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Role of phonotactic frequency in nonword repetition by children with specific language impairments

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Abstract

Background—Children with specific language impairments (SLI) repeat nonwords less accurately than typically developing children, suggesting a phonological deficit. Much work has attempted to explain these results in terms of a phonological memory deficit. However, subsequent work revealed that these results might be explained better as a deficit in phonological sensitivity.

Aims—This study used a nonword repetition task to examine how children with SLI extract phonological regularities from their language input.

Methods & Procedures—Eighteen English-speaking children with SLI (7;3–10;6) and 18 age-matched controls participated in two English nonword repetition tasks. Three- and four-syllable nonwords varied in a single phonotactic frequency manipulation, either consonant frequency or phoneme co-occurrence frequency, while all other factors were held constant. Repetitions were scored in terms of accuracy as either the percentage of phonemes correctly produced or phoneme co-occurrences (diphones) correctly produced. In addition, onset-to-onset reaction times and repetition durations were measured.

Outcomes & Results—Accuracy results revealed significant group, length, and phonotactic frequency effects. Children with SLI repeated nonwords less accurately than age-matched peers, and all children repeated three-syllable nonwords and those with higher frequency phonotactic patterns more accurately. However, phonotactic frequency by group interactions were not significant. Timing results were mixed, with group reaction time differences for co-occurrence frequency, but not consonant frequency, and no group repetition duration differences.

Conclusions & Implications—While children with SLI were less accurate overall, non-significant interactions indicate that both groups of children were comparably affected by differences in consonant and diphone frequency.

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Keywords

specific language impairment (SLI); nonword repetition; vocabulary; phonotactics

Introduction

Children with specific language impairments (SLI) have difficulty acquiring and using language despite having all of the requisite cognitive skills supporting language acquisition. These children have normal non-verbal intelligence, hearing, and oral-motor skills, with no history of social/emotional problems or significant neurological impairment. Nevertheless, their language acquisition lags behind their peers' (for example, Leonard 1998). Broadly speaking, researchers have attempted to explain these difficulties as resulting from deficits in either language competence or language performance. Descriptions focusing on language competence posit that children with SLI have a deficit in the putative syntactic module. These accounts vary in form, with some arguing that children with SLI are missing morphosyntactic features (Clahsen 1989, Gopnik 1990, Rice and Wexler 1996), others that they are missing grammatical rules (Gopnik and Crago 1991), with still others arguing that they have a deficit in underlying syntactic representations (van der Lely 1994, 1998). These competence-based accounts can be contrasted with performance-based accounts, which argue that the deficits experienced by children with SLI result from difficulty processing linguistic materials. These accounts vary concerning the source of the deficit and include: a generalized speed of processing deficit (Kail 1994, Miller *et al*. 2001, Montgomery and Leonard 1998); a surface account in which children with SLI are hypothesized to have difficulty perceiving and extracting meaning from the grammatical morphemes at the ends of words (Leonard *et al*. 1992); a temporal processing deficit (Tallal 2004); a verbal working memory deficit (Bishop 1997, Ellis Weismer *et al*. 1999); a phonological working memory deficit (Gathercole and Baddeley 1990); or, a deficit in establishing robust underlying linguistic representations that typically support acquisition of higher level structures (Bishop 2000, Coady *et al*. 2005, Joanisse and Seidenberg 1998, Stark and Heinz 1996a, 1996b).

One method used to explore the nature of deficits in children with SLI is the nonword repetition task (NRT). In this task, listeners hear nonsense words, such as *nibe* or *vope*, and repeat them immediately. While this task has been used increasingly to examine the linguistic deficits experienced by children with SLI, there really is no consensus as to what the task actually measures. Kamhi and colleagues (Kamhi and Catts 1986, Kamhi *et al*. 1988) used a NRT to show that children with SLI have reduced levels of phonological sensitivity. Gathercole and Baddeley (1990) used another version to show that children with SLI have reduced phonological memory capacity. Stark and Blackwell (1997) used yet another version of this task to show that children with SLI experience deficits in planning motor movements. Whatever the underlying cause, researchers have consistently found that children with SLI repeat nonwords less accurately than children developing language normally. These effects have been reported for phonologically complex languages like English (Gathercole and Baddeley 1990, Kamhi and Catts 1986, Kamhi *et al*. 1988, Stark and Blackwell 1997), Swedish (Sahlén *et al*. 1999), and Spanish (Girbau and Schwartz

2007, 2008), but not for a less phonologically complex language, Cantonese (Stokes *et al*. 2006).

One factor that affects how accurately speakers repeat nonwords is phonological complexity. Generally speaking, the more complex a nonword is, the less likely it is to be repeated accurately. Complexity effects appear to be universal in that they have been shown for children and adults, both with and without language impairments. Further, effects appear no matter how complexity is manipulated—in terms of articulatory complexity, in terms of adult ratings of subjective wordlikeness, or in terms of phonotactic pattern frequency.

Articulatory complexity has been manipulated in two different ways. Kamhi and colleagues (Kamhi and Catts 1986, Kamhi *et al*. 1988) had children with language impairment and typical controls repeat nonwords containing easily discriminable consonants (for example, *batheris*) or minimal phonetic contrasts (for example, *fathesis*). Gathercole and Baddeley (1989) used a different manipulation. They had typically developing children repeat nonwords with singleton consonants (for example, *woogalamic*) or consonant clusters (for example, *blonderstaping*). For both articulatory complexity manipulations, children repeated simple nonwords more accurately than complex non-words. These findings have been replicated both for typically developing children and for children with SLI (Bishop *et al*. 1996, Briscoe *et al*. 2001, Gathercole and Baddeley 1990, Gathercole *et al*. 1991a, cf. 1991b).

While Gathercole and Baddeley (1989) originally argued that nonword repetition provides a content-free measure of language processing, they later acknowledged that long-term language knowledge facilitates repetition accuracy (Gathercole *et al*. 1991b). Speakers more accurately repeat nonwords that are structurally similar to words they already know (see also Snowling *et al*. 1991). Gathercole and colleagues reported that children repeated nonwords that adults had rated high in wordlikeness more accurately than those that received low ratings (see also Gathercole 1995). Briscoe *et al*. (2001) extended these findings to children with SLI. Gathercole and colleagues offered two possible explanations for these wordlikeness effects. First, speakers may be using stored *lexical* knowledge to support repetition. Upon hearing a nonword, speakers would scan their own lexicons for specific words sharing phonological structures, which they would then use to support repetition. Dollaghan *et al*. (1995) tested this possibility by having typically developing boys repeat nonwords in which the stressed syllable either was or was not a real word in English (for example, *BATHesis* versus *FATHesis*). Results indicated that children do indeed use lexical knowledge to support nonword repetition. The second possibility is that speakers may be using stored *sublexical* knowledge to support repetition. In this case, they would be scanning their lexicons for similar phonological structures or frames to support repetition. Beckman and Edwards (2000) and Munson (2001) tested this possibility by having children repeat nonwords containing phoneme combinations differing in frequency of occurrence (see also Edwards *et al*. 2004). In these studies, typically developing children repeated nonwords with frequent consonant sequences (for example, [ft] in *moften*) more accurately than those with less frequent or non-occurring sequences (for example, [fk] in *mofken*). Stokes *et al*. (2006) reported similar findings for Cantonese speaking children with SLI and age-matched controls.

Finally, researchers have manipulated complexity by varying phonotactic pattern frequency, or the relative frequencies with which phonemes occur and co-occur in the syllables and words of the language. Zamuner *et al*. (2004) had very young children (1;8 to 2;4) repeat pairs of CVC nonwords in which one member of the pair contained a coda consonant in a frequently occurring phonetic context (for example, [nin]), while the other contained the same coda consonant in a less frequent phonetic context (for example, [von]). They found that children repeated coda consonants more accurately when they occurred in a more frequently occurring phonetic context. Coady and Aslin (2004) had very young children (aged 2;6 and 3;6) repeat nonwords varying in the frequency of individual segments or in the frequency of combinations of segments. They reported that children repeated nonwords containing more frequent phonological patterns more accurately than those containing less frequent phonological patterns. Munson *et al*. (2005) reported similar phonotactic frequency effects in older children, both developing language typically and with SLI.

These complexity variables reflect generalizations extracted from over the entire lexicon. As outlined by Edwards *et al*. (2004), phonological knowledge develops directly from vocabulary acquisition and use (see also Werker and Curtin 2005). As children are learning language, they gain experience in perceiving and producing new word forms. Over time, they encounter a representative sample of the possible phonological patterns. As their experience with words and their component phonological patterns grows, phonological knowledge becomes more robust. Just as children learn to use word knowledge to produce and perceive novel sentences, so too do they use phonological knowledge to produce and perceive novel words. In nonword repetition tasks, they use this phonological knowledge generalized from over their lexicons to perceive and produce novel phonological strings. Because speakers more accurately repeat nonwords that reflect the properties of their lexicons, Coady and Aslin (2004) reasoned that the nonword repetition task can be used to measure the degree to which children have extracted phonological regularities from their language input (see also Edwards *et al*. 2004). That is, NRTs can inform us about how well all children, including those with SLI, are able to extract regularities about the sound structure of their native language.

A number of studies have begun to question whether the challenges of extracting phonological regularities across the lexicon might be the underlying source of impairment for SLI. According to these studies, children with SLI have difficulty establishing robust linguistic representations, which in turn affects their ability to repeat or learn new words and their ability to add grammatical endings to known words (Bishop 2000). The bulk of this evidence comes from investigations of children's speech perception abilities. Relative to children acquiring language typically, children with SLI have more overlap between adjacent phonetic categories as indicated by shallower identification functions and poorer discrimination of tokens drawn from adjacent categories (Coady *et al*. 2005, 2007, Joanisse and Seidenberg 2003, Stark and Heinz 1996a, 1996b). These effects are exacerbated when children are asked to label and discriminate synthetic rather than naturally spoken versions of speech stimuli (Coady *et al*. 2007, Evans *et al*. 2002). Presumably, children with robust underlying representations are less susceptible to such perturbations, while children whose underlying representations are more fragile exhibit impaired patterns of perception.

Other studies have investigated the robustness of underlying linguistic representations in children with SLI by manipulating item frequency or familiarity. If children with SLI show reduced sensitivity to the frequency manipulation, then one may conclude that their underlying representations are less robust than those of their typically developing peers. Dollaghan (1998) and Montgomery (1999) reported results from gating studies in which children with SLI need more acoustic information to identify unfamiliar target words. However, these same children identified familiar words at the same gate durations as their typically developing peers (see also Mainela-Arnold *et al*. 2008). In a past-tense marking study, Marchman *et al*. (1999) reported that children with SLI made more errors producing past tense forms than did unimpaired peers. However, both groups were less likely to make errors on frequently occurring words. Further, when frequency conspired with other factors, such as the phonological form of the verb stem or the presence/absence of irregularly marked neighbours, group accuracy differences disappeared. Oetting and Rice (1993) reported similar findings from a plural marking task. Together, these findings suggest that children with SLI establish robust representations of highly familiar, frequently occurring words, while their representations of less familiar, less frequent words remain fragile.

If children with SLI establish robust representations, at least for frequent words, are they then able to extract phonological regularities that should facilitate language processing and subsequent acquisition? To test this, phonological pattern frequency, or phonotactic frequency, is typically manipulated. A study by Mainela-Arnold *et al*. (2008) examined lexical representations by having children with SLI and age-matched controls participate in a forward gating task where target words varied by word frequency and by neighbourhood density, or the number of phonologically similar words in the lexicon. Neighbourhood density is an indirect measure of phonotactic frequency in that words with many phonological or lexical neighbours contain frequently occurring phonotactic patterns, and *vice versa*. In adult studies of language processing, words from dense neighbourhoods are identified more slowly than words from sparse neighbourhoods because the many similar sounding words introduce greater lexical competition (Luce and Pisoni 1998). Results from the gating task replicated these findings. Children identified words from dense neighbourhoods at later gate durations than words from sparse neighbourhoods, and these effects were comparable for both groups of children. In another study, Coady *et al*. (under review) examined children's sensitivity to phonotactic frequency by having children with SLI and age-matched controls repeat acoustically degraded sentences containing target words varying in phonotactic frequency. They found that children with SLI repeated target words less accurately overall, but that they were as sensitive to phonotactic frequency as their typically developing peers.

The preliminary evidence suggests that children with SLI do extract and use phonotactic regularities to process real words. The question then becomes whether they can use this source of information to process novel phonological strings, or nonwords. A number of recent studies have compared how accurately children with SLI and their typically developing peers repeat nonwords differing in complexity. These studies repeatedly have found significant group effects, indicating that children with SLI are less accurate overall. However, potential differences in sensitivity to nonword complexity are tested by examining group by complexity interactions. Any lack of an interaction has been interpreted as evidence that children with SLI and typical controls are equally influenced by complexity, while significant interactions indicate that these two groups are differently affected. However, significant interactions can realistically result from two different patterns of results. First, children with SLI may be less affected by a phonotactic manipulation. Alternatively, children with SLI may be more sensitive to complexity than their typically developing peers. This may result either because of facilitatory effects due to frequent phonotactic patterns or because of inhibitory effects from infrequent patterns.

Gathercole and Baddeley (1990) reported that five children with language impairment and their typically developing peers were equally affected by articulatory complexity, as measured by the presence versus absence of consonant clusters. This finding was replicated by Edwards and Lahey (1998), who found no group differences due to articulatory complexity within their six nonwords. However, Bishop *et al*. (1996) tested a greater number of children on a larger set of nonwords and found that children with SLI were more severely affected by the presence of consonant clusters (see also Briscoe *et al*. 2001). While this suggests that children with SLI are disproportionately affected by the presence versus absence of consonant clusters within nonwords, Gathercole and Baddeley (1990) acknowledge that deficits due to this type of articulatory complexity are typically interpreted as poor articulatory control rather than in terms of phonological generalizations extracted from over the lexicon.

While articulatory complexity within nonwords affects children with SLI more than typically developing children, effects due to subjective wordlikeness appear to be similar for both groups. Briscoe *et al*. (2001) reported that children with SLI and their typically developing peers were equally influenced by subjective wordlikeness ratings. These effects, however, are difficult to decipher. A number of studies have found that subjective wordlikeness ratings are correlated with phonotactic probability (for example, Bailey and Hahn 2001, Frisch *et al*. 2000, Gathercole *et al*. 1991b). However, other work has shown that many different factors influence subjective wordlikeness ratings. Coleman and Pierrehumbert (1997) asked adults to judge the wordlikeness of nonwords containing both high-frequency combinations and unattested phonotactic sequences, which drop overall phonotactic probability to zero. They reported that these ratings were more variable than would be expected by phonotactic probability alone. Specifically, higher frequency phonotactic patterns could compensate for zero-probability, illegal sequences.

In the current study, the degree to which children with SLI are able to extract phonological regularities from their language input was examined by having a group of 18 children with SLI, mean age 9;2, and a group of 18 age-matched control children repeat two lists of three- and four-syllable nonwords differing in phonotactic frequency. Shorter one- and two-syllable nonwords were not included because a recent meta-analysis revealed that group differences are minimal for shorter nonwords, but robust for longer nonwords (Graf Estes *et al*. 2007). This corresponds to results for Spanish-speaking children with SLI (Girbau and Schwartz 2007), who had particular difficulty repeating three-, four- and five-syllable nonwords. The first list of nonwords varied in consonant frequency, while vowel frequency, diphone (co-occurrence) frequency, and ease of articulation were held constant. Successful repetition of these nonwords requires that children be sensitive to the frequency with which individual consonants occur. The second list varied in diphone frequency, while consonant frequency, vowel frequency, and ease of articulation were held constant. Successful repetition of this second set requires sensitivity to the frequency with which consonants and vowels co-occur. Children with SLI were hypothesized to repeat nonwords less accurately, more slowly (longer reaction times), and less fluently (longer durations), consistent with previous findings. However, of particular interest are potential interactions between group and phonotactic frequency. Significant interactions would suggest that children with SLI extract phonological regularities in a manner different from their typically developing peers, perhaps more slowly or less robustly. Alternatively, non-significant interactions would suggest that children with SLI are extracting phonological regularities from their language input comparably to their unimpaired peers.

Methods

Participants

Participants included 18 monolingual English-speaking children (ten females, eight males) with specific language impairment, mean age 9;2 (range = 7;3–10;6) and 18 typically developing children (twelve females, six males), mean age 8;10 (range = 7;4–10;0). The age difference between groups was not significant, $t(34) = 1.24$, $p = 0.22$. 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). Non-verbal IQs were at or above 85 (1 standard deviation (SD) below the mean or higher) as measured by the Leiter International Performance Scale—Revised (Leiter-R; Roid and Miller 1997) or the Columbia Mental Maturity Scale (CMMS; Burgemeister *et al*. 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 puretone screening at 25 dB for 500 Hz tones, and at 20 dB for 1000, 2000, and 4000Hz tones. One typically developing child was experiencing flu symptoms on her first visit, and so failed the hearing screen. She was not tested that day. She passed the hearing screen on her next visit, at which time she participated in the full experimental battery.

The language assessment measure was the Clinical Evaluation of Language Fundamentals—Revised (CELF-R; Semel *et al*. 1989). 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. Two additional language measures were collected but not used for diagnosis. The Nonword Repetition Task (NWR; Dollaghan and Campbell 1998) was collected as a descriptive measure of phonological working memory, defined as storage capacity for phonological materials such as words and nonwords.[1] The Competing Language Processing Task (CLPT; Gaulin and Campbell 1994) was collected as a descriptive measure of verbal working memory, defined as a global set of resources supporting both language processing and memory capacity. CLPT is a dual-processing task in which children hear a list of sentences, judge their veracity, and then recall the final words, thereby requiring simultaneous processing and recall.

The group of children with SLI included eight children with only expressive language impairments (SLI-E) and ten with both expressive and receptive language impairments (SLI-ER). The language criteria for SLI-E were ELS at least one standard deviation below the mean (< 85) and RLS greater than one standard deviation below the mean (> 85). Criteria for SLI-ER 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 measures: nonverbal intelligence, $t(34) = 3.755$, $p < 0.001$; CELF-R ELS, $t(34) = 7.543$, $p < 0.0001$; CELF-R Oral Directions subtest, $t(40) = 3.542$, $p = 0.001$; NWR, $t(34) = 4.564$, $p < 0.0001$; CLPT, $t(34) = 5.406$, $p < 0.0001$.

Stimuli

Two lists of 24 nonwords varying in phonotactic frequency were constructed. In the first list, phonotactic frequency differences were carried only by the consonants. In the second, differences were carried only by the diphones, or combinations of phonemes. As an example, consider two different consonants, fricative [s] and glide [j]. The former occurs very frequently, while the latter is less common. Nonwords in the first list varied along this dimension. Now pair these consonants with two different vowels, [i] and [u]. The [si] combination (‘*see*’) is quite common, but [su] (‘*sue*’) is less so. The diphone frequencies for [j] are the opposite, with [ji] (‘*yee*’) being quite rare and [ju] (‘*you*’) being very frequent. Non-words in the second list varied along this dimension. Consonant and diphone frequencies were estimated from the Brown (1973) corpus in the CHILDES database (MacWhinney 1991), as described in Coady and Aslin (2004). Both lists of nonwords varied orthogonally in phonotactic frequency and in the number of syllables. Each list contained twelve high phonotactic frequency nonwords and twelve low phonotactic frequency nonwords. Non-words were further divided by number of syllables. Half contained three syllables, while the other half contained four syllables.

Each list of nonwords contained three- and four-syllable nonwords with the basic structure (CV) CV·CV·CVC. For the three-syllable nonwords, stress was always placed on the penultimate syllable, as in ‘*banana*’ [bə·nǽn·ə]. For the four-syllable nonwords, primary stress was also placed on the penultimate syllable, with secondary stress placed on the first syllable, resulting in a strong–weak–STRONG–weak stress pattern, as in ‘*absolutely*’ [æb̀·sə·lút·li]. These stress patterns were chosen because they represent typical English stress patterns (Halle and Vergnaud 1987) that should be familiar to children. For both sets of nonwords, voiced fricatives ([v], [ð] as in ‘*that*’, [z], and [ʒ] as in ‘*vision*’) were excluded because they are late acquired. Lax vowels were also excluded so that ambisyllabicity was

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[1] Because the nonwords in Dollaghan and Campbell's NWR task are minimally word-like (low phonotactic probability), it typically is used as a measure of phonological working memory, but cannot be used to assess sensitivity to probabilistic phonotactic structure.

precluded.[2] Nasals, laterals and rhotics ([m], [n], [ŋ], [l], and [ɹ]) were excluded from word final position since they tend to colour the preceding vowel. Finally, none of the nonwords contained embedded real words that might facilitate repetition (Dollaghan *et al.* 1995).

For the first list, high- and low-consonant frequency nonwords differed in consonant frequency, $F(1, 80) = 117.50$, $p < 0.001$, but not in vowel frequency, $F(1, 80) = 0.34$, $p = 0.56$, or in diphone (cooccurrence) frequency, $F(1, 20) = 2.605$, $p = 0.12$. Further, high- and low-consonant frequency nonwords did not differ in ease of articulation, as measured by frequency of occurrence in infants' babbling repertoires $F(1, 80) = 0.39$, $p = 0.54$ (Locke 1980). For the second list, high- and low-diphone frequency nonwords differed in diphone frequency, $F(1, 20) = 12.733$, $p < 0.01$, but not in consonant frequency, $F(1, 80) = 0.72$, $p = .403$, or in vowel frequency, $F(1, 80) = 2.66$, $p = 0.11$. Further, nonwords did not differ in ease of articulation, $F(1, 80) = 2.51$, $p = 0.12$. Because of the limited number of diphones available, four medium-frequency diphones, [ʤa], [ka], [sa], and [ɹaᶷ], appeared in both lists of nonwords. In these cases, overall phonotactic frequency differences were carried by the other syllables in the nonwords.

A female speaker native to the Upper Midwest area recorded the stimuli directly onto a Windows-based waveform analysis program. A speaker of the local dialect was used so that children would not misperceive the nonwords due to any potential dialect differences. Nonword stimuli were digitized at a 44.1 kHz sampling rate with 16-bit resolution. Each nonword was excised and saved as its own soundfile. For the first set differing in consonant frequency, three-syllable nonwords were of shorter duration than four-syllable nonwords, $F(1, 20) = 173.149$, $p < 0.0001$. However, with practice, the speaker produced the nonwords without significant duration differences due to consonant frequency (high frequency: 837ms; low frequency: 860ms), $F(1, 20) = 2.791$, $p = 0.11$. For the second set of nonwords differing in diphone frequency, there was again a duration difference due to the number of syllables, $F(1, 20) = 56.011$, $p < 0.0001$. However, there were no duration differences due to diphone frequency (high frequency: 873 ms; low frequency: 885 ms), $F(1, 20) = 0.332$, $p = 0.57$. Soundfiles were transferred to compact discs for presentation in a fixed random order with a 5 s intervening silence for children's repetitions. They were blocked by condition, with all

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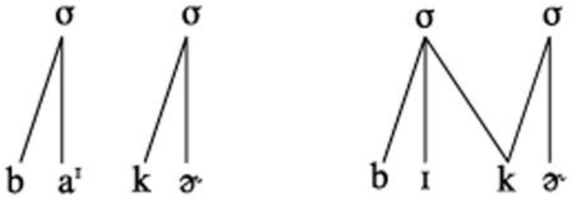
[2] English syllabification rules state that each vowel within a word serves as a syllable nucleus. Preceding consonants are then attached to vowels as syllable onsets. A vowel can take as many consonants as are permitted by phonotactic rules. Finally, any remaining consonants are attached as coda consonants (Kahn 1980). In some cases, vowel quality affects syllabification such that a single consonant serves both to close a preceding syllable and to open a following syllable, that is, it is ambisyllabic. Tense vowels such as /aI/ in '*bye*' can close a syllable and so do not require a coda consonant.
But lax vowels such as /I/ in '*bit*' cannot close a syllable and so must be followed by a coda consonant. Consider two bisyllabic words '*biker*' and '*bicker*'. '*Biker*' contains a tense vowel, and so there is a clear syllable boundary between it and the following consonant. '*Bicker*' on the other hand contains a lax vowel that must be followed by a consonant. In this case, the single word-medial consonant simultaneously closes the first syllable and opens the second. While the consonant attaches to both syllables, it is only a single consonant of no longer duration than a similar consonant that attaches to a single syllable. This ambisyllabicity will necessarily affect how phonotactic frequency is calculated



children hearing nonwords differing in consonant frequency first, followed by those differing in diphone frequency. The fixed ordering may have introduced an unintended ordering effect, but this would apply equally to all children. Phonetic transcriptions of nonwords and their English orthographic approximations are provided in the appendix.

Procedure

Children participated in the nonword repetition tasks as a part of a larger experimental protocol. Listeners 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 to be acceptably flat, and presentation level was calibrated at the beginning of each session. The speaker was positioned approximately 2 feet in front of the listener. Children were told that they would be hearing funny, made-up words, and their job was to repeat them back as quickly and as accurately as possible. Sessions were recorded for subsequent scoring.

Scoring

Children's responses were transcribed from the recordings of the experimental sessions. Each phoneme produced was scored relative to its target. Point-by-point accuracy was calculated via consensus scoring, thereby forcing 100% interscorer reliability. Two transcribers blind to children's language status each did a full first-pass transcription, their results were compared, and a third listener mediated any disagreements. For two of the children (one with and one without SLI), the third listener was unable to resolve all disagreements, so a fourth listener was consulted. It is interesting to note that, for the entire set of 48 nonwords, there were an average of 84.7 points of discrepancy for the children with SLI (out of 384 target phonemes), but only 56.7 points of discrepancy for the typically developing children. This difference was significant, $t(34) = 4.429$, $p < 0.0001$, and suggests that transcribers were less likely to agree on speech by children with SLI, perhaps because of their less precise articulations. This replicates previous findings that children with SLI differ subtly from age-matched peers in the stability with which they produce multi-movement sequences, even though they show no evidence of overt articulatory difficulties (Goffman 1999). This inconsistency was addressed by the consensus scoring method which necessarily forces 100% interscorer reliability.

For nonwords differing in consonant frequency, accuracy was calculated as per cent phonemes correct (PPC), defined as the number of target phonemes correctly produced divided by the sum of the number of target phonemes plus the number of any added phonemes. Traditionally, phoneme deletions or substitutions are counted as errors, while phoneme additions are not because they do not represent any loss of information (Dollaghan and Campbell 1998). This is appropriate if the task is used as a measure of phonological working memory. However, the current version of the task is meant as a measure of children's sensitivity to phonotactic regularities. In this case, phoneme additions suggest that neither syllable structure nor phonotactic regularity has been maintained. Accordingly, additions were counted as errors. Phoneme substitutions and deletions affected accuracy by reducing the numerator, while phoneme additions affected accuracy by increasing the denominator. For nonwords differing in diphone frequency, scoring was modified such that the per cent of diphones correctly produced was calculated for each repetition response. Because nonwords did not differ in the frequency of phoneme occurrence, but rather in the frequency of cooccurrence, the percentage of diphones correctly produced (PDC) was calculated for each nonword. In order to be counted as correct, both phonemes in a diphone pair had to be veridically repeated in the correct order, without any intervening phonemes. As an example, one child's response to the nonword ‘poy·rah·foo·lahd’ was ‘poy froo·lahd’. In the first set of nonwords, this would have been counted as seven target phonemes correctly produced (the [r] would be counted as an error since its syllable position was not maintained) over the sum of nine target phonemes plus the added [r] phoneme, or 70%. For the purposes of the second experimental condition, this nonword contains five target diphones, [poy-], [rah-], [foo-], [lah-], and [-ahd]. Of these, only [poy], [lah], and [ahd] were produced in the correct order, without intervening phonemes. The added [r] increases the denominator in that the target [foo] diphone was produced as two diphones, [fr] and [roo]. Thus, this repetition included three target diphones correctly produced over the sum of five target diphones plus one added diphone, or 50%. PPC in the first condition and PDC in the second condition were arcsine transformed and submitted to statistical analyses.

Timing measures were also calculated by the first transcriber. For each child, the onset of the target nonword, and the onset and offset of the repetition response were recorded. Reaction time was calculated as the time between the onset of the target nonword and the onset of the repetition response. Duration was calculated as the lag between the onset and offset of the repetition. Reaction times and durations were calculated for all repetition responses, regardless of accuracy. A second transcriber calculated reaction times and durations for 13% of the participants, or five children chosen at random—three children with SLI (16%) and two children developing language typically (11%). Over both experiments, interscorer reliability correlation coefficients for reaction time measures ranged from 0.90 to 0.99, while those for duration measures ranged from 0.83 to 0.91.

Results

Accuracy

Raw accuracy scores are shown in Figure 1. For nonwords differing in consonant frequency, transformed accuracy scores (PPC) were entered into a stepwise multiple regression analysis, with language group, phonotactic frequency, nonword length, and performance IQ as the relevant variables. To account for within-subject variance, 17 dummy subject variables were created per group such that each participant's results were represented by one variable; the 18th participant's results were indicated by zeroes in all dummy variables. These subject variables were entered in the first step and accounted for a significant portion of the variance, $R^2 = 0.2142$, $F(34, 828) = 7.909$, $p < 0.0001$. The experimental variables group, phonotactic frequency, number of syllables, and all interaction terms were entered in the second step. Performance IQ was also entered as a potentially confounding variable, but age was not. Of these variables entered in the second step, the number of syllables accounted for the most variance and entered the analysis first, $\Delta R^2 = 0.1459$, $F(1, 17) = 158.007$, $p < 0.0001$. Phonotactic frequency entered next, also accounting for a significant portion of the variance, $\Delta R^2 = 0.0207$, $F(1, 17) = 28.518$, $p < 0.0001$. Group entered the analysis next and accounted for a significant portion of the variance, $\Delta R^2 = 0.0104$, $F(1, 17) = 14.375$, $p < 0.01$. The group by number of syllables interaction was significant, $\Delta R^2 = 0.0087$, $F(1, 17) = 11.915$, $p < 0.01$. Examination of this interaction revealed that effects due to the number of syllables were greater for children with SLI, $\Delta R^2 = 0.2064$, $F(1, 17) = 126.052$, $p < 0.0001$, than for typically developing children, $\Delta R^2 = 0.0732$, $F(1, 17) = 39.526$, $p < 0.0001$. None of the other interactions or performance IQ accounted for a significant portion of the variance, and consequently did not enter the analysis.

For nonwords differing in diphone frequency, accuracy scores (PDC) were entered into a separate stepwise multiple regression analysis, with diphone frequency, number of syllables, language group, and all interactions as the relevant variables. Performance IQ was also entered as a potentially confounding variable. Dummy subject variables were entered in the first step and accounted for a significant portion of the variance, $R^2 = 0.2453$, $F(34, 828) = 7.916$, $p < 0.0001$. Of the experimental variables, number of syllables entered the analysis first, $\Delta R^2 = 0.0639$, $F(1, 17) = 76.521$, $p < 0.0001$. The phonotactic frequency by number of syllable interaction entered the equation next, $\Delta R^2 = 0.0195$, $F(1, 17) = 23.960$, $p < 0.0001$. Examination of this interaction revealed significant phonotactic frequency effects for the three-syllable nonwords, $\Delta R^2 = 0.0657$, $F(1, 17) = 38.383$, $p < 0.0001$, but not for the four-syllable nonwords, $\Delta R^2 < 0.0001$, $F(1, 17) = 0.024$, *n. s*. Phonotactic frequency entered the equation next, $\Delta R^2 = 0.0180$, $F(1, 17) = 22.773$, $p < 0.001$. Language group entered the analysis in the fifth step, accounting for a significant portion of the variance, $\Delta R^2 = 0.0147$, $F(1, 17) = 18.954$, $p < 0.001$. Neither performance IQ nor any other interactions accounted for additional significant variance.

Reaction times

Onset-to-onset reaction times for both sets of nonwords are shown in Figure 2. Reaction time results for the first condition were entered into a stepwise multiple regression analysis. There were 22 cases out of 864 in which children did not attempt a response, in all cases, children with SLI. These instances were included in the accuracy analysis, but not in reaction time or duration analyses. Dummy subject variables were entered in the first step to account for within subjects variance, and accounted for a significant portion of the variance, $R^2 = 0.2206$, $F(34, 807) = 6.703$, $p < 0.0001$. Stimulus duration (in milliseconds) was forced into the equation in the second step as a confounding factor. Speakers take more time to initiate a response when the item to be produced is itself of longer duration (Sternberg *et al*. 1978). Therefore, the actual durations of spoken nonwords were factored out of the equation so that any remaining effects can be attributed to independent variables. This confounding variable accounted for a significant portion of the variance, $\Delta R^2 = 0.0444$, $F(1, 17) = 48.561$, $p < 0.0001$. Performance IQ and all experimental variables and interactions entered the equation in the third step. Of these, only number of syllables accounted for a significant portion of the variance, $\Delta R^2 = 0.0071$, $F(1, 17) = 7.846$, $p < 0.05$. That is, all children took longer to respond to four-syllable nonwords than three-syllable nonwords, even after the effects of stimulus duration were factored out of the analysis. No other variables were significant, and so did not enter the regression analysis. This analysis included all responses regardless of accuracy. Only 118 of 864 responses, or 13.66%, were scored as 100% accurate, making it impossible to limit the analysis to just accurate responses. Reaction time analyses limited to just those repetitions at a certain accuracy criterion, either 50% or 75%, revealed a similar pattern of results.

For the diphone nonwords, there were 16 cases out of 864 in which children did not attempt a response, always children with SLI. As in the previous analysis, these instances were included in the accuracy analysis, but not in reaction time or duration analyses. Dummy subject variables were entered into a stepwise multiple regression analysis, and accounted for significant variance, $R^2 = 0.2880$, $F(34, 812) = 9.672$, $p < 0.0001$. Stimulus durations were forced in the second step, $\Delta R^2 = 0.0987$, $F(1, 17) = 130.615$, $p < 0.0001$. Experimental variables and performance IQ were entered in the next steps. Number of syllables accounted for the most variance, $\Delta R^2 = 0.0091$, $F(1, 17) = 12.219$, $p < 0.01$, followed by language group, $\Delta R^2 = 0.0042$, $F(1, 17) = 5.681$, $p < 0.05$. No other variables or interactions accounted for any significant variance.

Response durations

Response durations, shown in Figure 3, were examined as a measure of how fluently children were repeating the nonwords. For consonant frequency nonwords, dummy subject variables were entered in the first step of a stepwise multiple regression analysis, and accounted for a significant portion of the variance, $R^2 = 0.2972$, $F(34, 807) = 10.013$, $p < 0.0001$. Because longer nonwords should take longer to repeat, stimulus duration was forced in the second step as a confounding variable, and accounted for significant variance, $\Delta R^2 = 0.1471$, $F(1, 17) = 212.805$, $p < 0.0001$. Experimental variables and performance IQ were entered in the third step. Of these, number of syllables accounted for the most variance and entered the equation first, $\Delta R^2 = 0.0376$, $F(1, 17) = 58.329$, $p < 0.0001$. Phonotactic probability also accounted for significant variance and entered the equation, $\Delta R^2 = 0.0099$, $F(1, 17) = 15.537$, $p < 0.001$. No other variables or interactions entered the analysis.

For diphone nonwords, dummy subject variables were entered first, $R^2 = 0.3141$, $F(34, 812) = 10.949$, $p < 0.0001$, followed by stimulus duration, $\Delta R^2 = 0.1479$, $F(1, 17) = 223.212$, $p < 0.0001$. Of the experimental variables, number of syllables entered the analysis first, $\Delta R^2 = 0.0055$, $F(1, 17) = 8.370$, $p < 0.01$, followed by phonotactic frequency, $\Delta R^2 = 0.0078$, $F(1, 17) = 12.107$, $p < 0.01$. No other variables entered the analysis. As in the previous condition, limiting both the reaction time and duration analyses to just responses at a particular accuracy level, either 50% or 75%, did not change the pattern of results.

Discussion

The purpose of the present study was to examine whether children with SLI have difficulty extracting specific types of phonological regularities from their language input relative to children developing language typically. Such difficulties extracting phonological regularities have been proposed to be an underlying cause of the basic language impairment. Sensitivity to these regularities was examined by having children with SLI and typically developing control children repeat nonwords constructed to vary in the frequency of different types of phonotactic patterns. In the first condition, nonwords differed in just the frequency with which the constituent consonants occur in the language environment. Vowel frequency, diphone frequency, and ease of articulation were held constant. In the second condition, nonwords differed in just the frequency with which the constituent phonemes co-occur in the language environment. Consonant frequency, vowel frequency, and ease of articulation were held constant. Consistent with previous findings, accuracy results for both lists of nonwords revealed that all main effects were significant. Children in both language groups repeated shorter nonwords more accurately than longer nonwords, and nonwords with more frequently occurring consonants or diphones more accurately than those with less frequently occurring phonotactic patterns (Beckman and Edwards Coady and Aslin 2004, Edwards *et al*. 2004, Munson 2001, Munson *et al*. 2005, Stokes *et al*. 2006, Zamuner *et al*. 2004). Further, children with SLI repeated nonwords less accurately than their typically developing peers (Bishop *et al*. 1996, Briscoe *et al*. 2001, Gathercole and Baddeley 1990, Gathercole *et al*. 1991a, Girbau and Schwartz 2007, 2008, Kamhi and Catts 1986, Kamhi *et al*. 1988, Munson *et al*. 2005, Sahlén *et al*. 1999, Stark and Blackwell 1997).

Two significant interactions were attested. First, for nonwords differing in consonant frequency, there was a significant group by number of syllables interaction, replicating previous findings (Gathercole and Baddeley 1990, Girbau and Schwartz 2007, 2008). This suggests that children with SLI had more difficulty with increasing nonword length than did typically developing children. However, in this condition both groups of children were similarly affected by differences in consonant frequency as evidenced by the nonsignificant group by phonotactic frequency interaction. Second, for nonwords differing in diphone frequency, there was a significant phonotactic frequency by nonword length interaction, which revealed accuracy differences due to diphone frequency for only three-syllable nonwords, not for four-syllable nonwords. Two factors might explain this effect. First, these results could reflect floor effects. If longer nonwords are at or beyond children's language processing capacities, then repetition accuracy will be so low that phonotactic effects will be minimized. However, all children did show phonotactic frequency differences in the previous condition, rendering floor effects unlikely. Another explanation is reduced statistical power. The four-syllable nonwords contain nine phonemes, but only five diphones. Taking fewer measurements per nonword necessarily reduces the precision of accuracy analyses. However, reduced statistical power also seems unlikely because visual inspection of the results (Figure 1, right side) gives no evidence of even a trend toward a significant difference. Neither explanation alone can account for non-significant results. But whatever the cause, both groups were comparably affected by the interaction between phonotactic frequency and nonword length.

Timing results were mixed. Children with SLI responded just as quickly as typically developing children when nonwords varied by consonant frequency, but were significantly slower when they varied by diphone frequency. Repetition duration results revealed no group differences. That is, repetitions of children with SLI were just as fluent as those of children developing language normally, albeit less accurate. These results are the opposite of those reported by Edwards and Lahey (1998), who found no group differences in reaction times, but significantly longer repetition durations by children with SLI. Results for number of syllables revealed that all children in the current study regardless of language status responded to three-syllable nonwords more quickly and more fluently than to four-syllable nonwords, even after target durations were statistically removed from the analyses. Finally, neither group responded more quickly to nonwords with frequent phonotactic patterns, but both groups repeated these nonwords more fluently, with shorter durations. These results from timing analyses do not reveal any sensitivities beyond those revealed by accuracy. Together, these results suggest that timing measures are unreliable in examining nonword repetitions by children, including those with SLI.

Conspicuously absent are the interactions between language group and phonotactic frequency. To date, a single study has reported a significant group by phonotactic frequency interaction. Munson *et al*. (2005) had three groups of children participate in a NRT—children with SLI, mean age 11;3, age-matched controls, and younger vocabulary-matched controls. The nonwords were taken from Frisch *et al*. (2000), and differed in both subjective wordlikeness and phonotactic frequency. Repetition accuracy results revealed significant main effects of group and phonotactic frequency, and a significant interaction. Examination of this interaction revealed that children with SLI and vocabulary-matched children showed similar phonotactic frequency effects, while both groups showed larger phonotactic frequency effects than age-matched control children. Munson and colleagues concluded that phonotactic frequency affects repetition accuracy, and that the size of the speaker's vocabulary mediates the size of this effect.

Their results suggest that children with SLI are more influenced by phonotactic frequency than are typically developing peers, suggesting difficulty extracting phonological regularities from the lexicon. However, several factors about their nonwords merit discussion. First, nonwords used in this and other studies were maximally distinct from one another, varying simultaneously in multiple sources of phonotactic frequency. For example, nonwords used by Jusczyk *et al.* (1994) to test infants' sensitivity to probabilistic phonotactics, used subsequently by Vitevitch and colleagues (for example, Vitevitch *et al.* 1997), varied in positional segment frequency, or frequency of occurrence in different word positions, and in biphone frequency, or segment-to-segment frequency of co-occurrence. Similarly, nonwords used by Munson *et al.* (2005), taken from Frisch *et al.* (2000), differed simultaneously in vowel, consonant, and biphone frequency. Simultaneous manipulation of multiple phonotactic complexity variables necessarily exaggerates differences between nonwords. Children in that study may have had difficulty with any or all of these phonotactic frequency manipulations. Second, eight of the ten high-frequency nonwords contained real words as stressed syllables, compared with only one real word as an unstressed syllable in the ten low-frequency nonwords. Dollaghan *et al.* (1995) reported that children repeat nonwords whose stressed syllables correspond to known words more accurately than those that do not. Third, the vowels were different for the two sets of nonwords, resulting in prosodic differences between the sets of nonwords. All of the unstressed syllables in the high-frequency nonwords contained reduced vowels (schwa or rhotic schwa), while only two of twenty unstressed syllables in the low-frequency nonwords did. Further, twice as many open syllables (eight versus four of 25) in the low-frequency nonwords contained lax vowels which require a coda consonant in English, thereby triggering ambisyllabicity and affected phonotactic probability. Based on different proportions of reduced vowels and of lax vowels in open syllables, the nonwords were not matched for their prosodic characteristics. Finally, 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/ ‘*SEE-sur-TAH-lep*’ and low frequency /zɔᶦ·wæ·ʧɝ·ʒɛð/ ‘*ZOY-wae-CHUR-zhethe*’. 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 ‘*zoy*’ the unattested combination ‘*zhe*’ and the combination ‘*ethe*’ 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. Three of these factors, embedded real words, prosodic differences, and unattested phoneme combinations, are established sources of repetition accuracy differences in children developing language typically. However, they have not been examined directly in children with SLI. As with the effects due to multiple sources of phonotactic frequency differences, the combinatorial effects of multiple sources of variability may have exaggerated group differences in sensitivity to phonotactic pattern frequency information.

In contrast, the results of the current study suggest that children with and without SLI are comparably affected by regularities related to consonant frequency and diphone frequency. One possibility is that group differences in phonotactic sensitivities result from a source of phonotactic frequency not manipulated in the present study; perhaps group differences in phonotactic sensitivity may be explained by differences in sensitivity to the frequency of vowel occurrence. A number of studies have reported that children with SLI have difficulty identifying spectrally similar vowels (for example, Evans *et al.* 2002, McArthur and Bishop 2005, Stark and Heinz 1996b), which may interfere with their ability to track differences in frequency of occurrence. However, evidence from the literature examining infants' speech perception abilities suggests that information is accessible developmentally earlier for vowels than for consonants (for example, Werker and Desjardins 1995). The current study suggests that children with SLI are extracting phonological regularities much like their age-matched peers, and consequently should show the same sensitivity to vowel frequency. While sensitivity to vowel frequency seems to be an unlikely source of difficulty, increased sensitivity to some unknown source of phonotactic frequency not included here could potentially explain this pattern of results.

Another reasonable explanation for the difference between studies is that children with SLI are more sensitive to simultaneous manipulation of multiple sources of phonotactic frequency, which necessarily maximizes differences between nonwords. When frequently occurring consonants are paired with frequently occurring vowels in frequently occurring combinations, resulting wordlikeness is maximized. On the other hand, when infrequent consonants are paired with infrequent vowels in infrequent combinations, wordlikeness is minimized. Thus, phonotactic frequency differences between groups of nonwords are exaggerated. While children with SLI have progressively more difficulty than typically developing children when repeating nonwords in which phonotactic frequency differences are maximized (Graf Estes *et al*. 2007), the results of the current study show that children with SLI are not disproportionately affected when only a single source of phonotactic frequency is manipulated. Children with SLI are less accurate overall, but they show the same sensitivity as typically developing children both to consonant frequency and to diphone frequency. However, the phonotactic aspect of non-word repetition is only a single component of a complex psycholinguistic task (Coady and Evans 2008). As the results of Munson *et al*. (2005) show, children with SLI are disproportionately affected when nonwords vary along multiple dimensions. While children with SLI may be delayed in the acquisition of any single aspect of language, their overall pattern of language performance suggests that they are disproportionately impaired in tasks requiring multiple levels of processing. In the language domain, children with SLI repeat single words as quickly and accurately as age-matched peers (Gathercole and Baddeley 1990), but repeat sentences with significantly less accuracy (Conti-Ramsden *et al*. 2001). Also, children with SLI can identify single words as accurately as typically developing children when they are presented in a random list, but not when they are embedded in a sentential context (Montgomery *et al*. 1990). In the non-linguistic domain, children with SLI have no difficulty repeating individual motor movements, but make sequences of these same movements less accurately than typically developing children (Dewey *et al*. 1988). Taken together, these studies show that children with SLI can successfully complete simple tasks, but their performance suffers when a number of such tasks must be coordinated.

Children with SLI repeated nonwords less accurately than their typically developing peers, but showed the same pattern of sensitivity to consonant frequency and to diphone frequency. Non-significant interactions suggest that their ability to extract phonological regularities from over their lexicons appears to be intact. The current results may be interpreted as supporting language delay rather than deviance, at least in extracting phonological regularities. Results also support a working memory deficit, either phonological working memory specifically (Gathercole and Baddeley 1990) or verbal working memory more generally (Bishop 1997, Ellis Weismer *et al*. 1999). According to the phonological working memory account, children with SLI have difficulty storing phonological materials such as nonwords. This difficulty may arise from reduced storage capacity or from rapid decay of phonological traces in memory. Either way, the deficit lies in the phonological loop component of working memory (for example, Baddeley 2003). This can be contrasted with the verbal working memory account, which also implicates a deficit in central executive functioning. According to this model, children with SLI have difficulty with the initial comprehension or processing of linguistic input, which in turn limits memory capacity (for example, Just and Carpenter 1992).

On the surface, the current results refute difficulty establishing robust linguistic representations. Children with SLI were comparably affected by differences in phonotactic frequency, suggesting that they are comparably sensitive to these frequency differences. However, verbal working memory deficits may result from inefficient access to stored long-term language knowledge, including knowledge of phonotactic regularities. One potential caveat of the current study has to do with the age of the children tested. Children ranged in age from 7;3 to 10;6, which is well after the time that young children are thought to be actively extracting phonotactic regularities (Walley 1993). Younger children with SLI may indeed show evidence of greater sensitivity to phonotactic frequency, which would indicate difficulty extracting phonological regularities. If these children are extracting regularities more slowly or less robustly than typically developing children, then those arenas that rely on phonological processing, such as word segmentation (Evans *et al*. 2009) or morphosyntax (Leonard 1989) are likely to be compromised, leading in turn to more pervasive language difficulties. However, the results of the present studies indicate that children with SLI show expected sensitivities to differences in phonotactic frequency within nonwords. Consequently, reduced accuracy on nonword repetition tasks by older children with SLI cannot be ascribed to reduced sensitivity to probabilistic phonotactic structure.

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Appendix

Non-words differing in consonant frequency, or the frequency of occurrence of constituent consonants, and in diphone frequency, or the frequency of phoneme co-occurrence.

High Consonant Frequency	**Low Consonant Frequency**
[daᶷ·ɹu·nas] “dao-roo-nahs”	[ʃeᶦ·paᶷ·boᶷf] “shay-pao-bofe”
[teᶦ·la-doᶷd] “tay-lah-dode”	[foᶷ·gi·pab] “foe-ghee-pahb”
[maᶷ·koᶷ-tik] “mao-koe-teek”	[ba·ʤaᶦ·jup] “bah-jye-yoop”
[sa·neᶦ·kaᶷt] “sah-nay-kaut”	[pɔᶦ·ʃeᶦ·goᶷb] “poy-shay-gobe”
[lu·maᶷ·seᶦs] “loo-mao-sace”	[jaᶷ·fa·gip] “yao-fah-gheep”
[nɔᶦ·taᶷ-lit] “noy-tao-leet”	[gaᶷ·ʃa·faᶦp] “gao-shah-fipe”
[li·ka·teᶦ·sud] “lee-kah-tay-sood”	[jaᶷ·faᶦ·ga·pig] “yao-fye-gah-peeg”
[ɹaᶷ·naᶦ·sa·doᶷc] “rao-nye-sah-doke”	[faᶦ·ʃaᶷ·foᶷ·jeᶦp] “fye-shao-foe-yape”
[koᶷ·daᶷ·neᶦ·kaᶦd] “koe-dao-nay-kide”	[ʤaᶦ·ba·faᶷ·goᶷb] “jye-bah-fao-gobe”
[naᶦ·ɹu·laᶷkit] “nye-roo-lao-keet”	[baᶷ·fu·ʤa·ʃeᶦf] “bao-foo-jah-shafe”
[kaᶦ·ɹa·nɔᶦ·taᶷs] “kye-rah-noy-tauss”	[feᶦ·pa·ʤaᶷ·boᶷp] “fay-pah-jao-bope”
[taᶷ·lu·kaᶦ·seᶦd] “tao-loo-kye-sade”	[ʃa·gi·faᶷʤig] “shah-ghee-fao-jeeg”
High Diphone Frequency	Low Diphone Frequency
[gi·naᶦ·ʤap] “ghee-nye-jahp”	[gaᶷ·ɹa·muk] “gao-rah-mook”
[daᶷ·koᶷ·naᶦd] “dao-koe-nide”	[ʤaᶦ·taᶷ·nas] “jye-tao-nahs”
[ʃeᶦ·ga·kus] “shay-gah-koose”	[ka·ʃaᶷ·beᶦf] “kah-shao-bafe”
[faᶦ·baᶷ·teᶦd] “fye-bao-tade”	[la·gaᶷ·joᶷp] “lah-gao-yope”
[ɹu·teᶦ·sat] “roo-tay-saht”	[ɹaᶷ·ʃa·pif] “rao-shah-peef”
[ba·li·feᶦp] “bah-lee-fape”	[sa·jaᶷ·ʤig] “sah-yao-jeeg”
[feᶦ·ga·maᶷ·ɹaᶦk] “fay-gah-mao-rike”	[ɹa·pɔᶦ·faᶷ·gub] “rah-poy-fao-goob”
[ka·neᶦ·faᶦ·loᶷt] “kah-nay-fye-lote”	[laᶷ·ʤa·nɔᶦ·boᶷf] “lao-jah-noy-bofe”
[kaᶦ·pa·foᶷ·gap] “kye-pah-foe-gahp”	[nɔᶦ·ʤaᶷ·fa·toᶷs] “noy-jao-fah-toce”
[neᶦ·daᶷ·lu·ɹaᶷs] “nay-dao-loo-rauss”	[sa·fu·paᶷ·ʃig] “sah-foo-pao-sheeg”
[maᶷ·foᶷ·gi·naᶷt] “mao-foe-ghee-naot”	[la·taᶷ·ʤaᶦ·suk] “lah-tao-jye-suke”

High Consonant Frequency	**Low Consonant Frequency**
[li·kaᶦ·ʃeᶦ·naᶷs] “lee-kye-shay-nauss”	[pɔᶦ·ɹa·fu·lad] “poy-rah-foo-lahd”

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What this paper adds

What is already known

Children with SLI repeat nonwords less accurately than their typically developing peers. Because nonwords contain no semantic or syntactic information, poorer repetition accuracy suggests a phonological deficit-either phonological memory or phonological sensitivity. While the task obviously contains a memory component, recent findings that repetition accuracy depends on phonological complexity implicate phonological sensitivity. However, it remains unclear whether children with SLI and typically developing peers are comparably affected by differences in complexity.

What this study adds

To examine group differences in sensitivity to phonological complexity, children with SLI and age-matched controls repeated nonwords differing in the frequency of their phonological patterns. One set of nonwords differed in frequency of phoneme occurrence, while another set differed in frequency of phoneme co-occurrence. Results revealed significant main effects of group, number of syllables, and phonological complexity. However, nonsignificant interactions suggested that children with and without SLI were comparably affected by differences in phonological complexity within nonwords, suggesting that their ability to extract phonological regularities is intact.

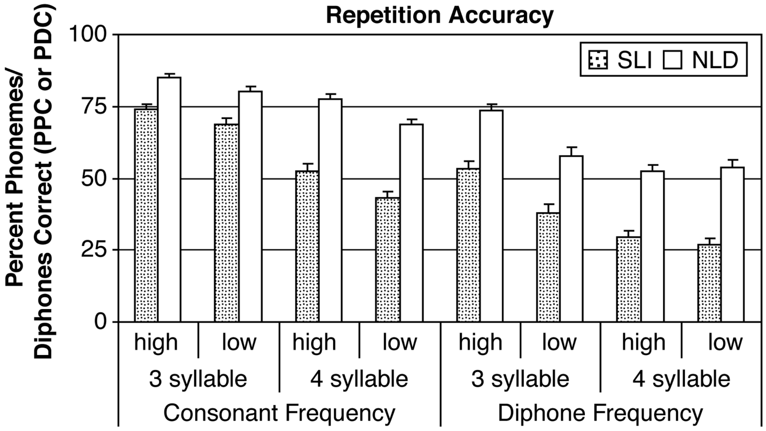

Figure 1.

Repetition accuracy for both sets of nonwords as a function of language group, phonotactic frequency, and number of syllables. The left side of the graph presents per cent phonemes correct (PPC) for nonwords differing in consonant frequency. The right side presents per cent diphones correct (PDC) for nonwords differing in diphone frequency.

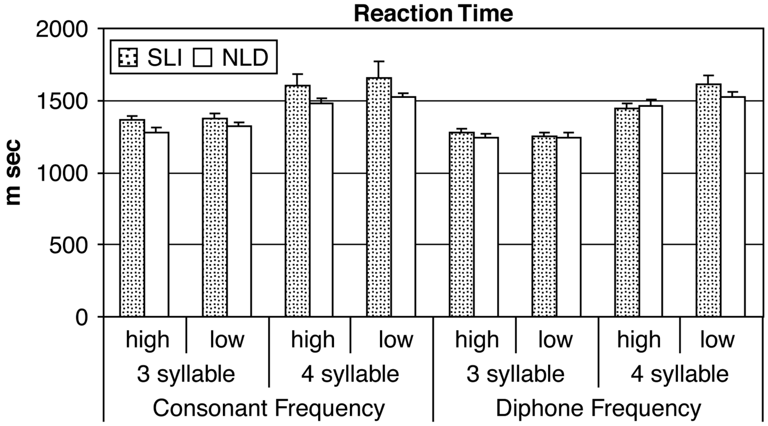

Figure 2.

Onset-to-onset reaction times (milliseconds) for both sets of nonwords as a function of language group, phonotactic frequency, and number of syllables. The left side of the graph presents reaction times for nonwords differing in consonant frequency. The right side presents reaction times for nonwords differing in diphone frequency.

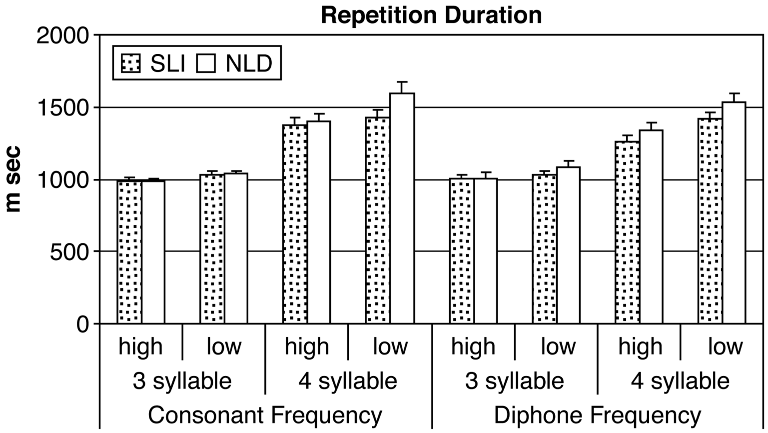

Figure 3.

Repetition durations (milliseconds) for both sets of non-words as a function of language group, phonotactic frequency, and number of syllables. The left side presents durations for nonwords differing in consonant frequency. The right side presents durations for nonwords differing in diphone frequency.

Table 1

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

	Children with SLI	Typically developing children
Age	9;2 (1;1) Range: 7;3–10;6	8;10 (0;11) Range: 7;4–10;0
CELF-ELS	70.5 (11.0) Range: 53–84	103.7 (15.1) Range: 91–146
CELF-RLS	77.6 (19.2) SLI-E range: 89–107 SLI-ER range: 50–80	–
NWR	67.9 (11.1) Range: 40–81	82.9 (8.4) Range: 69–95
CLPT	22.5 (15.8) Range: 0–52	48.3 (12.7) range 26–69
Non-verbal IQ	103.9 (10.6) Range: 87–122	118.1 (12.0) Range: 98–134

Note: Means, standard deviations (in parentheses) and ranges are presented for chronological age (years;months), composite Expressive (ELS) and Receptive (RLS) Language Scores on Clinical Evaluation of Language Fundamentals—Revised (CELF-R; Semel *et al*. 1989), per cent phonemes correct (raw scores) on the Nonword Repetition Task (NWR; Dollaghan and Campbell 1998), per cent final words recalled (raw scores) on Competing Language Processing Task (CLPT; Gaulin and Campbell 1994), and standard non-verbal intelligence scores, Leiter International Performance Scale—Revised (Leiter-R; Roid and Miller 1997) or Columbia Mental Maturity Scale (CMMS; Burgemeister *et al*. 1972).