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Nonword repetition errors of children with and without specific language impairments (SLI)

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Abstract

Background—Two ubiquitous findings from the literature are that (1) children with specific language impairments (SLI) repeat nonwords less accurately than peers with typical language development (TLD), and (2) all children repeat nonwords with frequent phonotactic patterns more accurately than low-probability nonwords. Many studies have examined repetition accuracy, but little work has examined children's errors.

Aims—To examine nonword repetition errors from a previously published study in terms of phonotactic probability.

Methods & Procedures—Eighteen children with SLI (mean age = 9;2) and 18 age-matched controls (mean age = 8;11) repeated three- and four-syllable nonwords. Substitutions were analysed in terms of phoneme frequency and phonotactic probability of the syllable containing the substitution.

Outcomes & Results—Results for all children show that phoneme substitutions generally involved replacement with more frequently occurring phonemes. Also, the resulting phonotactic probability within syllables containing substitutions was greater than the probability of the targets. This trend did not differ by group.

Conclusions & Implications—These results suggest that both children with SLI and children with TLD substitute less frequent phonemes with more frequent ones, and less probabilistic syllables with higher probability ones.

Keywords

specific language impairments; nonword repetition; error analysis; phonotactic probability

Introduction

The nonword repetition task has gained popularity in recent years for three primary reasons. First, nonword repetition accuracy is significantly correlated with vocabulary for children acquiring language typically (Bowey 1996, Gathercole and Baddeley 1989, Metsala 1999). Children who repeat nonwords more accurately also tend to score higher on standardized measures of receptive vocabulary. Second, nonword repetition is sensitive to a wide variety

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of language disorders, with lower levels of accuracy in clinical populations relative to children with typical language development (TLD) (for a review, see Coady and Evans 2008). The task taps a number of lower-level skills, including speech perception, phonological encoding, phonological memory, phonological assembly, motor planning and articulation. A deficit in any of these supporting skills will compromise accurate repetition. Finally, the nonword repetition task minimizes dialectal and cultural biases (Ellis Weismer *et al.* 2000, Rodekohr and Haynes 2001). Because it relies on language processing rather than language knowledge, it does not over-identify children from nonstandard language backgrounds.

While nonword repetition is a processing-dependent measure, it does in fact tap long-term language knowledge. As Bowey (2001) explained, ‘any manipulation that increases phonological complexity decreases non-word repetition performance’ (p. 443). Indeed, repetition is more accurate for nonwords containing (1) easily discriminable consonants, e.g. *daSEEpala* versus *saSHAHfasee* (Kamhi and Catts 1986); (2) singleton consonants versus consonant clusters, e.g. *woogalamik* versus *blonderstaping* (Gathercole and Baddeley 1989); (3) higher subjective wordlikeness ratings, e.g. *defermication* versus *loddernappish* (Gathercole *et al.* 1991); (4) embedded real words, e.g. *BATHesis* versus *FATHesis* (Dollaghan *et al.* 1993, 1995); (5) higher frequency phonotactic patterns, e.g. *chunfike* versus *thuznerg* (Vitevitch *et al.* 1997); and (6) attested versus unattested consonant sequences, e.g. *moften* versus *mofken* (Beckman and Edwards 2000). Because repetition accuracy depends on phonological complexity, we should expect repetition errors to reflect phonological simplification.

The primary purpose of this study was to examine errors in terms of complexity, measured as phonotactic probability. A secondary purpose was to compare the errors made by children with specific language impairments (SLI) and children with TLD. Researchers have consistently found children with SLI repeat non-words less accurately than children with TLD (for a review, see Coady and Evans 2008). A meta-analysis found that group differences averaged 1.27 standard deviations (Graf Estes *et al.* 2007). Furthermore, while children with SLI are less accurate than their peers with TLD, they too are affected by phonological complexity. When nonwords differ along a single phonotactic dimension (consonant frequency or phoneme co-occurrence frequency), children with SLI are affected by complexity comparably with children with TLD (Coady *et al.* 2010). But when nonwords differ along multiple dimensions, children with SLI show larger complexity effects than children with TLD (Coady 2010, Munson *et al.* 2005).

Very little work has directly examined children’s non-word repetition errors. The error analyses that have been completed focus on where errors occur, not on phonotactic probability. Analysing the types of errors based on phonotactic probability may provide evidence that children simplify nonwords by replacing less common phonemes and phoneme combinations with more frequent ones. Dillon *et al.* (2004) measured which phonemes were most likely to elicit errors by children with cochlear implants. They reported errors did not differ as a function of manner of articulation (stop, fricative, nasal, or liquid) or voicing (voiced or voiceless). However, they found that errors differed by place of articulation. Children with cochlear implants were more likely to make errors on labial and dorsal (velar) consonants than on coronal consonants. This analysis suggests that accuracy depends on consonant markedness. Markedness refers to a property of linguistic structures related to regularity or effort (Hume 2011). Coronal consonants are produced at a neutral place of articulation, and thus are unmarked and already simple. Labial and velar consonants have a less neutral place of articulation. That is, these consonants are marked, and so more complex and therefore subject to simplification.

Other work has found direct evidence for simplification. Dollaghan *et al.* (1995) asked boys with TLD to repeat multisyllabic nonwords in which the stressed syllable was either a real word or a nonword, such as *BATHesis* versus *FATHesis*. They found children repeated nonwords containing real-word syllables more accurately than those containing nonsense syllables. Further, accuracy effects extended beyond just the real-word syllables. The nonsense syllables in nonwords containing real words (*-esis* in *BATHesis*) were also repeated more accurately than the corresponding syllables in nonwords containing only nonsense syllables (*-esis* in *FATHesis*). Presumably, real words have established motor routines, and repeating nonwords containing real-word syllables freed up resources that allowed the entire nonword to be repeated accurately. The authors then analysed repetition errors and reported children were more likely to change a nonword syllable to a real-word syllable, even when that change involved a more difficult articulatory pattern. They suggested children were attempting to simplify nonwords by capitalizing on existing motor routines for real words.

A recent study (Riches *et al.* 2011) analysed errors made by adolescents with TLD, SLI, or Autism and language impairments (ALI). They examined nonword repetition performance to explore whether there was phenotypic overlap between children with SLI and children with ALI. They also used a computational algorithm to examine nonword repetition errors. The authors reported 60% of errors were structure-preserving (e.g., *class* → *glass*, CCVC → CCVC) while 40% were structure-changing (e.g., *class* → *lass*, CCVC → CVC). Further, when structure-preserving errors did occur, they typically involved substituting a target phoneme with a phoneme differing in manner of articulation. This trend did not differ by group.

In their study examining nonword repetition by Slovak-speaking children with and without language impairments, Kapalková *et al.* (2013) classified errors in terms of various phonological-level (e.g., stopping or vowel substitution), syllable-level (e.g., cluster reduction or consonant deletion), and word-level (e.g., nasal or alveolar assimilation) processes. They found that children with SLI made a greater number of errors of all types. Further, they reported that both children with SLI and TLD made phonological- and syllable-level errors, and only children with SLI made word-level assimilation errors. Based on this error analysis, the authors suggest that children with SLI make developmental phonological errors for a protracted period of time.

More recently, Scheer-Cohen *et al.* (2014) directly compared distributions of error types produced by children with SLI and TLD. They completed an error analysis in order to examine the extent to which speech motor demands affect nonword repetition. They separated errors into four broad categories: motor, articulatory complexity, omission, or unclassifiable. They then compared groups in terms of distributions of error types. Motor errors were narrowly defined as errors in (1) voicing, such as producing *doif* as *toif* or *doiv*, (2) metathesis, or phoneme switching, such as producing *doif* as *foid*, or (3) assimilation, or an error in which a substituted phoneme is identical to an earlier or later phoneme, such as producing *doif* as *doid* or *foif*. Articulatory complexity errors involved replacing a target phoneme with a less complex phoneme, defined as an earlier acquired phoneme, such as producing *doif* as *doip*. Omission errors involved failing to produce phonemes or syllables, such as producing *doif* as *doy*. Finally, unclassifiable errors were any errors that were not voicing, metathesis, assimilation, complexity, or omission errors, such as producing *doif* as *noif*. Results indicated significantly different distributions of error types. Children with SLI were more likely to make omission errors but less likely to make motor errors, while children with TLD made more articulatory complexity errors, but fewer omissions, all relative to expected values. Because children with SLI made many more omission errors than children with TLD (141 versus 30), a second analysis ignoring omission errors was conducted. Distributions were still different, with both groups making fewer motor errors than expected, and children with TLD making more articulatory complexity errors than expected. They concluded there is a significant motor component to nonword repetition tasks, and children with and without SLI differ in their sensitivity to those motor demands.

The current study was a re-analysis of nonword repetition errors made by children with SLI and TLD (Coady *et al.* 2010). The study included two sets of nonwords: one in which phoneme frequency varied and a second in which phoneme co-occurrence frequency varied. Results revealed that children with SLI repeated nonwords less accurately than children with TLD. Both groups repeated nonwords with higher frequency phonemes and phoneme combinations more accurately than nonwords with less frequent phonemes and combinations. A non-significant interaction revealed that phoneme frequency and phonotactic probability affected both groups similarly.

Substitution errors from the previous study were analysed by comparing phoneme frequencies and phoneme co-occurrence frequencies of targets to frequencies of the actual productions. The phoneme frequency analysis included a general analysis of all phonemes, and based on evidence that accuracy may be different for consonants and vowels (Kapalková *et al.* 2013), consonants and vowels were analysed separately. The phoneme co-occurrence analysis included substitutions only in syllables in which syllable structure was maintained. The working hypothesis was that children's substitution errors would involve replacing phonemes and phoneme combinations with more frequently occurring phonemes and combinations. A second analysis examined whether children with SLI and TLD simplify nonwords to the same extent. This question generates conflicting hypotheses. First, accuracy results indicated that children with SLI and TLD were comparably affected by differences in phoneme frequency and phonotactic probability (Coady *et al.* 2010). This finding suggests both groups of children should simplify nonwords comparably. That is, children with SLI and TLD should both substitute higher frequency phonemes and phoneme combinations at similar rates. Alternatively, there is evidence that the distributions of errors made by children with and without SLI are different (Scheer-Cohen *et al.* 2014). This would suggest the two groups should differ in the degree to which they simplify nonwords. The research questions were as follows:

- Do children with SLI and TLD replace target consonants and vowels with more frequently occurring consonants and vowels?
- Do children's consonant and vowel substitutions result in syllables with higher phonotactic probability?
- Do children with SLI and TLD simplify non-words to the same extent?

Methods

Participants

Participants from the original study (Coady *et al.* 2010) included 18 monolingual English-speaking children with SLI, 10 females, eight males, mean age = 9;2 (range = 7;3–10;6) and 18 age-matched typically developing children, 12 females, six males, mean age = 8;10 (range = 7;4–10;0). Based on parent report, none of the children had any frank neurological deficits, oral-motor disabilities, or social–emotional difficulties. All children had speech intelligibility measured at or above 98%, as measured by a certified speech–language pathologist. 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. Finally, while there was a group difference for nonverbal IQs, all were within the normal range at or above 85 (1 SD below the mean or higher) as measured by the Leiter International Performance Scale—Revised (Roid and Miller 1997) or the Columbia Mental Maturity Scale (Burgemeister *et al.* 1972).

Participants were given 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. Language status was determined based on the ELS. Children with SLI scored at least 1 standard deviation (SD) below the mean (< 85) while children with TLD scored above 85. Receptive language abilities were measured for children with SLI, but were not a criterion for inclusion. However, all children in the age-matched control group scored in the normal range on receptive language abilities by achieving either a standard score of 8 on the Oral Directions subtest or a standard score of 85 on full receptive language battery (RLS). Children with SLI scored significantly below typically developing children on all measures: nonverbal intelligence, $t(34) = 3.755$, $p < 0.001$, Cohen's $d = 1.29$; CELF-R ELS, $t(34) = 7.543$, $p < 0.0001$, Cohen's $d = 2.59$; CELF-R Oral Directions, $t(40) = 3.542$, $p = 0.001$, Cohen's $d = 1.22$. Cohen's d (Cohen 1988) is an effect size measure calculated as the group mean difference relative to pooled standard deviation. A Cohen's d of 0.2 represents a small effect, 0.5 a medium effect and 0.8 a large effect. Group summary statistics are provided in table 1.

Stimuli and procedure

Two lists of 24 nonwords varying in phonotactic frequency were created and used in the initial study (Coady *et al.* 2010). For the first list, phonotactic frequency differences were based solely on consonant frequency of occurrence. For the second list, differences were based on phoneme co-occurrence frequency. Consonant and phoneme co-occurrence 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 12 high- and 12 low-frequency nonwords. Nonwords were further divided by number of syllables. Half contained three syllables, while the other half contained four syllables. 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 syllable boundaries could be clearly identified. The 48 nonwords comprised 168 syllables containing 384 phonemes. Nonwords are provided in the appendix.

Children participated in the nonword repetition task as part of a larger experimental protocol. Each child was tested individually in a large sound-attenuated booth. The nonwords were presented over a single speaker at 75 dB SPL, approximately 60 cm from the child. The presentation level was calibrated prior to each session. Children were told they would hear made-up words and they were to repeat them back as quickly and accurately as possible. All children heard nonwords in a fixed random order, blocked by condition (phoneme frequency first, followed by phonotactic probability) and length (three-syllable first, then four-syllable nonwords). High- and low-probability nonwords were randomly ordered within each block. Sessions were recorded for later scoring.

Scoring and analysis

Children's responses were transcribed from the recordings. Two independent transcribers, blind to the children's language status, scored each phoneme relative to its target. Results from the two transcriptions were compared, and a third listener mediated disagreements; for two subjects, a fourth listener was consulted. Ultimately, interscorer reliability was forced to 100% using point-by-point consensus scoring.

Two separate error analyses were conducted. The first analysis compared the frequency of the target phoneme to the frequency of the phoneme substituted in error. As an example, consider the child who heard the target *sah-nay-kaut* [sa·neɪ kaʊt], but repeated *sah-nee-kaut* [sa·ni·kaʊt]. In this case the child made one substitution error, replacing [eɪ] in the second syllable with [i]. The frequency of [eɪ] is 1.63%, and the frequency of [i] is 3.49% (based on phoneme frequency counts described in Coady and Aslin 2004). That is, the child's substitution error involved replacing a less frequent phoneme with a more frequent one. Results were compared first for all phonemes, then for consonants and vowels separately.

The second analysis compared the phonotactic probability of the target syllable to the probability of the syllable resulting from the substitution error. Phonotactic probability was calculated as the product of phoneme co-occurrence frequencies, including syllable boundaries. Including syllable boundaries as part of the co-occurrence in the frequency value provides information about frequency by syllable position. Using the above example, the probability of the syllable *nay* [neɪ] was calculated as P(n|$) 0.0444 × P(eɪ|n) 0.0122 × P($|eɪ) 0.5872 = 0.00032. That is, the probability of *nay* is the probability that a syllable begins with [n] times the probability that [eɪ] follows [n] times the probability that a syllable ends with [eɪ]. The probability of the *nee* [ni] syllable is P(n|$) 0.0444 × P(i|n) 0.0459 × P($|i) 0.7932 = 0.00162. Again, this phoneme substitution resulted in a syllable with higher probability than the target.

Phoneme frequencies were calculated for all phoneme substitution errors, while phonotactic probability was only calculated for syllables containing substitution errors in which syllable structure was maintained. If any phonemes were added or deleted, phonotactic probability was not calculated. Adding or deleting phonemes necessarily changes the number of factors in the product calculation, and so are not directly comparable.

Results

Children with SLI made a total of 3025 errors, while children with TLD made a total of 1614 errors. This difference was significant, $t(17) = 6.61$, $p < 0.0001$, Cohen's $d = 3.21$. Children with SLI made more addition errors, $t(17) = 2.16$, $p = 0.038$, Cohen's $d = 1.05$, deletion errors, $t(17) = 3.52$, $p = 0.001$, Cohen's $d = 1.71$, and substitution errors, $t(17) = 3.95$, $p = 0.0004$, Cohen's $d = 1.92$, than children with TLD. For the substitution errors, children with SLI made a greater number of consonant substitutions, $t(17) = 3.31$, $p = 0.002$, Cohen's $d = 1.61$, and vowel substitutions, $t(17) = 3.96$, $p = 0.0004$, Cohen's $d = 1.92$. The mean number of different error types for both groups are presented in table 2.

Phoneme frequency

Children with SLI made a total of 2100 substitution errors, while children with TLD made 1405. A mean difference was calculated for each child, and then combined to get group means. Frequencies of targets and substitution errors are presented in figure 1. Difference scores between the frequency of the targets and the frequency of the substituted phonemes were analysed first by paired *t*-tests. Results for all children revealed that their substitution errors were higher frequency than targets, $t(35) = 10.31$, $p < 0.0001$, Cohen's $d = 1.72$. When phonemes were separated into consonants and vowels, results revealed that substituted consonant frequencies were not significantly different from target consonant frequencies, $t(35) = -1.40$, n.s., Cohen's $d = 0.23$, but substituted vowels were more frequent than targets, $t(35) = 22.64$, $p < 0.0001$, Cohen's $d = 3.77$. These statistics were based on raw frequency values. Other analyses using log frequency values gave similar results. When the two groups were compared, there were no differences for all phonemes, $t(17) = 0.51$, n.s., Cohen's $d = 0.25$, for consonants, $t(17) = -0.47$, n.s., Cohen's $d = 0.23$, or for vowels, $t(17) = 1.00$, n.s., Cohen's $d = 0.49$. That is, both groups were substituting higher frequency phonemes for lower frequency targets at similar rates.

Phonotactic probability

Phonotactic probability was calculated for all syllables containing substitution errors, in which syllable structure was maintained. Some phoneme substitution errors co-occurred with addition and/or deletion errors. For example, one child heard the nonword *fay-gah-mao-rike* [feɪ·ga·maʊ·ɹaɪk] but repeated *fay-nye-nye-bray* [feɪ·naɪ·naɪ·bɹeɪ]. The final syllable contains one addition error [ɹ → bɹ], one substitution error [aɪ → eɪ], and one deletion error [k → Ø]. In this example, syllable structure was not maintained (CVC →

CCV), and so phonotactic probability was not calculated. In other cases, there was more than one substitution within a single syllable. The same child heard the nonword *jye-tao-nahs* [dʒaɪ·taʊ·nas] but repeated *dye-tah-kersh* [daɪ·ta·kɝʃ]. In this case, the final syllable contained three substitution errors [n → k], [a → ɝ], and [s → ʃ]. In this example, syllable structure was maintained (CVC → CVC) and phonotactic probability was calculated. For these reasons, there was not a one-to-one correspondence between the number of phoneme substitutions analysed for phoneme frequency and the number of syllables analysed for phonotactic probability.

Syllable error rates are summarized in table 3. For children with SLI, there were a total of 1378 syllables containing substitution errors in which the original syllable structure was maintained (mean per child, 73.6). For children with TLD, there were 1122 such syllables (mean per child, 56.8). Probabilities of the syllable targets and of the syllables containing substitutions are shown in figure 2. Results revealed all children made substitutions that resulted in higher phonotactic probabilities, $t(35) = 11.85$, $p < 0.0001$, Cohen's $d = 1.98$. However, the two groups did not differ in the degree to which they produced higher probability syllables, $t(17) = 0.16$, n.s., Cohen's $d = 0.08$.

In some cases, phonotactic probability could not be calculated. For example, one child heard the word *gao-rah-mook* [gaʊ·ɹa·muk], but repeated *gao-rah-moog* [gaʊ·ɹa·mug]. The·word-final [k] → [g] substitution can be·explained as a simple voicing error. However the resulting [-ug] combination common across syllable boundaries (as in *bugle* or *cougar*) did not appear in the Brown corpus (1973; Coady and Aslin, 2004) within a single syllable (as in *fugue*), giving it a probability of zero in the database. Because phonotactic probability was calculated as the product of co-occurrence probabilities, a single zero-probability term made the overall probability zero. While all children in the study produced at least one syllable containing an unattested sequence, children with TLD were significantly more likely to produce syllables containing at least one very low probability phoneme sequence unattested in the database, such that phonotactic probability could not be calculated (5.56 versus 3.0), $t(17) = 3.17$, $p < 0.01$, Cohen's $d = 1.54$.

Discussion

The purpose of the present study was to examine children's nonword repetition errors in terms of phoneme frequency and phonotactic probability. These factors are known to affect repetition accuracy in that children and adults, with or without language impairments, repeat high-phoneme frequency nonwords and high-phonotactic probability nonwords more accurately than low-frequency or low-probability nonwords. This work extends previous findings by examining whether repetition errors are also determined by phoneme frequency and phonotactic probability. A second purpose was to compare children with SLI and children with TLD on the degree to which phoneme frequency and phonotactic probability affected repetition errors.

To meet this goal, phoneme frequencies and phonotactic probabilities of substitution errors from a previously published study (Coady *et al.* 2010) were compared to phoneme frequencies and phonotactic probabilities of targets. Results revealed, on average, children's substitution errors reflected simplification. Errors involved replacing a target phoneme with a more frequently occurring phoneme, which also resulted in a syllable with higher phonotactic probability. This is similar to and consistent with Dollaghan *et al.*'s (1995) findings that children simplified nonwords by substituting real-word syllables even when the substitution required a more complex articulation. They suggested real words have well-established articulatory routines, and using those routines freed up other resources for more accurate repetition. In terms of the present study, it seems likely that more frequent phonemes and phoneme combinations also have well established motor plans. Because nonwords are completely unfamiliar, children may have used a strategy of relying on familiar articulatory plans for more frequent phonemes and phoneme combinations in cases where their phonological memories were taxed.

Results also revealed no group differences between children with SLI and children with TLD in the degree to which they favoured both frequently occurring phonemes and frequently occurring combinations. That is, both groups of children showed comparable simplification patterns. These results are consistent with the accuracy findings from the original study (Coady *et al.* 2010). In their study, children with SLI were significantly less accurate than children with TLD, but they showed comparable effects due to phoneme frequency and phonotactic probability. Both groups repeated high-frequency and high-probability nonwords more accurately than low-frequency and low-probability nonwords, respectively; however, the difference was not statistically different for the two groups. Therefore, the children with SLI show similar phoneme frequency and phonotactic probability effects to peers with TLD, in terms of both repetition accuracy and an analysis of their errors.

While the current results are consistent with previous accuracy results, they are inconsistent with Scheer-Cohen *et al.*'s (2014) results that children with SLI and TLD have different error patterns. Scheer-Cohen and colleagues classified children's nonword repetition errors into four categories (motor, articulatory complexity, omission and unclassifiable) and compared the two groups on the distributions of these error types. Their analysis revealed the distributions of errors were significantly different. Children with SLI made more omission errors, but fewer motor errors than expected, while children with TLD made more articulatory complexity errors than expected, but fewer omission errors. While these results might appear inconsistent with those of the current study, the error analyses were different. Scheer-Cohen and colleagues considered different types of errors while the current study compared phoneme frequencies and phonotactic probabilities of substitution errors, regardless of any potential articulatory cause.

The only minor difference between groups was that children with TLD were more likely to make substitution errors for which phonotactic probability could not be calculated. For the most part, these were not illegal sequences, but rather very low probability sequences that were simply unattested in the source database (Brown 1973, Coady and Aslin 2004, MacWhinney 1991). This suggests children with SLI were more likely to be limited to higher frequency phoneme sequences, while children with TLD were freer to include phonemes independent of the surrounding phonetic context.

An unexpected finding was that vowel errors reflected simplification, while consonant errors did not. This result was surprising because children typically acquire vowels before consonants (Edwards 1997). Vowels are often mastered by age 3 for stressed syllables and by age 4–5 for unstressed syllables (Allen and Hawkins 1980). Also, vowel acquisition seems more accurate and stable than consonant acquisition. In cases of articulation or phonological disorders, assessment and therapy typically focus on consonants rather than vowels (Gibbon 2009, Kapalková *et al.* 2013). In spite of these facts, there were a disproportionate number of vowel errors in the current study. Vowels accounted for 44% of target phonemes, but 56% of substitution errors. One potential explanation references similar findings from studies on early reading abilities. Beginning readers are more likely to make vowel errors than consonant errors, presumably because phoneme-to-grapheme correspondences for vowels are less consistent than those for consonants (e.g., Shankweiler and Liberman 1972). To the extent that the nonword repetition task taps skills necessary for reading, including phonological awareness, then the higher proportion of vowel errors in the nonword repetition task might represent similar phonological processes implicated in reading.

Another potential explanation is related to the way the nonwords were created for the original study. The nonwords contained only tense vowels to ensure clear syllable boundaries. That is, lax vowels, which are more frequent than tense vowels, were excluded. Similarly, voiced fricatives were excluded because they are late acquired. That is, the nonwords were created using more frequent consonants and less frequent vowels. This would allow for simplification of vowels, but limit simplification of consonants. However, it is unlikely that this can explain the results. One set of nonwords was originally created to vary in phoneme frequency, and so some of the nonwords contain very frequent consonants while others contain very infrequent consonants. The infrequent consonants in this condition are ideal candidates for simplification. The other set of nonwords was created to vary in phonotactic probability, or phoneme co-occurrence frequency. The consonants in this set of nonwords were all in the mid-frequency range, and so were also subject to simplification. In spite of this, simplification did not happen for consonants.

Ultimately, the current results provide evidence that children with and without language impairments simplify nonwords. Children's vowel substitution errors involved replacing lower frequency targets with higher frequency vowels. However, children's consonant errors did not reflect simplification. The frequencies of targets and errors were not significantly different. However, even though the consonant errors did not themselves provide evidence for simplification, the frequencies of consonant–vowel combinations resulting from substitution errors were higher in the error productions than in the target syllables. These simplification patterns did not differ by group, suggesting that children with SLI and children with TLD simplify nonwords in similar ways. These results replicate the original finding that children with SLI repeat nonwords less accurately than peers with TLD, but they show comparable effects due to phoneme frequency and phonotactic probability (Coady *et al.* 2010). Taken together, these results show that (1) children repeat higher-frequency and probability nonwords more accurately, (2) errors involve replacing less frequent phonemes or phoneme combinations with more frequent ones, and (3) this effect does not vary by group.

Research and clinical implications

The results of this study support that children with SLI make similar errors as children with TLD from a phonotactic frequency perspective. However, it also revealed children made more errors on vowels than on consonants. In fact, each group substituted a higher percentage of vowels than consonants. This finding was particularly interesting for a couple of reasons. First, it is often regarded that vowels are mastered earlier than many consonants, which makes the finding that more vowels were simplified unexpected. Second, a lot of emphasis is placed on consonant errors for young children, including the use of articulation tests such as the Goldman–Fristoe Test of Articulation (Goldman and Fristoe 2000), that assess only consonant errors.

The results from this analysis indicate that reviewing vowel errors in addition to consonant errors may be necessary to provide a complete picture of children's phonological and/or memory abilities. This has been suggested for other languages with simpler vowel systems (Kapalková *et al.* 2013), but proposes a challenge for a language like English with a more complicated vowel system. Besides having a greater number of vowels, the English language also has vowel reduction in unstressed syllables and a great deal of dialectal variability. Despite these challenges, children with SLI tend to have more errors on vowels, which is worth exploring as an avenue to support intervention.

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Appendix

Nonwords 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·dʒaɪ·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·doʊk] 'rao-nye-sah-doke'	[faɪ·ʃaʊ·foʊ·jeɪp] 'fye-shao-foe-yape'
[koʊ·daʊ·neɪ·kaɪd] 'koe-dao-nay-kide'	[dʒaɪ·ba·faʊ·goʊb] 'jye-bah-fao-gobe'
[naɪ·ɹu·laʊ·kit] 'nye-roo-lao-keet'	[baʊ·fu·dʒa·ʃeɪf] 'bao-foo-jah-shafe'
[kaɪ·ɹa·nɔɪ·taʊs] 'kye-rah-noy-tauss'	[feɪ·pa·dʒaʊ·boʊp] 'fay-pah-jao-bope'

High consonant frequency	**Low consonant frequency**
[taʊ·lu·kaɪ·seɪd] 'tao-loo-kye-sade'	[ʃa·gi·faʊ·dʒig] 'shah-ghee-fao-jeeg'
High diphone frequency	*Low diphone frequency*
[gi·naɪ·dʒap] 'ghee-nye-jahp'	[gaʊ·ɹa·muk] 'gao-rah-mook'
[daʊ·koʊ·naɪd] 'dao-koe-nide'	[dʒaɪ·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·dʒig] '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·dʒa·nɔɪ·boʊf] 'lao-jah-noy-bofe'
[kaɪ·pa·foʊ·gap] 'kye-pah-fao-gahp'	[nɔɪ·dʒaʊ·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·dʒaɪ·suk] 'lah-tao-jye-suke'
[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 on the subject?

Phonological complexity affects nonword repetition accuracy. This finding has been demonstrated using a number of phonological manipulations, including phonotactic probability, or the probability of phoneme occurrence and co-occurrence in the language environment. Children both with and without language impairments repeat nonwords with higher frequency phonotactic patterns more accurately than nonwords with lower frequency patterns. However, it is not clear whether repetition errors are also affected by phonotactic probability. Do children replace lower probability phonemes and phoneme sequences with higher probability ones?

What this paper adds?

Children’s substitution errors in a nonword repetition task involve replacing a less frequently occurring phoneme with a higher frequency one, resulting in a higher probability phoneme sequence. This was true for both children with SLI and children with TLD, and this difference between targets and actual productions was similar for both groups. These results suggest that children simplify nonwords by attempting to capitalize on more frequently occurring phoneme sequences. In addition, both groups of children simplified vowels, but not consonants. This finding suggests vowel errors may warrant more clinical attention.

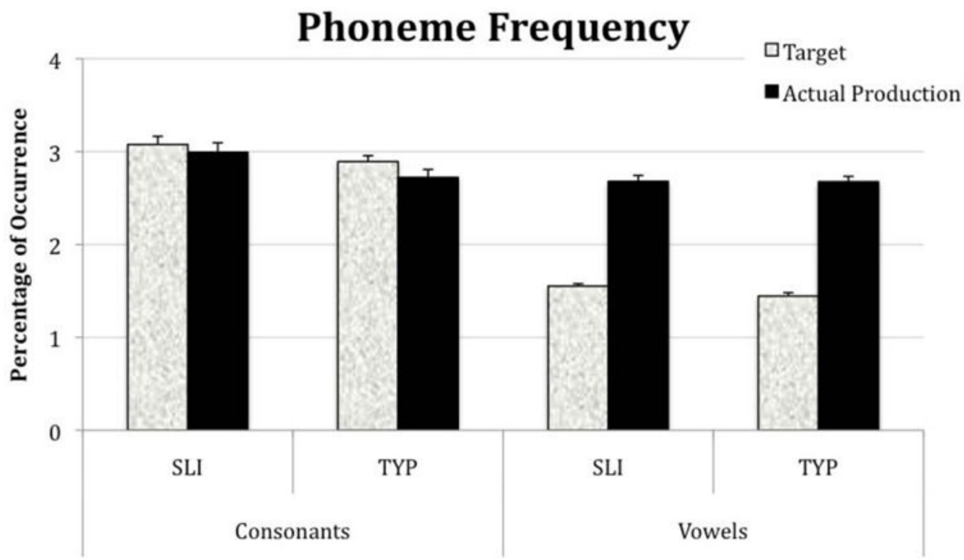

Figure 1.

Mean phoneme frequency of targets (shaded bars) and substitution errors (black bars). Error bars represent the standard error.

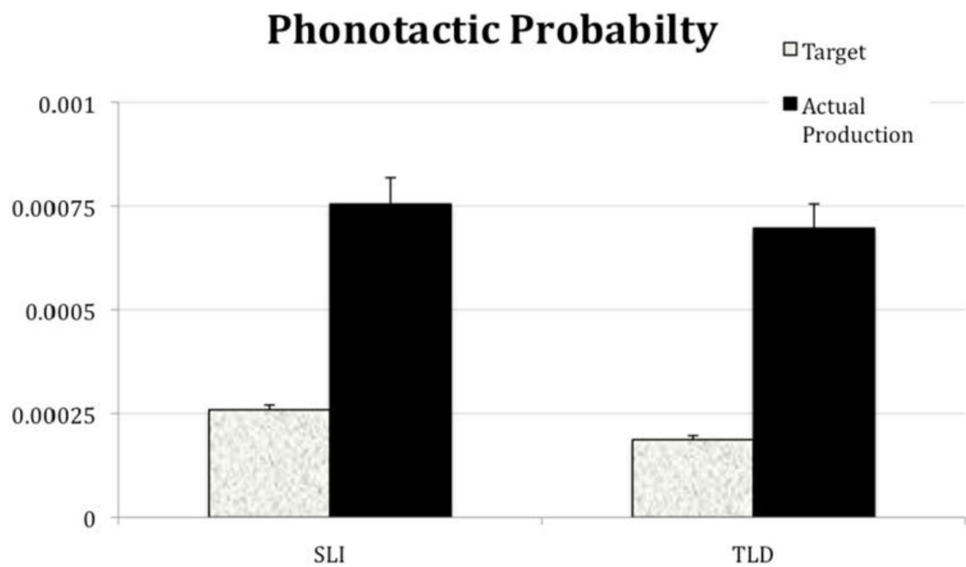

Figure 2.

Mean phonotactic probability of syllable targets (shaded bars) and syllables containing substitution errors (black bars). Error bars represent the standard error.

Table 1

Group summary statistics for children with SLI and for children with TLD

	Children with SLI			Children with TLD		
	Mean	**SD**	**Range**	**Mean**	**SD**	**Range**
Age	9;2	1;1	7;3–10;6	8;10	0;11	7;4–10;0
CELF-ELS[a]	70.5	11.0	53–84	103.7	15.1	91–146
Oral directions[a]	6.6	2.8	3–11	10.3	3.4	4–15
Nonverbal IQ[b]	103.9	10.6	87–122	118.1	12.0	98–134

Notes: Means, standard deviations and ranges are presented for chronological age (years;months), composite Expressive Language Scores (ELS), and Oral Directions sub-test scores, and standard nonverbal intelligence scores.

[a]Clinical Evaluation of Language Fundamentals—Revised (CELF-R; Semel *et al.* 1989).

[b]Leiter International Performance Scale—Revised (Leiter-R; Roid and Miller 1997) or Columbia Mental Maturity Scale (CMMS; Burgemeister *et al.* 1972).

Table 2

Means and standard deviations for the number of error types out of a possible 384 target phonemes

Error type	Children with SLI			Children with TLD		
	M	**SD**	**Range**	**M**	**SD**	**Range**
Addition	7.67	6.04	0–26	4.22	3.02	0–9
Deletion	43.72	43.51	6–162	7.39	4.90	1–19
Substitution	116.67	32.30	34–160	78.06	26.03	27–148
Consonant	52.06	19.46	15–87	33.34	14.05	11–61
Vowel	64.61	16.31	19–82	44.72	13.73	16–87
Total	168.06	40.31	108–250	89.67	30.15	36–166

Table 3

Means and standard deviations for number of syllables containing errors, out of a possible 168 target syllables

	Children with SLI		Children with TLD	
	Mean	**SD**	**Mean**	**SD**
Total number of syllables containing errors	111.0	17.0	72.4	19.5
Syllables containing errors that changed the syllable structure	34.4	20.8	10.0	5.3
Syllables containing errors where the probability could not be calculated	3.0	1.9	5.6	2.8
Syllables containing errors included in the phonotactic probability analysis	73.6	18.2	56.8	16.3