The Influence of Phonotactic Probability on Consonant Acquisition

A Senior Honors Thesis

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by

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Chapter 1
Introduction

Language acquisition in children begins at a very early age. In general, children with typical development begin to speak words at about the age of 1. By the age of 3, children are able to combine words into complete sentences (e.g., Lahey, 1988). Language acquisition involves many different components, including syntax, semantics, pragmatics, and phonology. The focus of this study is on the acquisition of phonology.

In phonological acquisition, some sounds are acquired earlier than others. In general, stops and nasals are acquired early, while affricates, some fricatives, and /r/ are commonly acquired later (Smit, et al., 1990). There are multiple reasons for this, including motor difficulty, perceptual saliency, and phoneme frequency. Motor difficulty affects the acquisition of speech sounds. Some sounds are physically much more difficult for children to produce. For example, the liquid consonants /r/ and /l/ are not typically acquired by 90% of children until the age of 6 or later. Part of the reason for this late acquisition is the difficulty of tongue configuration and bending required to produce these phonemes (Kent, 1992). Another reason for differences in order of acquisition may be that some sounds are less perceptually salient than others. Sounds that are not very perceptually salient (such as /θ/) may be acquired later. For example, Smit et al (1990) found that /θ/ is not acquired until age 6 for boys and age 8 for girls. Phoneme frequency in the lexicon also affects the acquisition of sounds. The frequency of a sound is the rate at which that particular sound occurs in words in the language. In one study, Yoneyama, Beckman, and Edwards (2002), examined the influence of phoneme frequency on order of acquisition of /k/ and /t/ in Japanese. In Japanese, /k/ is more frequent than /t/ in both the adult lexicon and in Japanese child-directed speech. Furthermore, children acquiring Japanese acquired /k/ before /t/. These results contrast with English, where /t/ is more frequent than /k/ and /t/ is also acquired earlier than /k/. This project will focus on this third factor, the effects phoneme sequence frequency on the acquisition of speech sounds. Phoneme sequence frequency, or phonotactic probability, is defined as the frequency with which a particular sequence of two phonemes occurs in a particular word position.

A large body of research shows that phonotactic probability affects phonological processing in adults. These findings are observed in both perception and production. For example, in a perception study, Pitt and McQueen (1998) found that sounds that are ambiguous between two phonemes are likely to be perceived and labeled as the phoneme that makes the stimulus part of a high-frequency phoneme sequence. In a repetition study, Vitevitch and Luce (1999) found that nonwords with high-frequency sequences were repeated faster than low-frequency sequences. In a speech processing task in the same study, participants were given pairs of nonwords and asked to label them as "same" or "different". Participants responded more quickly to pairs of nonwords with high-probability sequences than pairs of nonwords with low-probability sequences.

A limited body of research has also shown that lexical factors influence phonological processing in children. These factors include word frequency, phonotactic probability, and neighborhood density. A word has a high neighborhood density when many words differ from it by only a single phoneme substitution, such as the word "cat." The word "cat" has many neighbors, such as "mat," "sat," "cot," "cut," "cab," and "cap." A word has a sparse neighborhood density when no words differ from it by only a single phoneme, such as the word “voice.” The word “voice” has few neighbors, such as “choice,” “vase,” and “void.” Some research has shown that word frequency influences speech perception in children. In a gating study, Metsala (1997) examined the effects of word frequency and neighborhood density on spoken-word recognition. Results showed that it took longer gate durations for the youngest groups of children to correctly identify the low-frequency words than the older group of children. There was also an age effect on gate duration for high-frequency words in sparse neighborhoods, but not in dense neighborhoods. As age increased, high-frequency words in dense neighborhoods were recognized at shorter gate durations.

Phoneme sequence frequency has also been found to affect word learning in children. Storkel (2001) looked at the effect of phonotactic probability on word learning by children aged 3 to 6. The children were asked to perform three tasks: to identify the corresponding picture upon hearing a target nonword, to identify the corresponding nonword from an auditory list of three choices upon seeing the corresponding picture, and to spontaneously name a target nonword upon seeing the corresponding picture. In all three tasks, the children learned words more accurately when they contained high-frequency sequences as compared to low-frequency sequences, whether the experimental task was a measure of semantic or phonological knowledge.

Furthermore, research has shown that phoneme sequence frequency affects speech production. Edwards, Beckman, and Munson (2004) and Munson (2001) examined the influence of sequence frequency on accuracy of nonword repetition in children. Both studies found that children produced high-frequency sequences more accurately than low-frequency sequences.

Phonotactic probability has also been shown to influence production fluency. Fluency has often been measured by duration. Smit et al. (1990) found that /s/ was acquired by 90% of children between the ages of 7 and 9. However, Smith (1994) found that children did not produce /s/ with approximate adult duration until the age of 11. Munson (2001) studied the influence of phonotactic probability on the fluency of speech production in children. Fluency was measured by the duration of two-phoneme target sequences. All other factors being equal, a shorter duration should indicate greater fluency. Results showed that low-frequency phoneme sequences were produced with longer durations than high-frequency phoneme sequences. A regression analysis showed that phoneme sequence frequency had less influence on duration in adults than in children, suggesting that fluency becomes less influenced by frequency with age.

Research shows that child vocabulary size affects the influence of phonotactic probability on speech production. Edwards, Beckman, and Munson (2004) studied the relationship between sequence frequency and child’s vocabulary size. Accuracy was correlated with vocabulary size, even when the effect of age was controlled. The more words a child has in his/her lexicon, the smaller the influence of phoneme sequence frequency on production.

Word recall is another aspect of language acquisition that has been related to phonotactic probability. Gathercole et al. (1999) examined the influence of phonotactic probability on short-term memory, as well as the recall of words versus nonwords. Children were presented with several memory lists of words and nonwords. The experimenter read aloud one list at a time to the participant, and the children recited the list from memory back to the examiner. Results showed that words were recalled more correctly than nonwords.

Furthermore, high-probability nonwords were recalled more correctly than low-probability nonwords.

The purpose of the current study is to test whether phonotactic probability also influences accuracy and duration in production of familiar real words in English. Previous research on phonotactic probability effects in children has focused primarily on productions of nonwords. Furthermore, this study focuses on a range of sounds, including some that young children are in the process of acquiring (such as /tʃ/ and /s/), as opposed to much past research that has focused primarily on early-acquired sounds. The analysis examines whether frequency of the sound sequences within the real words affects whether children produce the component sounds correctly. This study also examines duration of speech sounds, as a measure of speech fluency. A shorter duration of a sound will be considered a sign of greater speech fluency. The two research questions addressed in this study were: 1) Does phoneme sequence frequency influence consonant accuracy in young children? 2) Does phoneme sequence frequency influence fluency, as measured by duration, in young children?

In summary, this study looks at the relations among phoneme sequence frequency, accuracy, and duration. Based on previous research, it is predicted that 1) consonants will be produced more accurately when they are in a high-frequency consonant-vowel (CV) or vowel-consonant (VC) context, as compared to a low-frequency context, and 2) consonants will be produced more fluently (that is, with shorter durations) when they are in a high-frequency CV context, as compared to a low-frequency context.

Chapter 2
Methods

Participants:

Forty children with typical development (TD) and forty children with developmental phonological disorders (PD), all aged 3 to 6, were matched on the basis of age (within 6 months), gender, and nonverbal IQ (within 2 standard errors of measurement). All children scored within normal limits, at or above one standard deviation below the mean, on both expressive and receptive language assessments. The *Expressive Vocabulary Test* (EVT, Williams, 1997) was administered for the expressive language assessment. The *Peabody Picture Vocabulary Test-III* (PPVT-III, Dunn & Dunn, 1997) was administered for the receptive language assessment. Children were diagnosed as having a phonological disorder if they scored at or below the tenth percentile on *The Goldman-Fristoe Test of Articulation* (GFTA, Goldman & Fristoe, 1986). Children were considered to be typically developing if they scored at or above the 40^{th} percentile on the GFTA. All children passed a hearing screening at 20dB at 500, 1000, 2000, and 4000 Hz. All children had normal structure and function of the peripheral speech mechanism, with a standard score of no more than one standard deviation below the mean on the oral movement subtest of the *Kaufman Speech Praxis Test for Children* (KSPT, Kaufman, 1995). All children had normal non-verbal IQ, with a standard score of no more than one standard deviation below the mean on the *Columbia Mental Maturity Scale* (CMMS, Burgemeister, Blum, & Lorge, 1972). The age range of 3 to 6 years was chosen, because even typically developing children have not acquired all the sounds in English at this age range. For example, /s/ is not acquired by 90% of children until the age of 8 (Sander, 1972). Children with phonological disorders will be even later than children with typical development in acquiring sounds. Consequently, these participants should show a range of accuracy scores for many of the consonants in English. See Table 2.1 for a description of the participants.

Stimuli:

Color drawings of 129 words familiar to young children were used. The pictures were chosen so that each consonant in English was elicited in both word-initial CV and word-final VC positions at least 3 times. Up to 15 different productions of a sound in a context were elicited. The focus on this experiment was on word-initial and word-final lingual obstruents: /t/, /d/, /k/, /g/, /s/, /z/, /ʃ/, /θ/, /ð/, /tʃ/, /dʒ/. Lingual obstruents were chosen because many of these sounds are still in the process of being acquired by the age range of participants and present a range of motor difficulty. See Table 2.2 for a count of all word-initial CV and word-final VC sequences.

Procedure:

The 80 children were tape-recorded using a digital audio tape recorder while they were naming pictures of the 129 words. The recordings were digitized and transcribed phonetically using a waveform editor to listen to the productions and view the acoustic waveforms. One researcher transcribed the productions of the children with phonological disorders and their typically developing controls. The recordings were transferred from the DAT to a digital file on a PC and the productions were transcribed in the International Phonetic Alphabet at the level of a careful, broad phonemic transcription. A waveform editor was used, so the transcriber could easily listen to each word as many times as necessary. A second researcher independently transcribed the words elicited with the PI for a subset of the children comprising two 3-year-olds, two 4-year-olds, and two 5-year-olds, with one child with PD and one child with TD for each of these three age ranges. Phoneme-by-phoneme inter-rater reliability for presence/absence of error ranged from 89 to 95 percent, with a mean of 92 percent. The data were collected prior to this experiment; this experiment is an additional analysis of the existing data. These data were originally collected and transcribed by Iserman (Iserman, 2001).

Analysis:

The phoneme sequence frequency was computed for each word-initial CV and word-final VC sequence using the MHR, a 6,000-word database based on the spoken language of 6-year-old children (Moe, Hopkins, & Rush, 1982). The natural log was then taken of the raw frequency number. For example, "teeth" is a target word which has a word-initial /ti/ sequence. There are 30 words in the MHR database that begin with /ti/. The natural log of 30 is 3.401. Appendix A lists all word-initial sequence types and their frequencies. Appendix B lists all word-final sequence types and frequencies. For the accuracy analysis, all words in the MHR with the target sequence were included in the frequency count. A separate analysis including only the words in the MHR with the same stress pattern as the target sequence was conducted, but results were nearly identical to those from the initial analysis. For the duration analysis, only the words in the MHR with the same stress pattern as the target sequence were included in the frequency count. This was done, because stress was found to significantly affect phoneme durations in this experiment.

To calculate the accuracy of the consonant productions, all lingual obstruents in word-initial CV and word-final VC positions were scored. Each consonant received up to three points for correct place, correct manner, and correct voicing. For example, if a child said /s/ for /t/, she would receive two points for correct place and voicing, but would lose one point for incorrect manner of production. Specific scoring rules are included in Table 2.3.

For the duration experiment, all five words with word-initial /s/ were included. This phoneme was chosen for several reasons. First, it is a fricative, whose onset and offset can be easily demarcated. Second, there were 5 different /s/-vowel sequences in the stimulus set. Last, the /s/-vowel sequences had the widest range of frequencies, as compared to the other fricatives. Table 2.4 lists these /s/-initial words and their frequencies. A waveform editor was used to measure the duration of /s/ in each of these five target words. The onset was defined as the beginning of the fricative sound, and the offset was defined as the last sign of the fricative sound on the waveform editor. Only the children with phonological disorders who produced /s/ correctly and their typically developing controls were included in this duration experiment. This included 12 children with phonological disorders and ten children with typical development. Data was lost for two of the typically developing controls. Table 2.4 shows all /s/-initial words and their frequencies. Figure 2.1 shows a typical example of an /s/-initial word spectrogram with onset and offset indicated by cursors.

Table 2.1
Demographic data and standard test scores (standard deviations in parentheses) for children with phonological disorders (PD) and children with typical phonological development (TD)

	Children with PD	Children with TD
Mean age in months	57 (9)	58 (10)
Age range in months Gender	40 - 76 13 female, 27 male	39 - 75 13 female, 27 male
GFTA percentile ranking	5 (3)	69 (19) *
CMMS standard score	107 (11)	109 (11)
EVT standard score	105 (13)	110 (11)
PPVT-III standard score	106 (12)	113 (11)*

*significant group difference, $p < 0.05$

Table 2.2
Count of all word-initial and word-final sequences for each consonant

Consonant	Word-Initial	Word-Final
/t/	7	7
/d/	4	3
/k/	10	4
/g/	4	3
/s/	5	6
/z/	3	15
/ʃ/	4	3
/θ/	3	3
/ð/	3	N/A*
/tʃ/	4	3
/dʒ/	3	3

*/ð/ is very low-frequency in word-final position and was not elicited.

Table 2.3
Specific scoring rules for consonant production accuracy

1. Only the first audible utterance of each child was scored. (Many children produced more than one response for each picture.)
2. The following place categories were used:
- labial - /b/, /p/, /m/, /w/, /f/, /v/
- alveolar - /t/, /d/, /n/, /s/, /z/, /l/, /j/, /r/
- palatoalveolar - /ʃ/, /ʒ/, /tʃ/, /dʒ/
- velar - /k/, /g/, /ŋ/
- glottal - /h/, /ʔ/
- interdental - /θ/, /ð/

3. The following manner categories were used:
- stop - /p/, /b/, /t/, /d/, /k/, /g/, /ʔ/
- nasal - /m/, /n/, /ŋ/
- fricative - /θ/, /ð/, /f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /h/
- affricate - /tʃ/, /dʒ/
- liquid/glide - /l/, /r/, /w/, /j/

4. If a child produced a related word that placed the target in a different context, e.g. "piggie" for "pig" (target is final /g/) or "bathtub" for "tub" (target is initial /t/), the target was not scored and was coded as missing data.
5. If a child produced an incorrect word ("boot" for "foot", target is final /t/ or "this" for "that", target is initial /ð/), the item was not scored and was coded as missing data.
6. If a plural word on the list was a target for final /z/ and was not produced as a plural, it was coded as missing data.
7. If a superscript was included in the transcription of a produced target word, it was listened to on an individual basis by the experimenter to correctly score it.
8. In the transcription, a period after a vowel signaled a lengthened vowel. These did not affect the scoring.
9. Dentalized /t/ and /d/ were considered to have an alveolar placement for scoring.
10. The alveolar lateral click /!/ was considered a non-stop manner, alveolar place, and voiceless.
11. Consonants produced at the uvular place of articulation were categorized as velar.
12. A sequence of a stop and a fricative was considered an affricate if they were produced at the same place of articulation. When writing affricates, the symbols "t" and "d" covered the following places: interdental (as for /θ/), alveolar (as for /s/), and alveopalatal (as for /ʃ/). Therefore, a sequence of [t] followed by any of [θ], [s], or [ʃ] counted as an affricate. However, a /ps/was not counted as an affricate.
13. A token transcribed with a period/dot between the stop and the fricative of a target affricate was considered a stop-fricative sequence rather than an affricate. Hence, it was considered an error of manner for a target affricate.

14. Palatal off-glide for a target stop was an error in place. If there was an error in place already (e.g. /t/ for /k/), then the child didn't get more than one point off for the wrong place. If there was no other error in place (e.g., /dj/ for /d/), then 0.5 point was taken off.
15. An /ɫ/ was considered a voiced liquid, with a place in both alveolar and velar placements. Therefore, the place was scored as a 0.5 for either a target alveolar or a target velar.

Table 2.4
/s/-initial words, their MHR raw frequencies, and the natural log of their raw frequencies

/s/-initial word	/s/-V MHR frequency	/s/-V natural log frequency
sausage	14	2.64
socks	14	2.64
soap	17	2.83
sun	46	3.83
scissors	51	3.93

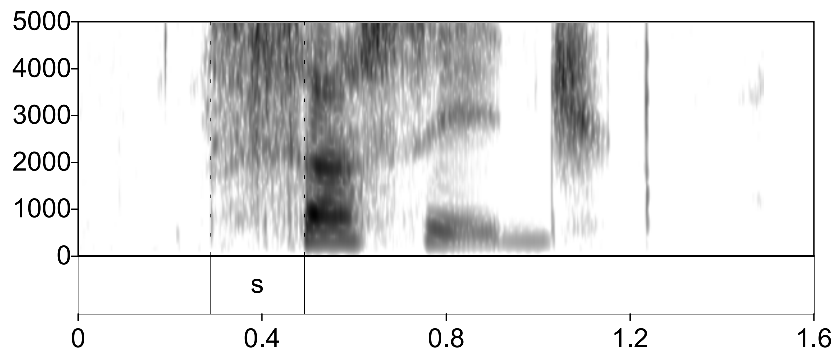

Figure 2.1 Spectrogram of the word "sausage"; onset and offset of /s/ indicated by cursors.

Chapter 3
Results

Mean accuracy scores were computed for each consonant in a CV or VC sequence. Word-initial and word-final sequences were analyzed separately. Correlations were made separately for the children with TD, the children with PD, and the overall group. For both sequence types, the accuracy score was correlated with the frequency measure. For word-initial sequences, all three correlations were significant ($r^2 = 0.46$, $p < 0.01$ for the children with TD, $r^2 = 0.41$, $p < 0.01$ for the children with PD, and $r^2 = 0.69$, $p < 0.01$ for the overall group). These results are shown in Figure 3.1.

For word-final sequences, all three correlations were also significant ($r^2 = 0.12$, $p < 0.05$ for the children with TD, $r^2 = 0.15$, $p < 0.01$ for the children with PD, and $r^2 = 0.16$, $p < 0.01$ for the overall group). These results are shown in Figure 3.2. It can be noted that the correlations for the word-final sequences were considerably lower than those for the word-initial sequences.

Median duration scores were computed for each of the five stimulus items. Median scores were used instead of mean scores, because the data were skewed. Any particular duration can be much longer than the average duration, but it cannot be less than zero. Because there were fewer children, the data for the whole group was analyzed together. The median durations were correlated against the frequency measures. The r^2 value of 0.16 was not significant ($p > 0.1$). It can be observed in Fig. 3.3 that there was no consistent relationship between frequency and duration for these stimuli. However, the standard error bars show that there is more variability among the children with PD than the children with TD.

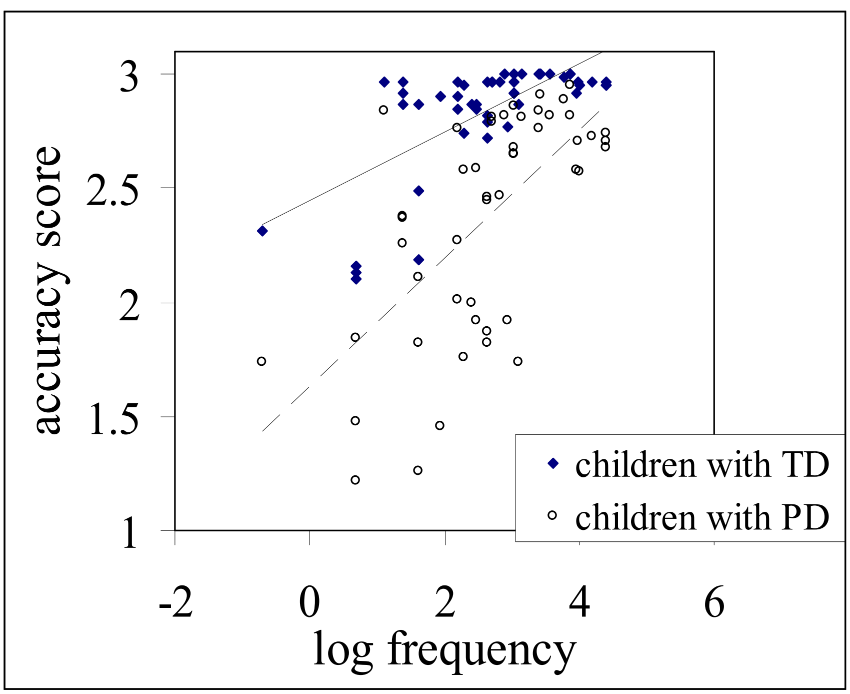

Figure 3.1. Accuracy plotted against log frequency for word-initial sequences for the children with TD (filled diamonds) and for the children with PD (open circles).

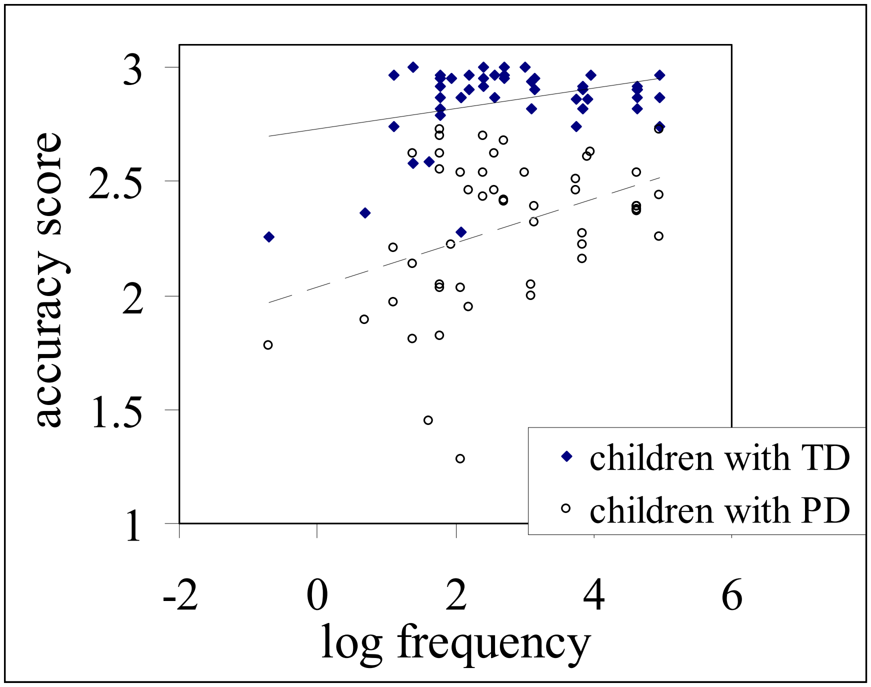

Figure 3.2. Accuracy plotted against log frequency for word-final sequences for the children with TD (filled diamonds) and for the children with PD (open circles).

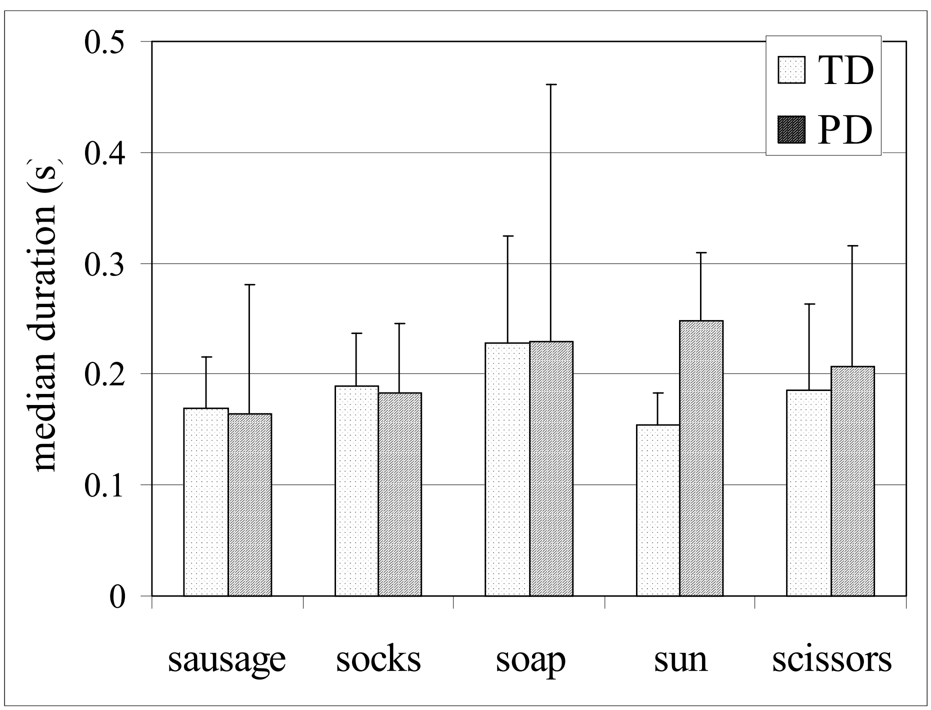

Figure 3.3. Median duration against /s/-initial words, lowest to highest frequency from left to right. Children with TD represented by dotted bars. Children with PD represented by filled bars. Standard deviation bars are included above the TD and PD bars.

Chapter 4
Discussion

There were two research questions addressed in this study: 1) Does phoneme sequence frequency influence consonant accuracy in young children (aged 3 to 6)? 2) Does phoneme sequence frequency influence fluency, as measured by duration, in young children (aged 3 to 6)?

The results of this study showed that phoneme sequence frequency influences consonant production accuracy in both word-initial CV and word-final VC sequences. In high-frequency sequences, the consonants were produced more accurately than in low-frequency sequences. This result was more pronounced in word-initial CV sequences. There was no systematic relationship between word-initial phoneme sequence frequency and fluency of the word-initial consonant, as measured by duration. This non-significant result may have been due to the small number of stimulus items, the small number of participants, and/or the limited range of sequence frequencies of the /s/-initial words. A future experiment designed to control for these factors may yield different results.

The results of this study suggest that a clinician should test consonants in more than one vowel context, especially in the word-initial position. Currently, most articulation tests only assess consonants in one context. For example, *The Goldman-Fristoe Test of Articulation, Second Edition* (GFTA 2, Goldman & Fristoe, 2000) elicits the consonant /k/ in the word “cat” (/kæt/). The phoneme sequence /kæ/ has a relatively high frequency, with an MHR raw frequency of 82 and natural log frequency of 4.41. If the child were to correctly produce /k/ in that context, it may be an overestimation of his capabilities, as children are better able to produce consonants in high-frequency contexts. The GFTA 2 elicits the consonant /t/ in the word “top” (/tɑp/). The phoneme sequence /tɑ/ has a relatively low frequency, with an MHR raw frequency of 21 and natural log frequency of 3.04. If the child were to incorrectly produce /t/ in that context, it may be an underestimation of his capabilities. If a clinician tests a consonant in both a low-frequency context and a high-frequency context, at least in initial position, the clinician would have a better general estimation of the child’s performance. For remediation, the results of this study may imply that a clinician should first introduce a consonant in a high-frequency sequence. The results suggest that a high-frequency sequence context would be easier for a child to master. Once the consonant is mastered in the high-frequency sequence, then the clinician should introduce the consonant in the more challenging low-frequency sequence.

Future research may include a better-controlled duration study. This would allow the experimenter to control for the number of stimulus items, the number of participants, and sequence frequency range. Future research may also examine the clinical predictions of this experiment. A treatment study could investigate whether children learn more efficiently if sounds are introduced in high-frequency sequences than in low-frequency sequences.

References

Burgemeister, B. B., Blum, L. H., & Lorge, I. (1972). *Columbia Mental Maturity Scale*. New York: Harcourt Brace Jovanovich.

Dunn, L., & Dunn, L. (1997). *Peabody Picture Vocabulary Test-Third Edition*. Circle Pines, MN: American Guidance Services.

Edwards, J., Beckman, M. E., & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in nonword repetition. *Journal of Speech, Language, and Hearing Research, 47,* 421-436.

Gathercole, S. E., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 84-95.

Goldman, R., & Fristoe, M. (1986). *The Goldman-Fristoe Test of Articulation*. Circle Pines, MN: American Guidance Services.

Goldman, R., & Fristoe, M. (2000). *The Goldman-Fristoe Test of Articulation, Second Edition*. Circle Pines, MN: American Guidance Services.

Iserman, I. (2001). *Variability and Consistency in Children with Phonological Disorders*, Unpublished master's thesis, The Ohio State University, Ohio.

Kaufman, N. (1995). *Kaufman Speech Praxis Test for Children*. Detroit, MI: Wayne State University Press.

Kent, R. D. (1992). The biology of phonological development. C. A. Ferguson, L. Menn, & C. Stoel-Gammon (Eds.), *Phonological development: Models, Research, Implications* (pp. 65-90). Timonium, Maryland: York Press.

Lahey, M. (1988). *Language disorders and language development*. New York: Macmillan Publishing Company.

Metsala, J. L. (1997). An examination of word frequency and neighborhood density in the development of spoken-word recognition. *Memory Cognition, 25*, 47-56.

Moe, S., Hopkins, M., & Rush, L. (1982). *A vocabulary of first-grade children*. Springfield, IL: Charles C. Thomas.

Munson, B. (2001). Phonological pattern frequency and speech production in adults and children. *Journal of Speech, Language, and Hearing Research, 44*, 778-792.

Pitt, M. A., & McQueen, J. M. (1998). Is compensation for coarticulation mediated by the lexicon? *Journal of Memory and Language, 39*. 347-370.

Sander, E. K. (1972). When are speech sounds learned? *Journal of Speech and Hearing Disorders, 37,* 62.

Smit, A. B., Freilinger, J. J., Bernthal, J. E., Hand, L., & Bird, A. (1990). The Iowa Articulation Norms Project and its Nebraska replication. *Journal of Speech and Hearing Disorders, 55*, 779-798.

Smith, B. L. (1994). Effects of experimental manipulations and intrinsic contrasts on relationships between duration and temporal variability in children's and adults' speech. *Journal of Phonetics, 22*, 155-175.

Storkel, H. L. (2001). Learning new words: Phonotactic probability in language development. *Journal of Speech, Language, and Hearing Research, 44*, 1321-1337.

Vitevitch, M. S., & Luce, P. A. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language, 40*, 374-408.

Williams, K. (1997). *Expressive Vocabulary Test.* Circle Pines, MN: American Guidance Services.

Yoneyama, K., Beckman, M. E., & Edwards, J. (2002). *Phoneme frequencies and acquisition of lingual stops in Japanese*. Manuscript submitted for publication.

Appendix A

Word-initial sequence types, their MHR raw frequencies, and the natural log of their raw frequencies

Sequence type	Number of words	MHR raw frequency	Natural log frequency
/ti/	2	30	3.40
/te/	1	18	2.89
/tɑ/	1	21	3.04
/tʌ/	1	31	3.43
/tɑi/	1	23	3.14
/toi/	1	3	1.10
/dI/	2	48	3.87
/dɑ/	1	44	3.78
/dʌ/	1	35	3.56
/ke/	4	21	3.04
/kæ/	3	82	4.41
/kʊ/	1	12	2.48
/kɑ/	1	54	3.99
/kʌ/	1	67	4.20
/ge/	1	9	2.20
/gu/	1	10	2.30
/go/	1	15	2.71
/gʌ/	1	15	2.71
/sI/	1	55	4.01
/so/	1	17	2.83
/sɑ/	1	14	2.64
/sɔ/	1	14	2.64
/sʌ/	1	52	3.95
/zi/	1	4	1.39
/zI/	1	4	1.39
/zu/	1	4	1.39
/ʃi/	1	11	2.40
/ʃe/	1	12	2.48
/ʃu/	1	9	2.20
/ʃʌ/	1	5	1.61
/θo/	1	2	0.69
/θʌ/	1	5	1.61
/θɑi/	1	0	-0.69*
/ðI/	1	2	0.69

/ðæ/	1	5	1.61
/ðo/	1	2	0.69
/tʃi/	1	7	1.95
/tʃI/	1	22	3.09
/tʃɛ/	2	14	2.64
/dʒi/	1	10	2.30
/dʒɛ/	1	19	2.94
/dʒu/	1	9	2.20

* For calculation purposes, the natural log of 0.5 was taken for a raw frequency of zero.

Appendix B

Word-final sequence types, their MHR raw frequencies, and the natural log of their raw frequencies

Sequence type	Number of words	MHR raw frequency	Natural log frequency
/ət/	2	43	3.76
/æt/	3	15	2.71
/ʊt/	1	4	1.39
/ot/	1	11	2.40
/ɛd/	2	23	3.14
/ud/	1	9	2.20
/ek/	1	20	3.00
/ʊk/	1	9	2.20
/ʌk/	2	11	2.40
/Ig/	1	3	1.10
/ɛg/	1	4	1.39
/ʌg/	1	7	1.95
/Is/	1	13	2.56
/es/	1	13	2.56
/us/	1	8	2.08
/ʌs/	1	52	3.95
/ɑʊs/	2	6	1.79
/iz/	3	143	4.96
/Iz/	1	50	3.91
/oz/	3	47	3.85
/əz/	6	104	4.64
/oiz/	2	6	1.79
/Iʃ/	2	22	3.09
/ʌʃ/	1	6	1.79
/iθ/	1	4	1.39
/ɔθ/	1	0	-0.69*
/ɑʊθ/	1	2	0.69
/itʃ/	1	6	1.79
/Itʃ/	1	8	2.08
/ɑtʃ/	1	3	1.10
/Idʒ/	1	6	1.79
/edʒ/	1	5	1.61
/ədʒ/	1	8	2.08

* For calculation purposes, the natural log of 0.5 was taken for a raw frequency of zero.