Published in final edited form as:

J Commun Disord. 2011 ; 44(1): 91–102. doi:10.1016/j.jcomdis.2010.07.005.

Beyond Phonotactic Frequency: Presentation Frequency Effects Word Productions in Specific Language Impairment

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Abstract

Phonotactic frequency effects on word production are thought to reflect accumulated experience with a language. Here we demonstrate that frequency effects can also be obtained through short-term manipulations of the input to children. We presented children with nonwords in an experiment that systematically manipulated English phonotactic frequency and the frequency of presentation within the experiment. Both of these manipulations affected the accuracy and time to response for nonword production both for typically developing and children with specific language impairment. Children with SLI were less accurate in their productions overall, but still exhibited an effect of the short-term frequency manipulation. Children with SLI differed significantly from their typical peers in terms of time to response only when both English and experimental frequency were low. The results indicate that simple manipulations of the input can affect children's representation of word forms, and this can facilitate word production without the need for long term exposure or articulatory practice.

Keywords

specific language impairment; Nonword repetition; speech; phonology; word learning

1.1 Introduction

The fact that children are more accurate and more consistent at producing forms that are more frequent in their language is well established (Alt & Plante, 2006; Edwards, Beckman, & Munson, 2004; Mainela-Arnold & Evans, 2005; Munson 2001; Munson, Edwards, & Beckman, 2005; Munson, Kurtz, & Windsor, 2005; Munson, Swenson, Manthei, 2005; Storkel, 2001a; Storkel, 2001b; Storkel 2004; Zamuner, 2009). However, what remains a mystery is the mechanism by which more frequently occurring forms yield better production. One possibility is that more frequent forms in a language are produced by children more often and they benefit over time from the greater articulatory practice. Alternatively, simply hearing frequently-occurring forms may lead to stronger internal representations of these forms. Consequently, the stronger internal representation assists with production of similar phonological forms in production tasks.

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Articulatory complexity may contribute directly or indirectly to children's ability to produce novel forms (Gathercole and Adams, 1993, 1994; Graf Estes, Evans, & Else-Quest, 2007). Gathercole and colleagues have argued that articulatory skills may constrain performance on nonword repetition tasks (Gathercole & Adams, 1993), but that articulatory proficiency alone does not fully account for children's ability to add words to their lexicon (Gathercole, Service, Hitch, Adams, & Martin, 1999). However, it is logically possible that greater articulatory practice with frequent phonotactic sequences could lead children to a stronger sublexical representation of these sound sequences. This, in turn, could improve subvocal rehearsal during the operation of the phonological loop (Baddeley, 2003). A strong phonological loop, in turn, might then support vocabulary growth (Gathercole & Baddeley, 1989; Gathercole et al., 1999, but see also Gathercole, Adams, Hitch, 1994, concerning the issue of subvocal rehearsal by young children).

In contrast to this notion, others have argued that growth in vocabulary drives the frequency effect observed in nonword repetition tasks (Edwards et al., 2004; Munson, Kurtz, & Windsor, 2005; Munson, Swenson, Manthei, 2005; Munson, Edwards, & Beckman, 2005). This perspective posits that the development of the lexicon assists children in developing an abstract representation of the sublexical aspects of word forms. This abstract representation in turn influences children's performance on nonword tasks. The mental representation is influenced by the frequency with which specific phonological forms are common to the words in the child's lexicon, independent of articulatory ability. Gathercole and colleagues (Gathercole, Willis, Emslie, & Baddeley, 1991) also suggested that high frequency phonotactic forms in the child's lexicon may facilitate encoding into phonological working memory because encoding is supported by "phonological frames" that are abstracted from frequently occurring forms. The difference in these two perspectives relates to whether vocabulary development is thought to drive nonword repetition performance or the enhanced phonological working memory accounts for both vocabulary and nonword repetition results. Both positions are supported by associations between vocabulary test scores, particularly in the expressive domain, and frequency effects on nonword repetition tasks (Edwards et al., 2004; Munson, Swenson, Manthei, 2005; Munson, Edwards, & Beckman, 2005). However, children with phonological disorders exhibit the phonotactic frequency effect, even when the effect of vocabulary size is partialled out (Munson, Edwards, & Beckman, 2005). This leaves open the possibility that factors other than the size of a child's lexicon can influence production.

What is not in dispute in any of the above scenarios is the idea that children must represent the sounds of their language at a sufficient level of abstraction to serve speech production. Learners must convert the acoustic patterns in their input to some more abstract sequence of segments, which in turn can be used in their own productions. This view is partially supported by data from infants, who distinguish more frequent from less frequent phoneme sequences in their language before they produce their first word (Jusczyk, Luce, & Charles-Luce, 1994). Infants are also able to learn new phonotactic sequences in the laboratory, suggesting that they are highly sensitive to this kind of information (Chambers, Onishi, & Fisher, 2003; Saffran & Thiessen, 2003). The infant perception findings argue against the idea of articulatory practice as the sole driving force behind frequency effects in production. However, it is possible that infant sensitivity to what is frequent in their input has little to do with the production effects seen in older children, for whom greater experience with language might support alternate learning strategies. Children's experience with their native language is thought to change their sensitivity to various types of language and language-like input that they receive (e.g., Werker & Tees, 1984; Gerken & Boltt, 2008; Cristia, Seidl, & Gerken, under review). Data from infant studies, therefore, is not adequate to address the issue of whether articulatory practice, lexical or sublexical internal representations, or any

combination of these may account for frequency effects in word production of older children.

Recently, Richtsmeier, Gerken, Goffman, & Hogan (2009) addressed this theoretical issue in a study of typically-developing four-year-old children. These investigators designed a study that narrowed the range of potential explanations for frequency effects. They used CVCCVC nonwords for which the medial biphone was either relatively frequent or infrequent in English. This contrast was crossed with frequency of presentation within the context of their experiment by presenting some words ten times and other words just once. Children listened to presentations of nonwords for a brief period and then were given an opportunity to pronounce each nonword. Children heard multiple presentations of these nonwords before being asked to pronounce them.

Two findings from that study are particularly relevant for the present discussion. First, when a single talker presented each of the CVCCVC nonwords, the only effect on children's nonword production was that of frequency of occurrence in English, regardless of the frequency of presentation in the experiment. However, when each word was spoken by a different talker, then frequency of occurrence within the experiment had a greater effect than frequency of occurrence in English. This effect occurred not only for accuracy of the production of nonwords, but also for the time it takes for the child to respond (thought to reflect planning time). This pattern of results suggested that the talker-related variation in word production may have facilitated the development of an abstract internal representation in the way that high frequency presentation of the same nonword token from a single speaker had not. This interpretation is consistent with other work suggesting that multiple input tokens are required for learners to move from item-specific representations to general representations that allow for generalization beyond the input (Gómez, 2002).

The purpose of this study was to determine whether the frequency of speech input to children with specific language impairment (SLI) and their typically developing peers is sufficient to effect word production. We used the nonword stimuli of Richtsmeier and colleagues (2009) in order to replicate the effects in typically-developing children and to determine whether the results can be extended to include children whose language development is impaired. Although children with SLI are known to have difficulty with nonword repetition, they are also known to benefit in nonword production tasks when nonwords contain sound sequences that occur frequently in English (see Graf Estes et al., 2007 for a meta-analysis). Therefore, we expect an effect of English phonotactic frequency on their nonword productions. However, it is unknown whether children with SLI would be sensitive to a short-term manipulation of presentation frequency. An important benefit for these children for word acquisition might be derived if they could also be shown to be sensitive to frequency manipulations within a single experimental (or therapeutic) session.

The Richtsmeier et al. (2009) study demonstrated that the use of multiple talkers was critical for producing the type of perceptual learning that could drive experimental frequency effects. We will likewise employ multiple talkers when words are presented frequently within the experiment.

2.1 Methods

2.1.1. Participants

Sixty-four preschool children who were native English speakers participated in the study. Thirty-two of these children (23 boys and 9 girls) belonged to the SLI group and thirty-two (23 boys and 9 girls) comprised a typically-developing (TD) control group. Children were matched pair-wise by gender and by age (SLI = ages 48–71 months, $M = 59$ months; TD =

ages 49–71 months, $M = 58$ months). Mothers' educational level averaged 13.8 years of education overall (SLI mean=13.66, range=11–17 years; NL mean=14.0, range=9–17 years).

All participants passed an audiometric pure tone bilateral hearing screening at 25 dB HL at 500Hz and 20 dB HL at 1000, 2000, and 4000 Hz at the time of study. To rule out mental retardation, all children were administered the nonverbal scales of the *Kaufman Assessment Battery for Children Second Edition* (KABC-II, Kaufman & Kaufman, 2004). All children were required to achieve a standard score of 75 ($70 + 1$ SEM) or better on the KABC-II. Participants were excluded from the study if they were known to have hearing loss or a diagnosis of other medical/behavioral conditions that could explain poor speech or language (e.g., cleft palate, seizures).

Members of both the groups (SLI and TD) were identified using a combination of clinical judgment and standardized testing. The clinical judgment was based on a certified speech pathologist's impressions of the participants' language during informal conversation and through parent and teacher reports indicating impairment on a brief research questionnaire.

The *Structured Photographic Expressive Language Test—Preschool Second Edition* (SPELT-P2, Dawson, Eyer, & Fonkalsrud, 2005) was used as a formal measure of language status. The SPELT-P2 was previously shown to have high accuracy in discriminating between children with SLI and those with typically-developing language (Greenslade, Plante, & Vance, 2009). Children were included in the SLI category if their standard scores were below a cut-off score of 87, which was previously determined to maximally discriminate between children with SLI and their normal language peers (Greenslade et al., 2009). Conversely, all participants in the NL group were required to score above this cut-off. A small number of children in the SLI group had recently been administered the SPELT-3. This test has been separately validated as an identification test and requires children to score below 95 for accurate classification of SLI (Perona, Plante, & Vance, 2005). However, the content overlap between the SPELT-P2 and SPELT-3 is sufficient to warrant concern about giving both tests in within a short period of time (i.e., possibly inducing training effects that invalidate both measures for those children).

In addition, the following standardized tests were administered to the children for descriptive purposes: the *Peabody Picture Vocabulary Test—Third Edition* (PPVT-III; Dunn & Dunn, 1997), and the *Grammatic Understanding* subtest of the *Test of Language Development Primary - Third Edition* (TOLD-P3:GU; Newcomer & Hammill, 1997), and the *Goldman-Fristoe Test of Articulation – Second Edition* (GFTA-2; Goldman, & Fristoe, 2000). Finally, the children were administered a nonword repetition measure. This measure used a computer-delivered list of nonwords (Dollaghan, & Campbell, 1998) that were presented paired with novel pictures. Children were asked to repeat each nonword immediately after presentation. An experimenter transcribed each response and then advanced the program to present the next item. Although the SLI and TD groups did differ significantly on 3- and 4-syllable nonwords, they did not differ significantly on their production of 2-syllable words, similar to the length of the experimental stimuli used in this study. The test scores of children in the SLI and NL groups are reported in Table 1.

Scoring reliability for the norm-referenced tests was calculated for 19% of the participants by having a second experimenter score the tests during the test sessions. The average point-to-point reliability for the different norm-referenced tests ranged from 95.4% to 99.9% reliability (grand mean of 98.2%, range for all individual tests 90–100%).

Thirteen additional children (12 SLI and 1 NL) recruited for the study were eventually excluded either because they failed the hearing screening, English was not their primary language (which would change the effect of the English frequency manipulation), they

consistently exhibited a deviant phonological patterns that would interfere with the study paradigm (e.g., stopping, fronting), their score on SPELT-P2 was not consistent with the clinical impression of their spontaneous language, or they scored less than 75 (70 + 1 SEM) on the KABC-II.

2.1.2 Materials

The study used eight CVCCVC nonwords that were recorded by ten different talkers (see Table 2 for the word lists). These stimuli were those also used in Richtsmeier et al, (2009). The stimuli were digitally edited using Sony Sound Forge (2000). Ten adult female talkers were used to present stimuli during an initial familiarization phase. A single child (male) presented words during a test phase. All were speakers of standard English and pronounced the nonwords intelligibly. All words were pronounced with a trochaic stress pattern.

The nonword tokens included four pairs that were similar in terms of the initial and final phonemes, but differed in terms of the medial consonant cluster. For each pair of words, one medial cluster had a high frequency of occurrence in English (High English Frequency) and its counterpart had a medial consonant cluster that occurs infrequently in English (Low English Frequency). The frequency of occurrence data were taken from Munson (2001).

Each child was assigned two words for which the medial cluster had a high frequency of occurrence in English and two with a low frequency of occurrence in English. This assignment was done in a way that maximized the distinctness of the words in the different conditions (see Table 2). One of the words from each English frequency condition (High and Low) was presented ten times and the other was presented once. This resulted in a set of stimuli that crossed the factor of experimental frequency with English frequency. The four words and their assignment to the low and high frequency conditions are shown in Table 2. The words counterbalanced across four lists and assigned such that different children received different High English Frequency and Low English Frequency words in each Experimental frequency condition.

Four cartoon illustrations of novel animals were paired with nonwords. As with the nonwords, these illustrations were also used in Richtsmeier et al, (2009). The pairings of the novel animals and nonwords were counterbalanced across participants. Note that the presentation of a visual referent with the nonwords makes the task more like natural word acquisition compared to most nonword repetition tasks, in that children typically encounter new words along with a referent that suggests its meaning. However, the children here were not tested whether they mapped nonwords to pictures as part of this experiment.

2.1.3 Apparatus

Visual and auditory stimuli were presented via computer using Direct RT software. Children saw the novel animal image and heard the nonword simultaneously with the visual presentation. The audio output from the computer was routed through a digital recorder to a set of headphones worn by the child throughout the experiment. Responses from the child were recorded by a lapel microphone worn by the child. This microphone was also connected to the digital recorder. Thus, the digital audio record contained a clear recording of both the stimuli and the child's response. This was necessary to calculate the response times for the child's oral responses.

2.1.4 Procedures

Children faced a computer screen for the duration of the task. The session began with a familiarization phase during which the children were told that they would see some 'funny' animals and would hear unusual and funny names of those animals. Each child was shown

pictures of each of the four novel animals each paired with one of the nonwords. The pictures of the animals and the accompanying nonwords were presented in a computer-generated random order. The words in the High Experimental Frequency condition were presented 10 times each and the words in the Low Experimental Frequency condition were presented once each. Furthermore, the child heard each of the words presented ten times in a different talker's voice each time. For the words heard once, one of four talkers was used so that different children heard different individual talkers produce these words.

After the familiarization phase, children were told that they would see each of the animals one by one, hear their names, and that they would have to try and say those names. This constituted the test phase. A new speaker was heard presenting each test word (the male child). The four non-words were presented in a block containing one non-word of each type. The order of presentation of nonwords was randomized within the blocks. Each of the blocks of four nonwords was presented four times. Thus, the child repeated each non-word four times for a total of 16 nonword productions. The rate of stimulus presentation was controlled by the experimenter who pressed a key on the keyboard after the child responded. This assured that the next test item was not presented before the child was attending to the computer screen.

The consonants contained in all responses were transcribed by two individuals trained in narrow phonetic transcription. Words were transcribed with 98% reliability. Discrepancies were resolved prior to data analysis. The accuracy data consisted of the total number of consonants produced correctly, as a broad measure of word production accuracy. In addition, in a separate analysis we examined the total of medial consonants produced correctly across the four trials. This analysis was of interest because the medial clusters were the locus of the English frequency manipulation in this experiment.

In addition to production accuracy, we considered the length of time it took children to produce a response. This was taken as an indirect index of the strength of children's mental representations of the nonwords. Note that children could potentially form strong mental representations of words that were either correct (leading to fast and accurate productions) or incorrect (leading to fast, but inaccurate productions). They could also formulate weak representations, which would lead to slow productions. To distinguish between these possibilities, we calculated time to response on all responses, whether accurate or not.

Time to response was measured from the visual display of the sound recording using *Sony Sound Forge*. The final time-to-response measure was the duration between the offset of the prompt nonword to the onset of the child's production. However, measuring the offset-to-onset time directly from the recordings proved difficult. This was due to the difficulty in determining the true offset of the continuant /m/ at the end of each nonword. Therefore, we adopted a two-step measurement strategy that was designed to reduce the measurement variability. First, the duration of each of the four nonwords prompts was measured repeatedly and the average measurement calculated. This produced a stable estimate of the nonword prompt duration. We then measured the onset-to-onset duration from the prompt nonword to the child's production as recorded during the test phase. We then subtract the averaged duration of the nonword prompt from the prompt onset to onset of the child's response. This resulted in a reliable measure of time to response. By standardizing what would be considered the "end" of each nonword prompt in this way, measurement variability was minimized. Furthermore, using the resulting offset-to-onset time as the dependent measure (rather than onset-to-onset time) assured that the natural differences in duration between the four different nonwords in Table 2 did not influence the analysis of the time-to-response results. Outlier response times (> 2.0 SD from the total time-to-response

average) were removed from the data prior to analysis. The time-to-response data were then averaged across each of the four production trials for each nonword for statistical analysis.

3.1 Results

Prior to the main analyses, we examined whether there were significant version differences that might suggest that one list of words was easier or more difficult than another. We conducted one-way ANOVAs for each dependent variable (accuracy and time to response) with experimental list as a between-group variable. There were no significant version effects for the ANOVAs. Therefore, we collapsed the results obtained from the different lists for subsequent analyses.

The means and standard errors of the accuracy and time to response data are displayed in Figures 1, 2, and 3. These data were analyzed formally with $2 \times 2 \times 2$ mixed ANOVAs in which group (TD vs. SLI) was the between-group factor and Experimental frequency (high vs. low) and English frequency (high vs. low) were within group factors.

3.1.1 Response Accuracy

3.1.1.1 Total Consonants Correct—When children were prompted to repeat the target word, they either produced the target word correctly or their attempt substantially resembled the target word with errors on specific consonants. No child produced an alternative word from the experimental set (e.g., famkem for boktem). There were four consonants per nonword, and nonword was produced four times during the test phase. This resulted in 16 possible consonants correct per condition. The overall hypothesis was that the input frequency context would affect overall production. However, the two groups of children differed in terms of their overall articulation accuracy, with children in the SLI group making more errors overall on the GFTA-2 than the children in the NL group. In order to account for this obvious potential confound, we gave credit for sound omissions or substitutions in the nonword productions if the child also consistently failed to produce this sound correctly during on the GFTA-2 as well (i.e., the sound did not appear to be in the child's inventory). Given that most of the sounds in the nonwords were early-appearing, this was an infrequent occurrence (occurring for only three children in the SLI group).

An ANOVA revealed a significant group effect, ($F(1,62) = 28.93, p = .001; \eta_p^2 = 0.34$), a significant effect of English Frequency ($F(1,62) = 8.19, p < .01; \eta_p^2 = .13$), and a significant effect of Experimental Frequency ($F(1,61) = 7.96, p < .01; \eta_p^2 = .12$). The SLI group (mean(SD)=47.21[6.84]) was less accurate than the TD group (mean(SD)= 55.31[4.37]), even when children received credit for errors due to sounds not produced on the GFTA-2. All children were also less accurate in the low English Frequency (mean(SD)=12.47[2.74]) than high English Frequency (mean(SD)=13.16[2.68]) conditions. Likewise, the low Experimental Frequency condition was associated with lower consonant accuracy (mean(SD)=12.26[2.75]) than the high Experimental Frequency condition (mean(SD)=13.27[2.64]) for children overall. None of the interaction effects were statistically significant.

3.1.1.2 Medial Consonant Clusters—There were four repetitions of each medial consonant cluster for each nonword. This resulted in a total of 4 possible correct productions per frequency condition. An ANOVA conducted on the accuracy of the production of the medial consonant clusters revealed a significant group effect, ($F(1, 62) = 24.58, p < .001; \eta_p^2 = 0.28$; SLI mean(SD) =2.06(0.83); TD mean(SD)= 3.09[0.83]). There was also a significant main effect for English frequency ($F(1, 62) = 56.91, p < .001; \eta_p^2 = 0.47$; High English Frequency mean(SD)=3.27(0.86), Low English Frequency mean(SD)= 1.87(1.31). There were no other main effects or interaction effects. The group effect indicated that the

TD group was significantly more accurate overall than the SLI group. The English frequency effect suggested that words with medial consonant clusters that appear more frequently in English are produced more accurately than those that occur infrequently.

We examined the production of clusters produced on the GFTA-2 to consider whether consistent errors involving sound clusters may have influenced the results. Eight children in the SLI group (and none in the TD group) reduced clusters to single consonants on half or more of the items on the GFTA-2 that involved consonant clusters. None reduced or omitted all sound clusters on the GFTA-2, suggesting all children were minimally capable of cluster production. All children produced medial clusters on the experimental stimuli. Moreover, reduction of medial consonant clusters to singleton consonants that occurred within the experiment occurred most frequently for words in the Low English/High Experiment and Low English/Low Experiment conditions. This suggests that the word context, rather than a general tendency to reduce clusters, was driving cluster reductions for these children.

We re-ran both ANOVA for total consonants correct and the ANOVA for medial consonants correct without the three children who failed to produce sounds used on the experimental task on the GFTA-2, along with their matched controls. Once again, each of the effects that were significant in the initial analysis remained significant with these subjects removed, and none non-significant effects from the initial analyses became statistically significant when these children were removed.

3.1.2 Time to Response

Due to technical problems, the time-to-response data was not available for one participant with SLI. An ANOVA for the time-to-response for the oral production of the nonwords revealed a significant Group effect, ($F(1, 61) = 4.66, p < .05; \eta_p^2 = 0.07$) with the SLI group responding significantly more slowly overall (mean(SD)=0.716(0.342)sec) than the TD group (mean(SD)=0.619(0.232)sec). The main effect of English Frequency was also significant ($F(1, 61) = 24.00, p < .00001; \eta_p^2 = 0.28$). Responses to high English frequency nonwords were significantly faster (mean(SD)=0.591(0.266)sec) than those to low frequency nonwords (mean(SD)=0.748(0.305)sec). There was also a main effect for Experimental Frequency ($F(1, 61) = 15.34, p < .0001; \eta_p^2 = 0.20$) with faster times to response for nonwords presented frequently within the experiment (mean(SD)=0.613(0.271)sec) as compared to those presented infrequently (mean(SD)=0.720(0.309)sec). Finally, there was a significant group by English Frequency interaction effect ($F(1, 61) = 10.29, p < .001; \eta_p^2 = 0.14$). A Tukey HSD indicated that the SLI group was significantly slower than the TD group for the Low English Frequency, Low Experimental Frequency condition (SLI mean(SD)=0.930 (0.391)sec; TD mean(SD)=0.673(0.247), $p < .05$).

We asked whether specific participant characteristics may have contributed to the experimental effects obtained. To examine this issue, we constructed two new variables that reflected the size of the English and the Experimental frequency effects. For each participant, we combined the consonants correct for the High English/High Experiment and High English/Low Experiment nonwords and subtracted from this total the consonants correct from the Low English/High Experiment and Low English/Low Experiment words. This new variable reflected the magnitude of the difference between High and Low English frequency, collapsed across Experimental frequency. We likewise created a variable that reflected the magnitude of the difference between High and Low Experimental frequency. These two new variables were correlated with each of the behavioral tests administered to the participants (see Table 1). Note that since very few children received the SPEPT-II, we did not calculate correlations with this test. We used the standard scores for each measure, with the exception of the Nonword Repetition task. For this task, we used the total raw score. Separate correlations were calculated for the TD and SLI groups. No correlation (out

of 24 correlations total) was statistically significant, even without alpha adjustments to account for multiple statistical tests.

4.1 Discussion

The results replicate the frequently-reported effect of English phonotactic frequency on both nonword production accuracy and response time (Alt & Plante, 2006; Edwards et al., 2004; Mainela-Arnold & Evans, 2005; Munson 2001; Munson, Swenson, Manthei, 2005; Munson, Edwards, & Beckman, 2005; Storkel, 2001a&b, Storkel 2005; Zamuner, 2009). Furthermore, the independent effect of Experimental frequency replicates that reported by Richtsmeier et al. (2009). The dual effects of English and Experimental frequency were found for both the accuracy of children's consonant production and their time to response. Medial consonant clusters, which were the sounds manipulated to reflect English frequency, were only affected by the English frequency manipulation.

The results indicated that the frequency of presentation within the experimental session can produce significant effects on word production. Moreover, the results demonstrated that these frequency effects can be realized within a very short time period. This indicates that children's internal representations are not solely the result of either greater articulatory practice for frequent forms, given the lack of production practice prior to the test phase and that all nonwords, frequent or not, were produced the same number of times. Similarly, accumulated perceptual experience with the sounds of their native language cannot account for the experimental frequency effect, given that children brought the same accumulated experience to the learning of high and low experimental frequency words. Likewise, this study produced frequency effects that are unrelated to accumulated lexical knowledge, as the experimental frequency effect was independent of the English frequency effect. Children's accumulated lexical knowledge would only influence the effect of English frequency. Therefore, the occurrence of an Experimental frequency effect weakens the premise that vocabulary knowledge is the driving force behind the abstraction of phonological frames (Gathercole et al., 1991) or a general internal representation for common sound sequences (Edwards et al., 2004; Munson et al., 2005).

Both the English frequency and Experimental frequency effects on children's accuracy was not limited to the production of the medial consonant clusters (the locus of the English frequency manipulation). Their errors also included errors on early-developing sounds that occurred in word initial and final positions and these occurred even when the sounds in question were in the child's inventory. The occurrence of these types of sound errors indicates that frequency effects can influence production accuracy at a broad level and independently of general articulatory proficiency. This replicates the results of Richtsmeier et al (2009), in which consonant errors were not limited to the medial consonant clusters. Similarly, Leonard & Rittman (1971) reported children's sound production errors in a study of /s/ cluster production in low and high frequency contexts were not confined to the sound that was the target of the cluster frequency manipulation. Zamuner, Gerken and Hammond (2004) also found that the same coda consonant was differentially produced, based on the frequency in English of the preceding CV. Conversely, Storkel (2004) reported that the ability to produce sounds not demonstrated during articulation testing interacted with a word frequency effect in a nonword learning paradigm administered to children with phonological disorders.

It is important to emphasize that the Experimental frequency effect documented here probably only occurred because we used multiple talkers to present nonword stimuli. Richtsmeier et al (2009) reported that although the previously-documented English frequency effects could be produced under single-talker conditions, an effect of

Experimental frequency only occurred when multiple talkers presented nonword tokens in the high Experimental frequency condition. These authors suggested that input variability may be an important perceptual mechanism that promotes the formation of abstract representations. Indeed, multiple speakers prevent any focus on the idiosyncratic nature of any given speakers production of a particular speech token. It may that a degree of stochastic resonance in word production induces a more abstract mental representation because the speaker variability (the source of stochastic resonance) permits the brain to extract a representation that transcends the idiosyncrasies of any individual speaker to reflect only those characteristics common across word productions (a phonological- rather than phoneme-level representation). We know that variability in the input to listeners is also helpful in other domains, including categorization of speech sounds (Holt & Lotto, 2006), word learning (Singh, 2008) and learning of grammar-like structures in artificial languages (Gómez 2002).

Children with SLI, like their typically-developing counterparts, also showed an effect of English and Experimental frequency manipulations. This suggests that frequency manipulations, in the context of talker variability, enhanced their word production. Like the TD group, this was true for the production accuracy of the nonwords as well as the time to response. The time to response can influenced by both planning of sound production and processing time for the different classes of nonwords. In the present study, the highly similar word forms, and counterbalancing of word-initial phonemes across frequency conditions and limiting word final phonemes to /m/ reduces the likelihood that sound production planning will be the primary influence over any variability in children's time to response across frequency conditions.

Children with SLI, like their typically-developing counterparts, also showed an effect of English and Experimental frequency manipulations. This suggests that frequency manipulations, in the context of talker variability, enhanced their word production. Like the TD group, this was true for the production accuracy of the nonwords as well as response latency. The latter can be considered an index of response planning (cf. Munson, 2001), in that it included the time that elapsed between the end of the nonword prompt and the beginning of the child's production. The fact that children were faster for both high English and high Experimental frequency conditions is consistent with the idea that less planning was needed because children had a stronger internal representation which they could use to guide their production attempts (cf. Richtsmeier et al., 2009). The fact that manipulations over the short term (i.e., within the minutes that the experiment took to administer) could improve performance for children with SLI is encouraging. It suggests that learning new lexical forms by this group can be enhanced by relatively simple frequency manipulations over a very short period of time. This contrasts with the notion that learning by these children is necessarily laborious or that it is qualitatively different from that of their normal peers in all respects. If anything, the trend was for the SLI group to exhibit stronger frequency effects than their TD peers (although typically not significantly so). This may be, in part, because the poorer overall performance by this group provided more leeway for performance differences related to input conditions to emerge. In any case, the findings suggest that consideration of input frequency, paired with input variability, might be a technique that could be optimized to serve therapeutic needs.

Acknowledgments

This work was supported by the National Institute of Deafness and Other Communication Disorders Grant R01DC004726. The contents of this study were presented as a poster at the Society for Research in Child Language Disorders in June, 2008.

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Figure 1.

Accuracy of consonant production within nonwords. Accuracy was adjusted so that children were credited both for correct consonant production and for sounds that did not appear in their consonant inventory on the GFTA-2. Nonwords were constructed and presented so that frequency of occurrence in English (Hi Eng vs. Lo Eng) was crossed with frequency of occurrence in the experiment (Hi Exp vs. Lo Exp). The main effects for Group, English Frequency, and Experimental Frequency are statistically significant.

Figure 2.

Accuracy of production of middle consonant clusters. Nonwords were constructed and presented so that frequency of occurrence in English (Hi Eng vs. Lo Eng) was crossed with frequency of occurrence in the experiment (Hi Exp vs. Lo Exp). The main effects for Group and English Frequency are statistically significant.

Figure 3.

Time to response from the nonword prompt offset to the onset of spoken production of nonword stimuli. Nonwords were constructed and presented so that frequency of occurrence in English (Hi Eng vs. Lo Eng) was crossed with frequency of occurrence in the experiment (Hi Exp vs. Lo Exp). The main effects for Group, English Frequency, Experimental Frequency, and the Group x English Frequency effects are statistically significant.

Table 1

Test scores for participant groups.

Test	NL		SLI	
	Mean	SD	Mean	SD
Age (years:months)	4:10	0:7	4:11	0:8
K-ABC-II	111.03*	6.81	88.97	26.52
SPELT-P2 (n=58)	105.21*	19.06	67.31	12.80
SPELT-3 (n=6)	N/A		75.17	12.25
PPVT-III	105.53*	12.35	79.96	24.15
GFTA2	108.31*	7.46	86.13	27.03
TOLD-P2: GU	10.56	2.44	7.72	2.85
NWR Total Score	8.88	3.42	4.06	2.70
1 syllable length	3.50	0.91	2.28	1.17
2 syllable length	3.03	1.09	1.44	1.37
3 syllable length	1.72*	1.44	0.31	0.96
4 syllable length	0.69*	1.03	0.07	0.25

Note. SLI = specific language impairment; NL = normal language

K-ABC-II = *Kaufman Assessment Battery for Children* (standard score mean=100);

SPELT-P2 = *Structured Photographic Expressive Language Test—Preschool, Second Edition* (standard score mean=100);

SPELT-3 = *Structured Photographic Expressive Language Test—Third Edition* (standard score mean=100);

PPVT-III = *Peabody Picture Vocabulary Test-Third Edition* (standard score mean=100);

GFTA2 = *Goldman-Fristoe Test of Articulation* (standard score mean=100).

TOLD-P2: GU = *Test of Language Development-Primary, Second Edition* (standard score mean=10);

NWR = Nonword Word Repetition Test (Dollaghan & Campbell, 1998) reported as number of items correct.

* significant group difference at $p < .01$

Table 2

Stimulus assignment to conditions of low and high frequency of occurrence.

Frequency Condition	List 1	List 2	List 3	List 4
High English/High Experiment	Boktem	Fampem	Mastem	Fospem
	/bɒktɛm/	/fæmpɛm/	/mæstɛm/	/fɒspɛm/
High English/Low Experiment	Fampem	Boktem	Fospem	Mastem
	/fæmpɛm/	/bɒktɛm/	/fɒspɛm/	/mæstɛm/
Low English/High Experiment	Foshpɛm	Mafpɛm	Famkɛn	Bɒpkɛm
	/fɒʃpɛm/	/mæfpɛm/	/fæmkɛm/	/bɒptɛm/
Low English/High Experiment	Mafpɛm	Foshpɛm	Bɒpkɛm	Famkɛm
	/mæfpɛm/	/fɒʃpɛm/	/bɒptɛm/	/fæmkɛm/