Effect of vowel context on the accuracy of sibilant fricative production in children with cochlear implants as compared to normal hearing peers

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ABSTRACT

The /s/-/ʃ/ contrast undergoes a protracted period of development in children with normal hearing (NH), and this is even more true of children with cochlear implants (CIs). Additionally, NH children are sensitive to the effects of anticipatory coarticulation, which influences the production of /s/ or /ʃ/. Previous studies have suggested that children with CIs may not be sensitive to the effects of anticipatory coarticulation. The aim of this study was to determine if vowel context affected the accuracy of /s/ and /ʃ/ production in children with CIs as compared to NH peers when matched for chronological age.

Results indicated that vowel context matters for /s/, but not for /ʃ/. The low-back vowel context was a facilitating vowel context for /s/ production for children with CIs. The low-front and high-back vowel contexts were the most difficult vowel contexts. Vowel context mattered for children with CIs, but not for children with NH. Children with CIs produced significantly more stop consonant errors on /s/ than the NH children, who mainly made sibilant errors. For /ʃ/, children with CIs made significantly more fronting errors than NH children. These findings have implications for clinical practice. In working with children with CIs, /s/ should first be taught in syllables or words containing low-back vowels (e.g., *sock*, *soft*, and *sob*). However, a clinician should not consider a child with a CI's ability to produce /s/ as completely accurate until that child can also produce /s/ in words containing high-back and low-front vowel contexts.

SPECIFIC AIMS

The rate at which children who were born with hearing loss are being fitted with cochlear implants is rising rapidly. While cochlear implants (CIs) improve the auditory signal received by an individual with hearing loss, they are still not as effective as the auditory system of a person with normal hearing. As a consequence, children with CIs develop speech and language superior to their peers with hearing aids, but poorer than their peers with normal hearing. Because the cochlear implant degrades the spectral resolution of the auditory signal, it is difficult for children with CIs to perceive place-of-articulation contrast, which are signaled by spectral cues. Children with CIs not only have difficulties with the perception of spectral cues, but also with the production of contrasts that differ in spectral cues. One such contrast is the /s/-/ʃ/ contrast. Previous research has shown that children with cochlear implants produce a reduced acoustic contrast for the /s/-/ʃ/ contrast relative to normal hearing peers. This reduced acoustic contrast results in poorer perceptual ratings in sound productions, as well as in decreased intelligibility of speech for words containing these sounds.

The use of facilitating contexts in articulation therapy is widespread for both children with normal hearing and those with cochlear implants. There is some evidence from typical development that anticipatory coarticulation with the following vowel influences the accuracy of /s/ and /ʃ/ in normal-hearing children. However, there has been little research on this phenomenon in children with cochlear implants. Addressing this gap in knowledge was important because the identification of both facilitating and difficult contexts for the production of /s/ and /ʃ/ has clinical implications for the treatment of children with cochlear implants. This study evaluated the effect that the following vowel has on the accuracy of the preceding sibilant fricative, namely /s/ or /ʃ/. We analyzed this effect with the following specific aims:

1. Does vowel context influence the accuracy of sibilant fricative production in young children with cochlear implants, and is this influence different for productions of word-initial /s/ and /ʃ/?
2. Is the influence of vowel context on sibilant fricative production different for children with normal hearing and children with cochlear implants?

Analyzing the effects of vowel context on the /s/-/ʃ/ contrast provided both researchers and clinicians with much-needed information about phonological development, particularly sibilant fricative production, in children with cochlear implants. This research identified which contexts are facilitating, and which are difficult for the production of this sound contrast. Additionally, the results of this analysis indicated that clinicians should continue to work on difficult sound contrasts beyond the point when they are considered perceptually “correct”.

CHAPTER ONE

LITERATURE REVIEW

Since cochlear implants (CIs) were first approved by the Food and Drug Administration (FDA) for children over the age of 2 years in 1989, and subsequently for children 12 months and older in 2000, they have served as a marked improvement over traditional hearing aids (National Institute on Deafness and Other Communication Disorders [NIDCD], 2013). Briefly, a cochlear implant is an electronic device that bypasses the damaged hair cells in the cochlea (inner ear), and provides direct stimulation to the auditory nerve. This device is different from the way traditional hearing aid ameliorates sensorineural hearing loss, which merely amplifies sounds from the environment and still uses the damaged cochlea. A cochlear implant must take wideband signal and transform it into narrow-band parallel signals. In multichannel cochlear implants, bandpass filters separate sound into different frequency regions. Then, compression reduces the dynamic range of each band (approx. 20 dB). A normal cochlea has approximately 1000 inner hair cells to transmit the incoming acoustic signal to the auditory nerve, but an implanted ear only has up to 22 intracochlear electrodes that have poor spatial selectivity (Rubenstein, 2004).

The speech and language of prelingually deaf children who have been fitted with cochlear implants is better than their peers with comparable levels of hearing loss using hearing aids in every respect (that has been studied). Areas that have been studied include speech production and perception, language comprehension and production, and literacy outcomes (Chin, Bergeson, & Phan, 2012; Chin, Tsai, & Gao, 2003; Chuang, Yang, Chi, Weismer, & Wang, 2012; Connor & Zwolan, 2004; Geers, Strube, Tobey, Pisoni, & Moog, 2011; Johnson & Goswami, 2010; Spencer, Barker, & Tomblin, 2003; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Tomblin, Spencer, & Gantz, 2000). Spencer et al. (2003) found that children with cochlear implants read at grade levels comparable to their normal hearing peers, whereas children with profound hearing loss using only hearing aids graduate high school with reading levels 7-8 grade levels below age expectations. Furthermore, Tomblin et al. (1999) observed that school-age children (average age 10.0 years, SD=2.9) who had been implanted with cochlear implants had language skills that were no longer linguistically comparable to their un-implanted peers with similar hearing loss, as their expressive language development was significantly more advanced. Tomblin and colleagues concluded that, "Prelingually deaf children are better able to acquire English when provided with CIs than when provided with HAs [hearing aids]" (507).

Although the cochlear implant has been a great advance for prelingually deaf children, the speech and language development of children with CIs still lags behind that of their normal hearing peers. Besides the period of hearing deprivation before the child receives an implant, the signal provided by a cochlear implant is degraded in comparison to that provided by a healthy auditory system, resulting in limitations in both the perception and production of speech and language. Children with cochlear implants, as a group, have lower scores on all measures of speech and language than their normal hearing peers, when controlled for socioeconomic status, including speech intelligibility (Chin et al., 2003; Chin et al., 2012; Chuang et al., 2012; Huttunen, 2008; Geers et al., 2011; Peng, Spencer, & Tomblin, 2004), pre-literacy and literacy skills (Connor & Zwolan, 2004; Geers et al., 2011; Johnson & Goswami, 2010; Spencer et al., 2003), expressive language (Ertmer, Strong, & Sadagopan, 2003; Huttunen, 2008; Geers et al., 2011; Spencer et al., 2003; Spencer, 2004), and receptive language (Robbins, Osberger, Myamoto, & Kessler, 1994; Dawson, Blamey, Dettman, Barker, and Clark, 1995; Conner, Heiber, Arts, & Zwolan, 2000; Ertmer et al., 2003).

A major reason for these deficits is that cochlear implants deliver a degraded electric version of an acoustic signal. Cochlear implants are limited in the range of frequencies they can deliver to the auditory nerve, with the upper limit of a typical cochlear implant at around 8000Hz (Loizou, 2006). Furthermore, the processor of a cochlear implant does not divide the 0-8 kHz interval into channels of equal width. In particular, the channels at the higher end of this frequency range are wider than those at the lower end. This is a particular problem for sounds such as /s/ that have high-frequency spectral energy (Todd, Edwards, & Litovsky, 2011). Because of these limitations, children with cochlear implants are receiving less robust auditory input than their normal hearing peers, which may mean that children with cochlear implants miss important acoustic cues that children with normal hearing use to discriminate between speech sounds. Regarding speech sounds specifically, children with cochlear implants have more difficulty perceiving consonants than vowels (Kishon-Rabin et al., 2002). They also have more difficulty producing fricatives than plosives (Blamey, Barry & Jacq, 2001; Tobey, Pancamo, Staller, Brimacombe, & Beiter, 1991; Uchanski & Geers, 2003). Place of articulation contrasts, which rely on spectral cues, are more difficult than voicing and manner contrasts, which rely on amplitude and temporal cues.

One of the predominant ways researchers have measured the speech and language quality of children with cochlear implants is through speech intelligibility. The speech produced by children with normal hearing is roughly 100% intelligible (near adult-like, or adult-like intelligibility) by approximately age 4 (Chin et al., 2003; Coplan & Gleason, 1988; Gordon-Brannan & Hodson, 2000; Weiss, 1982; Weiss & Lillywhite, 1976). However, children with cochlear implants have reduced speech intelligibility in comparison to their normal hearing peers, and consonant production is typically more impaired than vowel production.

Peng et al. (2004) found that approximately 70% of sentences produced by children with CIs were intelligible to naïve adult listeners with normal hearing. Half of the child participants in this study had an intelligibility score of 85% or higher, but six of the 24 participants had intelligibility scores below 50%. These low scores could not be attributed to lack of hearing experience because the children in the study all had seven years experience with their CIs. As a group, the speech of children with CIs appears to be less intelligible than that produced by children with NH, which was intelligible 98—100% of the time, but more intelligible than that of profoundly deaf children using HAs, which has been found to be intelligible 20% of the time (Smith, 1975).

Similarly, Chin et al. (2003) examined the intelligibility of connected speech in both children with normal hearing and children with cochlear implants. They found that, while school-aged children with normal hearing reached ceiling, or near ceiling scores on the Beginners' Intelligibility Test (BIT), their age-matched peers with cochlear implants never reached the ceiling. Children with normal hearing had a median score of 94.7% correct on the BIT, while children with cochlear implants had a median score of only 18.0% correct, reflecting a significant gap in intelligibility. However, it is also important to note that some of these children received their cochlear implants relatively late (11 years) in comparison to the age at which most children today receive cochlear implants (11 months). A follow-up study by Chin et al. (2012), confirmed the 2003 finding that children with normal hearing have significantly higher intelligibility scores on the BIT than children with cochlear implants, even when the speech of children who received their implants considerably earlier than the children in the first study was examined.

One of the reasons the /s/-/ʃ/ contrast was chosen for this study is that both /s/ and /ʃ/ undergo a protracted period of development in normal hearing children. According to Smit, Hand, Freilinger, Bernthal, and Bird (1990), girls produce /s/ accurately at least 75% of the time by age 4;6 (years; months), but boys do not reach the same level until 6;0. By age 7;0 this gender difference disappears, and both boys and girls produce /s/ accurately 90% of the time by age 9;0. For /ʃ/, the sound is acquired more quickly, and both girls and boys surpass the 75% criterion by 4;0 and 5;0, respectively. Both boys and girls produce /ʃ/ accurately 90% of the time by age 7;0, but 100% accuracy is still not reached by age 9;0. The length of time that it takes for children to produce adult-like /s/ and /ʃ/ suggests that mastering these sounds requires auditory feedback, which is something that children with CIs do not receive prior to the activation of their prostheses.

In addition to a protracted period of development of both /s/ and /ʃ/, children produce fricatives perceived as /ʃ/ later than they start producing fricatives perceived as /s/. Nittrouer (1995) suggests that children have more difficulty producing the distinction between /s/ and /ʃ/ because, “these gestures require very precise configurations of the tongue” (521). These precise tongue configurations necessary for distinguishing /s/ and /ʃ/ require more finely-tuned motor control than earlier acquired contrasts, like /t/ and /k/, which are made with complete closings of the vocal tract. Even by 7 years of age, children are still fine-tuning the /s/-/ʃ/ contrast so that /s/ constrictions are sufficiently narrower than /ʃ/ constrictions, and that appropriate sub-lingual airspace (a space between the tongue base and mandibular arch) is created for /ʃ/, which are features present in adult productions of /s/ and /ʃ/ (Narayanan, Alwan, &Haker, 1995).

Acoustically, children’s productions of the /s/-/ʃ/ contrast are different from adult productions. Children have less differentiation in their /s/ and /ʃ/ productions, in terms of centroid frequency, than adults (Holliday, Reidy, Beckman, & Edwards, 2015; Li, 2012; Nittrouer et al., 1989; Nittrouer, 1995). This reduced differentiation means that there is less distance in centroid frequency between a child's production of /s/ and /ʃ/, which may make it more difficult for adults to perceive the difference between these two phonemes when produced by children. This overlap in the centroid frequencies of /s/ and /ʃ/ is resolved as a child matures and the centroid frequency of /ʃ/ decreases and the centroid frequency of /s/ stays relatively constant (Li, 2012). This indicates that children differentiate /s/ and /ʃ/ by making /ʃ/ dissimilar from /s/, rather than by changing /s/ or adjusting the production of both phonemes. There is also acoustic evidence indicating that the ratio of the area of anterior constriction to the area of the back cavity (area behind the tongue tip's constriction and forward of the glottis) is greater for children than adults in both /s/ and /ʃ/, but that this difference is greater for /s/ than /ʃ/, which indicates that the /s/ constriction of children is more open than those of adults (McGowan & Nittrouer, 1988). Since Fant (1960) found that adults' /ʃ/ constrictions are more open than their /s/ constrictions, this finding that children have less /s/ constriction than adults adds to the previous point that the production of the /s/-/ʃ/ contrast is more similar in children than adults.

The protracted period of development, requisite fine-motor control, and acoustically less differentiated productions of the /s/-/ʃ/ contrast all contribute to this contrast's particular difficulty, in regards to perception and production, for children with cochlear implants. When considering that children with cochlear implants undergo a period of auditory deprivation prior to implantation, children with cochlear implants have at least 11 months less experience with listening to and practicing the /s/-/ʃ/ contrast. However, the period of auditory deprivation alone cannot explain the difference in production of this contrast for children with CIs relative to their normal hearing peers. Children with cochlear implants produce even less distinction between /s/

and /ʃ/ than their normal hearing peers when matched for hearing age (Todd, 2009; Todd et al., 2011).

After establishing that /s/ and /ʃ/ have a protracted period of development in children, it is now important to remember that phonemes are not typically produced in isolation. Because of the mechanics of the articulators as they move to produce all of the sounds in a word or phrase, each sound is affected by its adjacent sounds. These shifts in adjacent sounds are known as coarticulatory effects. When a speech sound becomes more similar to the sound immediately following it, it is known as anticipatory coarticulation. Nittrouer (1995) found that all speakers, adults and children both, anticipated the upcoming vowel in their speech, at least to some extent. Katz and Bharadwaj (2001), found that, for /s/-vowel syllables, children's lingual positioning showed more extensive anticipatory coarticulation than adults; however this was not the case for /ʃ/-vowel syllables, which were similar to those of adults. Warner-Czyz, Davis, and MacNeilage (2010) examined the production of consonant-vowel (CV) syllables in infants and toddlers with normal hearing and with CIs, and found that both groups of children were more accurate on CV syllables with articulatory compatibility. Specifically, the children with normal hearing had a significant preference for CV sequences sharing the same place of articulation. The same place of articulation was a combination of consonant place of articulation and frontness of the vowel (e.g., labial consonant with a front vowel). This preference was not found among children with CIs. Reidy (2015) used peak ERB as an acoustic measure of anticipatory coarticulation effects in both adults and children. He found that, for adult /s/ productions, the trajectory for peak ERB during the frication was higher before front vowels and lower before rounded vowels. In adult productions of /ʃ/, Reidy found that the trajectory for peak ERB during the frication was higher before front vowels, but there was no effect of vowel rounding. In the children's productions, these results were both significant and in the same direction as would be expected from the adult model for both /s/ and /ʃ/.

Adults and children are sensitive to cues from anticipatory coarticulation in perception. However, some studies have indicated that children with cochlear implants do not use these cues. Summerfield et al. (2002) presented intermediate (ambiguous) consonant productions between /s/ and /ʃ/ in a CV syllable to both children with normal hearing and children with cochlear implants. The vowel in each presentation contained coarticulatory information indicating either /s/ or /ʃ/ and was unambiguous. The children were asked to identify the consonant produced in the CV syllable. Children with normal hearing were sensitive to this information contained in the vowels and used it to make a determination on whether the intermediate consonant presentation was /s/ or /ʃ/, but the children with cochlear implants did not. If children with cochlear implants are not using, or are unable to use the information from anticipatory coarticulation then they are at an even greater disadvantage at producing /s/ and /ʃ/ in an adult-like way.

Donaldson and Kreft (2006) examined the effects of coarticulation on consonant recognition in postlingually deafened adult users of cochlear implants. In this study, adults attempted to identify various phonemes in both the syllable-initial (CV) and syllable-medial (VCV) contexts when accompanied by either /ɑ/, /u/, or /i/. They found that place cues, which are coded in the spectral domain, were most sensitive to changes in vowel context. Overall, the participants were better at recognizing the target consonant in the /ɑ/ and /u/ contexts than they were when the target consonant was in the /i/ context. The affricate consonant /tʃ/ was identified with the highest level of accuracy (83%), and /s/ had context effects in the initial position. Specifically, accuracy scores for /s/ in the /u/ context were higher than scores for /s/ in the /i/ and /ɑ/ contexts. Although the average consonant-recognition scores were only slightly (6.5%) higher for consonants presented in the /ɑ/ or /u/ contexts rather than the /i/ context, this difference was statistically significant. It is important to keep in mind that the acoustic cue most difficult for individuals with cochlear implants to utilize (spectral cues) is the cue most affected by coarticulation.

Despite there being research on anticipatory coarticulation in general, and the ability of children with cochlear implants to recognize and utilize the information provided by anticipatory coarticulation, very little research has been conducted on how vowel context affects consonant production in children with cochlear implants. The purpose of this study was to examine the effect of the following vowel context on production accuracy of word-initial /s/ and /ʃ/. Two questions were addressed. First, does vowel context influence the accuracy of sibilant fricative production in young children with normal hearing and cochlear implants, and is this influence different for productions of word-initial /s/ and /ʃ/? Second, is the influence of vowel context on sibilant fricative production different for children with normal hearing and children with cochlear implants?

CHAPTER TWO

METHODS

Participants

This study included 23 participants with cochlear implants between 34-65 months of age. There were six participants who each had two recordings taken one year apart. Both audio files were analyzed for these individuals, making a total of 29 audio files for the children with CIs. The participants were all monolingual speakers of English and typically developing in all respects, except for hearing. There was a comparison group of normal hearing (NH) children who were matched based on chronological age. Each of the participants with normal hearing passed a hearing screening (25 dB HL at 1000, 2000, and 4000 Hz). All of the participants in the study were recruited from Minnesota and Wisconsin and were participating in a larger cross-sectional or longitudinal study conducted in the Learning to Talk Lab at the University of Wisconsin-Madison and the University of Minnesota-Twin Cities. The comparison group had the same number of males and females, and similar maternal education levels as the CI group. See Table 2.1 for demographic information on the participant groups.

Table 2.1. Demographic information for CI and NH groups (n=23)

	Mean Age (SD), Range in months	Number of Males; Females	Mean PPVT-4 Standard Score (SD)	Mean EVT-2 Standard Score (SD)	Maternal Education Level[1]
Children with CIs	46.5 (9.9) 34-65	12;13	91.7(24.4)	87.9(24.4)	19 = high 5 = mid 1 = low
Chronological age comparison group	46.5 (9.9) 34-65	12;13	119.4 (14.2)	116.5 (16.2)	19 = high 5 = mid 1 = low

[1]High = college or graduate degree; Mid = some college, associate's degree, technical school degree; Low = high school diploma, G.E.D., less than high school diploma.

Stimuli

All of the items on the word repetition task were words that were familiar to young children based on age of acquisition norms (Smit et al., 1990; Templin, 1957; Wellman, Case, Mengert, & Bradbury, 1931; Poole, 1934; Arlt & Goodban, 1976; Prather, Hedrick & Kern, 1975). Consonant accuracy is influenced by word familiarity, so it was important that the target words were highly familiar to children. Because children's vocabulary increases with age, the words presented to older children were different than the words presented to younger children. There were three sets of words for three age groups, and the three age groups were different for the normal hearing children and those with cochlear implants. For the normal hearing children these groups were: youngest (28 to 38 months), middle (40 to 50 months), and oldest (52 to 62 months). The three age groups for the children with CIs were adjusted because their vocabulary development is somewhat delayed in comparison to children with normal hearing. The three age groups for the children with CIs were: youngest (36-44 months), middle (45-57 months), and oldest (58-72 months). The /s/- and /ʃ/-initial words were a subset of a larger set of words presented in the word repetition task. For all sets of words, the target sound (either /s/ or /ʃ/) was always word-initial, and immediately followed by a vowel. For each target sound, the words were balanced across vowel contexts to control for anticipatory coarticulation. There were always four words for each of the four vowel quadrants (high-front, low-front, high-back, and low-back). If there were not four familiar words for /s/ or /ʃ/ in a particular vowel quadrant, then words were repeated more than once. For example, for the youngest group, the only two familiar words for the low-front quadrant were *sad* and *sandwich*, so both words were repeated twice. The words used for each age group are shown in tables 2.2, 2.3, and 2.4.

The auditory stimuli were recorded in Mainstream American English (MAE) by a young adult female in child-directed speech. The recordings were segmented and normalized for amplitude across all words in the task.

The visual stimuli were color photographs of the familiar objects, which were presented simultaneously with the auditory stimuli. Some words were nouns and were easily pictureable. For other words, a picture was chosen to represent the word and keep the child's interest. See Figure 2.1 for examples of pictures chosen for *sandwich*, *sad*, *sister*, and *sharing*.

The order of the words was pseudo-randomized, with the stipulation that two repetitions of a single word were not presented in a row. When a word had more than one repetition, a different image and sound file were used for each repetition.

Procedures

Participants completed a picture-prompted auditory word repetition task. Participants were told that they would see pictures and the computer would name the pictures, and they were instructed to repeat the picture names exactly as they heard them. Participants were trained and familiarized to the task with four practice words, which were always *shirt*, *girl*, *cold*, and *cow*. Throughout the task, the examiner accompanying the participant would redirect attention, but the examiner was instructed to never say the target word.

Throughout the task the participants were reinforced in a variety of ways. The task itself displayed a cartoon animal that gradually climbed a ladder as the participant progressed through the task, in order to keep the participant motivated. Participants were also given stickers, snacks, high fives, and verbal praise in the form of non-evaluative feedback.

The entire word repetition task was recorded and saved as an audio file. This file was then analyzed via Praat (Boersma & Weenink, 2011). Using multiple scripts designed specifically for analyzing the word repetition task, the recorded files were segmented and transcribed.

Segmenting was a preliminary step used to guide subsequent scripts for transcription. Segmenting consisted of marking an interval within a waveform that corresponded to an attempted elicitation of the target word. Boundaries were marked at the beginning and end of a target word. If the stimulus was presented to a participant, and s/he gave no response, an interval was segmented and marked as a NonResponse.

The transcriber used the audio recording and the waveform to transcribe both the consonant and the following vowel. Consonants were transcribed in a two-step process. First, a judgment was made regarding consonant type. All attempts at /s/ and /ʃ/ were sorted into the following categories: (1) Sibilant fricative ([s, ʃ]); (2) Sibilant affricate ([tʃ, dʒ, ts, ks]); (3) Non-sibilant fricative ([f, v, θ, ð, ɬ, ɮ]); (4) Non-sibilant Plosive ([p, b, t, d, k, g]); or (5) Other (distortions, deletions, nasals, liquids, glides, and approximants). Second, the consonants were given a place transcription or categorized as “other”. “Other” is a rare category that encompasses distortions that were not possible to transcribe, deletions (e.g. [u] for /ʃu/) and uncommon substitutions for /s/ (liquids, glides, nasals, and approximants). In the category “Sibilant fricative” a more fine-grained transcription was given. Transcribers were instructed to visualize a continuum from [s] to [ʃ]. Transcribers could assign one of four possible place transcriptions based on this continuum. From most /s/-like to most /ʃ/-like, transcribers were asked to assign one of the following place transcriptions: [s], [s: ʃ], [ʃ:s], and [ʃ]. The transcriptions s: ʃ and ʃ:s are intermediate place transcriptions, with [s: ʃ] being closer in place to /s/, and [ʃ:s] being closer in place to /ʃ/. See Figure 2.2 for a decision tree detailing the process of transcription for consonants.

A two-step process was used for vowel transcription. First, the transcriber indicated whether the target vowel matched the vowel produced by the participant. If the produced vowel matched the target vowel, no additional transcription was necessary. Second, if the produced vowel did not match the target vowel, the transcriber selected the produced vowel from a list of all possible vowels, separated by vowel quadrant (high-front, low-front, high-back, low-back). See Figure 2.3 for a decision tree detailing the process of transcription for vowels.

Table 2.2: Youngest Group Stimuli List for /s/ and /ʃ/

	High-Front	Low-Front	High-Back	Low-Back
/s/	scissors* sick*	sad * sandwich*	soup* soap*	sun* sock*
/ʃ/	sheep+	share+	shoe+	shovel* shower*

*Indicates stimuli was presented twice
+Indicates stimuli was presented 4 times

Table 2.3: Middle Group Stimuli List for /s/ and /ʃ/

	High-Front	Low-Front	High-Back	Low-Back
/s/	sister sink scissors sick	sad sandbox sandwich sidewalk	soup suitcase* soap	sunny sun sock*
/ʃ/	sheep* ship*	sharing* share shell	shoe shoes shoulder*	shovel* shower*

*Indicates stimuli was presented twice

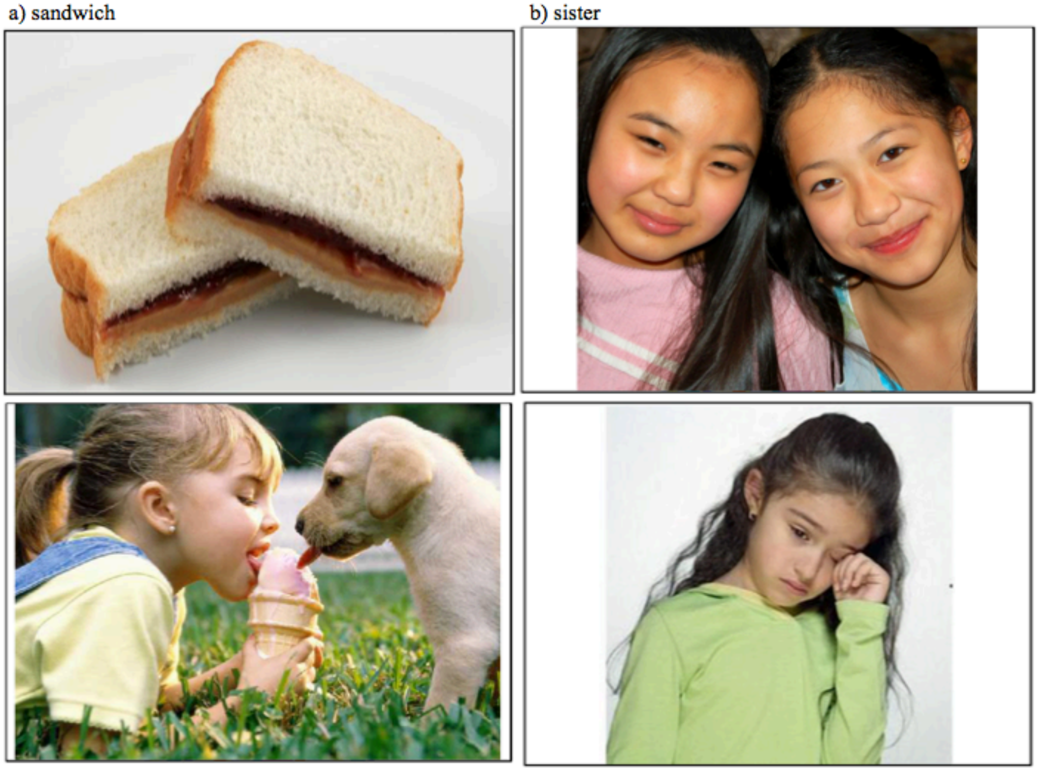
Table 2.4: Oldest Group Stimuli List for /s/ and /ʃ/

	High-Front	Low-Front	High-Back	Low-Back
/s/	cereal sister sink scissors	seven sidewalk sandwich sandbox	soup* suitcase*	summer* sun*
/ʃ/	sheep* ship*	shell sharing	shoes sugar	shovel* shower*

		shadow*	shoulder*	

*Indicates stimuli was presented twice

a) sandwich b) sister



c) sharing d) sad

Figure 2.1: Visual Stimuli

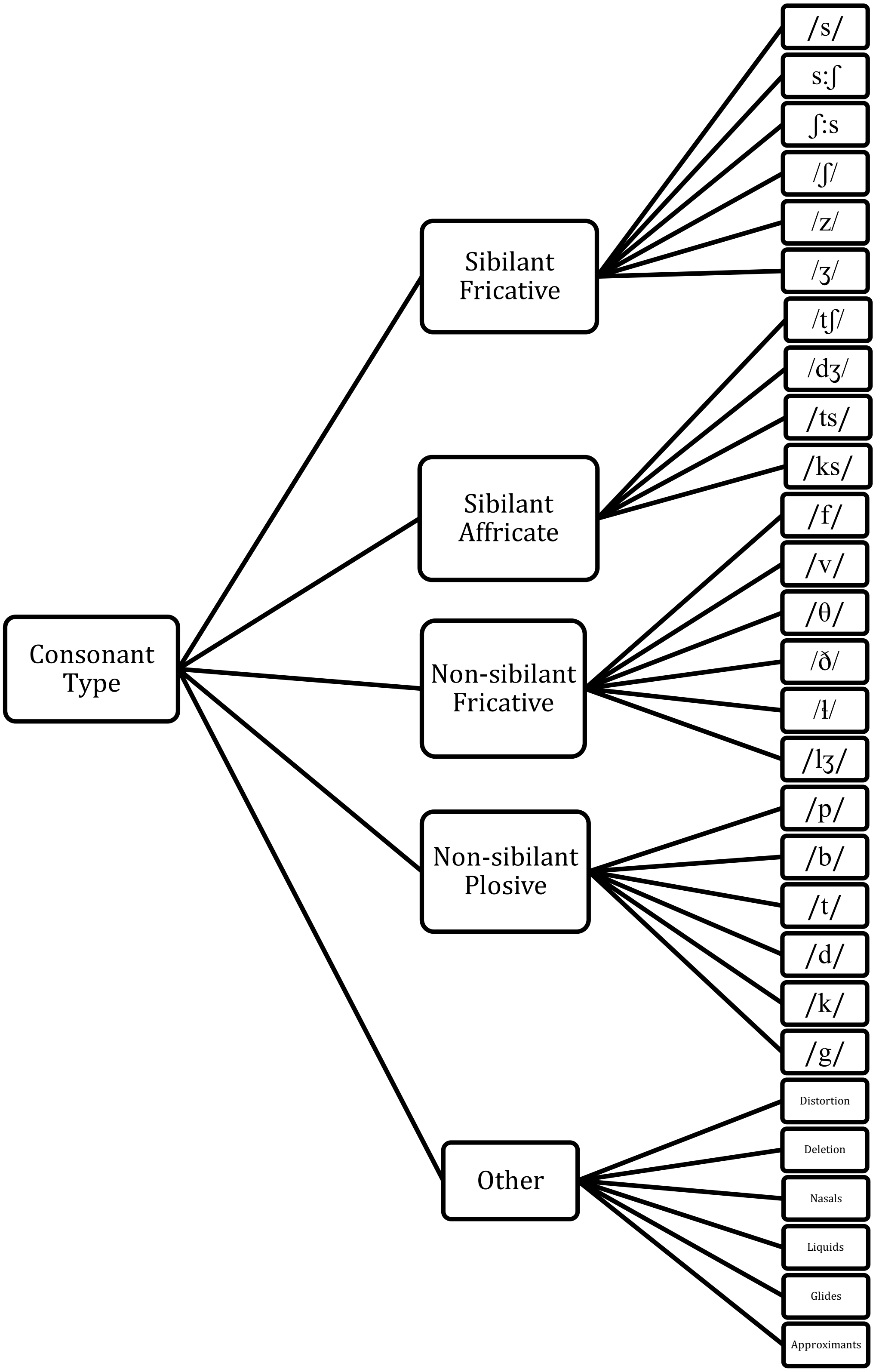


Figure 2.2: Consonant Decision Tree

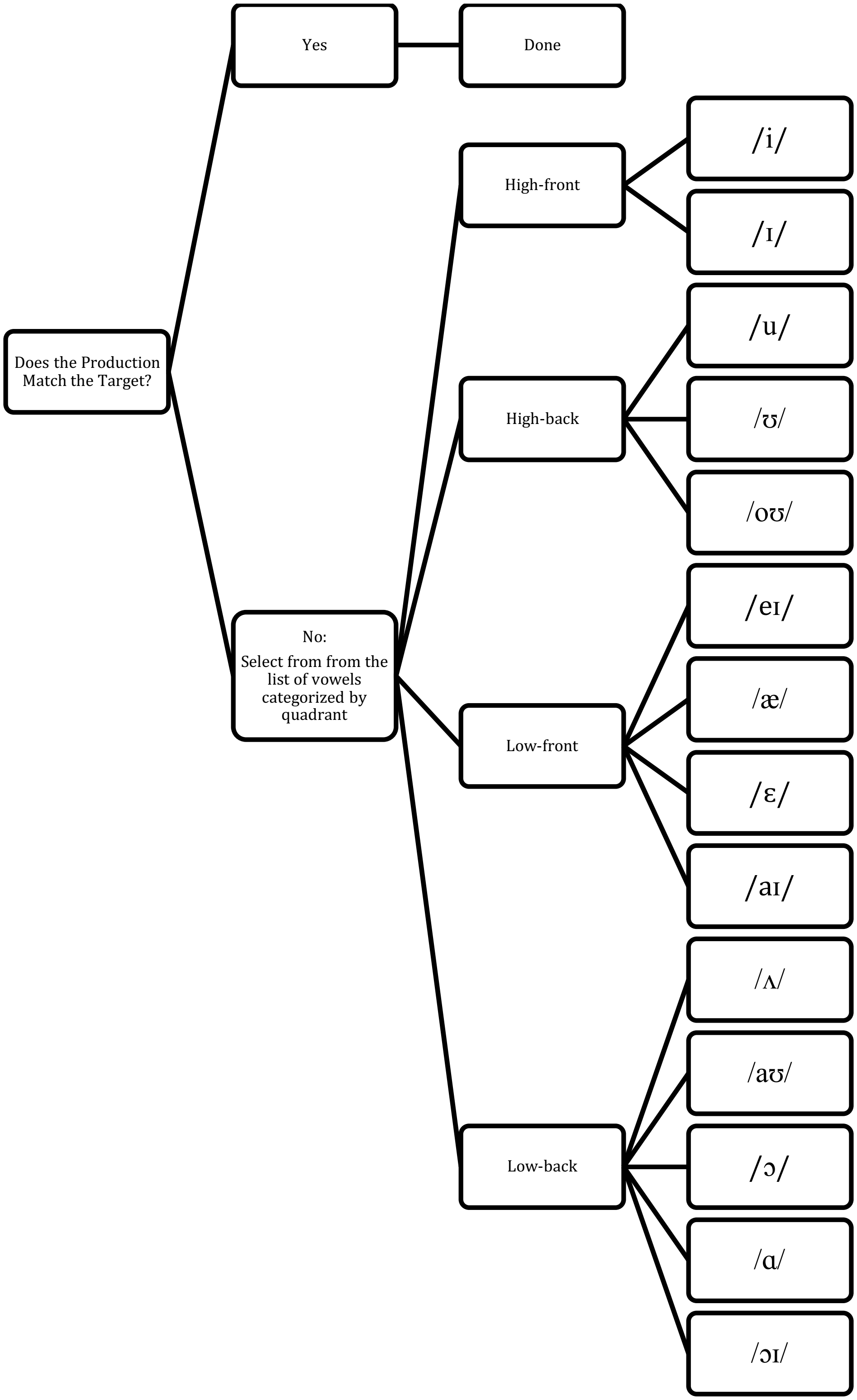


Figure 2.3: Vowel Decision Tree

CHAPTER THREE

RESULTS

The purpose of this study was to answer the following two questions: (1) Does vowel context influence accuracy of sibilant fricative production in young children cochlear implants, and is this influence different for /s/ and /ʃ/? (2) Is this influence different for children with normal hearing and children with cochlear implants?

We ran three separate mixed-effects logistic regression models for three dependent variables: accuracy ([s] and [s:ʃ] were considered accurate for target /s/, and [ʃ] and [ʃ:s] were considered accurate for target /ʃ/), stopping errors (including affricates), and fronting errors. All models included child-level random intercepts. The independent variables for all three models were: age in months, group (CI vs. NH), consonant (/s/ vs. /ʃ/) and vowel context (low-front, high-front, low-back, high-back). The reference categories for all three models were: children with CIs, the consonant /s/, and the low-back vowel context. In order to determine why we selected the low-back context as the most facilitative for children with CIs, we need to change the way we think about facilitative vowel contexts. Usually, facilitative vowel contexts are thought of in terms of production. However, for children with CIs, the primary deficit is in perception. The low-back vowel context is the most facilitative for children with CIs because anticipatory coarticulation between /s/ and the following vowel will result in a lower mean frequency for the /s/ friction, which should be more perceptible to children with CIs. All three models included the following interactions: group by consonant, group by vowel context, consonant by vowel context, and group by consonant by vowel context. In the paragraphs below, I report all significant effects. The appendix gives the complete results.

Figure 3.1 shows mean accuracy by consonant and vowel context for the two groups of children. There was a significant effect of age (*Estimate* = 0.85*, Std. Err* = 0.24*,* z = 3.56, p <

.001*),* indicating that accuracy increased as age increased for children with CIs for /s/ in the low-back context. There was a significant effect of group (*Estimate* = 2.08*, Std. Err* = 0.59*, z* = 3.54*, p* < .001*)*, indicating that the NH group was more accurate than the CI group on /s/ in low-back vowel contexts. There was also a significant effect of vowel quadrant for both low-front (*Estimate* = -0.94*, Std. Err* = 0.34*, z* = -2.76*, p* = 0.006*)* and high-back (*Estimate* = -1.43*, Std. Err* = 0.36, *z* = -4.04*, p* < .001) vowel contexts, indicating that, for children with CIs, /s/ was produced less accurately in low-front and high-back contexts relative to the low-back context. There was a significant group by consonant interaction (*Estimate* = -1.19*, Std. Err* = 0.53*, z* = -2.24, *p* = 0.02*)*, indicating that the difference in accuracy for /ʃ/ by the NH group relative to the CI group was less than the difference in accuracy for /s/ by the NH group relative to the CI group. There was a significant group by vowel quadrant interaction in the high-back context (*Estimate* = 1.51*, Std. Err* = 0.52*, z* = 2.90*, p* = .003*)*, indicating that the negative effect of the high-back context on accuracy for the CI group was not observed for the NH group for /s/. There was also a significant consonant by vowel quadrant interaction for the low-front (*Estimate* = 1.14*, Std. Err* = 0.50*, z* = 2.29*, p* = .02*)*, high back (*Estimate* = 1.94*, Std. Err* = 0.51*, z* = 3.81*, p* < .001*)*, and high-front (*Estimate* = 1.11*, Std. Err* = 0.51*, z* = 2.20*, p* = .03*)*, contexts, indicating that productions of /ʃ/ for children with CIs relative to productions of /s/ were significantly more accurate in the low-front, high-front, and high-back vowel contexts relative to the low-back context. Finally, there was a significant group by consonant by vowel quadrant interaction for the high-back context (*Estimate* = -1.57*, Std. Err* = 0.72*, z* = -2.18*, p* = .03*)*, indicating that there was a smaller difference between groups for high-back vs. low-back contexts for /ʃ/ as opposed to /s/.

Figure 3.2 shows the rate of fortition (stopping) errors by consonant and vowel context. There was a significant effect of age (*Estimate* = -0.59, *Std. Err* = 0.26, *z* = -2.27, *p* = 0.02), indicating that fortition errors decreased with age for children with CIs in the low-back context. There was also a significant effect of group (*Estimate* = -1.40, *Std. Err* = 0.62, *z* = -2.27, *p* = 0.02), which indicates that children with normal hearing produced fewer fortition errors than children with CIs for /s/ in the low-back vowel contexts. Because none of the interactions were significant, this same group difference applies for all other combinations of target consonant and vowel context. This is supported by the error bars in Figure 3.2.

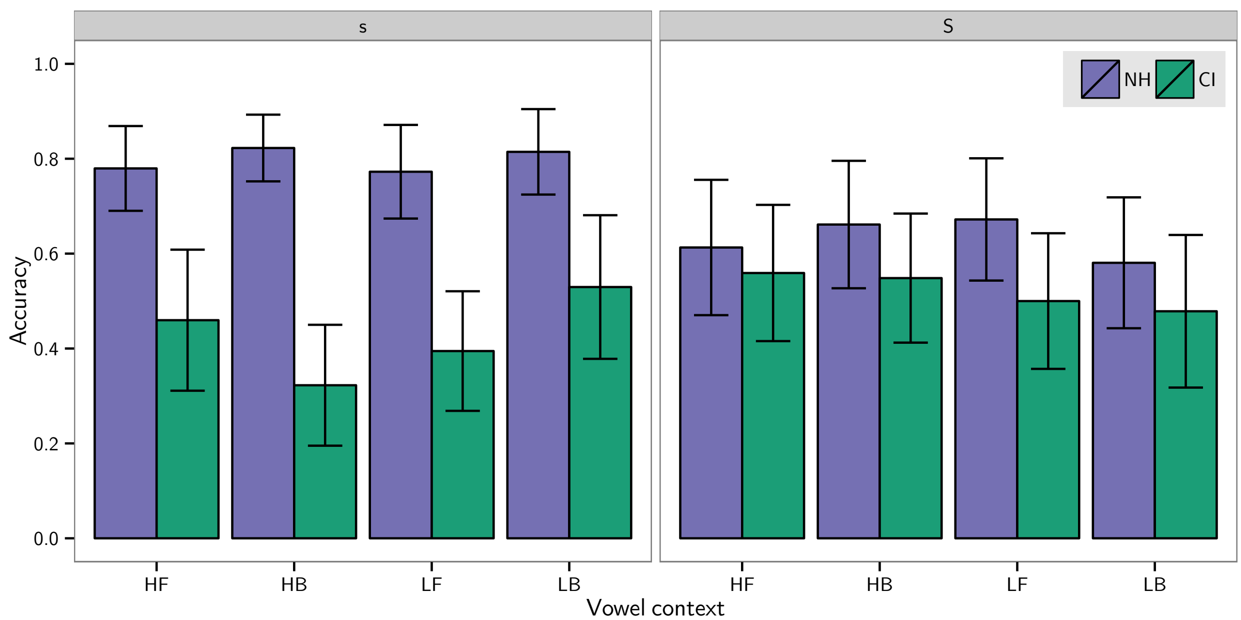


Figure 3.1 Mean accuracy (bars indicate standard errors) for /s/ (left plot) and /ʃ/ (right plot) for the high-front (HF), high-back (HB), low-front (LF), and low-back (LB) vowel quadrants for the two groups of children.

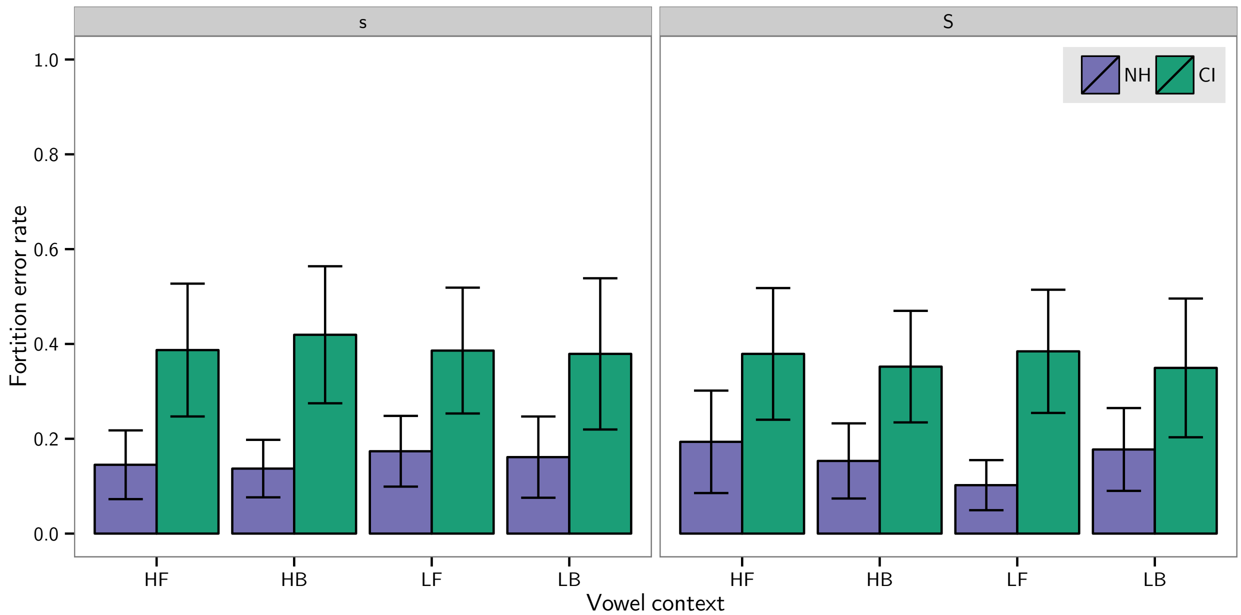


Figure 3.2 Rate of fortition (stopping) errors (bars indicate standard errors) for /s/ (left plot) and /ʃ/ (right plot) for the high-front (HF), high-back (HB), low-front (LF), and low-back (LB) vowel quadrants for the two groups of children

Figure 3.3 shows the rate of fronting errors by consonant and vowel context. There was a significant effect of age (*Estimate* = -1.18, *Std. Err* = 0.29, z = -4.10, p < 0.001), indicating that fronting errors decreased with age for children with CIs for /s/ in the low-back context. There was a significant effect of group (*Estimate* = -2.36, *Std. Err* = 0.94, z = -2.52, p = 0.01), indicating that children with NH produced fewer fronting errors than children with CIs. There was a significant effect of consonant (*Estimate* = 2.08, *Std. Err* = 0.47, z = 4.40, p < 0.001), indicating that children with CIs made more fronting errors for /ʃ/ relative to /s/ in the low-back vowel context. There was a significant group by consonant interaction (*Estimate* = 2.12, *Std. Err* = 0.89, z = 2.37, p = 0.02), indicating that children with NH had more fronting errors on /ʃ/ relative to /s/, as compared to children with CIs. There was a marginally significant consonant by vowel quadrant interaction for the low-front (*Estimate* = -1.17, *Std. Err* = 0.63, z = -1.87, p = 0.06) and high-front (*Estimate* = -1.16, *Std. Err* = 0.67, z = -1.75, p = 0.08) contexts, indicating that there was a smaller difference in the amount of stopping errors between /ʃ/ and /s/ for high-front and low-front vowel contexts vs. the low-back vowel context for children with CIs.

An error analysis was conducted for both the CI and NH groups. See tables 3.1 and 3.2 for the three most common errors for /s/ and /ʃ/ for both the CI and NH groups, and their rate of occurrence. Overall, /d/ was the most common error for /s/ for the CI group, although /ʃ/ was also a common substitution. For /ʃ/, /tʃ/ was the most common error for the CI group. For the NH group, /ts/ was the most common error for /s/, and /s/ was the most common error for /ʃ/. For a complete breakdown of the three most common errors for /s/ and /ʃ/ by vowel quadrant for both the CI and NH groups see Appendix D and Appendix E.

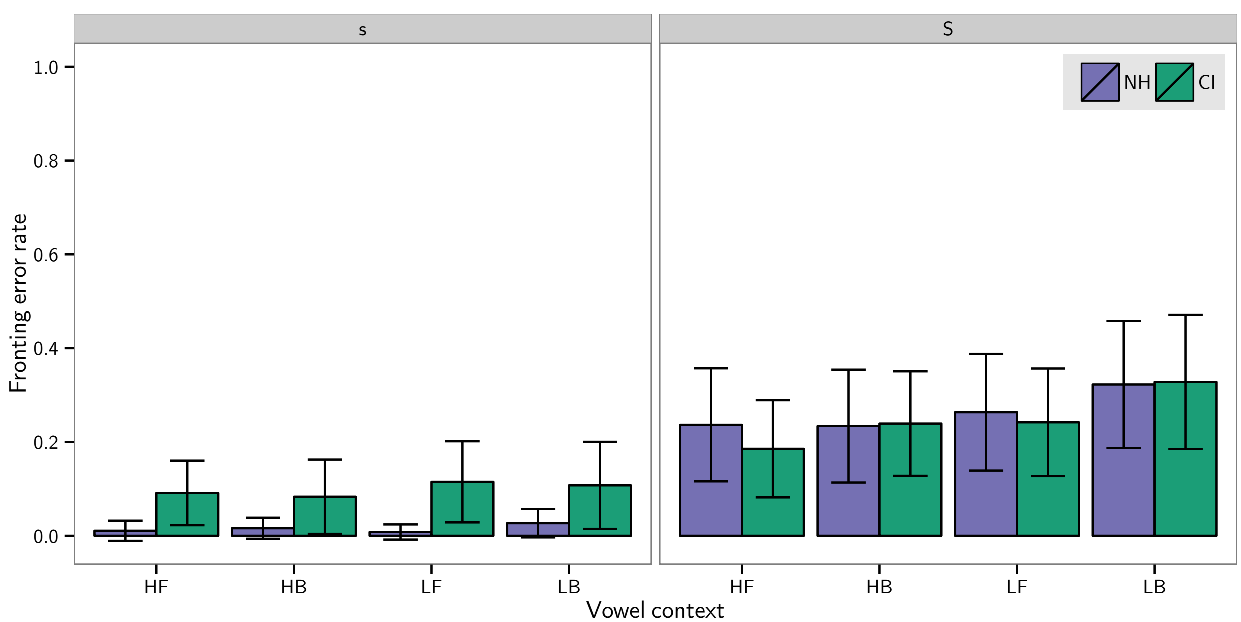


Figure 3.3 Rate of fronting errors (bars indicate standard errors) for /s/ (left plot) and /ʃ/ (right plot) for the high-front (HF), high-back (HB), low-front (LF), and low-back (LB) vowel quadrants for the two groups of children.

Table 3.1: Most common errors for /s/ and /ʃ/
errors for /s/ and /ʃ/ for
for the NH group

Target	Produced	Percent
s	s	79.64
	ts	7.86
	ks	2.82
	ʃ	3.47
ʃ	ʃ	63.56
	s	19.07
	tʃ	8.26
	ts	2.75

Table 3.2: Most common
the CI group

Target	Produced	Percent
s	s	42.33
	d	15.34
	ʃ	11.04
	tʃ	5.32
ʃ	ʃ	51.98
	tʃ	14.76
	d	5.73
	s	4.63

CHAPTER FOUR

DISCUSSION AND CONCLUSION

Based on the accuracy analysis, we can make the following claims: children with CIs were less accurate when producing sibilant fricatives than children with normal hearing, and there was a bigger accuracy difference for /s/ than for /ʃ/. The accuracy results from this study are consistent with previous research. Our finding that the NH group was more accurate on the production of /s/ and /ʃ/ than the CI group can be found in previous research (Todd et al., 2011). It is important to remember that the children in our study were younger than the children in many previous studies. Our children ranged in age from 36-72 months with an average of 46.5 months, whereas the children in the Todd et al. study ranged from 49-110 months. In our analysis, we found that children with CIs had particular difficulty with /s/, but not with /ʃ/. This was also the case in the research of Reidy and colleagues (Reidy, 2015; Reidy, Kristensen, Winn, Litovsky, and Edwards, 2016) and of Todd et al.'s (2011) research on the /s/-/ʃ/ contrast. There is likely a perceptual explanation for this, as the spectral information of /s/ is coded poorly by a CI.

For children with CIs, vowel context affected the production of /s/. Vowel context affected /s/ more than for /ʃ/. The low-back vowel context was a facilitating context for /s/ production for children with CIs. This was what had been predicted for perceptual reasons. Because of anticipatory coarticulation, /s/ before a low-back vowel should have a lower frequency spectrum, which should be easier for children with CIs to perceive. This finding suggests that it should be an initial context for therapy for children with CIs when teaching /s/. It should be noted that the facilitating effect of following vowel context that was observed in this study for /s/ production for children with CIs is different than the articulatory compatibility effects between vowel and consonants that have been observed for children with NH (Warner-Czyz et al., 2010). In this case, the facilitating effect was because of perception rather than because of articulatory compatibility in production.

It had also been predicted that the most difficult context for /s/ production for children with CIs would be the high-front context, as anticipatory coarticulation would result in a higher frequency spectrum for /s/ in this context, which should be difficult for children with CIs to perceive. However, this prediction was not supported by our results. Instead, the two contexts that were most difficult for /s/ production for children with CIs were the low-front and high-back contexts. While we do not have an explanation about why these contexts were more difficult, this is still useful information for our clinicians. Results from this study suggest that a child with a CI will have the most difficult time producing /s/ in words immediately followed by a low-front, or high-back vowel.

The results of the analysis suggested that vowel context affected the accuracy of sibilant fricative production in children with CIs for /s/, but not for /ʃ/. Furthermore, vowel context did not have an effect on the accuracy of sibilant fricative production in children with NH. Vowel context affected the accuracy of /s/ production in children with CIs. However, vowel context did not seem to affect the accuracy of /ʃ/ production in children with CIs, nor did it seem to affect the accuracy of either /s/ or /ʃ/ production in children with NH.

Based on the fortition error analysis, we can conclude that children with CIs produce significantly fewer fortition errors as age increases, and that children with NH produce significantly fewer fortition errors than children with CIs. This is consistent with the findings of Reidy, Beckman, Litovsky, and Edwards (2015), that younger children with CIs are most likely to produce stop consonant errors. Reidy and colleagues (2015) also found that children with CIs are more likely to produce sibilant or lenition errors once they had been using their prostheses for at least 4 years. Reidy and colleagues (2015) define lenition errors as “productions where the constriction is made at a location in the oral tract such that the airflow exiting the constriction does not strike the incisors with enough force to generate a secondary noise source. This comprises both ‘fronting’ and ‘backing’ errors since a [θ] or [x] substitution would count as a lenition error”. None of the children in this study were old enough to have had 4 years of experience with their cochlear implant, and therefore it makes sense that they produced fortition errors more frequently than sibilant or lenition errors. Although the current findings are different from the findings of Todd et al. (2011), who found that children with CIs most frequently produce lenition errors (/f/ or /θ/), it is likely that this difference can be explained by the age difference of the two groups studied. Participants in Todd et al. (2011) ranged from 4-9 years old, and were more likely to have had the 4 years experience with their implants that Reidy et al. (2015) found was the point at which CI users shifted from producing a preponderance of fortition errors to a preponderance of lenition errors. It is interesting that children with CIs were more likely to produce fortition errors than children with normal hearing because it suggests that children with CIs have a lesser degree of motor control in the production of sibilant fricatives than children with NH. Stop consonants require less motor control because they are created by a full occlusion of the oral tract as opposed to fricatives, which require a more fine-tuned narrowing of the oral tract.

Based on the fronting error analysis, we can claim that children with CIs made more fronting errors than children with NH, and this is particularly true for /ʃ/. Todd et al. (2011) also found that fronting was a common error for /ʃ/ in children with CIs. For /ʃ/, the low-back vowel context had the most fronting errors and the front vowel contexts had the least fronting errors.

Following the completion of this project, we are planning on conducting additional analyses, which will add more interactions to our multi-dimensional effects model: age by group, and age by group by consonant. We will attempt to answer the following questions: Does the difference between groups decrease as age increases? Is this the same for /s/ and for /ʃ/? These questions were not addressed in the scope of this project due to time constraints.

Further research on this topic could continue in a variety of directions. Research could be conducted on why some vowel contexts are facilitative and others are challenging. Other research could look into the effect of perception vs. production as it relates to the following vowel. Studies could also look at a variety of vowel contexts, including VCV and VC.

In any case, these findings have important clinical applications for speech-language pathologists working with children with CIs who are likely to have difficulty learning to produce /s/. In working with children with CIs, /s/ should first be taught in syllables or words containing low-back vowels (e.g., *sock*, *soft*, and *sob*). However, a clinician should not consider a child with a CI's ability to produce /s/ as completely accurate until that child can also produce /s/ in words containing high-back and low-front vowel contexts.

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APPENDIX A:
HEARING INFORMATION FOR CI GROUP

ID	Age at Hearing Loss (Months)	Age at activation of first CI (Months)	Reason for Hearing Loss	Type of First CI	Processing Strategy for First CI	Type of Second CI	Processing Strategy for Second CI
300E	0	13	genetic	Med-El	OPUS 2	Med-El	OPUS 2
301E	0	45	unknown	Med-El	OPUS 2	Med-El	OPUS 2
302E	0	13	unknown	Advanced Bionics	Neptune	Advanced Bionics	Neptune
303E	6	13	unknown	Med-El	OPUS 2	Med-El	OPUS 2
304E	0	12	genetic	Med-El	OPUS 2	Med-El	OPUS 2
305E	4	22	unknown	Advanced Bionics	Neptune	Advanced Bionics	Neptune
306E	0	8	unknown	Med-El	OPUS 2	Med-El	OPUS 2
307E	0	15	genetic	Cochlear	Nucleus 5	Cochlear	Nucleus 5
308E	0	13	genetic	Med-El	OPUS 2	Med-El	OPUS 2
309E	0.5	7	genetic	Cochlear	Nucleus 6	Cochlear	Nucleus 6
311E	9	13	unknown	Advanced Bionics	AB Harmony	Advanced Bionics	AB Harmony
312E	0	24	genetic	Advanced Bionics	Neptune		
314E	10	17	unknown	Advanced Bionics	Neptune	Advanced Bionics	Neptune
605L	0	16	unknown	Med-El	Opus 2		
608L	0.5	9	genetic - Connexin 26	Cochlear	Nucleus 5	Cochlear	Nucleus 5
665L	0	12	genetic	Med-El	Opus 2	Med-El	Opus 2
679L	0	29	genetic	Cochlear	Nucleus 6		
800E	30	37	genetic	Med-El	OPUS 2		
801E	1.5	15	unknown	Advanced Bionics	Neptune	Advanced Bionics	Neptune
803E	0	33	unknown	Cochlear	Nucelus 6		
804E	0	7	genetic	Cochlear	Nucleus 5	Cochlear	Nucleus 5
806E	14	34	genetic	Cochlear	Nucleus 6		
807E	6-10	22	Mondini malformation	Cochlear	Nucleus 5		
808E	0	6	genetic	Cochlear	Nucleus 5	Cochlear	Nucleus 5
809E	6	8	meningitis	Cochlear	Nucleus 5	Cochlear	Nucleus 5

APPENDIX B:
MEAN ACCURACY BY CONSONANT AND VOWEL CONTEXT FOR THE CI AND NH GROUPS

Intercept	Estimate	Standard Error	z-Value	p-Value
Age	0.84567	0.23738	3.563	0.000367
Group NH	2.08145	0.58868	3.536	0.000407
Target /s/	-0.36907	0.37738	-0.978	0.328087
Vowel Quadrant Low-Front	-0.93819	0.34027	-2.757	0.005830
Vowel Quadrant High-Back	-1.43475	0.35515	-4.040	5.35e-05
Vowel Quadrant High-Front	-0.51462	0.34787	-1.479	0.139045
Group NH by Target /s/	-1.18917	0.53114	-2.239	0.025163
Group NH by Vowel Quadrant Low-Front	0.64297	0.49861	1.290	0.197219
Group NH by Vowel Quadrant High-Back	1.51174	0.52202	2.896	0.003780
Group NH by Vowel Quadrant High-Front	0.22215	0.50991	0.436	0.663082
Target /s/ by Vowel Quadrant Low-Front	1.14076	0.49842	2.289	0.022092
Target /s/ by Vowel Quadrant High-Back	1.94487	0.51104	3.806	0.000141
Target /s/ by Vowel Quadrant High-Front	1.10896	0.50710	2.187	0.028754
Group NH by Target /s/ by Vowel Quadrant Low-Front	-0.32927	0.70368	-0.468	0.639838
Group NH by Target /s/ by Vowel Quadrant High-Back	-1.57108	0.72135	-2.178	0.029408
Group NH by Target /s/ by Vowel Quadrant High-Front	-0.68075	0.71183	-0.956	0.338896

APPENDIX C:
RATE OF FORTITION ERRORS BY CONSONANT AND VOWEL CONTEXT FOR THE CI AND NH GROUPS

Intercept	Estimate	Standard Error	z-Value	p-Value
Age	-0.58627	0.25842	-2.269	0.0233
Group NH	-1.40170	0.61878	-2.265	0.0235
Target /s/	-0.19487	0.40045	-0.487	0.6265
Vowel Quadrant Low-Front	0.02464	0.35573	0.069	0.9448
Vowel Quadrant High-Back	0.28893	0.36159	0.799	0.4242
Vowel Quadrant High-Front	0.08160	0.36550	0.223	0.8233
Group NH by Target /s/	0.28794	0.56810	0.507	0.6123
Group NH by Vowel Quadrant Low-Front	0.05011	0.51560	0.097	0.9226
Group NH by Vowel Quadrant High-Back	-0.53108	0.53504	-0.993	0.3209
Group NH by Vowel Quadrant High-Front	-0.23652	0.53494	-0.442	0.6584
Target /s/ by Vowel Quadrant Low-Front	0.17956	0.52909	0.339	0.7343
Target /s/ by Vowel Quadrant High-Back	-0.26867	0.53293	-0.504	0.6142
Target /s/ by Vowel Quadrant High-Front	0.10088	0.53747	0.188	0.8511
Group NH by Target /s/ by Vowel Quadrant Low-Front	-0.97211	0.77824	-1.249	0.2116
Group NH by Target /s/ by Vowel Quadrant High-Back	0.34544	0.77230	0.447	0.6547
Group NH by Target /s/ by Vowel Quadrant High-Front	0.25386	0.76727	0.331	0.7408

APPENDIX D:
RATE OF FRONTING ERRORS BY CONSONANT AND VOWEL CONTEXT FOR THE CI AND NH GROUPS

Intercept	Estimate	Standard Error	z-Value	p-Value
Age	-1.1755	0.2870	-4.095	4.21e-05
Group NH	-2.3601	0.9365	-2.520	0.0117
Target /s/	2.0804	0.4726	4.403	1.07e-05
Vowel Quadrant Low-Front	0.4192	0.4968	0.844	0.3988
Vowel Quadrant High-Back	-0.0248	0.5385	-0.046	0.9633
Vowel Quadrant High-Front	0.0165	0.5330	0.031	0.9753
Group NH by Target /s/	2.1214	0.8944	2.372	0.0177
Group NH by Vowel Quadrant Low-Front	-1.8683	1.3204	-1.415	0.1571
Group NH by Vowel Quadrant High-Back	-0.5773	1.1312	-0.510	0.6098
Group NH by Vowel Quadrant High-Front	-1.2170	1.3174	-0.924	0.3556
Target /s/ by Vowel Quadrant Low-Front	-1.1705	0.6258	-1.870	0.0614
Target /s/ by Vowel Quadrant High-Back	-0.6359	0.6559	-0.969	0.3323
Target /s/ by Vowel Quadrant High-Front	-1.1610	0.6651	-1.746	0.0809
Group NH by Target /s/ by Vowel Quadrant Low-Front	2.1895	1.4327	1.528	0.1265
Group NH by Target /s/ by Vowel Quadrant High-Back	0.5259	1.2596	0.418	0.6763
Group NH by Target /s/ by Vowel Quadrant High-Front	1.6926	1.4354	1.179	0.2383

APPENDIX E:
MOST COMMON ERRORS FOR /s/ AND /ʃ/ BY VOWEL QUADRANT FOR THE CI GROUP

Quadrant	Target	Produced	Manner	Place	Percent
High-Back	s	s	correct	correct	32.52
		d	fortition	correct	13.01
		ʃ	sibilant	back	19.51
		tʃ	fortition	back	8.13
	ʃ	ʃ	correct	correct	54.92
		tʃ	fortition	correct	14.75
		s	sibilant	front	6.56
		t	fortition	front	4.10
High-Front	s	s	correct	correct	45.90
		d	fortition	correct	16.39
		tʃ	fortition	back	4.92
		ʃ	sibilant	back	6.56
	ʃ	ʃ	correct	correct	56.56
		tʃ	fortition	correct	18.03
		d	fortition	front	4.10
		deletion	N/A	N/A	3.28
Low-Back	s	s	correct	correct	51.43
		d	fortition	correct	20.00
		b	fortition	front	4.76
	ʃ	ʃ	correct	correct	43.18
		d	fortition	front	14.77
		s	sibilant	front	11.36
		tʃ	fortition	correct	7.95
Low-Front	s	s	correct	correct	41.01
		d	fortition	correct	12.95
		ʃ	sibilant	back	12.23
		tʃ	sibilant	back	5.04
	ʃ	ʃ	correct	correct	50.82
		tʃ	fortition	correct	16.39
		s	sibilant	front	7.38
		deletion	N/A	N/A	4.92

APPENDIX F: MOST COMMON ERRORS FOR /s/ AND /ʃ/ BY VOWEL QUADRANT FOR THE NH GROUP

Quadrant	Target	Produced	Manner	Place	Percent
High-Back	s	s	correct	correct	82.26
		ts	fortition	correct	5.65
		ʃ	sibilant	back	4.03
		t	fortition	correct	2.42
	ʃ	ʃ	correct	correct	66.13
		s	sibilant	front	16.92
		tʃ	fortition	correct	8.87
		ts	fortition	front	3.23
High-Front	s	s	correct	correct	77.42
		ts	fortition	correct	8.87
		ʃ	sibilant	back	4.84
		ks	fortition	back	3.23
	ʃ	ʃ	correct	correct	61.29
		s	sibilant	front	16.92
		tʃ	fortition	correct	12.10
		ts	fortition	front	3.23
Low-Back	s	s	correct	correct	81.25
		ts	fortition	correct	8.04
		ks	fortition	back	2.68
		tʃ	fortition	back	2.68
	ʃ	ʃ	correct	correct	59.00
		s	sibilant	front	23.00
		tʃ	fortition	correct	8.00
		pʃ	fortition	front	3.00
Low-Front	s	s	correct	correct	77.94
		ts	fortition	correct	8.82
		ks	fortition	back	3.68
		ʃ	sibilant	back	3.68
	ʃ	ʃ	correct	correct	66.94
		s	sibilant	front	20.16
		tʃ	fortition	correct	4.03