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The Role of Phonotactic Frequency in Sentence Repetition by Children With Specific Language Impairment

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Abstract

Purpose—Recent work suggests that specific language impairment (SLI) results from a primary deficit in phonological processing. This deficit is most striking in nonword repetition tasks, where semantic and syntactic demands are eliminated. Children with SLI repeat nonwords less accurately than do their 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, phonological processing was measured by having children repeat meaningful sentences containing target words differing in phonotactic pattern frequency (PPF).

Method—Eighteen children with SLI (mean age = 9;0 [years;months]) and 18 age-matched controls repeated acoustically degraded sentences containing CVC target words differing in PPF, occurring in either subject position or sentence-final position.

Results—Accuracy results revealed significant main effects due to group, PPF, and sentence position (sentence final > subject). Further, the nonsignificant Group × PPF interaction suggests 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 PPF affects repetition of real words embedded in sentential contexts by both children with SLI and typically developing peers.

Keywords

SLI; phonotactics; sentence repetition; vocabulary; phonological development

Children with *specific language impairment* (SLI) have difficulty acquiring and using language despite having all of the apparent requisite cognitive abilities. These children perform within normal limits on hearing, oral–motor, and nonverbal intelligence assessments and do not have a history of social/emotional disturbance or significant

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neurological impairment. Even so, all available evidence suggests that they experience difficulties in all aspects of language (see, e.g., Leonard, 1998). Researchers have considered a number of potential underlying causes that can be grouped broadly based on the competence–performance distinction. Further, clinical markers consistent with both accounts have been identified. Language competence accounts posit that these children have a primary deficit in grammar resulting from a lack of knowledge of a rule, principle, or constraint. One such theory is the *extended optional infinitive* (EOI) account (Rice, Wexler, & Cleave, 1995), which argues that children with SLI go through an extended period during which they mistakenly believe that verb finiteness marking is optional. Rice and Wexler (1996) subsequently argued that tense marking can be used as a clinical marker for SLI. Language performance accounts posit that the source of impairment arises from a processing deficit, either domain general or language specific. One such domain-general theory is Kail's *generalized slowing hypothesis* (1994), which argues that children with SLI process information in all domains, including language, more slowly than do their unimpaired peers. One domain-specific theory is Gathercole and Baddeley's *phonological memory account* (1990), which argues that children with SLI have a primary deficit in storing phonological materials in memory. Consistent with processing accounts, Bishop, North, and Donlan (1996) suggested that nonword repetition is a reliable clinical marker for SLI.

Phonological Processing in SLI

Some recent work has focused on explaining SLI in terms of a primary phonological deficit. According to this theory, children with SLI experience phonological deficits (Chiat, 2001; Joanisse & Seidenberg, 2003). These deficits, in turn, compromise language acquisition and processing at higher language levels, including the ability to identify word boundaries (Evans, Saffran, & Robe-Torres, 2009) and to extract grammatical morphemes with low perceptual salience, which typically are marked by shorter duration and lower pitch and amplitude (Leonard, 1989). Some theories view these phonological deficits as the underlying source of the language impairment. Chiat (2001) recently presented a formal model explaining how a phonological deficit can lead to the pervasive linguistic deficits experienced by children with SLI. Joanisse and Seidenberg (2003) reported similar findings from computer simulation models. Other theories view these deficits as secondary—as simply an example of yet another combinatorial system with which children with SLI have difficulty (van der Lely, 2005).

Perhaps the strongest evidence for a phonological deficit in SLI comes from studies using the nonword repetition task. In this task, the listener hears a nonword such as "nibe" or "vope" and immediately repeats it. Because test items are meaningless, semantic and syntactic demands are eliminated, and the listener must rely on phonological processes to repeat nonwords. This task has gained wide acceptance in recent years for a number of reasons. First, the task has incredible face validity in that it closely approximates a child's task when learning a new word. Consequently, scores on nonword repetition tasks correlate with scores on standardized vocabulary measures, at least for children acquiring language typically (Bowey, 1996, 2001; Gathercole & Baddeley, 1989; Metsala, 1999). Second, performance on the task has high levels of sensitivity and specificity for ruling in or out language impairments (Conti-Ramsden, Botting, & Faragher, 2001; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000). A consistent finding in the literature is that children with SLI repeat nonwords less accurately than do their age-matched peers (for reviews, see Coady & Evans, 2008; Graf Estes, Evans, & Else-Quest, 2007). Third, the task minimizes cultural biases in that it does not overidentify children from nonstandard language backgrounds (Ellis Weismer et al., 2000; Rodekohr & Haynes, 2001).

In spite of all of this evidence, 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—(a) children with SLI only; (b) children with dyslexia only; (c) children with both SLI and dyslexia; and (d) 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 comorbid 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 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 suffer a phonological processing deficit.

Nonword Repetition as a Phonological Processing Measure

Because nonwords are nonoccurring (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 or phonological processing. However, 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 versus 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 versus unattested consonant sequences (Beckman & Edwards, 2000). As Bowey stated, “any manipulation that increases phonological complexity decreases nonword repetition performance” (2001, p. 443).

All of these complexity variables represent phonological generalizations extracted from the lexicon. A number of models have been developed to explain how this robust phonological knowledge is established (Edwards, Beckman, & Munson, 2004; Metsala & Walley, 1998; Werker & Curtin, 2005). Although these models differ in form, they all agree that pressure from the expanding lexicon forces children to attend to phonological information. As children learn more words, it becomes increasingly likely that they will encounter words that are structurally similar to one another, thereby forcing the child to attend to finer-grained phonological detail. Further, Edwards and colleagues (2004) suggest that this relationship 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 support language processing, including acquisition of more words. This provides an even larger corpus of speech, thereby increasing the robustness of the phonological knowledge.

Children with SLI experience a number of lexical deficits, so it is reasonable to conclude that they will experience difficulty gaining robust phonological knowledge. Retrospective studies suggest that children with SLI acquire their first words later than do children without language impairments (e.g., Trauner, Wulfeck, Tallal, & Hesselink, 2000). They learn new words more slowly (Alt & Plante, 2006; Dollaghan, 1987; Gray, 2004, 2005, 2006; Leonard et al., 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, children with SLI 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 are slower to name pictures (Lahey & Edwards, 1996; Leonard, Nippold, Kail, & Hale, 1983). Further, when naming pictures, children with SLI tend to make both phonological and semantic errors at higher rates than do their 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 do 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 terms of the nonword repetition task, children with and without SLI are influenced by the frequency of nonwords' phonotactic patterns. However, it is not clear whether children with SLI show the same pattern of sensitivity to phonotactic frequency as that of children developing language typically. Munson, Kurtz, and Windsor (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 pattern frequency (PPF). When they compared children with SLI and age-matched controls, they found significant main effects of group, length, and PPF along with a significant Group × PPF interaction, indicating that children with SLI had a larger effect due to PPF. When Munson and colleagues 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. Coady, Evans, and Kluender (2010) also presented a study examining the role of PPF 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 PPF, but no Group × PPF interaction. This lack of an interaction suggests that children with SLI and age-matched typically developing children are similarly affected by differences in PPF within nonwords. Although children with SLI were less accurate overall, they appear to be organizing their lexicons using the same distributional features (such as PPF) as their peers.

Sentence Repetition as a Phonological Processing Measure

Findings from the Munson et al. study (2005) suggest that children with SLI may have difficulty establishing robust representations of individual phonemes, whereas findings from the Coady et al. study (2010) suggest alternatively that children appear to have established lexical representations with similar phonological organization as CA peers across multiple levels of the phonology. For both studies, 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. Although knowledge-based, standardized language measures tend to overidentify children from nonstandard 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 et al., 2000). 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.

An alternative method for examining children's phonological processing would employ meaningful speech. However, the use of real words introduces other potential confounds. Generally speaking, the processing of nonwords depends on phonotactic probability, whereas the processing of real words depends on neighborhood density (ND). Vitevitch and Luce (1998, 1999) originally reported these findings, which they interpreted in terms of a lexical competition model. High-PPF nonwords are easier to process because they receive a boost from the frequently occurring phonotactic patterns. However, in real words, 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, PPF effects in nonwords are facilitatory, with the locus at the sublexical level, whereas PPF effects in words (ND effects) 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 PPF/ND in the processing of real words (see also Luce & Large, 2001). Subsequent work has shown that speakers are indeed sensitive to PPF in real words. For example, Roodenrys, Hulme, Lethbridge, Hinton, and Nimmo (2002) found that ND facilitated adults' word recall—that is, ND exerted a facilitatory effect typically ascribed to PPF.

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 use phonological regularities from their lexicons to support accurate repetition. Sentence repetition was favored over nonword repetition because it uses real words in meaningful combinations, thereby allowing children to exploit established language knowledge. 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 performance on nonword repetition tasks are highly correlated (Bishop et al., 1996; Conti-Ramsden et al., 2001; Kamhi & Catts, 1986). Further, Conti-Ramsden and colleagues (2001) reported that a sentence repetition task provided greater sensitivity and specificity for ruling in/ruling out SLI than did a nonword repetition task.

Serial Position Effects in SLI

For the purposes of this experiment, sentences were included if they contained a CVC target word in subject position or in sentence-final position. These positions were chosen because they should be the most prosodically prominent positions within sentences. Further, repetition should be good for both early- and late-presented information. For recall of long lists of items, there is a characteristic serial position curve in which recall tends to be better for items presented early and for items presented later (e.g., Crowder & Morton, 1969). Better recall for early-presented items, or *primacy*, presumably arises because those items are rehearsed more. The boost for later-presented items, or *recency*, occurs because those items are recalled before their traces have had a chance to decay.

Although children with SLI show evidence of both primacy and recency effects in recall, it is not clear that these effects are comparable for children with SLI and their typically developing peers. Gillam, Cowan, and Marler (1998) examined serial position effects in digit recall under auditory, visual, and audiovisual presentation conditions. There were two response conditions in which children either verbally repeated a list or responded by pointing, in order, to numbers presented on a computer screen. Gillam and colleagues reported that children with SLI showed the expected primacy effects but showed a reduced recency effect. Exploration of this effect revealed that it occurred because typically developing controls showed a larger recency effect in pointing conditions. Mainela-Arnold and Evans (2005) also examined primacy and recency effects in children with SLI by using a dual processing task. In this task, children hear a list of sentences (e.g., “Trains can fly”), judge their veracity, and then recall the last word from each sentence. Mainela-Arnold and Evans reported a reduced primacy effect, most likely because having to process sentences interfered with target-word rehearsal. Finally, Majerus et al. (2009) examined the serial position effect in children with SLI using word lists in a serial recall task. The authors reported comparable primacy and recency effects for children with SLI and age- and nonverbal IQ-matched typically developing children.

To examine the role of phonotactic pattern frequency on repetition, children repeated sentences containing CVC target words differing in phonotactic probability and occurring in either the subject position or the sentence-final position. The specific research questions were as follows: (a) In a sentence repetition task, will children repeat real words with frequent phonotactic patterns more accurately than words with less frequent phonotactic patterns? (b) Will children with SLI show a similar or different pattern of sensitivity to PPF as compared with age-matched typically developing controls?

Method

Participants

Participants included a total of 36 children: Eighteen monolingual English-speaking children with SLI (10 females, 8 males; mean age = 9;0 [years;months], 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, $t(34) = 0.72$. 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 (1 *SD* 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% 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 screening and was not tested that day. She passed the hearing screening on her next visit, at which time she participated in the full experimental battery.

Language assessment measures included (a) the Clinical Evaluation of Language Fundamentals—Revised (CELF–R; Semel, Wiig, & Secord, 1989); (b) the Nonword Repetition Task (NRT; Dollaghan & Campbell, 1998); and (c) 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, whereas 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 children with both expressive and receptive language impairments (ER-SLI). The language criteria for E-SLI were (a) an ELS of at least 1 *SD* below the mean (<85) and (b) an RLS of greater than 1 *SD* below the mean (>85). Criteria for ER-SLI were both ELS and RLS of at least 1 *SD* below the mean (<85). Language criteria for the age-matched control group were an ELS of above 85 and a standard score of 8 or above on the Oral Directions subtest. Group summary statistics are provided in Table 1. Children with SLI scored significantly below typically developing children on all diagnostic measures: CELF–R ELS, $t(34) = 7.50$, $p < .0001$, $\eta_p^2 = .623$, power = 1.00; CELF–R Oral Directions subtest, $t(40) = 3.51$, $p = .001$, $\eta_p^2 = .266$, power = .93; NRT, $t(34) = 3.93$, $p < .001$, $\eta_p^2 = .313$, power = .97; CLPT, $t(34) = 5.43$, $p < .0001$, $\eta_p^2 = .464$, power = 1.00. Individual scores for the children with SLI are provided in Appendix A.

Stimuli

Sentences were drawn from the Hearing in Noise Test (HINT; Nilsson, Soli, & Sullivan, 1994). The HINT was originally developed to measure hearing loss using speech reception thresholds in noisy environments. Instead of pure tones or word lists, the HINT uses real sentences, and so it is more representative of natural language. These sentences are simple declaratives—four to seven words in length (six to seven syllables)—that naïve English-language speakers have judged to be high in naturalness. A subset of these sentences containing vocabulary familiar to 6-year-old children makes up the Hearing in Noise Test for Children (HINT–C; Gelnett, Sumida, Nilsson, & Soli, 1995) and has been used to measure speech reception in noise for child listeners (Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000). That is, stimulus sentences were controlled for aspects of hearing and speech reception and are well established for measuring speech reception in children.

The particular sentences included in the present study contained CVC words in one of two prosodically salient positions—subject position or sentence-final position. Of the 130 sentences appropriate for children, 98 contained a total of 144 CVC words, including nouns, pronouns, verbs, adjectives, adverbs, and prepositions. Of these, 33 were excluded because they did not contain CVC target words in subject position or in 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.

Besides position within sentences, CVC target words were divided by means of a median split into high- and low-PPF groups. PPF was calculated from a segmental analysis of the Brown corpus in the Child Language Data Exchange System (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 (a) the probability of [h] given a syllable (or word) boundary multiplied by (b) the probability of [æ] given [h] multiplied by (c) the probability of [t] given [æ] multiplied by (d) 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, $t(48) = 11.80$, $p < .001$, $\eta_p^2 = .744$, power = 1.00, and in log-frequency-weighted ND, $t(48) = 2.67$, $p < .01$, $\eta_p^2 = .129$, power = .74, but not in log word frequency, $t(48) = 1.51$, *ns*, $\eta_p^2 = .045$, power = .32.

For words in subject position (all nouns), 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, $\chi^2(2) = 1.76$, *ns*. 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, $\chi^2(3) = 4.97$, *ns*. Stimulus sentences are listed in Appendix B.

Linguistic forms of previously recorded stimulus sentences were not altered in any way. However, acoustic forms of the original sentences were degraded. These sentences were simple declaratives, so children should have been able to repeat them at or near 100% accuracy. The acoustic degradation should have circumvented any potential ceiling effects, thereby forcing participants to use existing language knowledge to support repetition. The HINT sentences did 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 ND. As described above, including words in meaningful sentence contexts should have reduced neighborhood effects due to lexical competition. Accordingly, any differences in accuracy could be attributed to knowledge of phonotactic pattern frequency.

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 same 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% accuracy when sentences were divided into eight frequency bands (Eisenberg et al., 2000). One potential problem with this type of acoustic degradation is that fricatives may have been 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 11 fricatives, whereas the 25 low-PPF words contained 14 fricatives, a nonsignificant difference, $t(48) = -0.69$, $\eta_p^2 = .010$, power = .10. Acoustically modified sentences were transferred to a CD for presentation.

Procedure

Children participated in the sentence repetition task as a part of a larger experimental battery lasting 75–120 min, 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 et al., 2005). After the two previous tasks and requisite breaks, the sentence repetition task occurred approximately 60–75 min into the session and lasted approximately 4–5 min.

Children were tested individually in a large soundproof 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 was found to be acceptably flat. The speaker was positioned approximately 2 ft in front of the listener and was 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 retranscribed by a listener unfamiliar with the task. This transcriber was given the target sentences but was blind to children's language status and to the purpose of the study. Inter-scorer reliability for the four children with SLI was $r = .89$ (96% agreement) and for the four age-matched controls was $r = .95$ (99% agreement). 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 analysis of variance (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 did age-matched controls, $F(1, 34) = 9.44$, $p < .01$, $\eta_p^2 = .217$, power = .85. All children repeated CVC target words with frequently occurring phonotactic patterns more accurately than did those with less frequent phonotactic patterns, $F(1, 34) = 7.42$, $p = .01$, $\eta_p^2 = .179$, power = .75. Also, all children repeated CVC target words more accurately in sentence-final position than in subject position, $F(1, 34) = 12.04$, $p = .001$, $\eta_p^2 = .261$, power = .92. None of the two-way interactions was significant. Both groups of children showed similar effects due to PPF, $F(1, 136) = 0.024$, *ns*, $\eta_p^2 = .001$, power = .05, and due to sentence position, $F(1, 136) = .006$, *ns*, $\eta_p^2 = .001$, power = .05. Also, for the entire group of children, the effects due to PPF did not differ by sentence position, $F(1, 136) = 0.013$, *ns*, $\eta_p^2 = .001$, power = .05. However, the three-way Group × PPF × Sentence Position interaction was significant, $F(1, 34) = 5.072$, $p = .03$, $\eta_p^2 = .130$, power = .59. Exploration of this interaction revealed that children with SLI were not affected by PPF for words in subject position, $F(1, 17) = 0.128$, *ns*, $\eta_p^2 = .007$, power = .06, but they showed a significant effect due to PPF for words in sentence-final position, $F(1, 17) = 5.577$, $p = .03$, $\eta_p^2 = .247$, power = .61. Age-matched typically developing children showed the opposite effect. Their accuracy for words in subject position was affected by PPF, $F(1, 17) = 6.798$, $p = .02$, $\eta_p^2 = .286$, power = .69, but their accuracy for words in sentence-final position was not, $F(1, 17) = 0.359$, *ns*, $\eta_p^2 = .021$, power = .09.

Children’s errors could be broadly separated into three categories: (a) semantic errors, (b) nonword errors, and (c) no-response errors. *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 made by children with SLI and 1.9% of the errors made by 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, whereas for typical controls, 33.3% of the errors were no-response errors. The distribution of errors types was different for the two groups, $c^2(11) = 32.16$, $p < .001$. Generally speaking, children with SLI were more likely to make no-response errors, whereas typical controls were more likely to make semantic substitution errors.

Discussion

The purpose of the present study was to examine whether children with SLI can use phonological and phonotactic regularities extracted from the corpus of speech that they hear and produce to facilitate language processing. 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 revealed that children with SLI were less accurate overall, but all children repeated high-PPF target words more accurately than they repeated low-PPF target words. Further, the nonsignificant Group × PPF interaction revealed that the magnitude of this effect was similar for both groups.

There are three reasonable explanations for the non-significant Group × PPF interaction. First, there may not have been sufficient statistical power to find a significant interaction. This seems unlikely because statistical analysis resulted in an F value of less than 1, which did not even approach significance. The second possibility is that the nonsignificant interaction truly indicates comparable levels of group sensitivity to PPF. If this is the case, children with SLI have extracted phonotactic regularities and established robust phonological knowledge that they can use to support nonword and sentence repetition, at least by the age of 9;0. This replicates previous findings by Coady and colleagues (2010) for a nonword repetition task but fails to replicate previous findings reported by Munson and colleagues (2005). The latter study reported significant effects due to language group and PPF, and a significant interaction between the two, likely mediated by vocabulary. Differences in stimuli are the most reasonable explanation for different results between studies and lead to the third possibility. The interaction may require large phonotactic frequency differences between stimulus items. Munson and colleagues used high-PPF nonwords containing frequently occurring consonants and vowels in frequent phonotactic contexts compared with low-PPF nonwords containing infrequent phonemes in potentially unattested contexts. The present 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 were those in subject position. In retrospect, this effect was not surprising, considering that the stimuli were semantically plausible sentences. A reasonable explanation is that the beginnings of these sentences are uncertain, whereas 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, whereas age-matched controls were more affected by PPF in subject position.

There are three possible explanations for this interaction effect. 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 were 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) versus later (sentence-final position) items, or primacy versus recency. Gillam and colleagues (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. Although 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. This explanation gains support from analysis of error patterns. For incorrect repetitions, typically developing children were most likely to substitute a semantically plausible real-word alternative, but children with SLI were most likely to make no response. The accuracy results and error analysis suggest that children with SLI were less able to use other sources of higher level language information such as semantic predictability to support 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 whereas 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 present 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, whereas PPF effects in nonwords are assumed to result from facilitatory effects at the sublexical level. However, studies reporting inhibition due to ND 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 ND could be attenuated under conditions in which lexical competition was reduced. In the present 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. This replicates previous findings in which ND exerts a facilitatory effect, typically ascribed to PPF, for words embedded in a meaningful sentential context (Yates, Friend, & Ploetz, 2008). When interpreting effects of PPF, it is important to note that PPF is necessarily conflated with ND. Because words from dense neighborhoods share phonetic overlap with many other words, phonotactic patterns are more frequent. By contrast, words with infrequent phonotactic patterns typically reside in sparser neighborhoods. Accordingly, ND may well have contributed to facilitation for high-PPF words. As described previously, PPF effects are typically facilitatory, sublexical-level effects, whereas ND effects are typically inhibitory, lexical-level effects. Some studies have attempted to examine these two variables independently to better understand how facilitation due to PPF and inhibition due to ND might interact with one another in word identification (Luce & Large, 2001; Vitevitch & Luce, 1998, 1999). This distinction between PPF and ND has been useful in describing differences in performance between processing of words versus nonwords (Vitevitch & Luce, 1998, 1999). However, it is not clear that this distinction is useful in describing the processing of real words independent of nonwords. Previous work has shown that ND can exert inhibitory effects for words presented in isolation (Luce & Pisoni, 1998) but facilitatory effects for words embedded in sentential contexts (Yates et al., 2008). Similarly, PPF has been shown to exert facilitatory effects in word identification tasks (Luce & Large, 2001; Magnuson, Dixon, Tanenhaus, & Aslin, 2007) but inhibitory effects in word learning tasks (Storkel, Armbrüster, & Hogan, 2006; Storkel & Hoover, 2010). Magnuson and colleagues (2007) suggested that effects of PPF and ND are time dependent, with sublexical effects prevailing at earlier time points in the word recognition process and lexical effects prevailing at later time points. Results from the present study suggest that it also may be useful to consider the nature of the tasks when describing these effects. Inhibition may predominate in cases of uncertainty, as in identifying words in isolation or learning novel words. Facilitation would then arise in cases where uncertainty is reduced, such as when a meaningful sentence provides semantic expectancies or when a simple “same” or “different” response is required.

The results of the present 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, ND, 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, considering they are equally unfamiliar to all children. The alternative described here is to use simple words and sentences that should be familiar to all children. Although it is not a foregone conclusion that these sentences are equally familiar to children with different language abilities, using phonologically simple, known words in familiar syntactic frames should force children to use established language knowledge to support repetition.

This study provides further evidence that phonological knowledge extracted from across their lexicon can be used to support nonword repetition and sentence repetition by children with and without SLI. The results of a nonword repetition task (Coady et al., 2010) provided such evidence from a processing-based task using stimuli with which all children are equally unfamiliar, and the results from the present study provide similar evidence from a processing-based task using stimuli with which all children are familiar. Although 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

Appendix A

Chronological age, composite expressive language scores (ELS) and receptive language scores (RLS) on the CELF–R, percent phonemes correct on NRT, percent final words recalled on the CLPT, and standard scores onc nonverbal IQ measured for children with SLI.[a]

CHILD	AGE[b]	ELS	RLS	NRT	CLPT	Nonverbal IQ[a]
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

CHILD	AGE[b]	ELS	RLS	NRT	CLPT	Nonverbal IQ[a]
SLI-ER 2	7;5.2	70	70	0[c]	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

Note. CELF–R = Clinical Evaluation of Language Fundamentals—Revised; NRT = Nonword Repetition Task; CLPT = Competing Language Processing Task; IQ = intelligence quotient; SLI = specific language impairment; E = expressive language impairment; ER = expressive and receptive language impairments.

[a] For nonverbal IQ, either the Leiter International Performance Scale—Revised or the Columbia Mental Maturity Scale was used.

[b] Expressed in years;months.days.

[c] This child would not repeat any nonwords.

Appendix

Appendix B

Stimulus sentences used in the repetition task.

Sentence number	Stimulus sentence	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

Sentence number	Stimulus sentence	Target word	Sentence position	PPF
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

Note. PPF = phonotactic pattern frequency.

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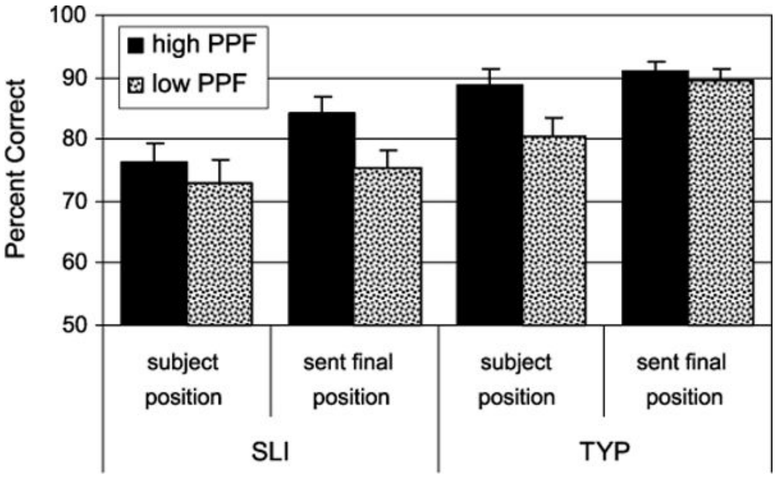

Figure 1.

Repetition accuracy. SLI = specific language impairment; TYP = typical language development.

Table 1

Group summary statistics for children with SLI and for typically developing children.

Variable	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)

Note. Means (with SDs) are presented for chronological age (years; months); composite expressive language scores (ELS) and receptive language scores (RLS) on the Clinical Evaluation of Language Fundamentals—Revised (CELF–R); percent phonemes correct on the Nonword Repetition Task (NRT); and percent final words recalled on the Competing Language Processing Task (CLPT).