ERROR ANALYSIS OF CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT AND CHILDREN WITH TYPICALLY DEVELOPING LANGUAGE COMPLETING A NONWORD REPETITION TASK

by

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Error Analysis of Children with Specific Language Impairment and Children with Typically Developing Language Completing a Nonword Repetition Task

Thesis directed by Associate Professor Jeffry A. Coady

Nonword repetition has become popular in research and clinical practice because it has a significant relationship with vocabulary, a high sensitivity to a variety of language disorders, and minimal cultural bias. A universal finding in literature is that children with specific language impairment (SLI) repeat nonwords less accurately than peers with typical language development (TLD). While many studies have reported accuracy differences between children with SLI and children with TLD, little work has analyzed the errors. The current study examined children's nonword repetition errors. Ten children with SLI and ten age-matched controls repeated three- and four-syllable nonwords. Phoneme substitutions were analyzed in terms of (1) phoneme frequency, (2) phoneme diphone frequency within a syllable containing a substitution, and (3) ease of articulation. Results for all children show a general trend in which phoneme substitutions involved replacement of the target phoneme with a more frequently occurring phoneme; however the effect was driven by differences in frequency for vowels. There was not a difference between groups. The resulting phonotactic probability within syllables containing substitutions was also greater than the probability of the targets. However, this trend did not differ by group either. Finally, the results for ease of articulation indicated that children replaced target vowels with easier to articulate vowels; but did not replace consonants for phonemes with easier articulation. This suggests that children with SLI, just like children with TLD, substitute less frequent phonemes with more frequent ones, resulting in higher probability combinations. In addition, children with SLI, as well as their peers with TLD, substitute vowels that are easier to articulate, but do not substitute consonants with greater ease of articulation.

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CHAPTER 1: INTRODUCTION

Children with specific language impairment (SLI) have the requisite cognitive skills to support language, yet have difficulty acquiring and using language (Gathercole, 2006; Leonard, 1998). One method that has been used to explore the nature of deficits in children with SLI is the nonword repetition task (NRT) (Coady & Evans, 2008). The NRT has become popular for three primary reasons. First, it strongly correlates with vocabulary acquisition as it follows the same pattern as the initial stages of word learning, i.e. hearing a novel phonological string, breaking it down into the component parts, reassembling the parts into a motor plan, and then linking the novel string to a referent (Coady & Evans, 2008). In addition, there is a high correlation between performance on NRT and standardized vocabulary measures, with typically developing children who more accurately repeat nonwords also scoring higher on the standardized vocabulary measures (Coady & Evans, 2008; Gathercole, 2006). Second, NRT has shown a high level of sensitivity and specificity for ruling in or ruling out a variety of language impairments (Coady & Evans, 2008). The task is inherently multidimensional and difficulty within any single domain will inhibit accurate repetition. Finally, NRT has minimal cultural bias as the task relies more on language processing rather than on established language knowledge, thus preventing over-identification of children from nonstandard language backgrounds.

A pervasive finding in the literature is that children with SLI repeat nonwords less accurately than their peers with typical language development (TLD). Group differences, which average 1.27 standard deviations (Graf Estes, Evans, & Else-Quest, 2007), are so robust that some researchers have suggested it be used as a behavioral marker for SLI (Bishop et al., 1996).

While many studies have reported significant differences in accuracy between the groups, the reason for this discrepancy remains unclear. Gathercole (2006) has argued the deficit is with phonological memory, or storage. She postulates that the reason why children with SLI have difficulty producing nonwords is that they have either reduced memory capacity or impaired memory processes that limit their abilities to repeat nonwords. In other words, children with SLI have difficulties with the rehearsal, or subvocal rehearsal, aspect of repeating a novel phonological string, in this case the NRT. In contrast, Snowling (1991) and Bowey (1996; 2001) argue that phonological memory alone does not account for entire deficit. They propose that additional aspects of phonological processing, such as phonological sensitivity, also contribute to the difficulty children with SLI have repeating nonwords and with vocabulary acquisition. Bowey's findings provide evidence that phonological memory alone does not account for reduced accuracy of NRT for children with SLI and indicates that a more fundamental deficit in phonological processing, i.e. phonological sensitivity, also accounts for the lack of accuracy.

Gathercole's keynote article (2006) sparked a litany of responses. A common theme in the commentaries included the need for further research, including how children's motor abilities contribute to NRT accuracy (Smith, 2006; Ellis Weismer, & Edwards, 2006). In fact, very little research has examined the nature of the repetition errors made by children in either group, instead focusing primarily on accuracy rates. One study that did consider the motoric demands of nonword repetition was conducted by Scheer-Cohen & Evans (2007). They compared children with SLI to typical controls in terms of the distribution of error types made in a NRT. Scheer-Cohen and Evans (2007) classified nonword repetition errors as motor, articulatory complexity, omission, or unclassifiable errors. Their analysis showed that the distribution of errors between the two groups was significantly different. The results demonstrated that children with SLI made fewer motor and articulatory complexity errors than would be predicted, but more omission errors than expected. Children with TLD showed the opposite pattern with a greater number of motor and articulatory complexity errors, but fewer omission errors than expected. This finding suggests that the types of repetition errors made by children with SLI are different from those made by children with TLD.

The current study is a re-analysis of the repetition errors made during an NRT completed by children with SLI and TLD (Coady, Evans, & Kluender, 2010). The primary objective was to determine if there were differences in the types of errors made between the two groups of children. The secondary objective was to determine whether substitutions included productions that are higher frequency phonemes, produce higher phonotactic frequency for phoneme combinations (i.e. syllables), or included phonemes with easier articulation. Historically, the field has primarily viewed errors as primarily motoric in nature. Richtsmeier (2010) takes an extreme view discounting the concept of substitutions altogether and proposes that errors are not truly substitutions, but instead are instances of missed articulation; thus, they are purely motoric. This analysis takes on a different perspective that there may be phonotactic influences on children's abilities to repeat nonwords.

The original analysis of the data used in the current study concluded that children with SLI and TLD were comparably affected by phonological complexity; however, there are many other aspects that lack exploration. For example, one factor that has not yet been examined is the phonotactic probability of children's phonological substitutions in NRT such as whether children replace less frequently occurring phonemes and phoneme combinations (i.e. syllables) with higher frequency or higher probability items. Similarly, it remains unclear if children substitute phonemes with easier articulation (i.e. earlier developing consonants or reduced vowels).

Finally, it is still unknown if there is a difference in the phonological substitutions made by children with SLI and children with TLD with respect to these phonological factors.

Based on the results from on the findings from the original study (Coady et al., 2010), the following hypotheses were made. First, for phoneme frequency, it was anticipated that children would substitute target phonemes with other higher frequency phonemes, but that there would not be a significant difference between the two groups. Second, for phonotactic probability, it was anticipated that substitutions would create syllables with higher phonotactic probability, but again that there would not be a significant difference between the two groups. Finally, for ease of articulation, it was hypothesized that children would replace target phonemes with phonemes with easier articulation, and that children with SLI would make significantly more substitutions based on ease of articulation than peers with TLD.

CHAPTER 2: STUDY DESIGN

Participants

Participants for the original study (Coady et al., 2010) included 18 monolingual English-speaking children (10 females, eight males) with SLI, mean age 9;2 (range = 7;3-10;6) and 18 typically developing children (12 females, six males), mean age 8;10 (range = 7;4-10;0). For the current re-analysis a subset from each group was chosen. The 10 children with receptive-expressive SLI were chosen (6 females, 4 males, mean age 9;2). Ten controls (6 females, 4 males) with TLD were selected to most closely match the 10 children with SLI in age, non-verbal IQ, and gender. The age difference between groups was not significant, $t(18) = -0.62$, $p = 0.65$. The difference in non-verbal IQ was significant but matched as closely as possible from the group of children with TLD, $t(18) = 3.95$, $p = .009$, and all children were within the normal range.

Table 1: Group Statistics for Children with SLI and Children with TLD

	Children with SLI	Children with TLD
Age	9;2 (1;1) Range: 7;3-10;4	8;11 (0;11) Range: 7;9-9;11
CELF-ELS	64.4 (10.82) Range: 53-84	105.1 (18.24) Range: 91-146
CELF-RLS	63.3 (12.25) Range: 50-80	N/A
Oral Directions	4.7 (1.77) Range: 3-8	9.7 (3.53) Range: 4-15
Non-verbal IQ	97.7 (9.26) Range: 87-116	109.2 (8.18) Range: 98-119

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), Oral Directions subtest from the CELF-R, 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).

Stimuli

Two lists of 24 nonwords varying in phonotactic frequency were created and used for the initial study (Coady et al., 2010). Phoneme and phoneme co-occurrence frequencies were taken from Coady and Aslin (2004). They estimated the phonotactic structure of English based on the words produced by Adam and Sarah and their mothers (Brown, 1973; MacWhinney, 1991). For the first list of nonwords, phonotactic frequency differences were based only on the consonants. For the second list, differences were based on diphones, or combinations of phonemes. Each list contained 12 high phonotactic frequency nonwords and 12 low phonotactic frequency nonwords. These lists were further divided into three- and four-syllable words. For the current study, errors on only the first list of 24 words, differing in the frequency of occurrence of the component consonants, were analyzed (see Appendix for the full list of nonwords included in the analysis).

All nonwords used the basic structure of (CV) CV-CV-CVC. All nonwords reflected typical English stress patterns with the stress placed on the penultimate syllable; for four syllable words, secondary stress was placed on the first syllable. A female speaker with a local dialect (Madison, WI) recorded the words, which were then digitized and saved separately.

Procedure

Children participated in the NRT 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 approximately 2 feet 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. Sessions were recorded for later scoring.

Scoring

Children's responses were transcribed from the recordings. Transcribers, blind to the children's language status, scored each phoneme produced relative to its target. Two transcribers each completed a first pass transcription. Their results were then 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 accuracy consensus scoring.

Error Analysis

Data collected from the original study (Coady et al., 2010) were analyzed, comparing children's error productions to the target. Three analyses were completed. First, the errors were analyzed to determine whether phoneme substitutions resulted in a production with a higher phoneme frequency than the target's phoneme frequency. Second, each syllable was analyzed for phonotactic probability of the phoneme combinations of the child's production as compared to the target. Third, errors were analyzed to determine whether children substituted phonemes with greater ease of articulation. For each of the above factors, two results were of interest. First, whether children as a whole tend to make phoneme substitutions that have a higher individual phoneme frequency, higher diphone frequency (i.e. higher phonotactic frequency at the syllable level), and greater ease of articulation. The second factor of interest was whether there were statistically significant differences between the groups of children for each area.

In order to facilitate explanation of each area, the following example will be used. For this example, the child heard [fɑi-ʃɑʊ-foʊ-jeip] and produced [fɑi-ʃoʊ-goʊ-gip].

Target: [fɑi –ʃoʊ – goʊ – gip]

[fɑi – shɑʊ – foʊ – jeip]

Production:

Phoneme Frequency

The first analysis focused on phoneme frequency. All phoneme substitutions were considered; for example, if a child heard [ʃeif] and said [ʃi], the substitution of [i] for [ei] was included in the analysis even though the final consonant [f] was omitted. For each nonword, the probability of the child's production (i.e. error) was compared to the probability of the target phoneme (child's production – target = difference). This analysis was further broken down to determine if there were differences between consonant and vowel substitutions. Using the example from above, this analysis looked like:

Target	Frequency	Production	Frequency	Result
[ɑʊ]	.0078	[oʊ]	.0295	Produced more frequent V
[f]	.011	[g]	.0173	Produced more frequent C
[j]	.0246	[g]	.0173	Produced less frequent C
[ei]	.0163	[i]	.0349	Produced more frequent V

Overall, three out of four of this child's substitutions involved replacing the target phoneme with a more frequently occurring phoneme, with both vowels and one of two consonants being more frequently occurring.

Phonotactic Probability

The second analysis, similar to the first, examined phonotactic probability for diphones at the syllable level; meaning, when the child substituted one or more phonemes in a syllable, it was analyzed to determine if the resulting syllable had a higher probability. Only syllables where the syllable structure was maintained were included in this part of the analysis as adding or deleting a phoneme inherently changes the phonotactic probability. Syllable probability was calculated using the following formula: probability the first phoneme starts a syllable X probability the second phoneme will follow the first X probability the third phoneme (if applicable) will follow the second X probability the last phoneme will end a syllable. Using the same example from above, this analysis looked like:

Target	Probability	Production	Probability	Result
[ʃɑʊ]	.00002	[ʃoʊ]	.0005	Produced more frequent combo
[foʊ]	.0005	[goʊ]	.0075	Produced more frequent combo
[jeip]	.0000002	[gip]	.00001	Produced more frequent combo

For this analysis, all four substitutions this child made resulted in syllables with higher phonotactic probability.

Articulatory Ease

Finally, the children's productions were reviewed for ease of articulation. This analysis posed an initial challenge as as there is not an agreed upon metric for ease of articulation. For the purpose of quantifying this analysis, age of articulation was used as the overall determination for ease of articulation for consonants and reduction of vowels (i.e., diphthong to monophthong to schwa) was used to quantify ease of articulation for vowels. However, choosing age of acquisition as the basis for ease of articulation of consonants left more to be determined as there is much variation among popular studies reviewing age of acquisition.

Lof (2004) noted the extreme variability among many of the most popular models used as guidelines for age of acquisition (Goldman-Fristoe Test of Articulation, 2000, Prather, Hedrick, & Kern, 1975; Sander, 1972; Shriberg & Kwiatkowski, 1993; Smit et al., 1990; Templin, 1957). In order to establish a model for the current analysis, an average was taken of all the studies included in Lof's analysis. The averages aligned most closely with the age of acquisition outlined by Kent (1992), which included four levels. However, a couple of modifications to Kent's model were made to more closely align with the other studies including moving [t, ŋ] to the second stage and moving [r, l] to the last level, thus eliminating the 3 level.

Table 2: Final Hierarchy for Consonants

Easiest/First Acquired (Level 1)	m, n, p, h, w
Middle Group (Level 2)	b, t, f, d, k, g, ŋ, j
Hardest/Latest Acquired (Level 3)	s, ʃ, tʃ, r, l, dʒ, z, v, θ, ð, ʒ

In addition, [tʃ] substituted with either /t/ or /ʃ/ and /dʒ/ substituted with either /d/ or /ʒ/ were also considered simplifications.

Similarly, a three-level hierarchy was developed for vowels based on vowel reduction.

Table 3: Hierarchy for Vowels

Easiest/Most Reduced (Level 1)	ə, ɚ
Monophthongs (Level 2)	Including: i, ei, oʊ, u
Diphthongs (Level 3)	ɑi, ɑʊ, ɔi

Using the same example from above, this analysis looked like:

Target	Production	Substitution Description	Result
[f]	[g]	Level 2 – Level 2	Difference of 0 (comparable)
[j]	[g]	Level 2 – Level 2	Difference of 0 (comparable)

Target	Production	Substitution Description	Result
[ɑʊ]	[oʊ]	Level 3 – Level 2	Difference of +1 (easier)
[ei]	[i]	Level 2 – Level 2	Difference of 0 (equivalent)

For this example analysis, the average difference for consonants was 0 (i.e. comparable substitutions as compared to targets) and the average difference for vowels was +0.5 (i.e. less complex substitutions as compared to targets).

Interscorer Reliability

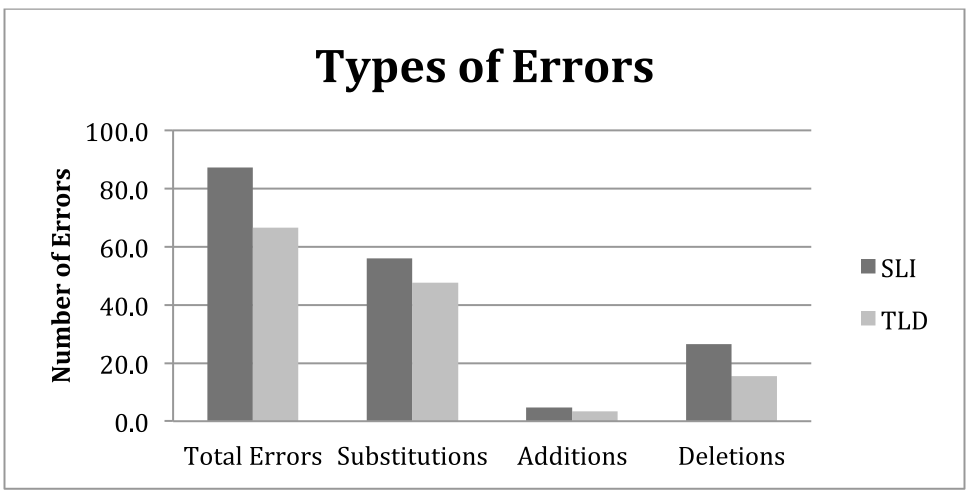
A second scorer calculated phoneme frequency, phonotactic probability, and ease of articulation for two children with SLI and two children with TLD (i.e. 20% of the data). The results from both scorers were compared. For phoneme frequency, correlations ranged from 0.97 to 1.0. For phonotactic probability, correlations ranged from 0.97 to 1.0. For ease of articulation, correlations ranged from .95 to 1.0.

CHAPTER 3: RESULTS

Error Analysis

The results of the error analysis are displayed in Figure 1. Consistent with all previous studies and the previously published results for this data (Coady et al., 2010), children with SLI made a greater number of errors overall when compared to their peers with TLD, $t = 4.39$, $p < 0.05$. Furthermore, once broken down into additions, deletions, and substitutions children with SLI had more additions ($t = 2.24$, $p < 0.05$), deletions ($t = 2.79$, $p < 0.05$) and a marginally significant greater number of substitutions ($t = 2.08$, $p = 0.0525$) than children with TLD.

Figure 1: Types of Errors Made by Children with SLI & TLD



Phoneme Frequency

All children, i.e. both groups combined, showed a general trend of making phoneme substitutions in which a target phoneme was replaced with a more frequently occurring phoneme, $t(19) = 8.06$, $p < 0.05$. When consonants and vowels were analyzed separately, the results indicated that children replaced vowels with higher frequency vowels, $t(19) = 15.56$, $p < 0.05$; however, for consonants the result was not significant, $t(19), = 1.75$, n.s. Therefore, the vowels were driving the overall effect.

Figures 2 and 3 show the results for average phoneme frequencies for targets and errors for children with SLI as compared to children with TLD. While children made substitutions with higher frequency phonemes than the targets, there was not a significant difference between the two groups: consonants and vowels were analyzed together, $t(18) = -0.51$, $p = 0.61$; consonants only, $t(18) = 0.05$, $p = 0.96$; vowels only, $t(18) = -0.70$, $p = 0.50$.

Figure 2: Average Phoneme Frequency of Target Compared to Error for Children with SLI & TLD - All Phonemes

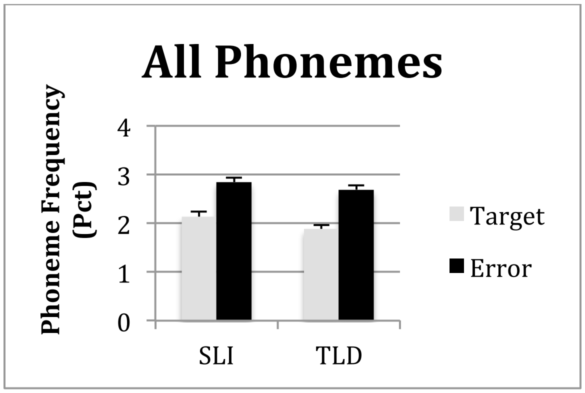
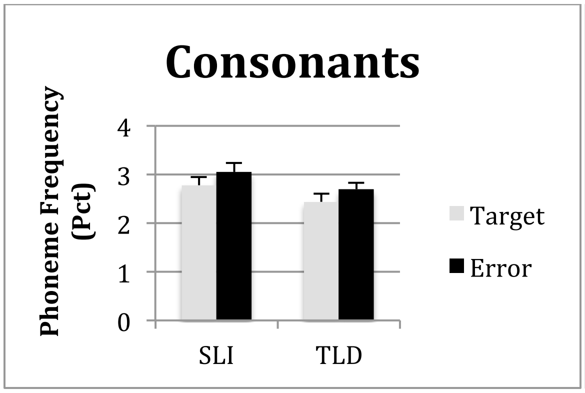
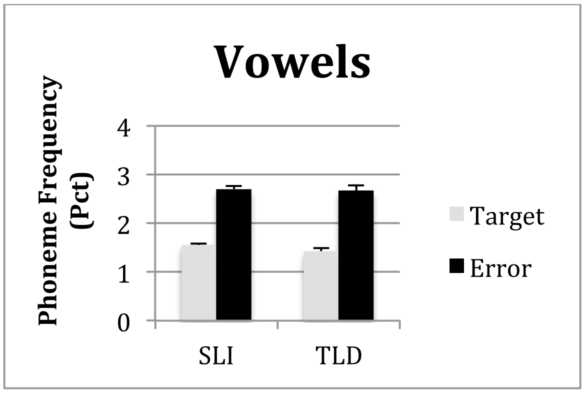


Figure 3: Average Phoneme Frequency of Target Compared to Error for Children with SLI & TLD - Consonants versus Vowels



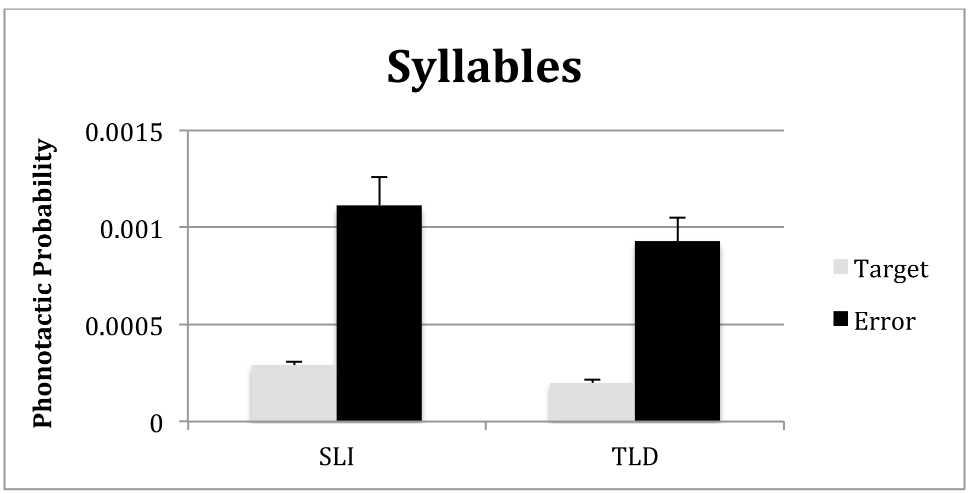


Note: Graphs display means and standard error bars. Higher frequency phonemes result in higher percentage values.

Phonotactic Probability

The phonotactic probabilities at the diphone/syllable level showed similar results as the individual phoneme frequency comparisons. Children's productions for syllables containing substitutions were greater than the probability of the targets, $t(19) = 8.20$, $p < 0.05$. Because this involves all phonemes within a syllable, a breakdown between vowel errors and consonant errors was not conducted. Figure 4 shows the results for average phonotactic probability for target syllables and syllables containing one or more substitutions without changing the syllable structure for children with SLI as compared to children with TLD. Although children replaced target syllable combinations with higher probability combinations, there was not a significant difference between the two groups, $t(18) = 0.49$, $p = 0.63$.

Figure 4: Average Phonotactic Probability of Target Syllable Compared to Error for Children with SLI & TLD

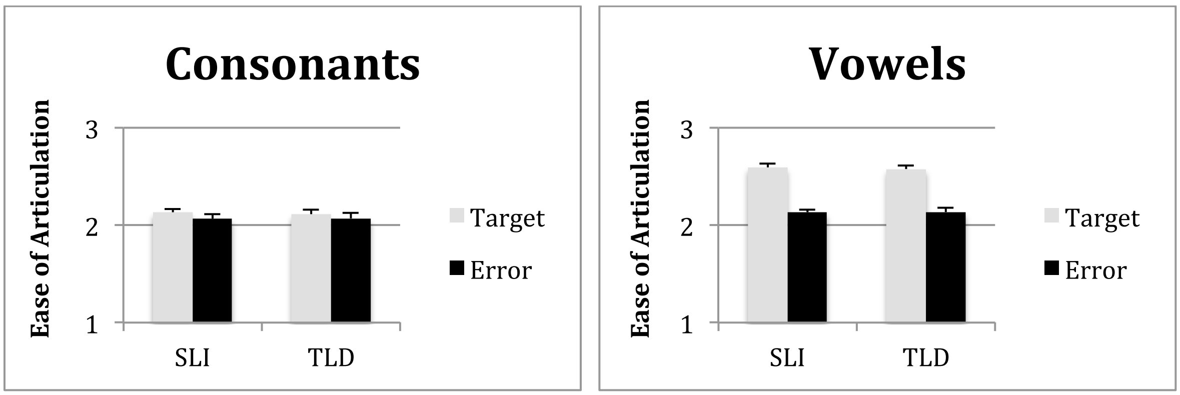


Note: Graphs display means and standard error bars. Syllable combinations with higher phonotactic probabilities result in higher values.

Articulatory Ease

Figure 5 shows the results for average ease of articulation for target and error consonants and vowels for children with SLI as compared to children with TLD. Similar to phoneme frequency, results for all children indicate they choose vowels with easier articulation, t(19) = 10.94, p < 0.05. For consonants, the overall average of the difference between target and substitution was positive; however, the result was not statistically significant, t(19) = 1.27, p < 0.05. Again, the results for ease of articulation did not differ by group, t(18) = 0.27, p = 0.79 for consonants, and t(18) = 0.24, p = 0.82 for vowels.

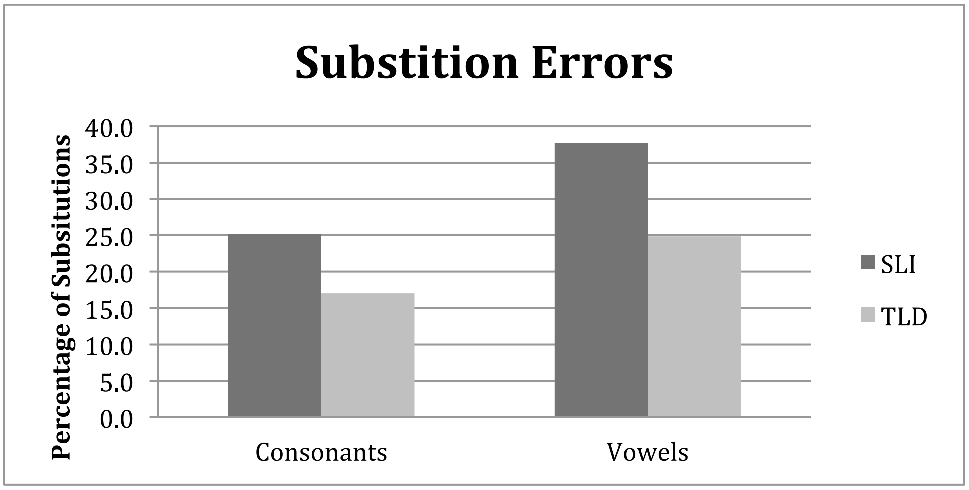
Figure 5: Average Ease of Articulation of Target Compared to Error for Children with SLI & TLD - Consonants versus Vowels



Note: Graphs display means and standard error bars. Phonemes with greater ease of articulation have a value of 1 (i.e. earliest acquired consonants and schwa).

Due to interesting findings when consonants and vowels were analyzed separately, the percentage of consonant substitutions was compared to the percentage of vowel substitutions. Both groups had more substitutions for vowels than consonants, and the number of substitutions was significant for each (t(19) = 9.63, t(19) = 13.47, respectively at p < 0.05). The percentage of consonants substituted was marginally significant for children with SLI producing more errors than children with TLD (t = 2.0002, p = 0.06) and the percentage of vowels substituted showed a significant difference with children with SLI producing more vowels with higher ease of articulation than children with TLD (t = 3.48, p = .0027).

Figure 6: Average Percentage of Consonant versus Vowel Errors for Children with SLI & TLD



CHAPTER 4: DISCUSSION

Results for all children show a general trend in which phoneme substitutions involved replacing one phoneme with a more frequently occurring phoneme; likewise, the resulting phonotactic probability for syllables containing substitutions was greater than the probability of the targets. For ease of articulation, the results were different for consonants and vowels. Results for all children showed a positive average for consonants indicating that consonant phonemes were earlier acquired; however, the finding was not statistically significant. Results for all children indicated they chose vowels with easier articulation (i.e. they reduced vowels). While the patterns above were clear when all children were analyzed together, the trends did not differ by group. These results suggest that children with SLI, just like children with TLD, substitute less frequent phonemes with more frequent ones, resulting in higher probability combinations. Furthermore, children's vowel substitutions involved easier articulation, but consonant substitutions did not.

Error Analysis

The results from this study were consistent with findings from previous studies. Children with SLI made significantly more errors than children with TLD. The question this analysis endeavored to answer was whether there was a difference in the type of errors made by children with SLI as compared to their matched peers. Based on the findings of the subset of data, the results indicate that while children with SLI make more errors overall, the types of errors made are the same in regards to phoneme frequency, phonotactic probability, and ease of articulation.

Phoneme Frequency

The first part of the hypothesis for phoneme frequency was that most errors would involve selecting a phoneme with a higher phoneme frequency. Based on the analyses, this hypothesis was shown to be true when all phonemes were reviewed in one pool. However, once consonant errors were separated from vowel errors, the results indicate that children of both groups often are not making substitutions with phonemes with significantly higher probabilities.

The second part of the hypothesis for this aspect of the investigation was that there would not be a significant difference between the two groups based on the original study findings (Coady et al., 2010). This aspect of the hypothesis was also supported by the analysis. Regardless of whether the phonemes were reviewed all together, or analyzed separately by consonants and vowels, there were not significant differences between the two groups of children.

Phonotactic Probability

For phonotactic probability, the hypothesis was that most errors would involve children producing syllables with higher phonotactic probabilities as compared to the target, and that there would not be significant differences between the two groups based on the findings from the original study (Coady et al., 2010). The results were similar to the findings for individual phoneme frequency, with all children producing syllables with higher phonotactic probabilities as compared to the targets. The second part of the hypothesis was also supported as, again, there were not group differences.

Articulatory Ease

The final hypothesis was that most errors would involve greater ease of articulation. For this element, it was expected that there would be a significant difference between the groups, with children with SLI making more substitutions based on ease of articulation when compared to peers with TLD. Ease of articulation proved to be the most difficult to define and presented the most interesting findings. For all children combined, the results revealed that they substituted target vowels for vowels with greater ease of articulation (i.e. reduced vowels), but did not substitute target consonants with consonants that had easier articulation (i.e. with earlier acquired consonants). While the results were split between consonants and vowels for the first part of the hypothesis, when it came to identifying group differences, it was unexpected to find there were not group differences for either measure.

The difference in results for consonants versus vowels was surprising. Vowel substitutions involved more frequently occurring phonemes and vowels that were easier to articulate, whereas consonant substitutions did not. This result was unexpected because vowels are typically acquired earlier and because the speech-language pathology field tends to focus primarily on consonant errors. One reason for this discrepancy may be founded in the target phonemes for each category of phoneme. In reviewing Figures 3 and 5, it is clear that the target vowels had low phoneme frequencies and low ease of articulation values (i.e. they were harder). In contrast, the consonant targets had relatively high phoneme frequencies and higher ease of articulation values (i.e. the starting values were representative of a mix of age of acquisition with the average falling just over level two). This means that there was more room for substitution error differences for vowels than consonants.

Alternate Hypothesis

While the findings for each aspect analyzed supported the hypotheses based on the Coady et al. (2010) findings, they did not replicate the findings of Scheer-Cohen and Evans (2007) that children with SLI had a different distribution of types of errors when compared to children with TLD. It may be that the results of this study are not comparable to the findings by Scheer-Cohen and Evans (2007) since this study focused on the phoneme frequency and phonotactic probability rather than looking at the error pattern differences (i.e. motoric, articulatory complexity, omissions, other) between the two groups of children.

Research Applications and Limitations of the Study

There are a few potential reasons for the findings of the current analysis. It is likely that ease of articulation is confounded with phoneme frequency, which may explain the consistent findings between these two measures. However, there are exceptions to this idea. For example, there are some phonemes that are very difficult or complex that have high phoneme frequencies, such as /r, l, ɑi /, and others that are easy, but relatively infrequent, such as /b/.

Also, the study may have been limited by low statistical power. We analyzed repetition of 24 nonwords by two groups of 10 children. Perhaps the results may have been more significant had the repetitions been analyzed for all 36 children and for all 48 nonwords; however, the group differences for each of the variables did not even approach significance, with p values greater than 0.5.

In addition, the set of nonwords utilized for the initial study were designed to highlight differences between phoneme frequency and phonotactic probability, not ease of articulation. The findings from the original study using this set of nonwords (Coady et al., 2010) were similar to the findings of the current study showing significant accuracy differences, but not differences in the magnitude of the phonotactic frequency effect. Conversely, a study by Munson, Kurtz, and Windsor (2005) did report group differences in repetition accuracy when comparing high probability nonwords to low probability nonwords. This suggests it is possible that a different set of nonwords focusing on differences in ease of articulation (e.g. age of acquisition for consonants) would have provided different results.

Finally, it may be that the three-level ranking may not have been robust enough to highlight the differences in ease of articulation, at least in respect to consonants. However, the three-level ranking for vowel reduction was solid enough to reveal differences. It would be interesting to perform additional analyses with a more refined schema. For example, the Williamson (2010) model for speech sound development could provide a more gradated ranking (i.e. eight levels) based on the age at which 50% of children produce the consonant and use it in speech. Similarly, vowels could be further refined into additional levels by including factors such as tenseness/laxness; although this refinement seems unnecessary based on the differences found based on the three-level ranking.

Clinical Implications

There are clinical implications in addition to the research implications noted above. First, the results from this study revealed that children made more errors on vowels than on consonants, which was unexpected. In fact, each group substituted a higher percentage of vowels than consonants. In addition, there were group differences showing that children with SLI substituted a significantly higher percentage of vowels, and a marginally significant higher percentage of consonants. This particular finding was particularly interesting in light of the amount of emphasis placed on consonant errors, including the use of articulation tests such as the Goldman-Fristoe Test of Articulation that assess only consonant errors. The results from this analysis indicate that reviewing vowel errors may be as important, or more important in utilizing NRT as a tool for determining behavioral differences for children with SLI.

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APPENDIX

Nonwords differing in consonant frequency, i.e. the frequency of occurrence of constituent consonants.

<u>High Consonant Frequency</u>

[daʊ·ɹu·nas] "dao-roo-nahs"
[teɪ·la·doʊd] "tay-lah-dode"
[maʊ·koʊ·tik] "mao-koe-teek"
[sa·neɪ·kaʊt] "sah-nay-kaut"
[lu·maʊ·seɪs] "loo-mao-sace"
[nɔɪ·taʊ·lit] "noy-tao-leet"

[li·ka·teɪ·sud] "lee-kah-tay-sood"
[ɹaʊ·naɪ·sa·doʊk] "rao-nye-sah-doke"
[koʊ·daʊ·neɪ·kaɪd] "koe-dao-nay-kide"
[naɪ·ɹu·laʊ·kit] "nye-roo-lao-keet"
[kaɪ·ɹa·nɔɪ·taʊs] "kye-rah-noy-tauss"
[taʊ·lu·kaɪ·seɪd] "tao-loo-kye-sade"

<u>Low Consonant Frequency</u>

[ʃeɪ·paʊ·boʊf] "shay-pao-bofe"
[foʊ·gi·pab] "foe-ghee-pahb"
[ba·ʤaɪ·jup] "bah-jye-yoop"
[pɔɪ·ʃeɪ·goʊb] "poy-shay-gobe"
[jaʊ·fa·gip] "yao-fah-gheep"
[gaʊ·ʃa·faɪp] "gao-shah-fipe"

[jaʊ·faɪ·ga·pig] "yao-fye-gah-peeg"
[faɪ·ʃaʊ·foʊ·jeɪp] "fye-shao-foe-yape"
[ʤaɪ·ba·faʊ·goʊb] "jye-bah-fao-gobe"
[baʊ·fu·ʤa·ʃeɪf] "bao-foo-jah-shafe"
[feɪ·pa·ʤaʊ·boʊp] "fay-pah-jao-bope"
[ʃa·gi·faʊ·ʤig] "shah-ghee-fao-jeeg"