	The girl is washing her hair.	girl	Subj	high
		hair	Final	high
C130	He's washing his face with soap.	soap	Final	low

Table 1

Group summary statistics for children with SLI and for typically developing children. Means (with standard deviations) are presented for chronological age (years;months), composite Expressive (ELS) and Receptive (RLS) Language Scores on CELF-R, percent phonemes correct on NRT, and percent final words recalled on CLPT.

	Children with SLI	Typically Developing Children
Age	9;0 (1;1)	8;10 (0;11)
CELF-ELS	71.2 (10.5)	103.7 (15.1)
CELF-RLS	78.7 (18.1)	--
NRT	63.5 (19.1)	82.9 (8.4)
CLPT	21.6 (16.6)	48.3 (12.7)


Repetition Accuracy
Percent Correct
100
90
80
70
60
50
high PPF
low PPF
subject position
sent final position
subject position
sent final position
SLI
TYP