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Phonological Process Use in the Speech of Children Fitted With Cochlear Implants

Rhonda Gale Parker
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Rhonda Gale Parker entitled "Phonological Process Use in the Speech of Children Fitted With Cochlear Implants." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Speech Pathology.

Peter Flipsen, Major Professor

We have read this thesis and recommend its acceptance:

Ilsa Schwartz, Lori Swanson

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Acceptance for the Council:

Vice Chancellor and
Dean of Graduate Studies

PHONOLOGICAL PROCESS USE IN THE SPEECH OF CHILDREN FITTED WITH COCHLEAR IMPLANTS

A Thesis Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Rhonda Gale Parker
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[illegible] Peter Furness [illegible] encouragement and efforts in assisting me to become familiar with the concept of phase [illegible] preservation and the particular application of this concept [illegible]

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Finally I would like to thank my family [illegible]

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ABSTRACT

Objective: The purpose of this study was to examine the use of both developmental and non-developmental phonological processes in a group of young children using cochlear implants.

Participants: 6 preschool children with severe to profound binaural hearing loss with cochlear implants

Method: 15-25 minute conversational speech samples from six children were collected at three-month intervals over a period of 12-21 months for a prior study. These samples were then transcribed and analyzed using Natural Phonological Analysis (NPA) and a data collection form created solely for the purpose of this study.

Data Analysis: Pearson correlations were used to determine relationships among the variables. Z-scores were also used to make comparisons with the available normative data.

Results: Possible explanations for the use of developmental as well as non-developmental processes in this population are discussed. These results have implications for the assessment and clinical treatment of phonological errors in the speech of children with cochlear implants.

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LIST OF ABBREVIATIONS

ACE = Advanced Combination Encoder
CA = Chronological Age
CI = Cochlear Implant
CIS = Continuous Interleaved Sampling
HA = Hearing Aid
HI = Hearing Impairment
ID = Identification
MPEAK = Multi Peak
NH = Normal Hearing
NPA = Natural Process Analysis
PIA = Post-implantation Age
PTA = Pure Tone Average
SAS = Simultaneous Analog Sampler
SLP = Speech-Language Pathologist
SPEAK = Spectral Peak

CHAPTER 1

INTRODUCTION

Hearing and Hearing Impairment

In a normal hearing system, sound (waves of acoustic pressure) is collected and amplified by the outer ear, converted to mechanical energy in the middle ear via the ossicular chain, converted to hydraulic energy in the cochlea (moving through perilymph and endolymph), and eventually becomes an electrical signal due to the displacement of the hair cells that line the basilar membrane of the cochlea (Bess & Humes, 2003). This displacement triggers the release of neurotransmitters at the synaptic cleft of the spiral ganglion cells and the fibers of the acoustovestibular nerve (CN VIII). Once a sufficient amount of neurotransmitter is released, an action potential is generated in the nerve, sending the electrical translation of the sound to the temporal lobes of the brain.

The cochlea is described as having a tonotopic organization, with low frequency sounds resulting in hair cell displacement closer to the apex (tip), and high frequency sounds resulting in the greatest displacement near the base (starting point). It has been shown that damage to certain areas of the cochlea can account for hearing loss in the range of frequencies that correspond to that location (Bess & Humes, 2003).

When someone is said to have a sensorineural hearing loss, this means that they have reduced function of the inner ear. Typically, this occurs as a result of damage or malformation to the hair cells of the cochlea or the acoustovestibular nerve. The predominant causes of sensorineural hearing loss in children include congenital disorders, meningitis, and exposure to ototoxic drugs. Some risk factors for childhood deafness include extended stays in the Neonatal Intensive Care Unit (NICU), a family history of hearing loss, exposure to in-utero infections (e.g., rubella or cytomegalovirus), and craniofacial abnormalities.

Cochlear Implants

The first cochlear implant device was developed in 1972 by 3M/House *(ASHA, 2004).* The people implanted with this single channel device (many of them children) showed improved speechreading abilities and some open set word recognition. In 1984, the first multi-channel implant system, the Nucleus 22, was introduced to the market by Cochlear Corporation. The first candidates for implantation were postlingually deafened adults who could not benefit from hearing aids. By 1990, the FDA had approved implantation for children age 2 years and over with a pure tone average (PTA) of 70 dB HL or greater. As of 2000, the FDA has approved monaural implantation for children as young as 12 months with bilateral, profound, sensorineural hearing loss who receive minimal benefit from amplification (Discolo & Hirose, 2002). Earlier implantation is still somewhat controversial due to the rapid structural changes that take place during a child's first year of life, an increased risk for otitis media during this time, and an increased risk of surgical complications in infants (even though the cochlea is fully formed at birth).

A cochlear implant is a prosthetic hearing device used to stimulate the auditory nerve fibers directly via electric current (Moore & Teagle, 2002). Most implants cover a frequency range of 200-7500 Hz and consist of both external and internal components. The external components include a microphone, a speech processor that converts the sound into an electrical signal, a transmitter that sends the electrical signals to an electrode array, and a power supply (using various types of batteries). The transmitter is held in place by a magnet, which connects it to a subcutaneous receiver. The speech processor can be connected to a variety of other devices, such as frequency modulated (FM) systems and telephone adapters. The internal components consist of a receiver and an electrode array that is inserted by a surgeon into the cochlea near the round window.

There are currently three types of cochlear implant devices available on the market: Nucleus Cochlear Implant System by Cochlear Corporation, Clarion by Advanced Bionics Corporation, and Med-El by Medical Electronics Corporation (ASHA, 2004). All three of these devices make use of 1) multichannel stimulation (multiple contacts/electrodes in the array), 2) transcutaneous (through the skin – no wires pass through) communication between externally worn hardware and the electronic implant, 3) telemetry (allows for monitoring of the intracochlear electrodes), 4) a choice of several speech processing options, and 5) programming which involves establishing a threshold and maximum stimulation level for each of the electrodes (customized for each person implanted and typically adjusted quite often during the first year of implantation). All three types of implants are similar in cost.

The speech processor strategies available in cochlear implants typically fall into 3 categories (Moore & Teagle, 2002). F0/F1/F2, multipeak (MPEAK), and spectral peak (SPEAK) strategies emphasize the frequency components of speech while compressed analog (CA), simultaneous analog sampler (SAS), and continuous interleaved sampling (CIS) strategies emphasize the temporal or timing characteristics of speech. There are also hybrid strategies, which combine both frequency and temporal emphasis, including advanced combination encoder (ACE) and n of m (n = number of electrode sites available for stimulation for a given speech input, m = total number of sites).

Phonological Processes

In acquiring the speech sounds of a given language, all children make systematic errors in their productions. One way of describing these errors is through the use of phonological process labels (e.g., cluster reduction, final consonant deletion). Advocates of the theory of "natural phonological processes" assume that these labels represent true mental operations by which children simplify speech targets in order to produce output that they are more capable of producing at that moment in time (Edwards, 1992; Shriberg & Kwiatkowski, 1980; Stampe, 1979). Critics of this theoretical position suggest that such labels only reflect alternative ways to describe error patterns (Fey, 1992; Locke, 1983). Such critics argue that a true evaluation of a child's underlying representation cannot be obtained by examining their surface representations. Basically, the argument is that one can never truly know what is going on inside a child's head – analyses based on surface representation are just a "best guess".

Regardless of the theoretical position one takes, early speech development is full of examples of speech sound production errors that can be easily described using phonological process labels (Bauman-Waengler, 2000). These errors do not resemble adult speech forms, however they are representative of phonological growth (Ingram, 1989). Although there may be individual variation, children with normal hearing generally show a gradual reduction in the appearance of these errors (i.e., in the use of these processes) from ages 2;6-8;0, with very few, if any, being productive in their speech after the age of 4 years (Grunwell, 1987; Hodson & Paden, 1981; Roberts, Burchinal, & Footo, 1990).

Phonological processes have been described as being either developmental or non-developmental; there is however no strong consensus on which of these errors fall into which category. The general approach has been to assign those processes which show up with the most regularity in the speech of young normally developing children to the developmental group with all others falling into the non-developmental group (Edwards & Shriberg, 1983; Dodd & Iacano, 1989). Dodd and Iacano have also suggested that identification of non-developmental processes (such as initial consonant deletion, medial consonant deletion or substitutions, insertion of extra consonant sounds, backing, denasalization, devoicing of stops, and sound preference substitutions) is crucial due to the fact that these processes appear to be less conducive to spontaneous change. Dodd and Iacano reported that children making use of both developmental and non-developmental processes made more therapeutic gains in the reduction of non-developmental than developmental processes. This suggests that non-developmental process use may be more responsive to therapeutic reduction, even though these processes tend to persist longer when intervention is not provided.

Research has shown that the speech errors observed in children with hearing impairments who use hearing aids can be described with the same phonological process labels as normally hearing children (Abraham, 1989; Dodd, 1976). However these children produce them to a greater extent and for a longer period of time. In a descriptive study of phonological process use in 19 children with hearing-impairment using hearing aids, Meline (1997) found a significant relationship between hearing loss and phonological process use. Children with a profound hearing loss persisted in the use of phonological processes, particularly final consonant deletion and cluster reduction, for a much longer period than did the children with moderate to severe losses. Stoel-Gammon (1983) also reported that young children using hearing aids used the non-developmental processes of glottal replacement, frication, and backing in their speech. To date, the literature has suggested that similar trends will be seen in the speech of hearing impaired children who use cochlear implants (Grogan, Barker, Dettman, & Blamey, 1995).

Children with hearing impairment have also been shown to make use of vowel-based phonological processes (Dodd, 1976; Levitt & Stromberg, 1983; Markides, 1983; Stoel-Gammon, 1983). Common vowel errors include substitution, prolongation of back vowels, and diphthongization of pure vowels. Common diphthong errors include neutralization, monophthongization, and prolongation of the first component, causing the diphthong to sound as two distinct vowels (Levitt & Stromberg, Markides). Using conversational speech samples, Tye-Murray and Kirk (1993) found that hearing impaired children using cochlear implants increased the diversity and accuracy of their vowel and diphthong productions over time. Together with Ertmer (2001), their results indicated that the electrode stimulation pattern that the child is being exposed to for F1 and F2 information might have an impact on vowel acquisition. Both of these studies suggested that the separation of the vowel information carried in these formants leads to improved accuracy of high, stressed vowels. Research by Maassen and Povel (1985) has also suggested that increased vowel accuracy may have a greater impact on improving overall speech intelligibility than does improved consonant accuracy.

Children who receive cochlear implants early in life are able to acquire speech with greater levels of intelligibility than children with hearing aids (Chin, Tsai, & Gao, 2003). However, they have not been shown to produce speech that is commensurate with their age-matched peers with normal hearing. A number of factors appear to continue to mitigate against the development of fully-normal speech in this population. Geers (2004) for example, found that children with cochlear implants who had normal hearing for even a brief period after birth had better speech abilities than those identified with hearing loss at birth. Earlier implantation (typically around age 2 years) and greater duration of implant use were shown to improve, but not ensure, the chances of the child achieving near-normal speech production. In a study that focused specifically on phonological patterns, Grogan et al. (1995) found that children with cochlear implants produced initial consonants with greater accuracy than those occurring in medial or final position. In this study, the most commonly used phonologic processes were errors of consonant deletion, voicing, stopping, and cluster reduction. The only process that reached a statistically significant level of reduction post-implantation was consonant deletion. The average length of implant use for the children in this study was 2 years and 6 months.

Based upon investigations that focused upon typically developing children with normal hearing ability, it would appear that phonological process use in hearing impaired children could easily be considered non-developmental or unusual. There is evidence suggesting that children with hearing impairment make use of developmental processes as well as non-developmental processes.

While several investigations have examined the phonetic inventory development of children using cochlear implants (Blamey, Barry, & Jacq, 2001; Chin, 2002; Dodd & So, 1994; Grogan et al., 1995), phonological process use in this population remains largely unexplored. The following questions appear to remain unanswered and were the focus of the current study:

1) Do children with cochlear implants exhibit a similar pattern of phonological process suppression as normally hearing children?

2) Do children with cochlear implants make use of phonological processes that are non-developmental when compared with normally hearing children?

3) Do children with cochlear implants have similar patterns of vowel process use in comparison to children using hearing aids?

CHAPTER 2

REVIEW OF LITERATURE

Speech Characteristics of Children with Hearing Impairment

The vocalizations of young hearing-impaired children (15 to 26 months) have been shown to closely resemble those produced by younger normally hearing infants (Stark, 1983). This might imply that hearing impairment results in delayed speech sound development. However, with increasing age, there is greater heterogeny in the speech output of hearing-impaired children, which would suggest that factors other than hearing ability are involved (Dodd, 1976).

Many researchers have indicated that speech sounds involving more visible articulatory gestures (such as labiodentals) are easier for hearing impaired speakers to produce due to the increased visual input provided when compared with sounds such as alveolars which are more concealed in the mouth (Monsen, 1983; Seaton, 1974; Stoel-Gammon, 1983). There also appears to be a relationship between the frequency composition (i.e., the acoustic characteristics) of the sound and the type of hearing loss. Vowels and nasals have the lowest frequency energy, whereas voiceless continuants (/s, ʃ, f, θ, h/) have the highest frequency energy and are also more difficult to discern based solely on auditory information (Seaton, 1974). Thus, children with a high frequency sensorineural loss will be more prone to have errors on voiceless continuants. Higgins and Carney (1996) suggested that an over-reliance on visual information on the part of the hearing impaired speaker often leads to the use of the maladaptive, but systematic, speech behaviors that are commonly observed in this population.

In general, the speech of children with severe to profound hearing impairment has been described in terms of poor voice quality (particularly increased breathiness), reduced rate, vowel and consonant substitutions, vowel and consonant distortions, prolongations, excessive nasality, inappropriate pitch and loudness variations, and abnormal prosody (Hudgins & Numbers, 1942; Markides, 1983; Smith, 1975). Ling (1976) also noted these same characteristics in the speech of children with hearing impairments, but attributed them to the effectiveness (or lack thereof) of speech therapy the children had received. Specifically, those children who had received intensive speech therapy did not produce as many of these errors in their speech.

In an early study of 192 hearing impaired children, aged 8-20 years, Hudgins and Numbers (1942) reported the following error patterns: vowel substitutions, initial consonant deletion, devoicing of stops, vowel neutralization, cluster reduction, final consonant deletion, denasalization, simplification of diphthongs, vowel nasalization, consonant substitutions (other than stops), and vowel insertion. This study covered a wide range of hearing impairment (slight to profound) and the data were based upon listener judgments of productions of 6 to 12 word sentences. More recent investigations have generally agreed with these findings (see Table 1), even though the methods and subject groupings have varied considerably. In a comparison of deaf and partially-hearing children, Markides (1983) found that deaf children made more vowel and diphthongs errors, with vowel neutralization occurring most frequently. The deaf subjects also had an even distribution of errors on consonants in the initial and final position of words, whereas the partially hearing group had a much larger percentage of errors on final

Table 1. Studies of Speech Production in Children with HI

Study	Subjects	Age Range	Degree of Hearing Impairment	Method	Findings
Hudgins & Numbers (1942)	192 HI (86 female: 106 male)	8-20	Slight -profound	Oral reading of 1200 simple sentences (6 to 12 words); recorded and transcribed, then "audited" by 5-10 (avg. 7) people familiar with deaf speech, asked to "write down what you think the child says"	More speech sound errors occurred in the speech of those participants with more severe hearing losses; errors common in this group included vowel substitutions, initial consonant deletion, devoicing of stops, vowel neutralization, cluster reduction, final consonant deletion, denasalization, simplification of diphthongs, vowel nasalization, consonant substitutions (other than stops), and vowel insertion
Markides (1967) (as cited in Markides, 1983)	58 deaf (80+ dB HL) 27 partial hearing (<80dB HL)	7-10	Moderate-profound	24 monosyllabic words; recorded and transcribed	Deaf children made more vowel and diphthongs errors, with vowel neutralization occurring most frequently; even distribution of errors on consonants in the initial and final position of words, whereas the partially hearing group had a much larger percentage of errors on final consonants; mostly omitted the target sound, whereas the partially hearing children made predominately substitution errors
Smith (1975)	40 HI congenital deafness	8-15	Severe-profound (avg. 92dB HL)	20 sentences (reading); recorded and transcribed by a set of 11 "phoneticians" using broad transcription	Avg. intelligibility of 18.7%; voicing errors; more final than initial consonant deletions; stopping; liquid simplification; glottal stop substitutions; vowel and diphthong errors; best productions occurred on bilabial, glides, and /f,v/; poorest occurred on fricatives, affricates, and velars
Dodd (1976)	10 HI congenital deafness	9:5-12:4	>102dB	45 flash cards of pictures to name; recorded and transcribed by two speech pathologists	Processes in use by the children were those that are also seen in children with normal hearing at some point in development; definitely appeared to be using a rule-governed system with detriments arising in the face of reduced visual input (lipreading) as apposed to frequency (Hz)
Oller, Jensen & Lafayette (1978)	1 male HI	6:1	>75dB	Shown pictures, asked to name; recorded and transcribed (3 transcribers)	Processes in use by the child were those that are also seen in children with normal hearing (with normal and abnormal language development) at some point in development; preference for singletons as opposed to clusters
Markides (1980) (as cited in Markides, 1983)	28 HI	9:8-13:3	3 Groups: A) Sloping (15-20dB steps/octave) B) Flat (+/- 20dB) C) Combination	27 monosyllabic words; recorded and transcribed	All 3 groups had more errors on final than initial consonants; children with a sloping HL made more substitution errors than did the other two groups, with little difference noted for any other parameters

Table 1. Continued.

Stoel-Gammon (1983)	21 HI 25 Normal	HI: 2;4-7:3 Norm: 1:5-3:10	Moderate-profound	Photo Articulation Test: recorded and transcribed (2 transcribers)	HI group used FCD and stopping of fricative and affricates to a greater extent than the normal group: HI group made more substitutions for /□/ and /□/ than did normal group: HI group made use of glottal stop subsitution. deaffrication. and backing. which were very uncommon in the normal group
Abraham (1989)	13 HI (11 female. 2 male)	5:11-15:11	Severe-profound	Goldman-Fristoe Test of Artictulation (GFTA): Test of Minimal Articulatory Competency (T-MAC): Phonological Process Analysis (PPA): Khan-Lewis Phonological Analysis (KLPA): transcribed by two independent judges	Subject showed a increased inventory of consonants used in initial word position than in final word position: most commonly occurring processes including cluster reduction. liquid simplification. deaffrication. final consonant deletion and stridency deletion: processes that were observed but not scored included initial consonant deletion (6 subjects) and vowel errors (all subjects)
Dodd & So (1994)	12 HI (7 male. 5 female)	4:2-6:11	Moderate-Profound	Cantonese Segmental Phonology Test: Cantonese Lexical Comprehension Test: recorded and transcribed	Processes in use were similar to those used by younger normally hearing Cantonese children (e.g.. cluster reduction. stopping) with the exception of frication. sound additions. initial consonant deletion. and backing. at least one of which were being used by most of the children
Meline (1997)	19 HI (11 male. 8 female)	5-12	10 Moderate-Severe 9 Profound	Goldman-Fristoe Test of Articulation: Khan-Lewis Phonological Analysis (KLPA):	Subjects with profound losses had more productive use of processes than the moderate-profound group: common processes in use included final consonant deletion. cluster reduction. initial consonant deletion. gliding. backing. stopping. and glottal stop substitution
Huttunen (2001)	10 HI (6 male. 4 female) 5 NH (2 male. 3 female)	4-6 3	Moderate (avg. 49dB HL)	Picture-naming task (62 items): recorded and transcribed (two transcribers)	HI children had more voicing and final consonant deletion errors and twice as many vowel substitutions as the NH children: vowel neutralization was unique to the HI group

consonants. In regards to the type of error, the deaf children mostly omitted the target sound, whereas the partially hearing children made predominately substitution errors.

Speech Characteristics of Children Using Cochlear Implants

Children who receive cochlear implants early in life are able to acquire speech that often closer to normal than that of children with hearing aids (Chin et al., 2003). However, they do not have a consistent ability to produce speech that is commensurate with their age-matched peers with normal hearing. Geers (2004) found that children with cochlear implants who had normal hearing for even a brief period after birth had better speech abilities than those identified with hearing loss at birth. Earlier implantation (typically around age 2) and greater duration of implant use were shown to improve, but not ensure, the chances of the child achieving near-normal speech production.

In a 1999 study of 9 children, aged 5 years or younger at implantation, Serry and Blamey collected spontaneous speech samples at roughly 6-month intervals. They used a 50% criterion for mastery of a speech sound (phone). At 4 years post-implant, 5 or more of the children had reached the criterion for 29 of 44 phones (66%). Blamey et al. (2001) conducted a follow up study using the same children, now with 6 years of CI experience, and showed some growth in phonetic inventory. At this stage of development, 36 of 44 phones (82%) had reached the mastery criteria. The following phones had not been mastered by 5 or more of the 9 children: /ɔ͡ɪ , ʊə , ʒ , t , s , z , tʃ , θ/. Suggested explanations for the slow acquisition of these phones included a low frequency of occurrence for /ɔ͡ɪ , ʊə , ʒ/, the articulatory characteristics of /t , s , z , tʃ , θ/, and possibly a plateau in performance abilities. They postulated that perceptual similarities and the fine control of place of articulation required in producing these sounds may have resulted in their prolonged acquisition period by users of cochlear implants.

A study conducted by Chin (2003) suggested that children with cochlear implants have highly variable phonetic inventories. Chin noted some significant differences between normal and CI phonological systems including the absence of velar stops, the presence of non-English stops, and the absence of interdental and alveolar fricatives in the speech of the CI group. In the normal hearing group, velar stops were established early. However, he noted that the acquisition of alveolar fricatives was highly variable, even in the children with normal hearing. Errors on velar sounds are also known to be common to young and older speech-delayed children with normal hearing abilities (Bauman-Waengler, 2000).

Speech Intelligibility of Children with Hearing Impairment

Smith (1975) showed that the speech intelligibility of hearing impaired children increases with a reduction in speech sound errors. The children studied by Smith had profound hearing impairments and were approximately 20% intelligible to naïve listeners. Monsen (1978) suggested that the degree of hearing loss in the 250-4000 Hz (speech frequencies) range is directly related to intelligibility, with increased severity of loss resulting in a corresponding reduction in speech intelligibility. Other factors that appear to impact intelligibility include age of onset of deafness, duration of deafness, communication method, the proper use of hearing devices, and linguistic ability (Osberger, Maso, & Sam, 1993; Peng, Spencer, & Tomblin, 2004).

While children with normal hearing appear to become fully intelligible around 4 years of age (Weiss, Gordon, & Lillywhite, 1987), it is not necessarily the case that children with cochlear implants achieve this level after 4 years of use; nor do they necessarily reach maximal development at that point. They do tend to show a linear progression over time, although such children may still be significantly less intelligible than normal hearing peers (Chin et al., 2003). Some studies have shown a gradual reduction in the rate of improvement with increasing implant use (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003; Peng et al., 2004). Considering that cochlear implants are a rather recent innovation, further investigations with more experienced users of these devices may be able to determine if these children show a plateau in intelligibility or if they continue to improve with experience. Interestingly enough, Tye-Murray, Spencer, Bedia, and Woodworth (1996) found no real differences (i.e., only minor degradation) in the speech characteristics of children using cochlear implants when produced with the device turned on versus off, regardless of overall intelligibility. This would suggest that these children may not always be using the on-line feedback provided by the implant to regulate their speech production. However, the observed lack of speech differentiation could have been only a transient effect due to the relatively small amount of time that the device was off (only 1 hour for 3 of the 8 participants).

Overall, the speech intelligibility of children using cochlear implants appears to improve with prolonged device exposure (Chin et al., 2003; Tobey et al., 2003; Peng et al., 2004). In a study of 181 children aged 8 to 9 years with an average of 5.5 years of CI experience, Tobey et al. observed an average intelligibility of 63.5% during the oral reading of 3, 5, and 7 syllable sentences. The judges were a panel of three listeners unfamiliar with the speech of the hearing impaired who orthographically transcribed the recordings.

Another study conducted with 24 children who had at least 7 years of CI experience, indicated a gradual trend of improvement with average intelligibility of 68 to 72% (Peng et al., 2004). Judges were again a panel of three listeners, listening and orthographically transcribing recordings of the children imitating a set of 6-10 word sentences presented verbally. Judgments included both orthographic transcription and the use of a five-point rating scale. There was a great deal of variability in the overall intelligibility outcomes with some children having intelligibility scores >85% while others were still below 50%. Possible explanations for this wide range included differences in age of implantation, type of processing strategy used, post implantation language development, duration of deafness, age of onset of deafness, duration of device use, number of surviving ganglion cells, and electrode placement, insertion depth, and electrode frequency (Hz) coverage.

Vowel Productions of Children with Hearing Impairment

Several studies have suggested that a hearing impairment increases the likelihood of a child having problems with the production of vowels, most often citing substitution and neutralization of vowels and simplification of diphthongs as recurring errors (Hudgins & Numbers, 1942; Smith, 1975; Markides, 1983; Huttunen, 2001). In children with normal hearing, vowel productions are most variable from 18 to 24 months of age, with stability of the vowel system being reached around the age of 3 years (Donegan, 2002). Just as with consonant sounds, vowel errors may be described using process descriptors. For example, the consonant sounds adjacent to a vowel may appear to influence its production (described as an assimilation error). In contrast to consonant substitution errors, vowel substitutions do not typically occur in a particular context, but rather have been described as serving the purpose of enhancing a particular property of the sound (Donegan, 2002). Vowels possessing more of a particular property (height, advancement) are thought to be subject to processes that further enhance that property (fortitive), while those with a lower amount of a chosen property may be subject to weakening or loss of the property (lentitive) (Donegan, 2002).

Vowel and diphthong errors are common in the speech of the hearing impaired (Dodd, 1976; Levitt & Stromberg, 1983; Markides, 1983; Stoel-Gammon, 1983). Particularly, front vowels such as /i/ and /ɪ/ are difficult for hearing impaired children to perceive and produce due to the high frequency of the F2 information (Monsen, 1978). Common vowel errors include the substitution of high front vowels with more central vowels, neutralization of /æ/ and /ɛ/, prolongation of back vowels /ɑ, ɔ, ʊ, u/, and diphthongization (least common error) of pure vowels, mostly for /ɑ/ and /i/ with /ɑ/produced as /ɔ͡ɪ/or /o͡ʊ/ and /i/ produced as /iə/ or /iʊ/. Common diphthong errors include the substitution of the diphthong with /ə/, prolongation of the first component (onglide) followed by dropping of the second component (/aɪ/→/aː/), and prolongation of the first component, causing the diphthong to sound like two distinct vowels (/ɔɪ/→/ɔːɪ/) (Levitt & Stromberg, 1983; Markides, 1983).

In a longitudinal study of eight children with cochlear implants, Tye-Murray and Kirk (1993) found that the vowel and diphthong productions became more diverse and more accurate over time. Samples of spontaneous speech were collected pre-implantation and at 6 month intervals post-implantation. Over the course of 24 to 36 months, the production of front vowels showed the most improvement. The data also revealed a trend in improvement with /i/ initially replaced by central vowels, then shifting to replacement with /ɪ/. There was also a pattern of improvement in the production of diphthongs, with early attempts characterized by pure central vowel substitution progressing to substitution of the second member only. Analysis by Tye-Murray and Kirk suggested that processing strategy and electrode placement could have an impact on early perception and production of the vowels. When F1 and F2 information was processed on two separate electrodes (as is the case with the Nucleus devices in this study), the children's production of /i/ was improved. Data from Ertmer (2001) supported this finding in a case study of a congenitally deaf child who exhibited a substantial increase in vowel diversity and accuracy after only 12 months of implant use. After this period of implant use, the child was producing the high, stressed vowels /i/ and /u/ consistently in her speech, which implied a faster rate of acquisition for these sounds than what has been observed in normal hearing infants with a similar amount of speech development. The electrode stimulation for this child was such that F1 and F2 were widely separated for /i/ and positioned close together for /u/, perhaps making these the most prominent vowels for her to perceive. This finding is in contrast to the evidence provided by Monsen (1978), which suggested that hearing impaired children (without cochlear implants) had particular difficulty with high, front vowels due to the high frequency values of F2 information.

A series of three experiments by Maassen and Povel (1985) showed that the degree of intelligibility increased most with increased accuracy of vowels. In this study, 30 productions by 10 deaf children speaking Dutch were digitally manipulated and resynthesized to more closely match the speech of a child with normal hearing reading the same sentences. Maasen and Povel found that intelligibility increased by 24% when vowel segments were manipulated, whereas manipulation of certain classes of consonant sounds (stops, fricatives, affricates) only resulted in a small improvement (around 3%).

Phonological Processes

Theoretical Background

In 1968 Chomsky and Halle described the sound changes that occur within an individual speaker in the English language as a set of internally derived rules. These rules are thought to be systematically applied to a speaker's sound productions in order to more closely approximate a targeted form (referred to as the underlying representation). Earlier work by Jakobson and Halle (1956) had provided evidence that the acquisition of phonemes in the inventory of a given language occurs in a particular sequence, with the acquisition of one sound or class of sounds giving rise to another. Thus, the interrelationships between sounds based upon their distinctive features are crucial to their mastery. This structuralist approach provided little in the way of explaining sound changes that often appear to contradict each other depending upon context (Stampe, 1979). For example, Stampe noted that speakers of the Appalachian English dialect make use of diphthongization of pure vowels in formal speech but monophthongization of diphthongs in rapid, casual speech. In contrast to prior research, Stampe took a more functionalist approach and defined a phonological process as "a mental operation that applies in speech to substitute for a class of sounds or sound sequences presenting a common difficulty to the speech capacity of the individual" (p.1). This Theory of Natural Phonology contended that phonological process use is innate, and thus, natural, to the learning of one's native tongue. Thus, a child in the course of acquiring the speech sounds of a language will be in a constant state of revision until their sound system matches that of adults. These revisions involve the limitation, ordering, and suppression of sound changes, or processes based upon the child's abilities (motoric, cognitive, social, etc.) at the time. Children with normal hearing generally show a sharp reduction in the use of these phonological processes from ages 2;6-8;0, with very few, if any, being observed in their speech after the age of 4 years (Grunwell, 1987; Hodson & Paden, 1981; Roberts et al., 1990). This reduction in the use of processes over time is often described as process suppression. Thus, we have two slightly different views. According to Chomsky and Halle, children learn the rules of the language, while according to Stampe, children suppress processes while they learn the rules.

The change in perspective brought about by the work of Jakobson, Chomsky, Halle and Stampe led clinicians to question the use of traditional approaches that primarily focused on articulatory movements (Stoel-Gammon, Stone-Goldman & Glaspey, 2002). Clinicians recognized that the use of pattern-based approaches had the potential for increased efficiency and generalization of treatment. The use of phonological process descriptions was supported, because it had the potential to capture these patterns without compromising the description of errors affecting syllable structure (which is a limitation of the then-current distinctive features approach). Since that time, several researchers have applied these theories to the assessment and treatment of children with both developmental (e.g., Hodson & Paden, 1983; Ingram, 1989; Shriberg & Kwiatkowski, 1980;Weiner, 1979), and organically based (e.g., with the hearing impaired) speech sound problems (Abraham, 1989; Dodd, 1976; Levitt & Stromberg, 1983; Meline, 1997; Oller, Jensen & Lafayette, 1978; Stoel-Gammon, 1983). The application of this theory has had a significant impact on the approach taken in the remediation of speech sound disorders.

Description and Categorization of Processes

In general, phonological processes can be categorized as syllable structure processes, assimilation processes, or phoneme substitution processes (Edwards & Shriberg, 1983; Grunwell, 1987; Ingram, 1989). Each of these types serves the overriding purpose of simplification, but varies in the way in which this goal is accomplished.

Syllable structure processes operate to simplify a syllable, often resulting in an open syllable form (CV) (Ingram, 1989). Some common syllable structure processes include final consonant deletion, weak syllable deletion, cluster reduction and reduplication. Assimilation processes involve the adaptation of one sound in the word so that it becomes similar in some way to another sound in the word. When the sound in question is assimilating to an adjacent sound, the assimilation is said to be contiguous, whereas assimilation to a nonadjacent sound is referred to as noncontiguous. Also, a sound may assimilate aspects of a sound that it precedes (progressive assimilation) or follows (regressive assimilation). Phoneme substitution processes operate to replace a targeted sound with another sound that varies in place or manner of articulation (Edwards

& Shriberg, 1983). Some common substitution processes include velar fronting, stopping, and gliding of liquids. A more detailed description of several phonological processes can be found in Appendix A.

As noted previously, one advantage that has been observed with the phonological processes approach is that patterns can be identified. This, at least in principle, may optimize intervention by allowing treatment to focus on the pattern rather than individual sounds treated in a haphazard way. One example of the 'pattern approach' is seen with some processes that describe sound changes that affect classes of sounds. For example, the process of fronting typically affects velar sounds while the process of gliding typically affects liquid sounds. It should also be noted that a child may have multiple processes at work for a given sound or class of sounds within a single production. For example, the production of /bɪt/ for the target word *pig* may be seen as the result of both prevocalic voicing (/p/→/b/) and velar fronting (/g/→/t/).

Natural processes have been described as either developmental or non-developmental. Developmental processes include those that are observed in the speech of young typically developing children. Non-developmental processes include those that represent errors not usually seen in the course of normal development. In 1983, Edwards and Shriberg compiled a listing of processes and described each as being developmental or non-developmental in a somewhat different way; these authors based the labels upon the studies available at the time. Non-developmental processes were simply those that did not occur with any regularity in the literature regarding normal phonological development. Dodd and Iacano (1989) later used this set in examining the phonological process changes that occurred during treatment for phonological disorders. Dodd and

Iacano recognized the following processes as non-developmental: initial consonant deletion, medial consonant deletion or substitutions (glottal replacement), insertion of extra consonant sounds, backing (fricatives, affricates, stops), denasalization, devoicing of stops, and sound preference substitutions. The Khan-Lewis Phonological Analysis (KLPA; Khan & Lewis, 1983) also lists initial consonant deletion, glottal replacement and backing as non-developmental processes. It is noteworthy that the three lists (Dodd & Iacano; Edwards & Shriberg; Khan & Lewis) are not identical. Table 2 highlights processes in each category that are agreed-upon among the three lists.

Normal Process Suppression

There are many studies available in the literature describing phonological process suppression in children with normal hearing using a wide range of methods, age groups, and designs (e.g., Grunwell, 1987; Roberts, Burchinal, & Footo, 1990; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). The focus of the majority of these studies was to gain a better understanding of normal phonological process use; thus, they did not track the suppression of processes that would be considered non-developmental. Stoel-Gammon and Dunn (1983) have suggested a division of processes into those suppressing before and after the age of 3 for normally developing children (as cited in Freiberg & Wicklund, 2003). Based on the results of Stoel-Gammon and Dunn's work, children show some individual variation in the patterns of suppression, but tend to cluster in their abilities around age 3. The processes of dimunization, reduplication, weak syllable deletion, fronting, consonant assimilation, final consonant deletion, and prevocalic voicing appear to become suppressed by age 3 years for a large majority of children whereas gliding,

Table 2. Categorization Agreements for Phonological Processes.

(Dodd & Iacano, 1989; Edwards & Shriberg, 1983; Khan & Lewis, 1983)

Developmental Processes	**Non-developmental Processes**
▪ Final consonant deletion	▪ Initial consonant deletion
▪ Cluster reduction	▪ Medial consonant deletion
▪ Weak syllable deletion	▪ Intrustive consonants
▪ Reduplication	▪ Backing (stops, fricatives, and affricates)
▪ Context sensitive voicing	▪ Medial consonant substitutions
▪ Depalatalization	▪ Denasalization
▪ Fronting (fricative and velar)	▪ Devoicing of stops
▪ Alveolarization (stop and fricative)	▪ Sound preference substitutions
▪ Labialization (stops)	▪ Deletion of unmarked cluster element (*story* /sori/)
▪ Stopping (fricatives and affricates)	▪ Glottal stop substitution (*happy* /hæʔi/)
▪ Gliding (fricatives and liquids)	▪ Final vowel addition (*shoe* /ʃuwə/)
▪ Deaffrication	
▪ Epenthesis	
▪ Metathesis	
▪ Sound migration	
▪ Vocalization	

stopping, vocalization, depalatalization, final consonant devoicing, cluster reduction, and epenthesis take longer to become fully suppressed.

Age estimates for suppression of some processes vary across studies; differences appear to have resulted from different interpretations and specificity of process definitions. For example, Roberts et al. (1990) described weak syllable deletion as a process that is suppressed quite early (around 2;6), whereas Grunwell (1987) and Smit et al. (1990) described this same process as one that persists, in some cases, past the age of 4 years. The age estimations developed by Grunwell (1987) and Smit et al. (1990) were based upon larger normative samples than the Roberts et al. (1990) study. A comparison of these studies also shows that there is disagreement in regards to specificity of process definitions; for example some studies refer to cluster reduction in general (Roberts et al., 1990; Grunwell, 1987), which would imply later suppression, and others refer to specific types of clusters, mostly separating out those involving 's' (Smit et al., 1990). When looking at cluster reduction from the more specific stance, it is estimated that children with normal hearing will suppress the reduction of non-'s' clusters before 's' clusters.

Phonological Process Use by Children with Hearing Impairment

Research has shown that children with hearing impairments who use hearing aids use both developmental and non-developmental phonological processes in their speech (see Tables 3 & 4). Relative to children with normal hearing, they tend to use both types of processes to a greater extent and for a longer period of time. In a descriptive study of phonological process use in hearing-impaired children, Meline (1997) found a significant relationship between hearing loss and phonological process use. The KLPA was used to

Table 3. Developmental Phonological Processes Reported to be used by Children with Hearing Impairment.

Study	final consonant deletion	cluster reduction	devoicing of stops	stopping	fronting	denasalization	liquid simplification	gliding
Hudgins & Numbers (1942)	●	●	●	●		●		●
Markides (1967)	●			●			●	
Smith (1975)	●		●	●			●	
Dodd (1976)		●	●	●	●	●	●	●
Oller, Jensen & Lafayette (1978)	●	●	●	●	●			●
Markides (1980)	●							
Stoel-Gammon (1983)	●			●		●		
Abraham (1989)	●	●		●			●	
Dodd & So (1994)	●	●		●	●			
Meline (1997)	●	●		●				●
Huttunen (2001)	●							

Table 4. Non-developmental Phonological Processes Reported to be used by Children with Hearing Impairment.

Study	initial consonant deletion	glottal stop substitutions	backing	vowel substitutions	vowel neutralization	simplifiaction of diphthongs
Hudgins & Numbers (1942)	●	●		●	●	●
Markides (1967)	●			●	●	●
Smith (1975)	●	●		●	●	●
Dodd (1976)	●		●			
Oller, Jensen & Lafayette (1978)	●		●			
Markides (1980)	●				●	●
Stoel-Gammon (1983)		●	●			
Abraham (1989)						
Dodd & So (1994)	●		●	●		
Meline (1997)	●	●	●			
Huttunen (2001)	●			●	●	

evaluate data recorded from the administration of the Goldman-Fristoe Test of Articulation. The KLPA requires a process to be used in at least 33% of obligatory contexts before it is considered to be in "use". Meline noted that seven processes were being used by the 19 elementary aged children with hearing impairments in this study including: final consonant deletion, cluster reduction, initial consonant deletion, gliding of liquids, backing to velars, stopping, and glottal replacement, with final consonant deletion being the most common by far (45% of errors). Children with a profound hearing loss persisted in the use of phonological processes, particularly final consonant deletion and cluster reduction, with a higher percentage of use than did children with moderate to severe losses. Stoel-Gammon (1983) also reported that young children using hearing aids used the non-developmental processes of glottal replacement, substitution of the palatal fricative /ʃ/ for the affricates /tʃ/ and /ʤ/, and backing in their speech. Chin and Pisoni (2000) reported the use of /ʃ/ as a substitution for several non-labial sounds including /s/, /t/, and /k/, which would suggest that this process was serving to neutralize several manner and place distinctions.

Phonological Process Use by Children with Cochlear Implants

Only two studies to date appear to have looked at process use in children with cochlear implants (Chin & Pisoni, 2000; Grogan et al., 1995). In a study that focused on phonological pattern use, Grogan et al. found that children with cochlear implants produced initial consonants with greater accuracy than those occurring in medial or final position. This more closely resembles the pattern observed in children with normal hearing than the near even distribution of initial and final consonant errors reported for children using hearing aids (Markides, 1983). Grogan et al. reported that the most commonly used phonological processes were deletion, voicing, stopping, and cluster reduction for consonants and elongation, nasalization, and monopthongization for vowels. The only process that reached a statistically significant level of suppression post-implantation (average of 2 years and 6 months implant use) was consonant deletion. These findings would suggest that phonological process use of children with cochlear implants more closely resembles that of younger normally hearing children than children using hearing aids. However, this conclusion should be taken with caution due to the small sample size (20 children) and lack of norm-referenced comparisons (data were analyzed using the Computer Aided Speech and Language Analysis software program which had been developed for another study). In the other study in this area, Chin and Pisoni (2000) also noted the use of context-sensitive voicing (initial voiceless stops became voiced before vowels), stopping, fronting, gliding of liquids, and the production of a voiceless alvelopalatal fricative /ʃ/ in place of several nonlabial sounds such as /s/, /k/, and /t/ in the speech of a prelingually deafened child with two years of implant experience.

Natural Process Analysis (NPA)

One method for analyzing phonological process use is Natural Process Analysis (NPA), which was developed by Shriberg and Kwiatkowski (1980). NPA was intended for clinical use in the assessment of children with delayed speech. It was also designed specifically for the analysis of continuous speech samples. Based upon the phonological literature available at the time and information regarding the reliability of phonological process transcription, the NPA method focuses on the following eight deletion and substitution processes: final consonant deletion, cluster reduction, unstressed syllable deletion, stopping, liquid simplification, velar fronting, palatal fronting, and assimilation. Without taking into account hearing ability, this analysis method presumes that children's phonological errors occur for one of two reasons: 1) the sound is not in the child's phonetic inventory or, 2) the sound is in the phonetic inventory, but some type of simplification process is required in order for the child to produce it.

Other methods of assessing phonological process use include the Assessment of Phonological Processes (APP; Hodson, 1980) which uses a predetermined set of single words and the Procedures for Phonological Analysis of Children's Language (PPACL) (Ingram, 1981), which, like NPA, uses a continuous speech sample. While NPA focuses on the eight processes mentioned above, both APP and PPACL include larger lists of processes. Overall, APP makes note of 42 processes and PPACL uses 27. In a comparison of these three methods, Paden and Moss (1985) found that all of these revealed the use of predominately the same phonological processes. However, the criterion level that would suggest remediation of the process in question varied somewhat across the three. NPA is somewhat vague in interpreting the results for this purpose since processes are only identified as being used "always", "sometimes", or "never". Obviously, a process that is productive all of the time would be targeted for remediation, but those falling into the "sometimes" category are questionable. On the other hand, APP requires that a process be used in at least 40% of the opportunities before it is viewed as a legitimate remediation target, whereas PPACL only sorts the process use into 0-20%, 21-49%, 50-79%, and 80-100% categories (leaving the decision as to when to remediate up to the person interpreting the results). It should also be noted that the most recent version of the APP, now the HAPP-3 (Hodson Assessment of Phonological Patterns, Third Edition; Hodson, 2004), analyzes the use of 28 processes (previously 42) and continues to use the 40% level of context use as the cutoff for a process to be considered in need of remediation.

Another study drew similar conclusions in comparing the use of Phonological Process Analysis (PPA; Weiner, 1979) and the Khan-Lewis Phonological Analysis (KLPA; Khan & Lewis, 1986) for the assessment of hearing impaired speech (Abraham, 1989). Although Abraham supported the use of such measures in assessing the speech of hearing impaired children, she pointed out that these two analysis tools yielded different results, mostly due to discrepancies between the categorization of the processes by the authors. Higgins and Carney (1996) have also questioned the use of measures developed for the normal hearing population when assessing the speech abilities of the hearing impaired. They suggested that hearing-impaired children could be using unique strategies in developing their phonological systems including misinterpretations of visual cues, over-generalized speech behaviors, and maladaptive ways of using kinesthetic feedback that would not be captured by the use of assessments developed for children with normal hearing abilities.

CHAPTER 3

METHOD

Participants

The six participants in the current study were hearing impaired children who had received their cochlear implants by 3 years of age. All were prelingually deafened and had severe to profound binaural hearing loss (90+ dB HL). They were recruited through the University of Tennessee's Child Hearing Services program. All were in an Aural-Oral communication program, with the goal of placement in mainstream educational environments with typically hearing peers. On average, the children received 2.5 hours of auditory habilitation therapy per week. At the time of initial data collection, these participants had 23-42 months of implant experience. More details regarding the participants can be found in Table 5.

Materials

As part of a previous study, conversational speech samples for each child were recorded in a sound-treated booth using a tabletop microphone connected to a SONY digital audiotape recorder sampling at 48 KHz. The samples were elicited using a variety of topics and materials, such as descriptions of daily routines, favorite people/pets/places, story telling, and free play with age-appropriate toys.

Procedures

Transcriptions of the 15-25 minute conversational speech samples collected for a previous study were analyzed using Natural Process Analysis (NPA) as defined by Shriberg and Kwiatkoski (1980). In total, 40 samples were collected and analyzed using

Table 5. Study Participants.

Participant	Gender	Age of ID	Implantation Age	Implant Type	Initial Testing Age	PPVT-III Scores
1	Female	0;6	2;4	Clarion	5;3	89
2	Female	0;0	2;6	Nucleus	4;5	99
3	Female	1;0	3;0	Clarion	6;2	72
4	Female	0;3	2;0	Nucleus	5;6	77
5	Female	1;3	2;7	Clarion	4;10	81
6	Male	0;11	1;3	Nucleus	3;9	76

the NPA output of an updated version of the Programs to Examine Phonetic and Phonologic Evaluation Records (PEPPER) software tool (Shriberg, Allen, McSweeny, & Wilson, 2001). A randomly chosen subset of the samples (20%) was also analyzed manually using the NPA approach by the author.

The samples were also analyzed for the use of phonological processes affecting both consonants and vowels not covered by NPA, many of which are cited frequently in analyses of hearing impaired speech; these included initial consonant deletion, glottal stop substitution, backing, vowel substitution, vowel neutralization, and simplification of diphthongs (Hudgins & Numbers, 1942; Meline, 1997; Smith, 1975; Stoel-Gammon, 1983). The matrix evaluation method put forth by Bauman-Waengler (2000) was used to record and analyze the individual sounds in words as well as any errors that occurred on the production attempt. This method is also similar to that employed by Tye-Murray and Kirk (1993) in their analysis of the vowel productions of children with hearing impairment. For the purpose of this study, a process was considered to be productive if it was used in at least 33% of obligatory contexts. This is similar to the method employed by the KLPA.

Data Analysis

Pearson correlations were used to determine the presence and strength of relationships between the use of each process and both chronological age and post-implantation age (i.e., amount of implant use). Each participant's use of the developmental processes was also compared to normative age ranges established by Roberts et al. (1990) through the use of z-scores. A cutoff Z-score of -1.5 was used to categorize the persistent use of a particular process past the age range suggested by the normative data. Finally, the individual sounds affected by the use of non-developmental processes were identified.

Reliability Testing

Although not a true measure of reliability, 20% (8) of the original transcripts were manually analyzed using a printed form of NPA. The original NPA method does not require analysis of all of the words in the transcript (as does the PEPPER output for NPA), however, it was necessary to do so in order to have a closer match with the PEPPER output. The correlation of percentages derived using these two methods (PEPPER vs. manual) for all processes combined was 0.994. Correlation values for individual processes appear in Appendix B.

The reliability of non-developmental process identification was established by reanalysis of 15% (6) of the original transcripts by another graduate student with training in transcription and speech sound disorders. Inter-judge reliability using point-to-point comparison was found to be 96% (95/99). When compared by overall percentage use, a Pearson correlation between the two result sets was found to be 0.996. Correlation values for individual processes appear in Appendix B.

CHAPTER 4

RESULTS

Developmental process use ranged from 0% to 100%, with the most commonly used process being initial stopping at an average of 36.82%. The least commonly used process was regressive assimilation, accounting for an average of only 0.14% of use. A complete listing of the descriptive statistics for non-developmental processes can be found in Table 6. Z-score comparisons for developmental processes ranged from +0.73 to –51.14 with initial stopping averaging at –18.958 (most common process falling below –1.5). Other processes falling below the -1.5 cut-off level included initial cluster reduction, final consonant deletion, initial liquid simplification, unstressed syllable deletion – 2 syllables, and unstressed syllable deletion – 3+ syllables. As with percentage use comparisons, regressive assimilation was never used at or below the –1.5 Z-score level.

Non-developmental process use ranged from 0% to 26.67%, with the most commonly used process being vowel substitution at an average of 2.37%. The least commonly used process was glottal stop substitution – initial, which did not appear in any of the 40 transcripts (0%). A complete listing of the descriptive statistics for non-developmental processes can be found in Table 7.

Suppression of Developmental Process Use

Using Pearson correlations, only initial cluster reduction and final liquid simplification were significantly correlated ($p<0.05$) with both chronological age and post-implantation age in a negative direction. As the children's age increased, the use of

Table 6. Descriptive Statistics for Developmental Process Use.*

Developmental Process	Minimum	Maximum	Mean	Standard Deviation
Regressive Assimilation	0.0000	0.8000	0.1350	0.2348
Progressive Assimilation	0.0000	1.1000	0.1075	0.2768
Cluster Reduction – Initial	0.0000	88.2000	36.3300	25.8000
Cluster Reduction-Final	0.0000	85.7000	32.1000	23.5000
Final Consonant Deletion	0.0000	34.2000	14.1300	9.8300
Liquid Simplification – Initial	0.0000	100.0000	17.7800	24.8000
Liquid Simplification – Final	0.0000	60.0000	12.7000	17.2100
Palatal Fronting – Initial	0.0000	10.0000	0.3500	1.6880
Palatal Fronting – Final	0.0000	12.5000	0.3130	1.9760
Stopping – Initial	0.0000	75.0000	36.8200	20.3000
Stopping-Final	0.0000	21.1000	1.8100	3.7850
Unstressed Syllable Deletion – 2 Syllables	0.0000	13.4000	2.7600	3.0140
Unstressed Syllable Deletion – 3+ Syllables	0.0000	66.7000	15.9900	17.6600
Velar Fronting – Initial	0.0000	92.3000	5.5400	18.4100
Velar Fronting – Final	0.0000	11.1000	0.5480	2.0950

*Values derived from NPA program.

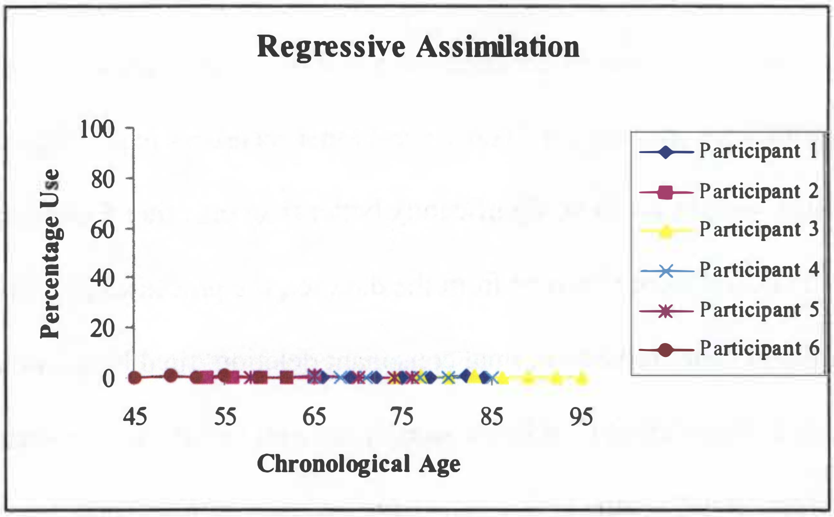
Table 7. Descriptive Statistics for Non-developmental Process Use.

Non-developmental Process	Minimum	Maximum	Mean	Standard Deviation
Initial Consonant Deletion	0.0000	18.4600	1.9540	3.0410
Glottal Stop Substitution – Initial	0.0000	0.0000	0.0000	0.0000
Glottal Stop Substitution – Medial	0.0000	26.6700	1.6220	4.8180
Glottal Stop Substitution – Final	0.0000	2.1500	0.1213	0.4133
Backing – Initial	0.0000	5.0000	0.8480	1.3300
Backing – Final	0.0000	7.1400	0.5670	1.4270
Vowel Substitution	0.0000	8.6200	2.3720	2.0010
Diphthong Simplification	0.0000	8.8900	1.2480	1.6560

these processes in their speech declined. As noted in a prior study (Colvard, 2002), one child's performance (participant 2) on several other measures (e.g., language, intelligibility) was shown to be significantly better than the other 5 children. When the results for this child were removed from the data set, the processes of initial cluster reduction, final cluster reduction, final consonant deletion, final liquid simplification, and unstressed syllable deletion (2 syllable words) were all significantly correlated in a negative direction with both chronological age and post-implantation age. Overall process use by chronological age can be seen in Figure 1. A complete listing of correlation values both with and without participant 2 appears in Appendix C. Overall, there was a great deal of variability in the percentage of individual process use throughout the data collection period, with the processes of initial cluster reduction, initial liquid simplification, and initial stopping still appearing above the level of 33% in obligatory contexts at the completion of the study.

Comparisons to Normative Data

Using a z-score comparison and the -1.5 standard deviation cut-off level, the processes of initial cluster reduction, final consonant deletion, initial liquid simplification, initial stopping, unstressed syllable deletion (2 syllables) and unstressed syllable deletion (3+ syllables) were found to be significantly higher than usage levels observed in children with normal hearing. There was a significant reduction in the number of samples with processes falling below the –1.5 level when compared by chronological age and post-implantation age which is evidenced in Table 8. Each participant's z-score comparison per process by chronological age appears in Appendix



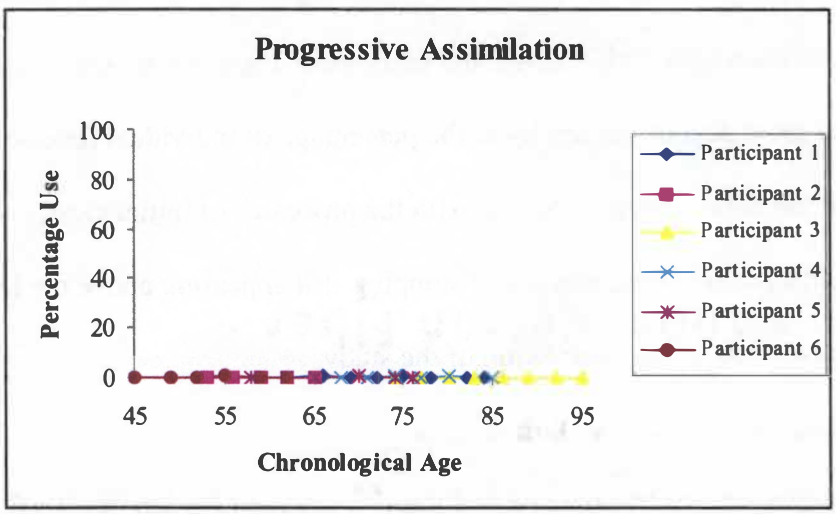
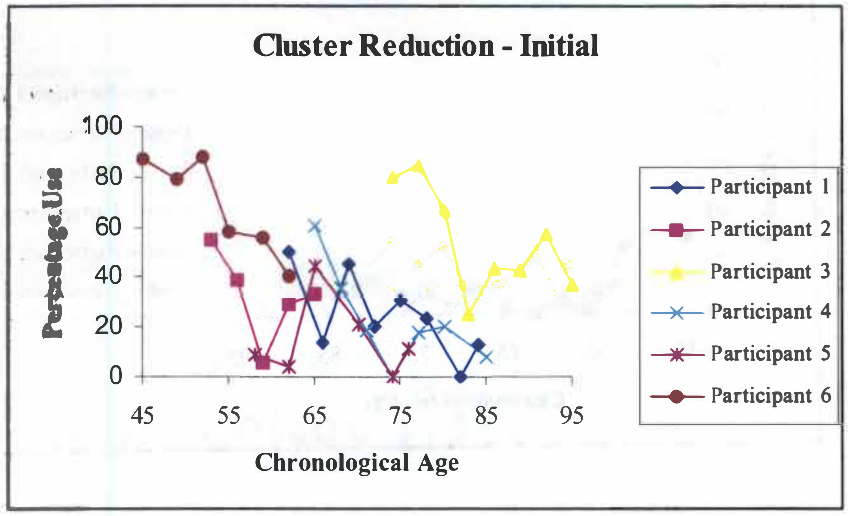


Figure 1. Developmental Process Use (All Samples).



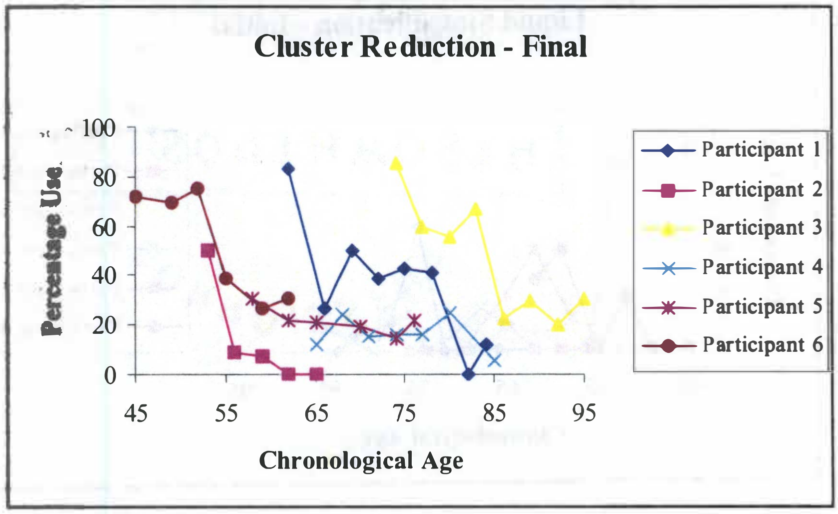
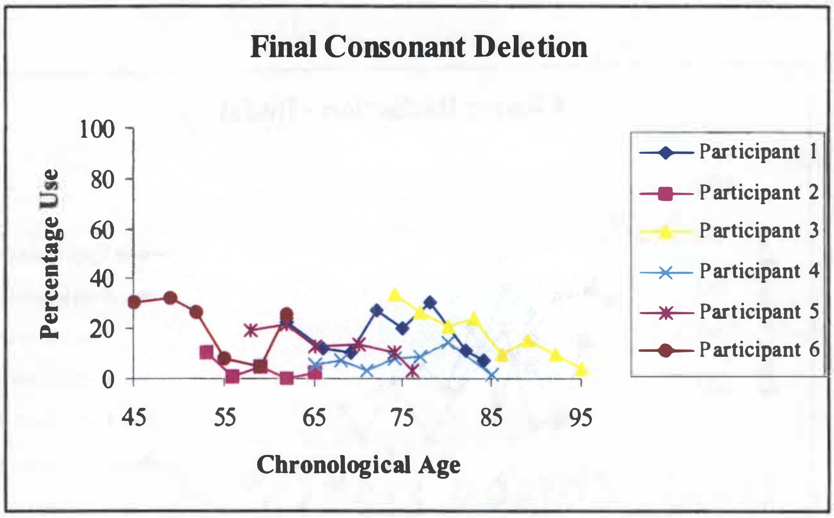
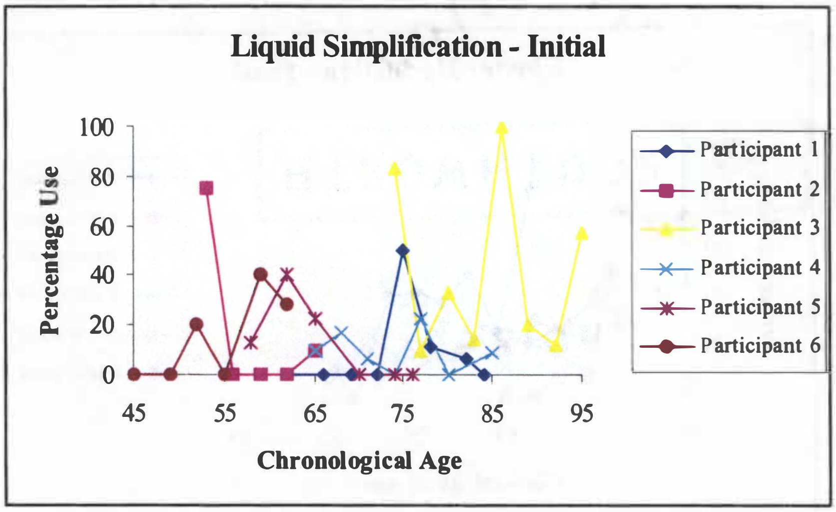


Figure 1. Continued.





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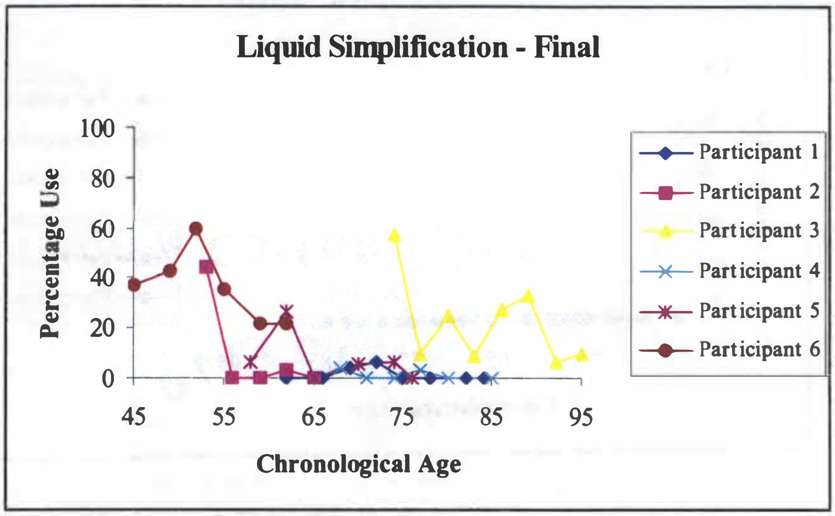

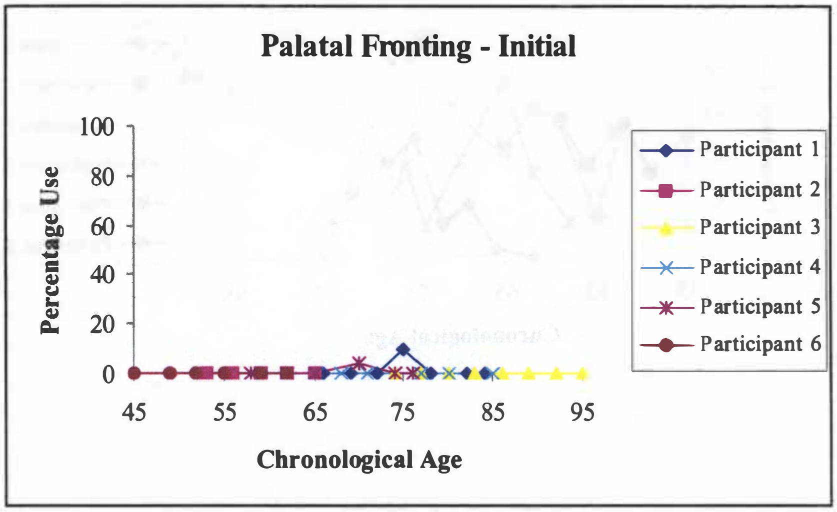

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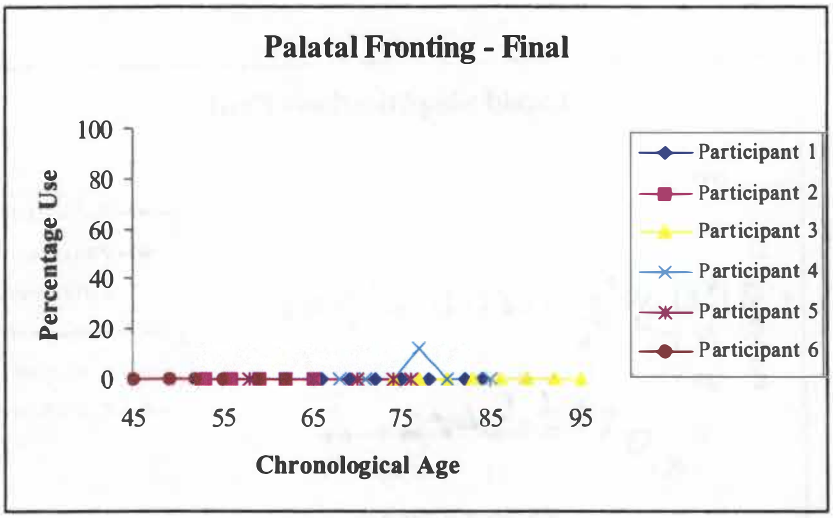

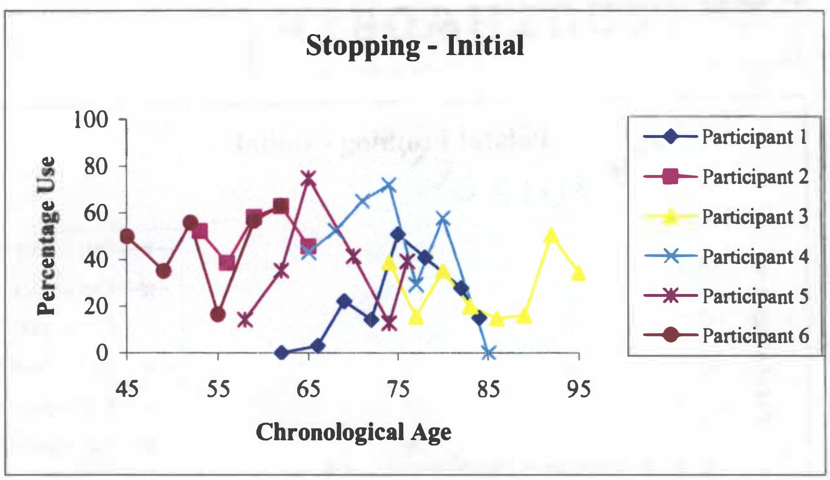

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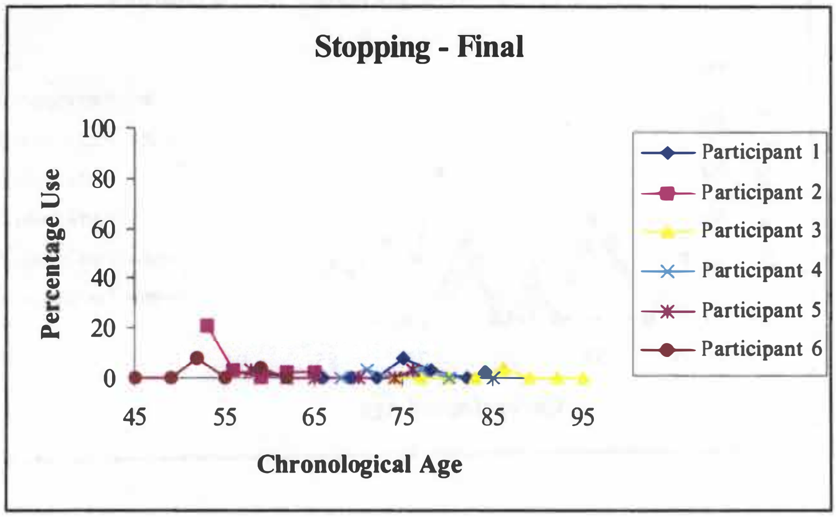

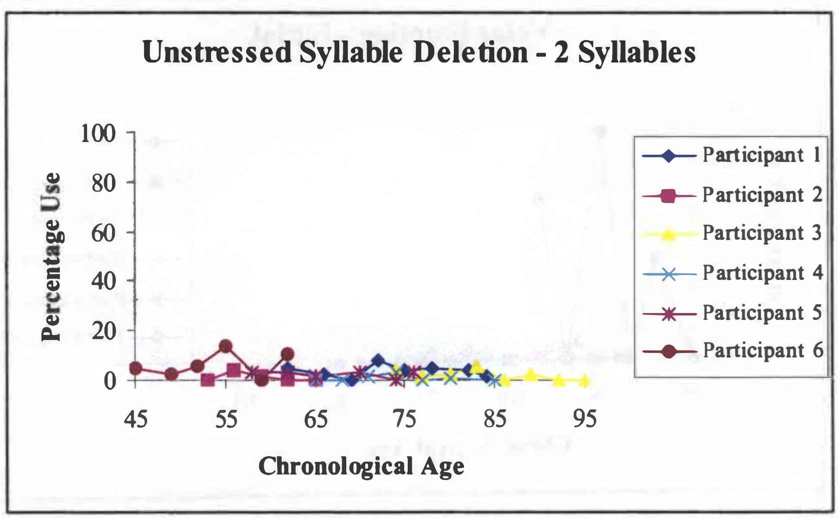

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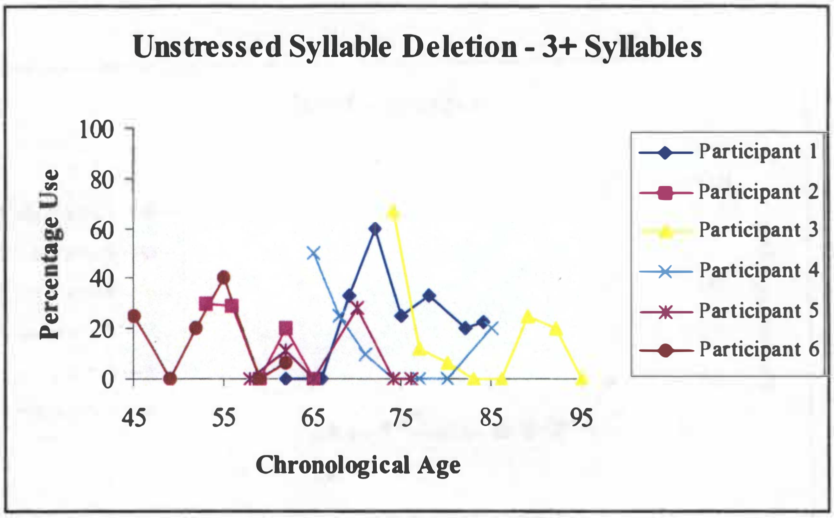

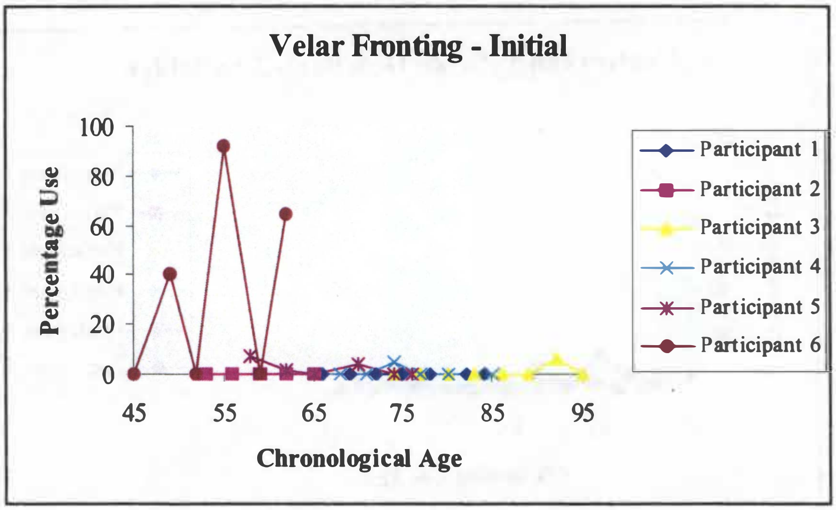

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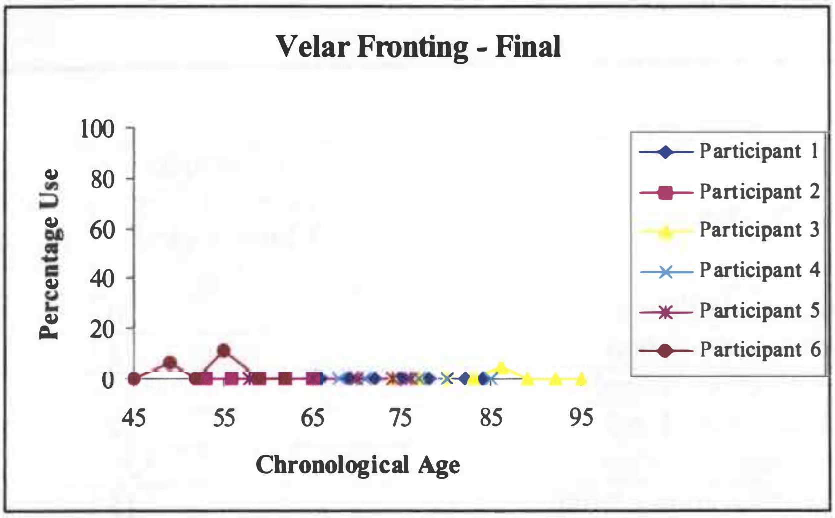


Figure 1. Continued.

Table 8. Samples Falling Below –1.5 Standard Deviation Level by Chronological Age and Post-implantation Age.

Phonological Process	# of Samples below –1.5 by Chronological Age	# of Samples below –1.5 by Post-implantation Age
Regressive Assimilation	0	0
Progressive Assimilation	1	1
Cluster Reduction - Initial	*22	6
Cluster Reduction - Final	17	3
Final Consonant Deletion	*25	16
Liquid Simplification - Initial	15	9
Liquid Simplification - Final	12	5
Palatal Fronting - Initial	1	0
Palatal Fronting - Final	1	1
Stopping - Initial	*37	*35
Stopping - Final	8	1
Unstressed Syllable Deletion - 2 Syllable	18	6
Unstressed Syllable Deletion - 3+ Syllable	*24	*23
Velar Fronting - Initial	4	2
Velar Fronting - Final	2	0

D. Each participant's z-score comparison per process by post-implantation age appears in Appendix E.

Suppression of Non-developmental Process Use

Using a Pearson correlation (and data for all six participants), initial consonant deletion and vowel substitution were significantly correlated ($p<0.05$) with both chronological age and post-implantation age in a negative direction. The use of glottal stop substitution in medial word position was significantly correlated with chronological age in a negative direction ($p<0.05$), but not with post-implantation age. When the data for participant 2 were removed from the analysis, these processes (initial consonant deletion, vowel substitution and medial glottal stop substitution) as well as simplification of diphthongs were significantly correlated ($p<0.05$) with both chronological age and post-implantation age in a negative direction. The groups' process use by chronological age can be seen in Figure 2. None of these processes were being used at the level of 33% in obligatory contexts during the data collection period.

Speech Sounds Affected by Non-Developmental Process Use

Consonants

The voiced inter-dental fricative /ð/accounted for 46.9% of initial consonant deletions and 28.6% of the instances of backing in initial position. This contrasts with its cognate /θ/, which only accounted for 3.6% of backing in initial position and 8.3% of backing in final position. Other notable speech sound observations included 83.3% of final glottal stop substitution affecting /k/ targets, 45% of medial glottal stop substitution affecting /ŋ/ targets, and 58.3% of final backing affecting /t/. The majority

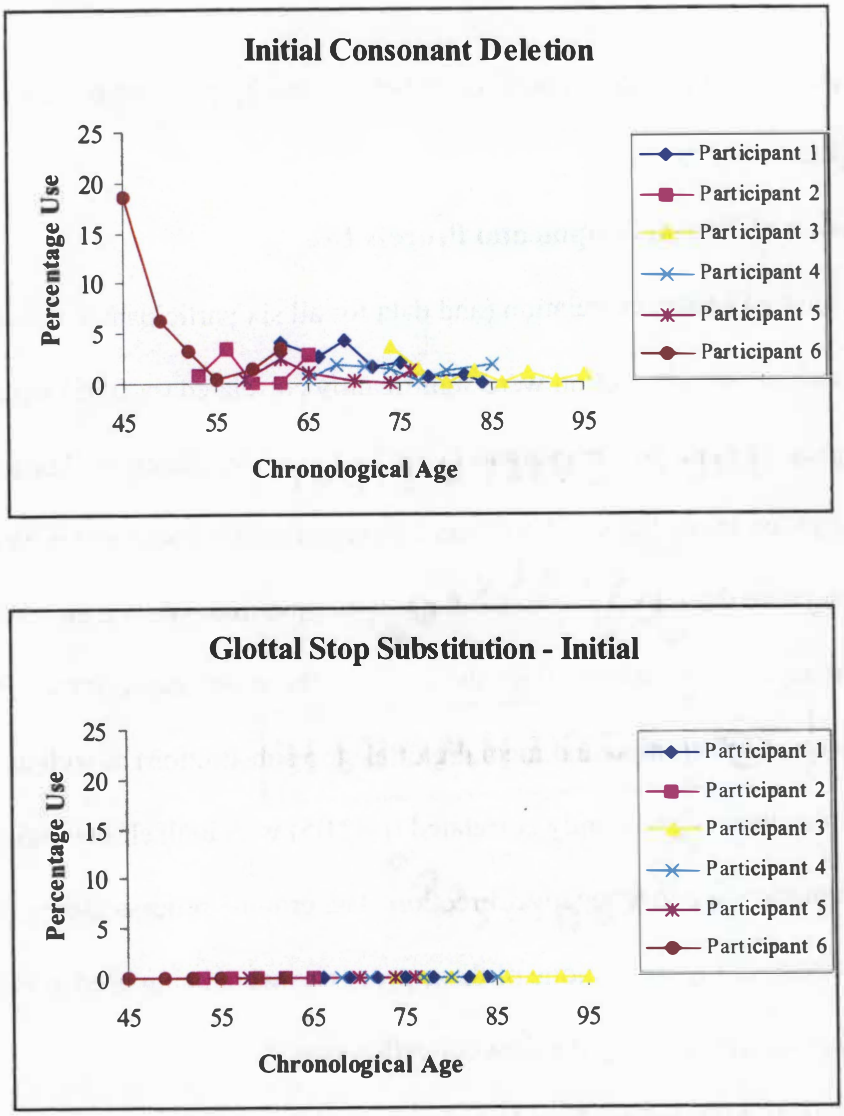
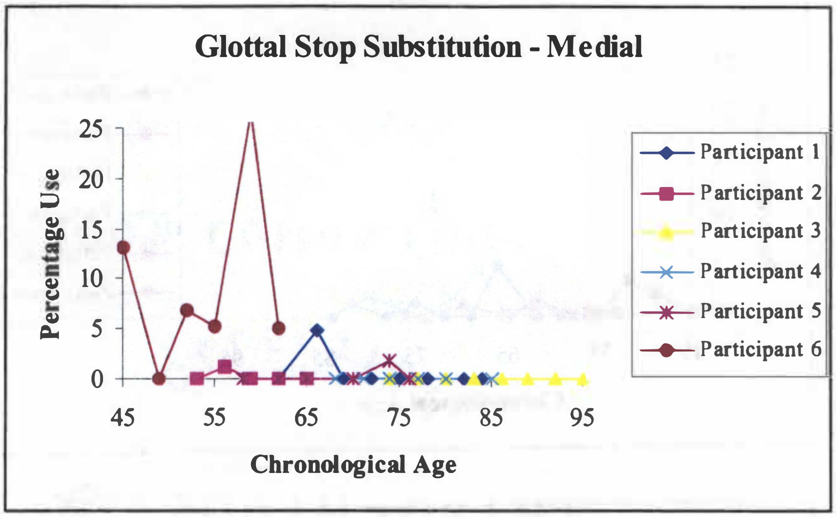
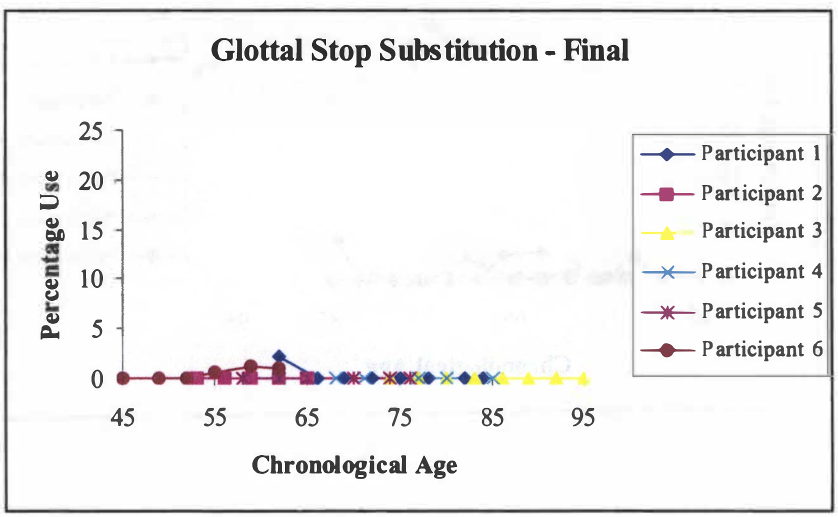


Figure 2. Non-developmental Process Use (All Samples).





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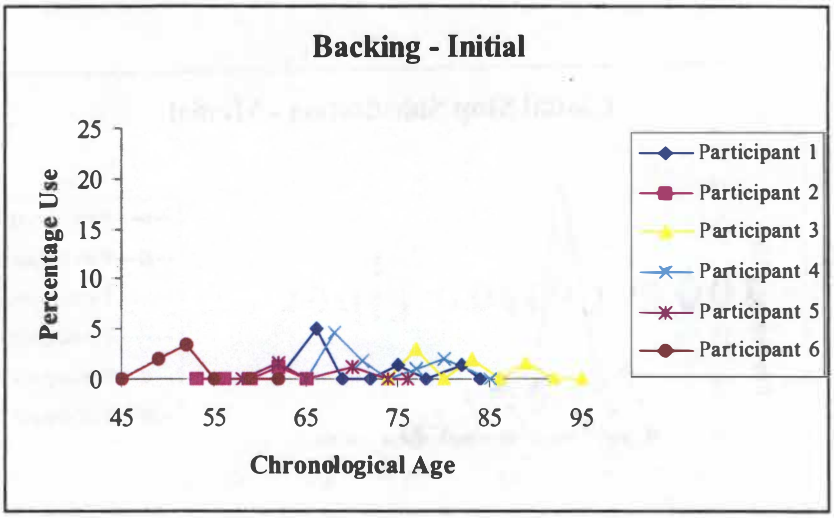

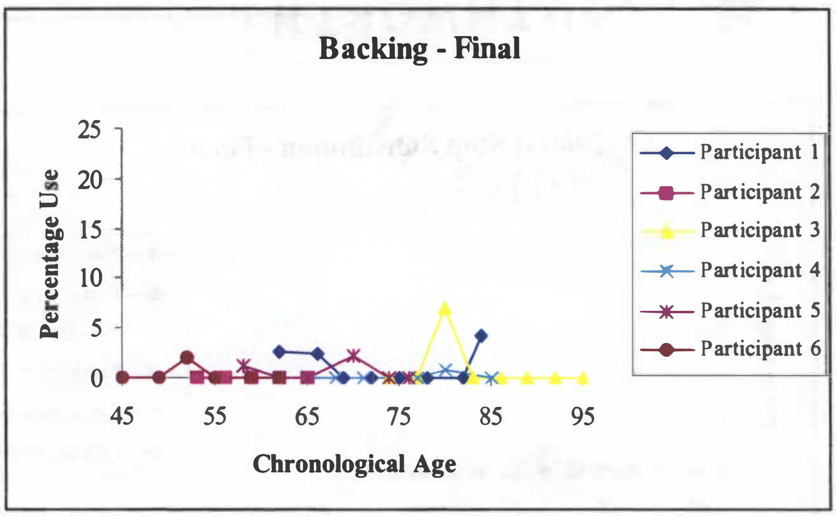

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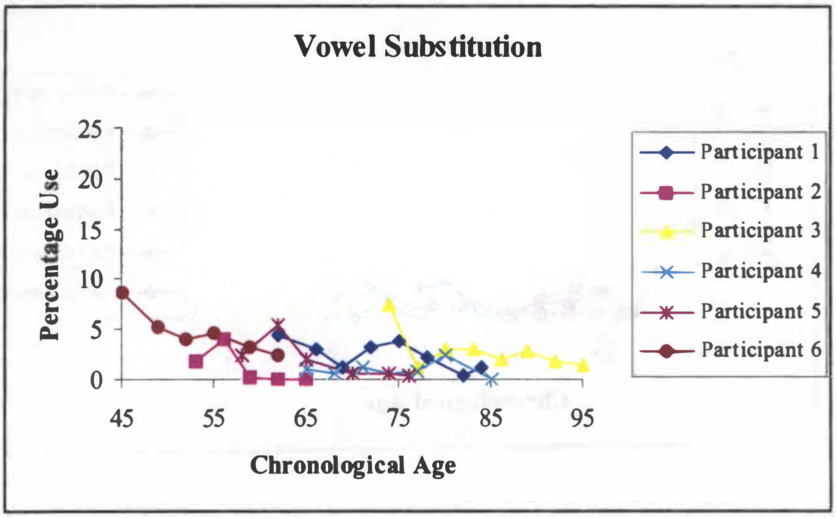

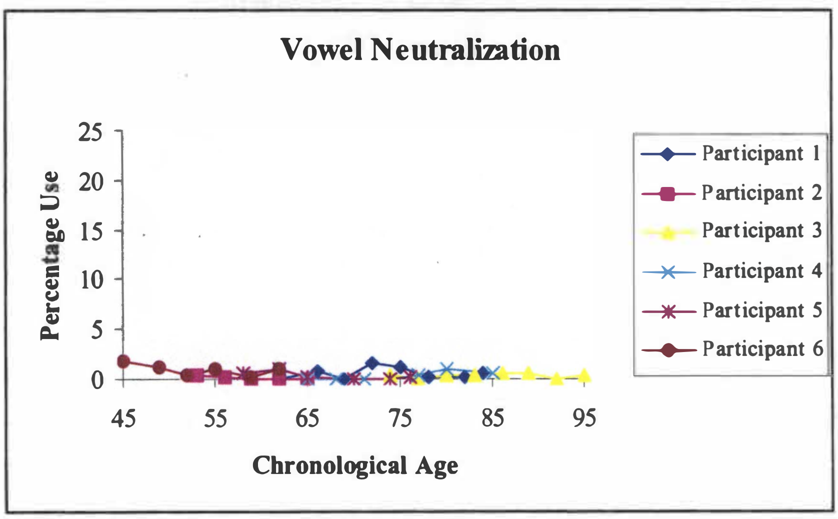

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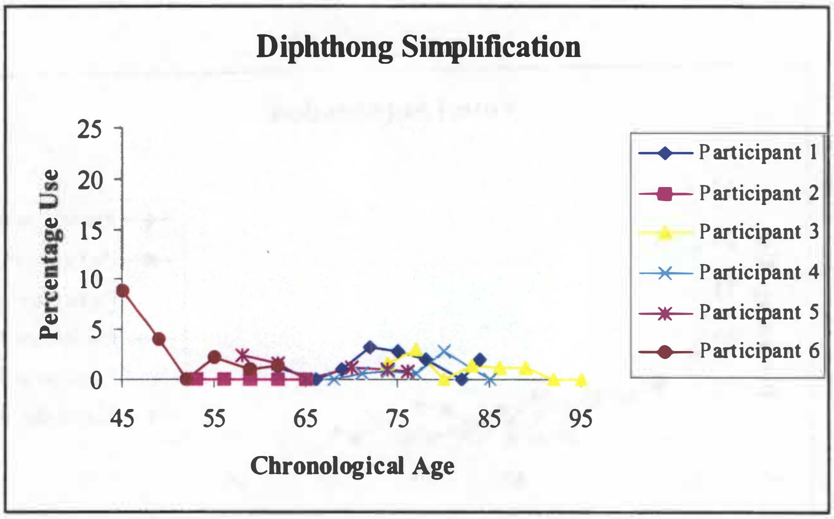

Figure 2. Continued.

of /ŋ/ substitutions occurred on the word "monkey", which was used frequently throughout the set of samples (the microphone in the testing booth was attached to a stuffed monkey). A complete listing of speech sounds affected by the selected non-developmental processes appears in Table 9. Although there was a low frequency of occurrence for backing in final position (12 instances), this process occurred in the transcripts of 5 of the 6 participants (1, 2, 4, 5, and 6), whereas glottal stop substitution in final position (6 instances) only appeared in the transcripts of 2 of the 6 participants (1 and 6).

Vowels

The predominance of vowel substitutions occurred on /ɚ/ (34.9%) and /ɝ/ (17.03%), typically resulting from substitution with /ʊ/. This type of substitution may be expected for these children considering that they are still within the age range for typical acquisition of the /r, ɚ, ɝ/ phonemes when adjusted for post-implantation age (Bauman- Waengler, 2000). When the analysis did not include these vowels, the vowel /ɪ/ accounted for 34.55% of vowel substitutions and 26.83% of vowel neutralizations. Also, the diphthongs /a͞ɪ/ and /e͞ɪ/ together accounted for 61.7% of diphthong simplifications, usually resulting from dropping of the /ɪ/ component.

Table 9. Speech Sounds Affected by Non-developmental Process Use.

Process	Speech Sound	Percentage of Process Instances
Initial Consonant Deletion		
	ð	46.94 (69/147)
	w	8.84 (13/147)
	r	7.48 (11/147)
	h	6.80 (10/147)
	g	6.80 (10/147)
	l	4.08 (6/147)
	k	3.40 (5/147)
	d	2.72 (4/147)
	m	2.72 (4/147)
	t	2.72 (4/147)
	b	2.72 (4/147)
	ʃ	2.04 (3/147)
	n	1.36 (2/147)
	j	0.68 (1/147)
	ʤ	0.68 (1/147)
Glottal Stop Substitution – Medial		
	ŋ	45.00 (9/20)
	k	40.00 (8/20)
	t	5.00 (1/20)
	l	5.00 (1/20)
	b	5.00 (1/20)
Glottal Stop Substitution - Final		
	k	83.33 (5/6)
	m	16.66 (1/6)
Backing – Initial		
	ð	28.57 (8/28)
	s	17.86 (5/28)
	t	17.86 (5/28)
	l	7.14 (2/28)
	b	7.14 (2/28)
	ʃ	7.14 (2/28)
	n	3.57 (1/28)
	r	3.57 (1/28)
	w	3.57 (1/28)
	θ	3.57 (1/28)
Backing – Final		
	t	58.33 (7/12)
	d	25.00 (3/12)
	θ	8.33 (1/12)
	m	8.33 (1/12)
Vowel Substitution		
	ɚ	34.93 (80/229)
	ɝ	17.03 (39/229)
	ɪ	16.59 (38/229)
	æ	8.30 (19/229)
	i	4.80 (11/229)
	ɑ	3.93 (9/229)
	ʌ	3.93 (9/229)
	ə	3.93 (9/229)
	ɛ	3.49 (8/229)
	u	2.62 (6/229)
	ʊ	0.44 (1/229)
Vowel Neutralization		
	ɪ	23.91 (11/46)
	o͡ʊ	19.57 (9/46)
	a͡ɪ	17.39 (8/46)
	ɑ	10.87 (5/46)
	ɝ	8.70 (4/46)
	e͡ɪ	6.52 (3/46)
	u	4.35 (2/46)
	ɔ	2.17 (1/46)
	ʊ	2.17 (1/46)
	æ	2.17 (1/46)
	ɚ	2.17 (1/46)
Diphthong Simplification		
	a͡ɪ	38.30 (18/47)
	e͡ɪ	23.40 (11/47)
	o͡ʊ	21.28 (10/47)
	a͡ʊ	12.77 (6/47)
	ɔ͡ɪ	4.26 (2/47)

CHAPTER 5

DISCUSSION

Similar to the studies of children with hearing impairments using hearing aids reviewed in Table 1, the results of the current study indicated that children who use cochlear implants make use of both developmental and non-developmental phonological processes. However, they did not appear to persist in the use of developmental processes to the same extent as children who use hearing aids. Unlike children with hearing aids, these children suppressed most developmental processes within the same amount of time expected for children with normal hearing. When compared to the process use by children with profound hearing losses using hearing aids by Meline (1997), children in the current study did not make consistent use of final consonant deletion. However, they did persist in the use of cluster reduction. Also in comparison to children using hearing aids, these children did not make productive use of /ʃ/ substitutions or backing in their speech (Chin & Pisoni, 2000; Stoel-Gammon, 1983).

In agreement with the findings of Grogan et al. (1995), which also examined phonological process use by children with cochlear implants, these children did make significant gains in the reduction of initial and final consonant deletion, stopping, and vowel-based process errors. However, the consistent use of voicing errors noted by both Grogan et al. (1995) and Chin and Pisoni (2000) was not seen in the current data. Also, /ʃ/ substitutions serving to neutralize several place and manner distinctions were not observed in these data (Chin & Pisoni, 2000). However, children in the current study did exhibit sound-specific patterns of process use, particularly affecting the sounds /ð, ŋ, k, s, t, ɹ/, with various substitutions occurring for each sound.

The first question in this study was whether the pattern of phonological suppression exhibited by these children was similar to children with normal hearing. Overall, the children in this study were no longer using processes (they were mostly suppressed) that are typically exhibited by younger children with normal hearing. The only developmental processes found to be significantly related to chronological age and post-implantation age (initial cluster reduction and final liquid simplification) are also later-suppressing in normal hearing children. However, there was a great deal of variation in individual process use among the 6 participants, resulting in very jagged downward trends of suppression. This too is similar to children with normal hearing, with studies of process use typically only providing overlapping age ranges or estimates of process suppression due to the high degree of variability across children. However, this inconsistency could have also resulted in the under-representation of some process use due to the small size of the data sample.

The second question raised in this study regarded the use of non-developmental phonological processes by children using cochlear implants when compared to children with normal hearing. All 40 samples in this data set exhibited some use of non-developmental processes that are uncommon in the speech of children with normal hearing. However, these processes are cited frequently in the HI literature. Like the hearing impaired children studied by Meline (1997) and Stoel-Gammon (1983), the children in this study made use of several non-developmental processes. However, they did not do so to the high degree that has been exhibited by children with profound hearing losses who use hearing aids. Like the developmental processes examined in this study, there also appeared to be heavier use of non-developmental processes affecting particular sounds including the following: /ð, ŋ, k, s, t, ɪ/. This would suggest that their hearing impairment (profoundly deaf in the unimplanted ear and typically within the mild-moderate loss range for the implanted ear) continues to have a significant impact on the production of certain sounds.

The use of non-developmental processes by the children in this group raises an interesting question regarding the definition of process "use". Should non-developmental processes be held to the same 33-50% cut-off percentages in order to determine productive use? This range could be considered acceptable if the errors appear to be more indicative of articulatory /phonetic problems. On the other hand, the use of these processes may have an even greater impact on overall speech intelligibility, which might suggest that they be addressed at a lower level of usage, perhaps using a norm-referenced comparison to determine productive use. A recent investigation by Flipsen, Hammer, and Yost (in press) has suggested that even experienced SLPs were more responsive (negatively) to atypical distortion errors when determining severity based upon speech samples in speech-delayed children with normal hearing.

Shriberg, Kent, Karlsson, McSweeny, Nadler & Brown (2003) have suggested that the use backing (a non-developmental process) could be used as a diagnostic marker for speech delay, with children having significant positive histories of otitis media with effusion (OME) making greater use of this particular process than other children with speech delay. Among sounds affected by OME in the speech of these children, stops and fricatives appeared to be the most susceptible to a backing process. They attributed the higher use of backing in this group to be most likely associated with the increased difficulty in the perception of acoustic cues due to the nature of the hearing loss associated with OME. Unlike the children in this study with OME, which results in a fluctuating mild-moderate conductive hearing loss, the children in the current study made little to no use of backing throughout the data collection period. Children using cochlear implants have a somewhat reversed pattern of hearing ability when compared to children with OME. Based upon the tonotopic organization of the cochlea and the CI device itself, high frequency areas of the cochlea receive increased electrode stimulation when compared to low frequency areas (Bess & Humes, 2003; Moore & Teagle, 2002). Thus, a speech sound delay associated with the use of a cochlear implant may need to be considered a separate category of organically based speech disorder.

The third question in this study involved the use of non-developmental vowel processes by these children when compared to other children with hearing impairment who use hearing aids. Every sample in the current data set included some use of vowel substitution, vowel neutralization, or diphthong simplification. Unlike the children in the current study, children with normal hearing would be expected to have mastered the vowel system with a similar amount of auditory exposure (Donegan, 2002). However, these errors have been shown to be quite prevalent in the speech of the hearing impaired, but with an increased level of use when compared to the current data set. In the current study, the use of all 3 of these vowel processes decreased over time, with vowel substitution showing the most reduction and vowel neutralization exhibiting the least change. This would suggest that the auditory exposure provided by the use of a unilateral cochlear implant is perhaps a better, but yet still insufficient, level of input for vowel acquisition comparable with normal hearing (i.e., these children do better than comparable children with hearing aids but not as well as those with normal hearing).

When compared to the data collected by Tye-Murray and Kirk (1993) and Ertmer (2001), the current data set provides evidence that /i/ will be mastered before /ɪ/ in this group. While the vowel /ɪ/ accounted for 34.6% of vowel substitutions and 26.8% of vowel neutralizations, /i/ only accounted for 5.38% and 12.5% respectively. Also, the diphthongs /a͡ɪ/ and /e͡ɪ/ together accounted for 61.7% of diphthong simplifications, usually resulting from dropping of the /ɪ/ (offglide) component.

Another interesting result of the current study revealed that the child who was identified at birth and subsequently implanted by age 2;6 in this data set (participant 2) had the highest PPVT-III score, the best intelligibility scores (Colvard, 2002), had the most consistent phonological process suppression when compared to the other participants. This child also had the least duration of implant use, which is in contrast to the results of Geers (2004). On the other hand, the child with the earliest implantation age (1;3) and slightly more implant experience (2;5 at the beginning of the data collection) exhibited the most phonological process use. This child was also the youngest in the study, which would be consistent with findings for children with normal hearing.

A hearing impairment affects the ability to hear one's own speech as well as that of others, regardless of any innate speech ability (Monsen, 1978). This is supported by the fact that there are shared characteristics among hearing impaired speakers across the world's languages. When a hearing impaired child imitates an incoming auditory signal that is perceived with distortion, it follows that it will be imitated with distortion. Thus, these children must be taught to produce sounds differently than they perceive them. However, technological advances in audiometry, such as the increasing sophistication and use of cochlear implants, have begun to 'close the gap' between the hearing and speech capabilities of individuals with significant hearing loss and the normal hearing population.

The results of the current study would suggest that the use of phonological processes and thus, the eventual suppression of them, in children using cochlear implants is most likely the result of a combination of innate and conditioned factors. Suppression appears to be innate due to the fact that the processes that appear most often in the speech of normal hearing children were also more predominant in the speech of these children than non-developmental processes. There was also some consistency in the time frame of process suppression. The children in this study were able to make gains in process suppression over a course of 3 ½ to 4 years of implant experience which is similar to findings that younger children with normal hearing also suppress most processes by approximately age 4 years (Grunwell, 1987; Hodson & Paden, 1981; Roberts et al., 1990). Suppression also appears to be conditioned (i.e., a function of abnormal input) due to the observation that children using cochlear implants made use of processes uncommon in the speech of children with normal hearing (i.e., non-developmental processes) and also that certain sounds appeared to be more heavily affected by process use than others by this group.

Clinical Implications

As suggested by Higgins and Carney (1996), current process-based assessment tools developed for children with normal hearing may not be sufficient to capture the full spectrum of speech behaviors exhibited by children using cochlear implants. These measures may tend to over-estimate the speech abilities of these children by disregarding non-developmental consonant and vowel process use, which may have a greater impact on overall speech intelligibility.

One solution that has been proposed for improving the speech assessment of children using cochlear implants is to adjust the age comparison used for normative values. Chin and Kaiser (2004) found that when adjusted for what they referred to as articulation age (the chronological age at which the number of errors on the Goldman-Fristoe Test of Articulation corresponded to the 50th percentile), children with cochlear implants were more accurately assessed using a tool developed for the normal hearing population. Without this type of adjustment, several of the children in their study (20 with cochlear implants), scored below the first percentile, which would make comparisons among them, as well as the measurement of longitudinal changes very difficult. It would be interesting to see if such adaptations to other assessment tools are also useful in evaluating this population.

Considering that all of these children were receiving aural habilitation therapy prior to and throughout this study, it is difficult to directly examine the effectiveness of intervention in the remediation of phonological processes. Considering the impact of process use compared to age-matched peers with normal hearing, it is likely that processed-based therapeutic approaches would be beneficial, particularly in the first few years post-implantation. However, the evidence that certain sounds are affected more heavily to process use than others would suggest that these children would benefit most from a combination of phonetic and process-based treatment. In addition, these data would suggest that vowels should be addressed early on due to their potential impact on overall intelligibility.

Conclusion

While children using cochlear implants appear to suppress developmental phonological processes at a rate similar to children with normal hearing, they also make limited use of non-developmental processes as is also seen in children with hearing impairments who use hearing aids. Thus, assessment tools and remediation methods intended for children with normal hearing abilities do not easily address process-based sound errors in the speech of these children. While most of these results would be consistent to the innate mechanism proposed by Stampe, Chomsky, Jakobson and Halle, there also appears to be a definite impact of hearing ability on process use.

Research thus far has tended to focus predominately on the speech perception, phonological processing abilities and phonetic inventory development of children with cochlear implants. Further research on this topic could investigate the effectiveness of process-based intervention methods in the first few years following implantation, perhaps using a sound-based strategy as the comparison group. The results of such a study could also be indicative of the amount of spontaneous suppression of processes that occurs following implantation.

Acoustic analysis of the speech of children with cochlear implants could also reveal both similarities and differences that even an experienced listener would not be able to perceive. As noted by Leonard (1985), listeners often fail to distinguish reliable acoustic differences that occur in speech. For instance, a listener may perceive a child's productions of two phonemes as being the same, when acoustic analysis reveals that the two are actually being produced differently with regularity. Revealing these acoustic differences would suggest that the child is in fact making a distinction between the two sounds, just not yet at a perceivable level. There has been some evidence to suggest that children receiving cochlear implants before their fourth birthday exhibit greater control over their speech when measured acoustically (F1:F2 ratio) than those who are implanted at a later age (Seifert, Oswald, Bruns, Vischer, Kompis &Haeusler, 2002). Horga and Liker (2005) have also shown that children with cochlear implants exhibit improved acoustic accuracy when compared to profoundly deaf children using hearing aids.

Knowledge of process use in the implanted population would also benefit from pre- and post- implantation comparisons of process use. Earlier data collection post-implantation would likely capture the pattern of suppression for early processes. Also, comparisons using a larger sample with matching could help to determine the influence of other factors such as implant type, side of implantation, and gender on process use.

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APPENDICES

Appendix A

Phonological Process Descriptions

(Sources: Bauman-Waengler, 2000; Edwards & Shriberg, 1983; Grunwell, 1987; Ingram, 1989)

Syllable Structure Processes

1. weak syllable deletion – omission of one or more unstressed syllables in a word, typically the one falling before a stressed syllable; *banana* [nɑnə]
2. initial consonant deletion – omission of a consonant in word-initial position; *gun* [ʌn]
3. final consonant deletion – omission of a consonant in word-final position; *juice* [du]
4. reduplication – repetition of the first syllable to constitute subsequent syllables, may be the whole syllable (complete) or just one constituent (consonant or vowel) (partial); *bottle* [bɑbɑ], *blanket* [bɑbə]
5. cluster reduction – simplification of a consonant cluster, typically resulting in the deletion of the cluster, followed by deletion of only the marked member, then substitution of the marked member, eventually resolving to the correct form; *truck* [ʌk]->[tʌk]->[twʌk]->[trʌk]
6. epenthesis – a sound segment is inserted into the medial portion of the word, typically, [ə] is inserted between two elements of a cluster; *blue* [bəlu]
7. metathesis – two sounds in a word are reversed; *most* [mots]
8. sound migration – one sound moves to another position in the word; *snake* [neɪks]

Assimilatory Processes (Consonant Harmony; Vowel Harmony)

Regressive – the affected sound comes before the one that is influencing it
Progressive – the affected sound comes after the one that is influencing it

1. Velar- sounds preceding or following a velar, typically alveolars, will be substituted with a velar (but only in that context – the sound is produced correctly in other contexts); *dog* [gɑg] BUT *door* [dɔ] (if no assimilatory evidence is present, this error would be described as a substitution process)
2. Labial – nonlabial produced as labial in the presence of another labial; *swing* [fwɪŋ]
3. Nasal – nonnasal produced as a nasal in the presence of another nasal; *bunny* [mʌni]
4. Liquid - nonliquid produced as a liquid in the presence of another liquid; *yellow* [lɛlo]
5. Vowel – consonants can assimilate to the vowel's place of articulation; *puddle* [pʌgu]

Substitution Processes

1. affrication – substitution of fricatives with homorganic affricates; *shoe* [tʃu]
2. alveolarization – interdental or labial sounds produced as alveolars; *bath* [bɑs]
3. backing - substitution of the sound with a more back place of articulation, typically palatals and alveolars are replaced by velars; *tea* [ki]
4. context sensitive voicing – production of a voiced or voiceless consonant in place of its counterpart, typically applies to the devoicing of stops in word final position, said to be assimilating to the silence that follows; *nose* [nos] and voicing of consonants preceding vowels (prevocalic voicing); *pig* [bɪg]
5. deaffrication - substitution of an affricate with either a homorganic fricative or stop; *cheese* [ʃiz]
6. denasalization - substitution of a nasal sound with a non-nasal sound, typically a homorganic stop; *room* [rub]
7. depalatalization – fronting of palatal sounds, usually resulting in the production of alveolars; *shoe* [su]
8. frication (gliding of fricatives) – substitution of a sound with a fricative; *yard* [zɑrd]
9. fronting – substitution of the sound with a more forward place of articulation, typically palatals and velars are replaced by alveolars; *key* [ti]
10. gliding – substitution of a consonant with a glide; *foot* [wʊt]
11. glottal replacement – substitution of a consonant in intervocalic or final position with a glottal stop [ʔ]; *bed* [bɛʔ]
12. liquid simplification – substitution of a liquid with a glide; *ride* [wa͞ɪd]
13. sound preference substitution – replacement of a consonant by another preferred consonant; all fricatives → [d] or [n]
14. stopping - substitution of the sound with a homorganic stop, typically affects fricatives and affricates; *this* [dɪt] (initial and final position affected)
15. vocalization (vowelization) – substitution of a consonant with a vowel, typically affects syllabic liquids and nasals; *flower* [fɑwɑ], *bottom* [bɑwɑ]

Vowel Processes

1. substitution – replacement of the targeted vowel with another vowel varying in tongue height or position; [ʊ]→[i]
2. neutralization (centralization) - a front or back vowel is replaced by a central vowel, typically /ʌ/ or /ə/; [ɪ]→[ə]
3. monophthongization (diphthong simplification) – a diphthong is produced as a monophthong, typically with the second member of the diphthong being deleted; [a͡ɪ]→[a]
4. diphthongization – a monophthong is produced as a diphthong; [ɑ]→ [ɔ͡ɪ]

Appendix B

NPA Reliability Correlations*

NPA Process	Pearson Correlation
Final Consonant Deletion	0.998
Stopping	0.998
Velar Fronting	1
Palatal Fronting	1
Liquid Simplification	0.992
Progressive Assimilation	1
Regressive Assimilation	1
Cluster Reduction	0.985
Unstressed Syllable Deletion – 2 Syllables	0.956
Unstressed Syllable Deletion – 3+ Syllables	0.998
ALL PROCESSES	0.994

Inter-Judge Reliability Correlations*

Non-developmental Process	Pearson Correlation
Initial Consonant Deletion	0.996
Glottal Stop Substitution-Initial	1
Glottal Stop Substitution-Medial	1
Glottal Stop Substitution-Final	1
Backing-Initial	1
Backing-Final	1
Vowel Substitution	0.996
Vowel Neutralization	0.942
Diphthong Simplification	1
ALL PROCESSES	0.996

* all $p < .05$

Appendix C

Natural Process Analysis (NPA) Correlations

Correlation by Chronological Age (All Participants)

Process	Correlation	P-Value
Regressive Assimilation	-0.020	0.903
Progressive Assimilation	-0.027	0.869
Cluster Reduction – Initial	*-0.321	0.044
Cluster Reduction – Final	-0.243	0.130
Final Consonant Deletion	-0.179	0.270
Liquid Simplification – Initial	0.185	0.254
Liquid Simplification – Final	*-0.347	0.028
Palatal Fronting – Initial	0.060	0.714
Palatal Fronting – Final	0.091	0.575
Stopping – Initial	-0.269	0.094
Stopping – Final	-0.251	0.118
Unstressed Syllable Deletion – 2 Syllable	-0.288	0.071
Unstressed Syllable Deletion – 3+ Syllable	-0.063	0.698
Velar Fronting – Initial	-0.310	0.051
Velar Fronting – Final	-0.231	0.151

* $p < .05$

Correlation by Post-Implantation Age (All Participants)

Process	Correlation	P-Value
Regressive Assimilation	0.031	0.850
Progressive Assimilation	0.053	0.744
Cluster Reduction – Initial	*-0.326	0.040
Cluster Reduction – Final	-0.289	0.071
Final Consonant Deletion	-0.219	0.174
Liquid Simplification – Initial	0.042	0.798
Liquid Simplification – Final	*-0.367	0.020
Palatal Fronting – Initial	0.055	0.737
Palatal Fronting – Final	0.189	0.243
Stopping – Initial	-0.177	0.276
Stopping – Final	-0.278	0.083
Unstressed Syllable Deletion – 2 Syllable	-0.212	0.190
Unstressed Syllable Deletion – 3+ Syllable	-0.057	0.728
Velar Fronting – Initial	-0.169	0.296
Velar Fronting – Final	-0.144	0.374

* $p < .05$

Correlation by Chronological Age (Without Participant 2)

Process	Correlation	P-Value
Regressive Assimilation	-0.107	0.54
Progressive Assimilation	-0.086	0.622
Cluster Reduction – Initial	*-0.365	0.031
Cluster Reduction – Final	*-0.382	0.023
Final Consonant Deletion	*-0.368	0.03
Liquid Simplification – Initial	0.254	0.141
Liquid Simplification – Final	*-0.395	0.019
Palatal Fronting – Initial	0.035	0.844
Palatal Fronting – Final	0.076	0.666
Stopping – Initial	-0.199	0.253
Stopping – Final	-0.083	0.637
Unstressed Syllable Deletion – 2 Syllable	*-0.396	0.018
Unstressed Syllable Deletion – 3+ Syllable	-0.044	0.801
Velar Fronting – Initial	*-0.381	0.024
Velar Fronting – Final	-0.289	0.093

* $p < .05$

Correlation by Post-Implantation Age (Without Participant 2)

Process	Correlation	P-Value
Regressive Assimilation	-0.082	0.638
Progressive Assimilation	-0.017	0.921
Cluster Reduction – Initial	*-0.396	0.019
Cluster Reduction – Final	*-0.493	0.003
Final Consonant Deletion	*-0.493	0.003
Liquid Simplification – Initial	0.103	0.556
Liquid Simplification – Final	*-0.44	0.008
Palatal Fronting – Initial	0.021	0.904
Palatal Fronting – Final	0.185	0.288
Stopping – Initial	-0.064	0.714
Stopping – Final	-0.003	0.987
Unstressed Syllable Deletion – 2 Syllable	*-0.355	0.036
Unstressed Syllable Deletion – 3+ Syllable	-0.031	0.858
Velar Fronting – Initial	-0.256	0.138
Velar Fronting – Final	-0.219	0.206

* $p < .05$

Appendix D

Table 10. Z-Score Comparisons by Chronological Age: Participant 1.

Participant 1	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Regressive Assimilation				
Sample 1 (CA=62; PIA=34)	0.1	0	0.6	0.167
Sample 2 (CA=66; PIA=38)	0.1	0	0.6	0.167
Sample 3 (CA=69; PIA=41)	0.1	0	0.6	0.167
Sample 4 (CA=72; PIA=44)	0	0	0	0.000
Sample 5 (CA=75; PIA=47)	0	0	0	0.000
Sample 6 (CA=78; PIA=50)	0	0	0	0.000
Sample 7 (CA=82; PIA=53)	0	0.5	0	0.000
Sample 8 (CA=84; PIA=56)	0	0	0	0.000
Progressive Assimilation				
Sample 1 (CA=62; PIA=34)	0.1	0	0.6	0.167
Sample 2 (CA=66; PIA=38)	0.1	1.1	0.6	-1.667
Sample 3 (CA=69; PIA=41)	0.1	0	0.6	0.167
Sample 4 (CA=72; PIA=44)	0	0	0	0.000
Sample 5 (CA=75; PIA=47)	0	1	0	0.000
Sample 6 (CA=78; PIA=50)	0	0	0	0.000
Sample 7 (CA=82; PIA=53)	0	0	0	0.000
Sample 8 (CA=84; PIA=56)	0	0	0	0.000
Cluster Reduction - Initial				
Sample 1 (CA=62; PIA=34)	9.7	50	15.6	-2.583
Sample 2 (CA=66; PIA=38)	9.7	13.6	15.6	-0.250
Sample 3 (CA=69; PIA=41)	9.7	45.5	15.6	-2.295
Sample 4 (CA=72; PIA=44)	6.5	20	12.1	-1.116
Sample 5 (CA=75; PIA=47)	6.5	30.8	12.1	-2.008
Sample 6 (CA=78; PIA=50)	6.5	23.1	12.1	-1.372
Sample 7 (CA=82; PIA=53)	6.5	0	12.1	0.537
Sample 8 (CA=84; PIA=56)	2.8	13.3	8	-1.313
Cluster Reduction - Final				
Sample 1 (CA=62; PIA=34)	9.7	83.3	15.6	-4.718
Sample 2 (CA=66; PIA=38)	9.7	26.7	15.6	-1.090
Sample 3 (CA=69; PIA=41)	9.7	50	15.6	-2.583
Sample 4 (CA=72; PIA=44)	6.5	38.9	12.1	-2.678
Sample 5 (CA=75; PIA=47)	6.5	42.9	12.1	-3.008
Sample 6 (CA=78; PIA=50)	6.5	40.9	12.1	-2.843
Sample 7 (CA=82; PIA=53)	6.5	0	12.1	0.537
Sample 8 (CA=84; PIA=56)	2.8	12.5	8	-1.213
Final Consonant Deletion				
Sample 1 (CA=62; PIA=34)	2.4	22.2	3.3	-6.000
Sample 2 (CA=66; PIA=38)	2.4	11.7	3.3	-2.818

Table 10. Continued.

Participant 1	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 3 (CA=69; PIA=41)	2.4	10.4	3.3	-2.424
Sample 4 (CA=72; PIA=44)	2.7	27.4	5.2	-4.750
Sample 5 (CA=75; PIA=47)	2.7	20	5.2	-3.327
Sample 6 (CA=78; PIA=50)	2.7	30.4	5.2	-5.327
Sample 7 (CA=82; PIA=53)	2.7	11.3	5.2	-1.654
Sample 8 (CA=84; PIA=56)	1.1	7.3	2.9	-2.138
Liquid Simplification - Initial				
Sample 1 (CA=62; PIA=34)	4.5	0	8.7	0.517
Sample 2 (CA=66; PIA=38)	4.5	0	8.7	0.517
Sample 3 (CA=69; PIA=41)	4.5	0	8.7	0.517
Sample 4 (CA=72; PIA=44)	2.7	0	7.6	0.355
Sample 5 (CA=75; PIA=47)	2.7	50	7.6	-6.224
Sample 6 (CA=78; PIA=50)	2.7	11.1	7.6	-1.105
Sample 7 (CA=82; PIA=53)	2.7	6.7	7.6	-0.526
Sample 8 (CA=84; PIA=56)	1.4	0	5.9	0.237
Liquid Simplification - Final				
Sample 1 (CA=62; PIA=34)	4.5	0	8.7	0.517
Sample 2 (CA=66; PIA=38)	4.5	0	8.7	0.517
Sample 3 (CA=69; PIA=41)	4.5	4.3	8.7	0.023
Sample 4 (CA=72; PIA=44)	2.7	6.3	7.6	-0.474
Sample 5 (CA=75; PIA=47)	2.7	0	7.6	0.355
Sample 6 (CA=78; PIA=50)	2.7	0	7.6	0.355
Sample 7 (CA=82; PIA=53)	2.7	0	7.6	0.355
Sample 8 (CA=84; PIA=56)	1.4	0	5.9	0.237
Palatal Fronting - Initial				
Sample 1 (CA=62; PIA=34)	1.6	0	4.4	0.364
Sample 2 (CA=66; PIA=38)	1.6	0	4.4	0.364
Sample 3 (CA=69; PIA=41)	1.6	0	4.4	0.364
Sample 4 (CA=72; PIA=44)	1.2	0	2.9	0.414
Sample 5 (CA=75; PIA=47)	1.2	10	2.9	-3.034
Sample 6 (CA=78; PIA=50)	1.2	0	2.9	0.414
Sample 7 (CA=82; PIA=53)	1.2	0	2.9	0.414
Sample 8 (CA=84; PIA=56)	0.1	0	0.7	0.143
Palatal Fronting - Final				
Sample 1 (CA=62; PIA=34)	1.6	0	4.4	0.364
Sample 2 (CA=66; PIA=38)	1.6	0	4.4	0.364
Sample 3 (CA=69; PIA=41)	1.6	0	4.4	0.364
Sample 4 (CA=72; PIA=44)	1.2	0	2.9	0.414
Sample 5 (CA=75; PIA=47)	1.2	0	2.9	0.414
Sample 6 (CA=78; PIA=50)	1.2	0	2.9	0.414
Sample 7 (CA=82; PIA=53)	1.2	0	2.9	0.414
Sample 8 (CA=84; PIA=56)	0.1	0	0.7	0.143
Stopping - Initial				
Sample 1 (CA=62; PIA=34)	0.8	0	1.9	0.421

Table 10. Continued.

Participant 1	Group Mean	Subject %	Group SD	Z-Score
Sample 2 (CA=66; PIA=38)	0.8	3	1.9	-1.158
Sample 3 (CA=69; PIA=41)	0.8	22.2	1.9	-11.263
Sample 4 (CA=72; PIA=44)	0.5	14.3	1.4	-9.857
Sample 5 (CA=75; PIA=47)	0.5	50.9	1.4	-36.000
Sample 6 (CA=78; PIA=50)	0.5	40.9	1.4	-28.857
Sample 7 (CA=82; PIA=53)	0.5	27.8	1.4	-19.500
Sample 8 (CA=84; PIA=56)	0.2	15.1	0.7	-21.286
Stopping - Final				
Sample 1 (CA=62; PIA=34)	0.8	0	1.9	0.421
Sample 2 (CA=66; PIA=38)	0.8	0	1.9	0.421
Sample 3 (CA=69; PIA=41)	0.8	0	1.9	0.421
Sample 4 (CA=72; PIA=44)	0.5	0	1.4	0.357
Sample 5 (CA=75; PIA=47)	0.5	8.3	1.4	-5.571
Sample 6 (CA=78; PIA=50)	0.5	3.6	1.4	-2.214
Sample 7 (CA=82; PIA=53)	0.5	0	1.4	0.357
Sample 8 (CA=84; PIA=56)	0.2	2.6	0.7	-3.429
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=62; PIA=34)	0.5	4.9	1.5	-2.933
Sample 2 (CA=66; PIA=38)	0.5	2.4	1.5	-1.267
Sample 3 (CA=69; PIA=41)	0.5	0	1.5	0.333
Sample 4 (CA=72; PIA=44)	0.3	7.9	1.1	-6.909
Sample 5 (CA=75; PIA=47)	0.3	4.2	1.1	-3.545
Sample 6 (CA=78; PIA=50)	0.3	4.5	1.1	-3.818
Sample 7 (CA=82; PIA=53)	0.3	4.2	1.1	-3.545
Sample 8 (CA=84; PIA=56)	0.3	1.9	1.1	-1.455
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=62; PIA=34)	0.5	0	1.5	0.333
Sample 2 (CA=66; PIA=38)	0.5	0	1.5	0.333
Sample 3 (CA=69; PIA=41)	0.5	33.3	1.5	-21.867
Sample 4 (CA=72; PIA=44)	0.3	60	1.1	-54.273
Sample 5 (CA=75; PIA=47)	0.3	25	1.1	-22.455
Sample 6 (CA=78; PIA=50)	0.3	33.3	1.1	-30.000
Sample 7 (CA=82; PIA=53)	0.3	20	1.1	-17.909
Sample 8 (CA=84; PIA=56)	0.3	22.2	1.1	-19.909
Velar Fronting - Initial				
Sample 1 (CA=62; PIA=34)	1.6	0	4.4	0.364
Sample 2 (CA=66; PIA=38)	1.6	0	4.4	0.364
Sample 3 (CA=69; PIA=41)	1.6	0	4.4	0.364
Sample 4 (CA=72; PIA=44)	1.2	0	2.9	0.414
Sample 5 (CA=75; PIA=47)	1.2	0	2.9	0.414
Sample 6 (CA=78; PIA=50)	1.2	0	2.9	0.414
Sample 7 (CA=82; PIA=53)	1.2	0	2.9	0.414
Sample 8 (CA=84; PIA=56)	0.1	0	0.7	0.143

Table 10. Continued.

Participant 1	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Velar Fronting - Final				
Sample 1 (CA=62; PIA=34)	1.6	0	4.4	0.364
Sample 2 (CA=66; PIA=38)	1.6	0	4.4	0.364
Sample 3 (CA=69; PIA=41)	1.6	0	4.4	0.364
Sample 4 (CA=72; PIA=44)	1.2	0	2.9	0.414
Sample 5 (CA=75; PIA=47)	1.2	0	2.9	0.414
Sample 6 (CA=78; PIA=50)	1.2	0	2.9	0.414
Sample 7 (CA=82; PIA=53)	1.2	0	2.9	0.414
Sample 8 (CA=84; PIA=56)	0.1	0	0.7	0.143

Table 11. Z-Score Comparisons by Chronological Age: Participant 2.

Participant 2	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=53; PIA=23)	0.1	0	0.6	0.167
Sample 2 (CA=56; PIA=27)	0.1	0	0.6	0.167
Sample 3 (CA=59; PIA=30)	0.1	0	0.6	0.167
Sample 4 (CA=62; PIA=33)	0.1	0	0.6	0.167
Sample 5 (CA=65; PIA=36)	0.1	0	0.6	0.167
Progressive Assimilation				
Sample 1 (CA=53; PIA=23)	0.1	0	0.6	0.167
Sample 2 (CA=56; PIA=27)	0.1	0	0.6	0.167
Sample 3 (CA=59; PIA=30)	0.1	0	0.6	0.167
Sample 4 (CA=62; PIA=33)	0.1	0	0.6	0.167
Sample 5 (CA=65; PIA=36)	0.1	0	0.6	0.167
Cluster Reduction - Initial				
Sample 1 (CA=53; PIA=23)	15.3	54.5	21.4	-1.832
Sample 2 (CA=56; PIA=27)	15.3	38.5	21.4	-1.084
Sample 3 (CA=59; PIA=30)	15.3	5.3	21.4	0.467
Sample 4 (CA=62; PIA=33)	9.7	29.4	15.6	-1.263
Sample 5 (CA=65; PIA=36)	9.7	33.3	15.6	-1.513
Cluster Reduction - Final				
Sample 1 (CA=53; PIA=23)	15.3	50	21.4	-1.621
Sample 2 (CA=56; PIA=27)	15.3	8.7	21.4	0.308
Sample 3 (CA=59; PIA=30)	15.3	7.4	21.4	0.369
Sample 4 (CA=62; PIA=33)	9.7	0	15.6	0.622
Sample 5 (CA=65; PIA=36)	9.7	0	15.6	0.622
Final Consonant Deletion				
Sample 1 (CA=53; PIA=23)	3.2	10.6	6.5	-1.138
Sample 2 (CA=56; PIA=27)	3.2	0.7	6.5	0.385
Sample 3 (CA=59; PIA=30)	3.2	5.1	6.5	-0.292
Sample 4 (CA=62; PIA=33)	2.4	0	3.3	0.727
Sample 5 (CA=65; PIA=36)	2.4	2.5	3.3	-0.030
Liquid Simplification - Initial				
Sample 1 (CA=53; PIA=23)	4.7	75	9.2	-7.641
Sample 2 (CA=56; PIA=27)	4.7	0	9.2	0.511
Sample 3 (CA=59; PIA=30)	4.7	0	9.2	0.511
Sample 4 (CA=62; PIA=33)	4.5	0	8.7	0.517
Sample 5 (CA=65; PIA=36)	4.5	10	8.7	-0.632
Liquid Simplification - Final				
Sample 1 (CA=53; PIA=23)	4.7	44.4	9.2	-4.315
Sample 2 (CA=56; PIA=27)	4.7	0	9.2	0.511
Sample 3 (CA=59; PIA=30)	4.7	0	9.2	0.511

Table 11. Continued.

Participant 2	Group Mean	Subject %	Group SD	Z-Score
Sample 4 (CA=62; PIA=33)	4.5	3.2	8.7	0.149
Sample 5 (CA=65; PIA=36)	4.5	0	8.7	0.517
Palatal Fronting - Initial				
Sample 1 (CA=53; PIA=23)	2.7	0	5.2	0.519
Sample 2 (CA=56; PIA=27)	2.7	0	5.2	0.519
Sample 3 (CA=59; PIA=30)	2.7	0	5.2	0.519
Sample 4 (CA=62; PIA=33)	1.6	0	4.4	0.364
Sample 5 (CA=65; PIA=36)	1.6	0	4.4	0.364
Palatal Fronting - Final				
Sample 1 (CA=53; PIA=23)	2.7	0	5.2	0.519
Sample 2 (CA=56; PIA=27)	2.7	0	5.2	0.519
Sample 3 (CA=59; PIA=30)	2.7	0	5.2	0.519
Sample 4 (CA=62; PIA=33)	1.6	0	4.4	0.364
Sample 5 (CA=65; PIA=36)	1.6	0	4.4	0.364
Stopping - Initial				
Sample 1 (CA=53; PIA=23)	1.9	52.2	3.3	-15.242
Sample 2 (CA=56; PIA=27)	1.9	38.6	3.3	-11.121
Sample 3 (CA=59; PIA=30)	1.9	58.3	3.3	-17.091
Sample 4 (CA=62; PIA=33)	0.8	62.9	1.9	-32.684
Sample 5 (CA=65; PIA=36)	0.8	45.7	1.9	-23.632
Stopping - Final				
Sample 1 (CA=53; PIA=23)	1.9	21.1	3.3	-5.818
Sample 2 (CA=56; PIA=27)	1.9	3.6	3.3	-0.515
Sample 3 (CA=59; PIA=30)	1.9	0	3.3	0.576
Sample 4 (CA=62; PIA=33)	0.8	2.4	1.9	-0.842
Sample 5 (CA=65; PIA=36)	0.8	2.3	1.9	-0.789
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=53; PIA=23)	0.7	0	1.8	0.389
Sample 2 (CA=56; PIA=27)	0.7	4.1	1.8	-1.889
Sample 3 (CA=59; PIA=30)	0.7	1.5	1.8	-0.444
Sample 4 (CA=62; PIA=33)	0.5	0	1.5	0.333
Sample 5 (CA=65; PIA=36)	0.5	0	1.5	0.333
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=53; PIA=23)	0.7	30	1.8	-16.278
Sample 2 (CA=56; PIA=27)	0.7	29.4	1.8	-15.944
Sample 3 (CA=59; PIA=30)	0.7	0	1.8	0.389
Sample 4 (CA=62; PIA=33)	0.5	20	1.5	-13.000
Sample 5 (CA=65; PIA=36)	0.5	0	1.5	0.333
Velar Fronting - Initial				
Sample 1 (CA=53; PIA=23)	2.7	0	5.2	0.519
Sample 2 (CA=56; PIA=27)	2.7	0	5.2	0.519
Sample 3 (CA=59; PIA=30)	2.7	0	5.2	0.519
Sample 4 (CA=62; PIA=33)	1.6	0	4.4	0.364
Sample 5 (CA=65; PIA=36)	1.6	0	4.4	0.364

Table 11. Continued.

Participant 2	Group Mean	Subject %	Group SD	Z-Score
Velar Fronting - Final				
Sample 1 (CA=53; PIA=23)	2.7	0	5.2	0.519
Sample 2 (CA=56; PIA=27)	2.7	0	5.2	0.519
Sample 3 (CA=59; PIA=30)	2.7	0	5.2	0.519
Sample 4 (CA=62; PIA=33)	1.6	0	4.4	0.364
Sample 5 (CA=65; PIA=36)	1.6	0	4.4	0.364

Table 12. Z-Score Comparisons by Chronological Age: Participant 3.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=74; PIA=39)	0	0	0	0.000
Sample 2 (CA=77; PIA=42)	0	0.6	0	0.000
Sample 3 (CA=80; PIA=45)	0	0	0	0.000
Sample 4 (CA=83; PIA=48)	0	0.8	0	0.000
Sample 5 (CA=86; PIA=51)	0	0	0	0.000
Sample 6 (CA=89; PIA=54)	0	0	0	0.000
Sample 7 (CA=92; PIA=57)	0	0	0	0.000
Sample 8 (CA=95; PIA=60)	0	0	0	0.000
Progressive Assimilation				
Sample 1 (CA=74; PIA=39)	0	0	0	0.000
Sample 2 (CA=77; PIA=42)	0	0	0	0.000
Sample 3 (CA=80; PIA=45)	0	0	0	0.000
Sample 4 (CA=83; PIA=48)	0	0	0	0.000
Sample 5 (CA=86; PIA=51)	0	0	0	0.000
Sample 6 (CA=89; PIA=54)	0	0	0	0.000
Sample 7 (CA=92; PIA=57)	0	0	0	0.000
Sample 8 (CA=95; PIA=60)	0	0	0	0.000
Cluster Reduction - Initial				
Sample 1 (CA=74; PIA=39)	6.5	80	12.1	-6.074
Sample 2 (CA=77; PIA=42)	6.5	84.6	12.1	-6.455
Sample 3 (CA=80; PIA=45)	6.5	66.7	12.1	-4.975
Sample 4 (CA=83; PIA=48)	6.5	25	12.1	-1.529
Sample 5 (CA=86; PIA=51)	2.8	43.8	8	-5.125
Sample 6 (CA=89; PIA=54)	2.8	42.9	8	-5.013
Sample 7 (CA=92; PIA=57)	2.8	57.1	8	-6.788
Sample 8 (CA=95; PIA=60)	2.8	36.7	8	-4.238
Cluster Reduction - Final				
Sample 1 (CA=74; PIA=39)	6.5	85.7	12.1	-6.545
Sample 2 (CA=77; PIA=42)	6.5	60	12.1	-4.421
Sample 3 (CA=80; PIA=45)	6.5	55.6	12.1	-4.058
Sample 4 (CA=83; PIA=48)	6.5	66.7	12.1	-4.975
Sample 5 (CA=86; PIA=51)	2.8	22.2	8	-2.425
Sample 6 (CA=89; PIA=54)	2.8	30	8	-3.400
Sample 7 (CA=92; PIA=57)	2.8	20	8	-2.150
Sample 8 (CA=95; PIA=60)	2.8	30.6	8	-3.475
Final Consonant Deletion				
Sample 1 (CA=74; PIA=39)	2.7	34.2	5.2	-6.058
Sample 2 (CA=77; PIA=42)	2.7	27	5.2	-4.673
Sample 3 (CA=80; PIA=45)	2.7	21	5.2	-3.519
Sample 4 (CA=83; PIA=48)	2.7	24.5	5.2	-4.192
Sample 5 (CA=86; PIA=51)	1.1	9.9	2.9	-3.034

Table 12. Continued.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Sample 6 (CA=89; PIA=54)	1.1	15.3	2.9	-4.897
Sample 7 (CA=92; PIA=57)	1.1	9.3	2.9	-2.828
Sample 8 (CA=95; PIA=60)	1.1	4.1	2.9	-1.034
Liquid Simplification - Initial				
Sample 1 (CA=74; PIA=39)	2.7	83.3	7.6	-10.605
Sample 2 (CA=77; PIA=42)	2.7	10	7.6	-0.961
Sample 3 (CA=80; PIA=45)	2.7	33.3	7.6	-4.026
Sample 4 (CA=83; PIA=48)	2.7	14.3	7.6	-1.526
Sample 5 (CA=86; PIA=51)	1.4	100	5.9	-16.712
Sample 6 (CA=89; PIA=54)	1.4	20	5.9	-3.153
Sample 7 (CA=92; PIA=57)	1.4	11.8	5.9	-1.763
Sample 8 (CA=95; PIA=60)	1.4	57.1	5.9	-9.441
Liquid Simplification - Final				
Sample 1 (CA=74; PIA=39)	2.7	57.1	7.6	-7.158
Sample 2 (CA=77; PIA=42)	2.7	10	7.6	-0.961
Sample 3 (CA=80; PIA=45)	2.7	25	7.6	-2.934
Sample 4 (CA=83; PIA=48)	2.7	9.1	7.6	-0.842
Sample 5 (CA=86; PIA=51)	1.4	27.3	5.9	-4.390
Sample 6 (CA=89; PIA=54)	1.4	33.3	5.9	-5.407
Sample 7 (CA=92; PIA=57)	1.4	6.5	5.9	-0.864
Sample 8 (CA=95; PIA=60)	1.4	10	5.9	-1.458
Palatal Fronting - Initial				
Sample 1 (CA=74; PIA=39)	1.2	0	2.9	0.414
Sample 2 (CA=77; PIA=42)	1.2	0	2.9	0.414
Sample 3 (CA=80; PIA=45)	1.2	0	2.9	0.414
Sample 4 (CA=83; PIA=48)	1.2	0	2.9	0.414
Sample 5 (CA=86; PIA=51)	0.1	0	0.7	0.143
Sample 6 (CA=89; PIA=54)	0.1	0	0.7	0.143
Sample 7 (CA=92; PIA=57)	0.1	0	0.7	0.143
Sample 8 (CA=95; PIA=60)	0.1	0	0.7	0.143
Palatal Fronting - Final				
Sample 1 (CA=74; PIA=39)	1.2	0	2.9	0.414
Sample 2 (CA=77; PIA=42)	1.2	0	2.9	0.414
Sample 3 (CA=80; PIA=45)	1.2	0	2.9	0.414
Sample 4 (CA=83; PIA=48)	1.2	0	2.9	0.414
Sample 5 (CA=86; PIA=51)	0.1	0	0.7	0.143
Sample 6 (CA=89; PIA=54)	0.1	0	0.7	0.143
Sample 7 (CA=92; PIA=57)	0.1	0	0.7	0.143
Sample 8 (CA=95; PIA=60)	0.1	0	0.7	0.143
Stopping - Initial				
Sample 1 (CA=74; PIA=39)	0.5	38.9	1.4	-27.429
Sample 2 (CA=77; PIA=42)	0.5	15.6	1.4	-10.786
Sample 3 (CA=80; PIA=45)	0.5	35.3	1.4	-24.857
Sample 4 (CA=83; PIA=48)	0.5	20	1.4	-13.929

Table 12. Continued.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Sample 5 (CA=86; PIA=51)	0.2	14.9	0.7	-21.000
Sample 6 (CA=89; PIA=54)	0.2	16.2	0.7	-22.857
Sample 7 (CA=92; PIA=57)	0.2	50.7	0.7	-72.143
Sample 8 (CA=95; PIA=60)	0.2	34.4	0.7	-48.857
Stopping - Final				
Sample 1 (CA=74; PIA=39)	0.5	0	1.4	0.357
Sample 2 (CA=77; PIA=42)	0.5	0	1.4	0.357
Sample 3 (CA=80; PIA=45)	0.5	0	1.4	0.357
Sample 4 (CA=83; PIA=48)	0.5	0	1.4	0.357
Sample 5 (CA=86; PIA=51)	0.2	3.8	0.7	-5.143
Sample 6 (CA=89; PIA=54)	0.2	0	0.7	0.286
Sample 7 (CA=92; PIA=57)	0.2	0	0.7	0.286
Sample 8 (CA=95; PIA=60)	0.2	0	0.7	0.286
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=74; PIA=39)	0.3	4.3	1.1	-3.636
Sample 2 (CA=77; PIA=42)	0.3	1.6	1.1	-1.182
Sample 3 (CA=80; PIA=45)	0.3	2.2	1.1	-1.727
Sample 4 (CA=83; PIA=48)	0.3	5.7	1.1	-4.909
Sample 5 (CA=86; PIA=51)	0.3	0	1.1	0.273
Sample 6 (CA=89; PIA=54)	0.3	2.7	1.1	-2.182
Sample 7 (CA=92; PIA=57)	0.3	0	1.1	0.273
Sample 8 (CA=95; PIA=60)	0.3	0	1.1	0.273
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=74; PIA=39)	0.3	66.7	1.1	-60.364
Sample 2 (CA=77; PIA=42)	0.3	11.8	1.1	-10.455
Sample 3 (CA=80; PIA=45)	0.3	6.7	1.1	-5.818
Sample 4 (CA=83; PIA=48)	0.3	0	1.1	0.273
Sample 5 (CA=86; PIA=51)	0.3	0	1.1	0.273
Sample 6 (CA=89; PIA=54)	0.3	25	1.1	-22.455
Sample 7 (CA=92; PIA=57)	0.3	20	1.1	-17.909
Sample 8 (CA=95; PIA=60)	0.3	0	1.1	0.273
Velar Fronting - Initial				
Sample 1 (CA=74; PIA=39)	1.2	0	2.9	0.414
Sample 2 (CA=77; PIA=42)	1.2	0	2.9	0.414
Sample 3 (CA=80; PIA=45)	1.2	0	2.9	0.414
Sample 4 (CA=83; PIA=48)	1.2	0	2.9	0.414
Sample 5 (CA=86; PIA=51)	0.1	0	0.7	0.143
Sample 6 (CA=89; PIA=54)	0.1	0	0.7	0.143
Sample 7 (CA=92; PIA=57)	0.1	6.7	0.7	-9.429
Sample 8 (CA=95; PIA=60)	0.1	0	0.7	0.143
Velar Fronting - Final				
Sample 1 (CA=74; PIA=39)	1.2	0	2.9	0.414
Sample 2 (CA=77; PIA=42)	1.2	0	2.9	0.414
Sample 3 (CA=80; PIA=45)	1.2	0	2.9	0.414

Table 12. Continued.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Sample 4 (CA=83; PIA=48)	1.2	0	2.9	0.414
Sample 5 (CA=86; PIA=51)	0.1	4.5	0.7	-6.286
Sample 6 (CA=89; PIA=54)	0.1	0	0.7	0.143
Sample 7 (CA=92; PIA=57)	0.1	0	0.7	0.143
Sample 8 (CA=95; PIA=60)	0.1	0	0.7	0.143

Table 13. Z-Score Comparisons by Chronological Age: Participant 4.

Participant 4	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Regressive Assimilation				
Sample 1 (CA=65; PIA=42)	0.1	0	0.6	0.167
Sample 2 (CA=68; PIA=45)	0.1	0.4	0.6	-0.500
Sample 3 (CA=71; PIA=48)	0.1	0.3	0.6	-0.333
Sample 4 (CA=74; PIA=51)	0	0	0	0.000
Sample 5 (CA=77; PIA=54)	0	0	0	0.000
Sample 6 (CA=80 PIA=57)	0	0.4	0	0.000
Sample 7 (CA=85; PIA=61)	0	0	0	0.000
Progressive Assimilation				
Sample 1 (CA=65; PIA=42)	0.1	0	0.6	0.167
Sample 2 (CA=68; PIA=45)	0.1	0	0.6	0.167
Sample 3 (CA=71; PIA=48)	0.1	0	0.6	0.167
Sample 4 (CA=74; PIA=51)	0	0.5	0	0.000
Sample 5 (CA=77; PIA=54)	0	0	0	0.000
Sample 6 (CA=80 PIA=57)	0	0.5	0	0.000
Sample 7 (CA=85; PIA=61)	0	0	0	0.000
Cluster Reduction - Initial				
Sample 1 (CA=65; PIA=42)	9.7	60.7	15.6	-3.269
Sample 2 (CA=68; PIA=45)	9.7	35.7	15.6	-1.667
Sample 3 (CA=71; PIA=48)	9.7	18.2	15.6	-0.545
Sample 4 (CA=74; PIA=51)	6.5	0	12.1	0.537
Sample 5 (CA=77; PIA=54)	6.5	17.9	12.1	-0.942
Sample 6 (CA=80 PIA=57)	6.5	20	12.1	-1.116
Sample 7 (CA=85; PIA=61)	2.8	8.3	8	-0.688
Cluster Reduction - Final				
Sample 1 (CA=65; PIA=42)	9.7	12.1	15.6	-0.154
Sample 2 (CA=68; PIA=45)	9.7	23.8	15.6	-0.904
Sample 3 (CA=71; PIA=48)	9.7	15.2	15.6	-0.353
Sample 4 (CA=74; PIA=51)	6.5	15.8	12.1	-0.769
Sample 5 (CA=77; PIA=54)	6.5	15.8	12.1	-0.769
Sample 6 (CA=80 PIA=57)	6.5	24.6	12.1	-1.496
Sample 7 (CA=85; PIA=61)	2.8	5.4	8	-0.325
Final Consonant Deletion				
Sample 1 (CA=65; PIA=42)	2.4	5.7	3.3	-1.000
Sample 2 (CA=68; PIA=45)	2.4	7	3.3	-1.394
Sample 3 (CA=71; PIA=48)	2.4	3.6	3.3	-0.364
Sample 4 (CA=74; PIA=51)	2.7	8.1	5.2	-1.038
Sample 5 (CA=77; PIA=54)	2.7	8.9	5.2	-1.192
Sample 6 (CA=80 PIA=57)	2.7	14.3	5.2	-2.231
Sample 7 (CA=85; PIA=61)	1.1	1.9	2.9	-0.276
Liquid Simplification - Initial				
Sample 1 (CA=65; PIA=42)	4.5	10	8.7	-0.632

Table 13. Continued.

Participant 4	Group Mean	Subject %	Group SD	Z-Score
Sample 2 (CA=68; PIA=45)	4.5	16.7	8.7	-1.402
Sample 3 (CA=71; PIA=48)	4.5	6.3	8.7	-0.207
Sample 4 (CA=74; PIA=51)	2.7	0	7.6	0.355
Sample 5 (CA=77; PIA=54)	2.7	22.2	7.6	-2.566
Sample 6 (CA=80 PIA=57)	2.7	0	7.6	0.355
Sample 7 (CA=85; PIA=61)	1.4	9.1	5.9	-1.305
Liquid Simplification - Final				
Sample 1 (CA=65; PIA=42)	4.5	0	8.7	0.517
Sample 2 (CA=68; PIA=45)	4.5	4.3	8.7	0.023
Sample 3 (CA=71; PIA=48)	4.5	0	8.7	0.517
Sample 4 (CA=74; PIA=51)	2.7	0	7.6	0.355
Sample 5 (CA=77; PIA=54)	2.7	2.9	7.6	-0.026
Sample 6 (CA=80 PIA=57)	2.7	0	7.6	0.355
Sample 7 (CA=85; PIA=61)	1.4	0	5.9	0.237
Palatal Fronting - Initial				
Sample 1 (CA=65; PIA=42)	1.6	0	4.4	0.364
Sample 2 (CA=68; PIA=45)	1.6	0	4.4	0.364
Sample 3 (CA=71; PIA=48)	1.6	0	4.4	0.364
Sample 4 (CA=74; PIA=51)	1.2	0	2.9	0.414
Sample 5 (CA=77; PIA=54)	1.2	0	2.9	0.414
Sample 6 (CA=80 PIA=57)	1.2	0	2.9	0.414
Sample 7 (CA=85; PIA=61)	0.1	0	0.7	0.143
Palatal Fronting - Final				
Sample 1 (CA=65; PIA=42)	1.6	0	4.4	0.364
Sample 2 (CA=68; PIA=45)	1.6	0	4.4	0.364
Sample 3 (CA=71; PIA=48)	1.6	0	4.4	0.364
Sample 4 (CA=74; PIA=51)	1.2	0	2.9	0.414
Sample 5 (CA=77; PIA=54)	1.2	12.5	2.9	-3.897
Sample 6 (CA=80 PIA=57)	1.2	0	2.9	0.414
Sample 7 (CA=85; PIA=61)	0.1	0	0.7	0.143
Stopping - Initial				
Sample 1 (CA=65; PIA=42)	0.8	43.1	1.9	-22.263
Sample 2 (CA=68; PIA=45)	0.8	52.4	1.9	-27.158
Sample 3 (CA=71; PIA=48)	0.8	65.1	1.9	-33.842
Sample 4 (CA=74; PIA=51)	0.5	72.1	1.4	-51.143
Sample 5 (CA=77; PIA=54)	0.5	29.3	1.4	-20.571
Sample 6 (CA=80 PIA=57)	0.5	57.9	1.4	-41.000
Sample 7 (CA=85; PIA=61)	0.2	0	0.7	0.286
Stopping - Final				
Sample 1 (CA=65; PIA=42)	0.8	0	1.9	0.421
Sample 2 (CA=68; PIA=45)	0.8	0	1.9	0.421
Sample 3 (CA=71; PIA=48)	0.8	3.3	1.9	-1.316
Sample 4 (CA=74; PIA=51)	0.5	0	1.4	0.357

Table 13. Continued.

Participant 4	Group Mean	Subject %	Group SD	Z-Score
Sample 5 (CA=77; PIA=54)	0.5	3.6	1.4	-2.214
Sample 6 (CA=80 PIA=57)	0.5	0	1.4	0.357
Sample 7 (CA=85; PIA=61)	0.2	0	0.7	0.286
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=65; PIA=42)	0.5	0	1.5	0.333
Sample 2 (CA=68; PIA=45)	0.5	0	1.5	0.333
Sample 3 (CA=71; PIA=48)	0.5	1.5	1.5	-0.667
Sample 4 (CA=74; PIA=51)	0.3	3.3	1.1	-2.727
Sample 5 (CA=77; PIA=54)	0.3	0	1.1	0.273
Sample 6 (CA=80 PIA=57)	0.3	1.2	1.1	-0.818
Sample 7 (CA=85; PIA=61)	0.3	0	1.1	0.273
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=65; PIA=42)	0.5	50	1.5	-33.000
Sample 2 (CA=68; PIA=45)	0.5	25	1.5	-16.333
Sample 3 (CA=71; PIA=48)	0.5	10	1.5	-6.333
Sample 4 (CA=74; PIA=51)	0.3	0	1.1	0.273
Sample 5 (CA=77; PIA=54)	0.3	0	1.1	0.273
Sample 6 (CA=80 PIA=57)	0.3	0	1.1	0.273
Sample 7 (CA=85; PIA=61)	0.3	20	1.1	-17.909
Velar Fronting - Initial				
Sample 1 (CA=65; PIA=42)	1.6	0	4.4	0.364
Sample 2 (CA=68; PIA=45)	1.6	0	4.4	0.364
Sample 3 (CA=71; PIA=48)	1.6	0	4.4	0.364
Sample 4 (CA=74; PIA=51)	1.2	5	2.9	-1.310
Sample 5 (CA=77; PIA=54)	1.2	0	2.9	0.414
Sample 6 (CA=80 PIA=57)	1.2	0	2.9	0.414
Sample 7 (CA=85; PIA=61)	0.1	0	0.7	0.143
Velar Fronting - Final				
Sample 1 (CA=65; PIA=42)	1.6	0	4.4	0.364
Sample 2 (CA=68; PIA=45)	1.6	0	4.4	0.364
Sample 3 (CA=71; PIA=48)	1.6	0	4.4	0.364
Sample 4 (CA=74; PIA=51)	1.2	0	2.9	0.414
Sample 5 (CA=77; PIA=54)	1.2	0	2.9	0.414
Sample 6 (CA=80 PIA=57)	1.2	0	2.9	0.414
Sample 7 (CA=85; PIA=61)	0.1	0	0.7	0.143

Table 14. Z-Score Comparisons by Chronological Age: Participant 5.

Participant 5	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=58; PIA=27)	0.1	0	0.6	0.167
Sample 2 (CA=62; PIA=30)	0.1	0	0.6	0.167
Sample 3 (CA=65; PIA=33)	0.1	0.5	0.6	-0.667
Sample 4 (CA=70; PIA=39)	0.1	0	0.6	0.167
Sample 5 (CA=74; PIA=42)	0	0	0	0.000
Sample 6 (CA=76 PIA=45)	0	0.3	0	0.000
Progressive Assimilation				
Sample 1 (CA=58; PIA=27)	0.1	0	0.6	0.167
Sample 2 (CA=62; PIA=30)	0.1	0	0.6	0.167
Sample 3 (CA=65; PIA=33)	0.1	0	0.6	0.167
Sample 4 (CA=70; PIA=39)	0.1	0.5	0.6	-0.667
Sample 5 (CA=74; PIA=42)	0	0	0	0.000
Sample 6 (CA=76 PIA=45)	0	0	0	0.000
Cluster Reduction - Initial				
Sample 1 (CA=58; PIA=27)	15.3	9.1	21.4	0.290
Sample 2 (CA=62; PIA=30)	9.7	4	15.6	0.365
Sample 3 (CA=65; PIA=33)	9.7	44.4	15.6	-2.224
Sample 4 (CA=70; PIA=39)	9.7	21.1	15.6	-0.731
Sample 5 (CA=74; PIA=42)	6.5	0	21.1	0.308
Sample 6 (CA=76 PIA=45)	6.5	11.1	21.1	-0.218
Cluster Reduction - Final				
Sample 1 (CA=58; PIA=27)	15.3	31	21.4	-0.734
Sample 2 (CA=62; PIA=30)	9.7	21.6	15.6	-0.763
Sample 3 (CA=65; PIA=33)	9.7	20.7	15.6	-0.705
Sample 4 (CA=70; PIA=39)	9.7	19	15.6	-0.596
Sample 5 (CA=74; PIA=42)	6.5	14.3	21.1	-0.370
Sample 6 (CA=76 PIA=45)	6.5	21.6	21.1	-0.716
Final Consonant Deletion				
Sample 1 (CA=58; PIA=27)	3.2	19.6	6.5	-2.523
Sample 2 (CA=62; PIA=30)	2.4	21.5	3.3	-5.788
Sample 3 (CA=65; PIA=33)	2.4	13	3.3	-3.212
Sample 4 (CA=70; PIA=39)	2.4	13.5	3.3	-3.364
Sample 5 (CA=74; PIA=42)	2.7	10.8	5.2	-1.558
Sample 6 (CA=76 PIA=45)	2.7	3.3	5.2	-0.115
Liquid Simplification - Initial				
Sample 1 (CA=58; PIA=27)	4.7	13.3	9.2	-0.935
Sample 2 (CA=62; PIA=30)	4.5	40	8.7	-4.080
Sample 3 (CA=65; PIA=33)	4.5	22.2	8.7	-2.034
Sample 4 (CA=70; PIA=39)	4.5	0	8.7	0.517

Table 14. Continued.

Participant 5	Group Mean	Subject %	Group SD	Z-Score
Sample 5 (CA=74; PIA=42)	2.7	0	7.6	0.355
Sample 6 (CA=76 PIA=45)	2.7	0	7.6	0.355
Liquid Simplification - Final				
Sample 1 (CA=58; PIA=27)	4.7	6.3	9.2	-0.174
Sample 2 (CA=62; PIA=30)	4.5	26.5	8.7	-2.529
Sample 3 (CA=65; PIA=33)	4.5	0	8.7	0.517
Sample 4 (CA=70; PIA=39)	4.5	5.9	8.7	-0.161
Sample 5 (CA=74; PIA=42)	2.7	6.3	7.6	-0.474
Sample 6 (CA=76 PIA=45)	2.7	0	7.6	0.355
Palatal Fronting - Initial				
Sample 1 (CA=58; PIA=27)	2.7	0	5.2	0.519
Sample 2 (CA=62; PIA=30)	1.6	0	4.4	0.364
Sample 3 (CA=65; PIA=33)	1.6	0	4.4	0.364
Sample 4 (CA=70; PIA=39)	1.6	4	4.4	-0.545
Sample 5 (CA=74; PIA=42)	1.2	0	2.9	0.414
Sample 6 (CA=76 PIA=45)	1.2	0	2.9	0.414
Palatal Fronting - Final				
Sample 1 (CA=58; PIA=27)	2.7	0	5.2	0.519
Sample 2 (CA=62; PIA=30)	1.6	0	4.4	0.364
Sample 3 (CA=65; PIA=33)	1.6	0	4.4	0.364
Sample 4 (CA=70; PIA=39)	1.6	0	4.4	0.364
Sample 5 (CA=74; PIA=42)	1.2	0	2.9	0.414
Sample 6 (CA=76 PIA=45)	1.2	0	2.9	0.414
Stopping - Initial				
Sample 1 (CA=58; PIA=27)	1.9	14.3	3.3	-3.758
Sample 2 (CA=62; PIA=30)	0.8	35.3	1.9	-18.158
Sample 3 (CA=65; PIA=33)	0.8	75	1.9	-39.053
Sample 4 (CA=70; PIA=39)	0.8	41.5	1.9	-21.421
Sample 5 (CA=74; PIA=42)	0.5	12.8	1.4	-8.786
Sample 6 (CA=76 PIA=45)	0.5	39.3	1.4	-27.714
Stopping - Final				
Sample 1 (CA=58; PIA=27)	1.9	3	3.3	-0.333
Sample 2 (CA=62; PIA=30)	0.8	0	1.9	0.421
Sample 3 (CA=65; PIA=33)	0.8	0	1.9	0.421
Sample 4 (CA=70; PIA=39)	0.8	0	1.9	0.421
Sample 5 (CA=74; PIA=42)	0.5	0	1.4	0.357
Sample 6 (CA=76 PIA=45)	0.5	3.3	1.4	-2.000
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=58; PIA=27)	0.7	3.5	1.8	-1.556
Sample 2 (CA=62; PIA=30)	0.5	3.5	1.5	-2.000
Sample 3 (CA=65; PIA=33)	0.5	1.3	1.5	-0.533
Sample 4 (CA=70; PIA=39)	0.5	3	1.5	-1.667
Sample 5 (CA=74; PIA=42)	0.3	0	1.1	0.273
Sample 6 (CA=76 PIA=45)	0.3	3.5	1.1	-2.909

Table 14. Continued.

Participant 5	Group Mean	Subject %	Group SD	Z-Score
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=58; PIA=27)	0.7	0	1.8	0.389
Sample 2 (CA=62; PIA=30)	0.5	11.1	1.5	-7.067
Sample 3 (CA=65; PIA=33)	0.5	0	1.5	0.333
Sample 4 (CA=70; PIA=39)	0.5	28.6	1.5	-18.733
Sample 5 (CA=74; PIA=42)	0.3	0	1.1	0.273
Sample 6 (CA=76 PIA=45)	0.3	0	1.1	0.273
Velar Fronting - Initial				
Sample 1 (CA=58; PIA=27)	2.7	7.1	5.2	-0.846
Sample 2 (CA=62; PIA=30)	1.6	2	4.4	-0.091
Sample 3 (CA=65; PIA=33)	1.6	0	4.4	0.364
Sample 4 (CA=70; PIA=39)	1.6	3.8	4.4	-0.500
Sample 5 (CA=74; PIA=42)	1.2	0	2.9	0.414
Sample 6 (CA=76 PIA=45)	1.2	0	2.9	0.414
Velar Fronting - Final				
Sample 1 (CA=58; PIA=27)	2.7	0	5.2	0.519
Sample 2 (CA=62; PIA=30)	1.6	0	4.4	0.364
Sample 3 (CA=65; PIA=33)	1.6	0	4.4	0.364
Sample 4 (CA=70; PIA=39)	1.6	0	4.4	0.364
Sample 5 (CA=74; PIA=42)	1.2	0	2.9	0.414
Sample 6 (CA=76 PIA=45)	1.2	0	2.9	0.414

Table 15. Z-Score Comparisons by Chronological Age: Participant 6.

Participant 6	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=45; PIA=26)	0.2	0	0.7	0.286
Sample 2 (CA=49; PIA=29)	0.1	0.6	0.6	-0.833
Sample 3 (CA=52; PIA=32)	0.1	0	0.6	0.167
Sample 4 (CA=55; PIA=35)	0.1	0.6	0.6	-0.833
Sample 5 (CA=59; PIA=38)	0.1	0	0.6	0.167
Sample 6 (CA=62; PIA=41)	0.1	0.4	0.6	-0.500
Progressive Assimilation				
Sample 1 (CA=45; PIA=26)	0.2	0	0.7	0.286
Sample 2 (CA=49; PIA=29)	0.1	0	0.6	0.167
Sample 3 (CA=52; PIA=32)	0.1	0	0.6	0.167
Sample 4 (CA=55; PIA=35)	0.1	0.7	0.6	-1.000
Sample 5 (CA=59; PIA=38)	0.1	0	0.6	0.167
Sample 6 (CA=62; PIA=41)	0.1	0	0.6	0.167
Cluster Reduction - Initial				
Sample 1 (CA=45; PIA=26)	24.7	87.5	21	-2.990
Sample 2 (CA=49; PIA=29)	15.3	79.2	21.4	-2.986
Sample 3 (CA=52; PIA=32)	15.3	88.2	21.4	-3.407
Sample 4 (CA=55; PIA=35)	15.3	57.9	21.4	-1.991
Sample 5 (CA=59; PIA=38)	15.3	55.6	21.4	-1.883
Sample 6 (CA=62; PIA=41)	9.7	40	15.6	-1.942
Cluster Reduction - Final				
Sample 1 (CA=45; PIA=26)	24.7	71.4	21	-2.224
Sample 2 (CA=49; PIA=29)	15.3	69.2	21.4	-2.519
Sample 3 (CA=52; PIA=32)	15.3	75	21.4	-2.790
Sample 4 (CA=55; PIA=35)	15.3	38.5	21.4	-1.084
Sample 5 (CA=59; PIA=38)	15.3	26.7	21.4	-0.533
Sample 6 (CA=62; PIA=41)	9.7	30.3	15.6	-1.321
Final Consonant Deletion				
Sample 1 (CA=45; PIA=26)	4.9	31	8.4	-3.107
Sample 2 (CA=49; PIA=29)	3.2	32.2	6.5	-4.462
Sample 3 (CA=52; PIA=32)	3.2	26.6	6.5	-3.600
Sample 4 (CA=55; PIA=35)	3.2	8.4	6.5	-0.800
Sample 5 (CA=59; PIA=38)	3.2	5.1	6.5	-0.292
Sample 6 (CA=62; PIA=41)	2.4	25.9	3.3	-7.121
Liquid Simplification - Initial				
Sample 1 (CA=45; PIA=26)	8	0	9.3	0.860
Sample 2 (CA=49; PIA=29)	4.7	0	9.2	0.511
Sample 3 (CA=52; PIA=32)	4.7	20	9.2	-1.663
Sample 4 (CA=55; PIA=35)	4.7	0	9.2	0.511
Sample 5 (CA=59; PIA=38)	4.7	40	9.2	-3.837
Sample 6 (CA=62; PIA=41)	4.5	28.6	8.7	-2.770

Table 15. Continued.

Participant 6	Group Mean	Subject %	Group SD	Z-Score
Liquid Simplification - Final				
Sample 1 (CA=45; PIA=26)	8	37.5	9.3	-3.172
Sample 2 (CA=49; PIA=29)	4.7	42.9	9.2	-4.152
Sample 3 (CA=52; PIA=32)	4.7	60	9.2	-6.011
Sample 4 (CA=55; PIA=35)	4.7	35.7	9.2	-3.370
Sample 5 (CA=59; PIA=38)	4.7	21.4	9.2	-1.815
Sample 6 (CA=62; PIA=41)	4.5	21.9	8.7	-2.000
Palatal Fronting - Initial				
Sample 1 (CA=45; PIA=26)	5.5	0	10.9	0.505
Sample 2 (CA=49; PIA=29)	2.7	0	5.2	0.519
Sample 3 (CA=52; PIA=32)	2.7	0	5.2	0.519
Sample 4 (CA=55; PIA=35)	2.7	0	5.2	0.519
Sample 5 (CA=59; PIA=38)	2.7	0	5.2	0.519
Sample 6 (CA=62; PIA=41)	1.6	0	4.4	0.364
Palatal Fronting - Final				
Sample 1 (CA=45; PIA=26)	5.5	0	10.9	0.505
Sample 2 (CA=49; PIA=29)	2.7	0	5.2	0.519
Sample 3 (CA=52; PIA=32)	2.7	0	5.2	0.519
Sample 4 (CA=55; PIA=35)	2.7	0	5.2	0.519
Sample 5 (CA=59; PIA=38)	2.7	0	5.2	0.519
Sample 6 (CA=62; PIA=41)	1.6	0	4.4	0.364
Stopping - Initial				
Sample 1 (CA=45; PIA=26)	2	50	4.1	-11.707
Sample 2 (CA=49; PIA=29)	1.9	35	3.3	-10.030
Sample 3 (CA=52; PIA=32)	1.9	55.8	3.3	-16.333
Sample 4 (CA=55; PIA=35)	1.9	16.4	3.3	-4.394
Sample 5 (CA=59; PIA=38)	1.9	56.6	3.3	-16.576
Sample 6 (CA=62; PIA=41)	0.8	63	1.9	-32.737
Stopping - Final				
Sample 1 (CA=45; PIA=26)	2	0	4.1	0.488
Sample 2 (CA=49; PIA=29)	1.9	0	3.3	0.576
Sample 3 (CA=52; PIA=32)	1.9	7.7	3.3	-1.758
Sample 4 (CA=55; PIA=35)	1.9	0	3.3	0.576
Sample 5 (CA=59; PIA=38)	1.9	3.8	3.3	-0.576
Sample 6 (CA=62; PIA=41)	0.8	0	1.9	0.421
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=45; PIA=26)	1.3	5	2.8	-1.321
Sample 2 (CA=49; PIA=29)	0.7	2.4	1.8	-0.944
Sample 3 (CA=52; PIA=32)	0.7	6	1.8	-2.944
Sample 4 (CA=55; PIA=35)	0.7	13.4	1.8	-7.056
Sample 5 (CA=59; PIA=38)	0.7	0	1.8	0.389
Sample 6 (CA=62; PIA=41)	0.5	10.7	1.5	-6.800

Table 15. Continued.

Participant 6	Group Mean	Subject %	Group SD	Z-Score
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=45; PIA=26)	1.3	25	2.8	-8.464
Sample 2 (CA=49; PIA=29)	0.7	0	1.8	0.389
Sample 3 (CA=52; PIA=32)	0.7	20	1.8	-10.722
Sample 4 (CA=55; PIA=35)	0.7	40	1.8	-21.833
Sample 5 (CA=59; PIA=38)	0.7	0	1.8	0.389
Sample 6 (CA=62; PIA=41)	0.5	6.3	1.5	-3.867
Velar Fronting - Initial				
Sample 1 (CA=45; PIA=26)	5.5	0	10.9	0.505
Sample 2 (CA=49; PIA=29)	2.7	40	5.2	-7.173
Sample 3 (CA=52; PIA=32)	2.7	0	5.2	0.519
Sample 4 (CA=55; PIA=35)	2.7	92.3	5.2	-17.231
Sample 5 (CA=59; PIA=38)	2.7	0	5.2	0.519
Sample 6 (CA=62; PIA=41)	1.6	64.7	4.4	-14.341
Velar Fronting - Final				
Sample 1 (CA=45; PIA=26)	5.5	0	10.9	0.505
Sample 2 (CA=49; PIA=29)	2.7	6.3	5.2	-0.692
Sample 3 (CA=52; PIA=32)	2.7	0	5.2	0.519
Sample 4 (CA=55; PIA=35)	2.7	11.1	5.2	-1.615
Sample 5 (CA=59; PIA=38)	2.7	0	5.2	0.519
Sample 6 (CA=62; PIA=41)	1.6	0	4.4	0.364

Appendix E

Table 16. Z-Score Comparisons by Post-implantation Age: Participant 1.

Participant 1	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Regressive Assimilation				
Sample 1 (CA=62; PIA=34)	0.1	0	0.5	0.200
Sample 2 (CA=66; PIA=38)	0.1	0	0.4	0.250
Sample 3 (CA=69; PIA=41)	0.1	0	0.4	0.250
Sample 4 (CA=72; PIA=44)	0.2	0	0.7	0.286
Sample 5 (CA=75; PIA=47)	0.2	0	0.7	0.286
Sample 6 (CA=78; PIA=50)	0.1	0	0.6	0.167
Sample 7 (CA=82; PIA=53)	0.1	0.5	0.6	-0.667
Sample 8 (CA=84; PIA=56)	0.1	0	0.6	0.167
Progressive Assimilation				
Sample 1 (CA=62; PIA=34)	0.1	0	0.5	0.200
Sample 2 (CA=66; PIA=38)	0.1	1.1	0.4	-2.500
Sample 3 (CA=69; PIA=41)	0.1	0	0.4	0.250
Sample 4 (CA=72; PIA=44)	0.2	0	0.7	0.286
Sample 5 (CA=75; PIA=47)	0.2	1	0.7	-1.143
Sample 6 (CA=78; PIA=50)	0.1	0	0.6	0.167
Sample 7 (CA=82; PIA=53)	0.1	0	0.6	0.167
Sample 8 (CA=84; PIA=56)	0.1	0	0.6	0.167
Cluster Reduction - Initial				
Sample 1 (CA=62; PIA=34)	67.7	50	21.4	0.827
Sample 2 (CA=66; PIA=38)	41.9	13.6	26.1	1.084
Sample 3 (CA=69; PIA=41)	41.9	45.5	26.1	-0.138
Sample 4 (CA=72; PIA=44)	24.7	20	21	0.224
Sample 5 (CA=75; PIA=47)	24.7	30.8	21	-0.290
Sample 6 (CA=78; PIA=50)	15.3	23.1	21.4	-0.364
Sample 7 (CA=82; PIA=53)	15.3	0	21.4	0.715
Sample 8 (CA=84; PIA=56)	15.3	13.3	21.4	0.093
Cluster Reduction - Final				
Sample 1 (CA=62; PIA=34)	67.7	83.3	21.4	-0.729
Sample 2 (CA=66; PIA=38)	41.9	26.7	26.1	0.582
Sample 3 (CA=69; PIA=41)	41.9	50	26.1	-0.310
Sample 4 (CA=72; PIA=44)	24.7	38.9	21	-0.676
Sample 5 (CA=75; PIA=47)	24.7	42.9	21	-0.867
Sample 6 (CA=78; PIA=50)	15.3	40.9	21.4	-1.196
Sample 7 (CA=82; PIA=53)	15.3	0	21.4	0.715
Sample 8 (CA=84; PIA=56)	15.3	12.5	21.4	0.131

Table 16. Continued. .

Participant 1	Group Mean	Subject %	Group SD	Z-Score
Final Consonant Deletion				
Sample 1 (CA=62; PIA=34)	5.8	22.2	6.6	-2.485
Sample 2 (CA=66; PIA=38)	7.5	11.7	10.8	-0.389
Sample 3 (CA=69; PIA=41)	7.5	10.4	10.8	-0.269
Sample 4 (CA=72; PIA=44)	4.9	27.4	8.4	-2.679
Sample 5 (CA=75; PIA=47)	4.9	20	8.4	-1.798
Sample 6 (CA=78; PIA=50)	3.2	30.4	6.5	-4.185
Sample 7 (CA=82; PIA=53)	3.2	11.3	6.5	-1.246
Sample 8 (CA=84; PIA=56)	3.2	7.3	6.5	-0.631
Liquid Simplification - Initial				
Sample 1 (CA=62; PIA=34)	24.5	0	17	1.441
Sample 2 (CA=66; PIA=38)	11.7	0	12.9	0.907
Sample 3 (CA=69; PIA=41)	11.7	0	12.9	0.907
Sample 4 (CA=72; PIA=44)	8	0	9.3	0.860
Sample 5 (CA=75; PIA=47)	8	50	9.3	-4.516
Sample 6 (CA=78; PIA=50)	4.7	11.1	9.2	-0.696
Sample 7 (CA=82; PIA=53)	4.7	6.7	9.2	-0.217
Sample 8 (CA=84; PIA=56)	4.7	0	9.2	0.511
Liquid Simplification - Final				
Sample 1 (CA=62; PIA=34)	24.5	0	17	1.441
Sample 2 (CA=66; PIA=38)	11.7	0	12.9	0.907
Sample 3 (CA=69; PIA=41)	11.7	4.3	12.9	0.574
Sample 4 (CA=72; PIA=44)	8	6.3	9.3	0.183
Sample 5 (CA=75; PIA=47)	8	0	9.3	0.860
Sample 6 (CA=78; PIA=50)	4.7	0	9.2	0.511
Sample 7 (CA=82; PIA=53)	4.7	0	9.2	0.511
Sample 8 (CA=84; PIA=56)	4.7	0	9.2	0.511
Palatal Fronting - Initial				
Sample 1 (CA=62; PIA=34)	18.3	0	16.9	1.083
Sample 2 (CA=66; PIA=38)	8.1	0	12	0.675
Sample 3 (CA=69; PIA=41)	8.1	0	12	0.675
Sample 4 (CA=72; PIA=44)	5.5	0	10.9	0.505
Sample 5 (CA=75; PIA=47)	5.5	10	10.9	-0.413
Sample 6 (CA=78; PIA=50)	2.7	0	5.2	0.519
Sample 7 (CA=82; PIA=53)	2.7	0	5.2	0.519
Sample 8 (CA=84; PIA=56)	2.7	0	5.2	0.519
Palatal Fronting - Final				
Sample 1 (CA=62; PIA=34)	18.3	0	16.9	1.083
Sample 2 (CA=66; PIA=38)	8.1	0	12	0.675
Sample 3 (CA=69; PIA=41)	8.1	0	12	0.675
Sample 4 (CA=72; PIA=44)	5.5	0	10.9	0.505
Sample 5 (CA=75; PIA=47)	5.5	0	10.9	0.505

Table 16. Continued.

Participant 1	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 6 (CA=78; PIA=50)	2.7	0	5.2	0.519
Sample 7 (CA=82; PIA=53)	2.7	0	5.2	0.519
Sample 8 (CA=84; PIA=56)	2.7	0	5.2	0.519
Stopping - Initial				
Sample 1 (CA=62; PIA=34)	9	0	15.1	0.596
Sample 2 (CA=66; PIA=38)	3.9	3	7.7	0.117
Sample 3 (CA=69; PIA=41)	3.9	22.2	7.7	-2.377
Sample 4 (CA=72; PIA=44)	2	14.3	4.1	-3.000
Sample 5 (CA=75; PIA=47)	2	50.9	4.1	-11.927
Sample 6 (CA=78; PIA=50)	1.9	40.9	3.3	-11.818
Sample 7 (CA=82; PIA=53)	1.9	27.8	3.3	-7.848
Sample 8 (CA=84; PIA=56)	1.9	15.1	3.3	-4.000
Stopping - Final				
Sample 1 (CA=62; PIA=34)	9	0	15.1	0.596
Sample 2 (CA=66; PIA=38)	3.9	0	7.7	0.506
Sample 3 (CA=69; PIA=41)	3.9	0	7.7	0.506
Sample 4 (CA=72; PIA=44)	2	0	4.1	0.488
Sample 5 (CA=75; PIA=47)	2	8.3	4.1	-1.537
Sample 6 (CA=78; PIA=50)	1.9	3.6	3.3	-0.515
Sample 7 (CA=82; PIA=53)	1.9	0	3.3	0.576
Sample 8 (CA=84; PIA=56)	1.9	2.6	3.3	-0.212
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=62; PIA=34)	2.8	4.9	3.4	-0.618
Sample 2 (CA=66; PIA=38)	2.3	2.4	4.7	-0.021
Sample 3 (CA=69; PIA=41)	2.3	0	4.7	0.489
Sample 4 (CA=72; PIA=44)	1.3	7.9	2.8	-2.357
Sample 5 (CA=75; PIA=47)	1.3	4.2	2.8	-1.036
Sample 6 (CA=78; PIA=50)	0.7	4.5	1.8	-2.111
Sample 7 (CA=82; PIA=53)	0.7	4.2	1.8	-1.944
Sample 8 (CA=84; PIA=56)	0.7	1.9	1.8	-0.667
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=62; PIA=34)	2.8	0	3.4	0.824
Sample 2 (CA=66; PIA=38)	2.3	0	4.7	0.489
Sample 3 (CA=69; PIA=41)	2.3	33.3	4.7	-6.596
Sample 4 (CA=72; PIA=44)	1.3	60	2.8	-20.964
Sample 5 (CA=75; PIA=47)	1.3	25	2.8	-8.464
Sample 6 (CA=78; PIA=50)	0.7	33.3	1.8	-18.111
Sample 7 (CA=82; PIA=53)	0.7	20	1.8	-10.722
Sample 8 (CA=84; PIA=56)	0.7	22.2	1.8	-11.944

Table 16. Continued.

Participant 1	Group Mean	Subject %	Group SD	Z-Score
Velar Fronting - Initial				
Sample 1 (CA=62; PIA=34)	18.3	0	16.9	1.083
Sample 2 (CA=66; PIA=38)	8.1	0	12	0.675
Sample 3 (CA=69; PIA=41)	8.1	0	12	0.675
Sample 4 (CA=72; PIA=44)	5.5	0	10.9	0.505
Sample 5 (CA=75; PIA=47)	5.5	0	10.9	0.505
Sample 6 (CA=78; PIA=50)	2.7	0	5.2	0.519
Sample 7 (CA=82; PIA=53)	2.7	0	5.2	0.519
Sample 8 (CA=84; PIA=56)	2.7	0	5.2	0.519
Velar Fronting - Final				
Sample 1 (CA=62; PIA=34)	18.3	0	16.9	1.083
Sample 2 (CA=66; PIA=38)	8.1	0	12	0.675
Sample 3 (CA=69; PIA=41)	8.1	0	12	0.675
Sample 4 (CA=72; PIA=44)	5.5	0	10.9	0.505
Sample 5 (CA=75; PIA=47)	5.5	0	10.9	0.505
Sample 6 (CA=78; PIA=50)	2.7	0	5.2	0.519
Sample 7 (CA=82; PIA=53)	2.7	0	5.2	0.519
Sample 8 (CA=84; PIA=56)	2.7	0	5.2	0.519

Table 17. Z-Score Comparisons by Post-implantation Age: Participant 2.

Participant 2	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=53; PIA=23)	0.1	0	0.5	0.200
Sample 2 (CA=56; PIA=27)	0.1	0	0.5	0.200
Sample 3 (CA=59; PIA=30)	0.1	0	0.5	0.200
Sample 4 (CA=62; PIA=33)	0.1	0	0.5	0.200
Sample 5 (CA=65; PIA=36)	0.1	0	0.4	0.250
Progressive Assimilation				
Sample 1 (CA=53; PIA=23)	0.1	0	0.5	0.200
Sample 2 (CA=56; PIA=27)	0.1	0	0.5	0.200
Sample 3 (CA=59; PIA=30)	0.1	0	0.5	0.200
Sample 4 (CA=62; PIA=33)	0.1	0	0.5	0.200
Sample 5 (CA=65; PIA=36)	0.1	0	0.4	0.250
Cluster Reduction - Initial				
Sample 1 (CA=53; PIA=23)	67.7	54.5	21.4	0.617
Sample 2 (CA=56; PIA=27)	67.7	38.5	21.4	1.364
Sample 3 (CA=59; PIA=30)	67.7	5.3	21.4	2.916
Sample 4 (CA=62; PIA=33)	67.7	29.4	21.4	1.790
Sample 5 (CA=65; PIA=36)	41.9	33.3	26.1	0.330
Cluster Reduction - Final				
Sample 1 (CA=53; PIA=23)	67.7	50	21.4	0.827
Sample 2 (CA=56; PIA=27)	67.7	8.7	21.4	2.757
Sample 3 (CA=59; PIA=30)	67.7	7.4	21.4	2.818
Sample 4 (CA=62; PIA=33)	67.7	0	21.4	3.164
Sample 5 (CA=65; PIA=36)	41.9	0	26.1	1.605
Final Consonant Deletion				
Sample 1 (CA=53; PIA=23)	5.8	10.6	6.6	-0.727
Sample 2 (CA=56; PIA=27)	5.8	0.7	6.6	0.773
Sample 3 (CA=59; PIA=30)	5.8	5.1	6.6	0.106
Sample 4 (CA=62; PIA=33)	5.8	0	6.6	0.879
Sample 5 (CA=65; PIA=36)	7.5	2.5	10.8	0.463
Liquid Simplification - Initial				
Sample 1 (CA=53; PIA=23)	24.5	75	17	-2.971
Sample 2 (CA=56; PIA=27)	24.5	0	17	1.441
Sample 3 (CA=59; PIA=30)	24.5	0	17	1.441
Sample 4 (CA=62; PIA=33)	24.5	0	17	1.441
Sample 5 (CA=65; PIA=36)	11.7	10	12.9	0.132
Liquid Simplification - Final				
Sample 1 (CA=53; PIA=23)	24.5	44.4	17	-1.171

Table 17. Continued.

Participant 2	Group Mean	Subject %	Group SD	Z-Score
Sample 2 (CA=56; PIA=27)	24.5	0	17	1.441
Sample 3 (CA=59; PIA=30)	24.5	0	17	1.441
Sample 4 (CA=62; PIA=33)	24.5	3.2	17	1.253
Sample 5 (CA=65; PIA=36)	11.7	0	12.9	0.907
Palatal Fronting - Initial				
Sample 1 (CA=53; PIA=23)	18.3	0	16.9	1.083
Sample 2 (CA=56; PIA=27)	18.3	0	16.9	1.083
Sample 3 (CA=59; PIA=30)	18.3	0	16.9	1.083
Sample 4 (CA=62; PIA=33)	18.3	0	16.9	1.083
Sample 5 (CA=65; PIA=36)	8.1	0	12	0.675
Palatal Fronting - Final				
Sample 1 (CA=53; PIA=23)	18.3	0	5.2	3.519
Sample 2 (CA=56; PIA=27)	18.3	0	5.2	3.519
Sample 3 (CA=59; PIA=30)	18.3	0	5.2	3.519
Sample 4 (CA=62; PIA=33)	18.3	0	4.4	4.159
Sample 5 (CA=65; PIA=36)	8.1	0	4.4	1.841
Stopping - Initial				
Sample 1 (CA=53; PIA=23)	9	52.2	15.1	-2.861
Sample 2 (CA=56; PIA=27)	9	38.6	15.1	-1.960
Sample 3 (CA=59; PIA=30)	9	58.3	15.1	-3.265
Sample 4 (CA=62; PIA=33)	9	62.9	15.1	-3.570
Sample 5 (CA=65; PIA=36)	3.9	45.7	7.7	-5.429
Stopping - Final				
Sample 1 (CA=53; PIA=23)	9	21.1	15.1	-0.801
Sample 2 (CA=56; PIA=27)	9	3.6	15.1	0.358
Sample 3 (CA=59; PIA=30)	9	0	15.1	0.596
Sample 4 (CA=62; PIA=33)	9	2.4	15.1	0.437
Sample 5 (CA=65; PIA=36)	3.9	2.3	7.7	0.208
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=53; PIA=23)	2.8	0	3.4	0.824
Sample 2 (CA=56; PIA=27)	2.8	4.1	3.4	-0.382
Sample 3 (CA=59; PIA=30)	2.8	1.5	3.4	0.382
Sample 4 (CA=62; PIA=33)	2.8	0	3.4	0.824
Sample 5 (CA=65; PIA=36)	2.3	0	4.7	0.489
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=53; PIA=23)	2.8	30	3.4	-8.000
Sample 2 (CA=56; PIA=27)	2.8	29.4	3.4	-7.824
Sample 3 (CA=59; PIA=30)	2.8	0	3.4	0.824
Sample 4 (CA=62; PIA=33)	2.8	20	3.4	-5.059
Sample 5 (CA=65; PIA=36)	2.3	0	4.7	0.489
Velar Fronting - Initial				
Sample 1 (CA=53; PIA=23)	18.3	0	16.9	1.083

Table 17. Continued.

Participant 2	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 2 (CA=56; PIA=27)	18.3	0	16.9	1.083
Sample 3 (CA=59; PIA=30)	18.3	0	16.9	1.083
Sample 4 (CA=62; PIA=33)	18.3	0	16.9	1.083
Sample 5 (CA=65; PIA=36)	8.1	0	12	0.675
Velar Fronting - Final				
Sample 1 (CA=53; PIA=23)	18.3	0	16.9	1.083
Sample 2 (CA=56; PIA=27)	18.3	0	16.9	1.083
Sample 3 (CA=59; PIA=30)	18.3	0	16.9	1.083
Sample 4 (CA=62; PIA=33)	18.3	0	16.9	1.083
Sample 5 (CA=65; PIA=36)	8.1	0	12	0.675

Table 18. Z-Score Comparisons by Post-implantation Age: Participant 3.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=74; PIA=39)	0.2	0	0.7	0.286
Sample 2 (CA=77; PIA=42)	0.2	0.6	0.7	-0.571
Sample 3 (CA=80; PIA=45)	0.2	0	0.7	0.286
Sample 4 (CA=83; PIA=48)	0.1	0.8	0.6	-1.167
Sample 5 (CA=86; PIA=51)	0.1	0	0.6	0.167
Sample 6 (CA=89; PIA=54)	0.1	0	0.6	0.167
Sample 7 (CA=92; PIA=57)	0.1	0	0.6	0.167
Sample 8 (CA=95; PIA=60)	0.1	0	0.6	0.167
Progressive Assimilation				
Sample 1 (CA=74; PIA=39)	0.2	0	0.7	0.286
Sample 2 (CA=77; PIA=42)	0.2	0	0.7	0.286
Sample 3 (CA=80; PIA=45)	0.2	0	0.7	0.286
Sample 4 (CA=83; PIA=48)	0.1	0	0.6	0.167
Sample 5 (CA=86; PIA=51)	0.1	0	0.6	0.167
Sample 6 (CA=89; PIA=54)	0.1	0	0.6	0.167
Sample 7 (CA=92; PIA=57)	0.1	0	0.6	0.167
Sample 8 (CA=95; PIA=60)	0.1	0	0.6	0.167
Cluster Reduction - Initial				
Sample 1 (CA=74; PIA=39)	24.7	80	21	-2.633
Sample 2 (CA=77; PIA=42)	24.7	84.6	21	-2.852
Sample 3 (CA=80; PIA=45)	24.7	66.7	21	-2.000
Sample 4 (CA=83; PIA=48)	15.3	25	21.4	-0.453
Sample 5 (CA=86; PIA=51)	15.3	43.8	21.4	-1.332
Sample 6 (CA=89; PIA=54)	15.3	42.9	21.4	-1.290
Sample 7 (CA=92; PIA=57)	15.3	57.1	21.4	-1.953
Sample 8 (CA=95; PIA=60)	9.7	36.7	15.6	-1.731
Cluster Reduction - Final				
Sample 1 (CA=74; PIA=39)	24.7	85.7	21	-2.905
Sample 2 (CA=77; PIA=42)	24.7	60	21	-1.681
Sample 3 (CA=80; PIA=45)	24.7	55.6	21	-1.471
Sample 4 (CA=83; PIA=48)	15.3	66.7	21.4	-2.402
Sample 5 (CA=86; PIA=51)	15.3	22.2	21.4	-0.322
Sample 6 (CA=89; PIA=54)	15.3	30	21.4	-0.687
Sample 7 (CA=92; PIA=57)	15.3	20	21.4	-0.220
Sample 8 (CA=95; PIA=60)	9.7	30.6	15.6	-1.340
Final Consonant Deletion				
Sample 1 (CA=74; PIA=39)	4.9	34.2	8.4	-3.488
Sample 2 (CA=77; PIA=42)	4.9	27	8.4	-2.631
Sample 3 (CA=80; PIA=45)	4.9	21	8.4	-1.917

Table 18. Continued.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Sample 4 (CA=83; PIA=48)	3.2	24.5	6.5	-3.277
Sample 5 (CA=86; PIA=51)	3.2	9.9	6.5	-1.031
Sample 6 (CA=89; PIA=54)	3.2	15.3	6.5	-1.862
Sample 7 (CA=92; PIA=57)	3.2	9.3	6.5	-0.938
Sample 8 (CA=95; PIA=60)	2.4	4.1	3.3	-0.515
Liquid Simplification - Initial				
Sample 1 (CA=74; PIA=39)	8	83.3	9.3	-8.097
Sample 2 (CA=77; PIA=42)	8	10	9.3	-0.215
Sample 3 (CA=80; PIA=45)	8	33.3	9.3	-2.720
Sample 4 (CA=83; PIA=48)	4.7	14.3	9.2	-1.043
Sample 5 (CA=86; PIA=51)	4.7	100	9.2	-10.359
Sample 6 (CA=89; PIA=54)	4.7	20	9.2	-1.663
Sample 7 (CA=92; PIA=57)	4.7	11.8	9.2	-0.772
Sample 8 (CA=95; PIA=60)	4.5	57.1	8.7	-6.046
Liquid Simplification - Final				
Sample 1 (CA=74; PIA=39)	8	57.1	9.3	-5.280
Sample 2 (CA=77; PIA=42)	8	10	9.3	-0.215
Sample 3 (CA=80; PIA=45)	8	25	9.3	-1.828
Sample 4 (CA=83; PIA=48)	4.7	9.1	9.2	-0.478
Sample 5 (CA=86; PIA=51)	4.7	27.3	9.2	-2.457
Sample 6 (CA=89; PIA=54)	4.7	33.3	9.2	-3.109
Sample 7 (CA=92; PIA=57)	4.7	6.5	9.2	-0.196
Sample 8 (CA=95; PIA=60)	4.5	10	8.7	-0.632
Palatal Fronting - Initial				
Sample 1 (CA=74; PIA=39)	5.5	0	10.9	0.505
Sample 2 (CA=77; PIA=42)	5.5	0	10.9	0.505
Sample 3 (CA=80; PIA=45)	5.5	0	10.9	0.505
Sample 4 (CA=83; PIA=48)	2.7	0	5.2	0.519
Sample 5 (CA=86; PIA=51)	2.7	0	5.2	0.519
Sample 6 (CA=89; PIA=54)	2.7	0	5.2	0.519
Sample 7 (CA=92; PIA=57)	2.7	0	5.2	0.519
Sample 8 (CA=95; PIA=60)	1.6	0	4.4	0.364
Palatal Fronting - Final				
Sample 1 (CA=74; PIA=39)	5.5	0	10.9	0.505
Sample 2 (CA=77; PIA=42)	5.5	0	10.9	0.505
Sample 3 (CA=80; PIA=45)	5.5	0	10.9	0.505
Sample 4 (CA=83; PIA=48)	2.7	0	5.2	0.519
Sample 5 (CA=86; PIA=51)	2.7	0	5.2	0.519
Sample 6 (CA=89; PIA=54)	2.7	0	5.2	0.519
Sample 7 (CA=92; PIA=57)	2.7	0	5.2	0.519

Table 18. Continued.

Participant 3	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 8 (CA=95; PIA=60)	1.6	0	4.4	0.364
Stopping - Initial				
Sample 1 (CA=74; PIA=39)	2	38.9	4.1	-9.000
Sample 2 (CA=77; PIA=42)	2	15.6	4.1	-3.317
Sample 3 (CA=80; PIA=45)	2	35.3	4.1	-8.122
Sample 4 (CA=83; PIA=48)	1.9	20	3.3	-5.485
Sample 5 (CA=86; PIA=51)	1.9	14.9	3.3	-3.939
Sample 6 (CA=89; PIA=54)	1.9	16.2	3.3	-4.333
Sample 7 (CA=92; PIA=57)	1.9	50.7	3.3	-14.788
Sample 8 (CA=95; PIA=60)	0.8	34.4	1.9	-17.684
Stopping - Final				
Sample 1 (CA=74; PIA=39)	2	0	4.1	0.488
Sample 2 (CA=77; PIA=42)	2	0	4.1	0.488
Sample 3 (CA=80; PIA=45)	2	0	4.1	0.488
Sample 4 (CA=83; PIA=48)	1.9	0	3.3	0.576
Sample 5 (CA=86; PIA=51)	1.9	3.8	3.3	-0.576
Sample 6 (CA=89; PIA=54)	1.9	0	3.3	0.576
Sample 7 (CA=92; PIA=57)	1.9	0	3.3	0.576
Sample 8 (CA=95; PIA=60)	0.8	0	1.9	0.421
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=74; PIA=39)	1.3	4.3	2.8	-1.071
Sample 2 (CA=77; PIA=42)	1.3	1.6	2.8	-0.107
Sample 3 (CA=80; PIA=45)	1.3	2.2	2.8	-0.321
Sample 4 (CA=83; PIA=48)	0.7	5.7	1.8	-2.778
Sample 5 (CA=86; PIA=51)	0.7	0	1.8	0.389
Sample 6 (CA=89; PIA=54)	0.7	2.7	1.8	-1.111
Sample 7 (CA=92; PIA=57)	0.7	0	1.8	0.389
Sample 8 (CA=95; PIA=60)	0.5	0	1.5	0.333
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=74; PIA=39)	1.3	66.7	2.8	-23.357
Sample 2 (CA=77; PIA=42)	1.3	11.8	2.8	-3.750
Sample 3 (CA=80; PIA=45)	1.3	6.7	2.8	-1.929
Sample 4 (CA=83; PIA=48)	0.7	0	1.8	0.389
Sample 5 (CA=86; PIA=51)	0.7	0	1.8	0.389
Sample 6 (CA=89; PIA=54)	0.7	25	1.8	-13.500
Sample 7 (CA=92; PIA=57)	0.7	20	1.8	-10.722
Sample 8 (CA=95; PIA=60)	0.5	0	1.5	0.333
Velar Fronting - Initial				
Sample 1 (CA=74; PIA=39)	5.5	0	10.9	0.505
Sample 2 (CA=77; PIA=42)	5.5	0	10.9	0.505
Sample 3 (CA=80; PIA=45)	5.5	0	10.9	0.505
Sample 4 (CA=83; PIA=48)	2.7	0	5.2	0.519

Table 18. Continued.

Participant 3	Group Mean	Subject %	Group SD	Z-Score
Sample 5 (CA=86; PIA=51)	2.7	0	5.2	0.519
Sample 6 (CA=89; PIA=54)	2.7	0	5.2	0.519
Sample 7 (CA=92; PIA=57)	2.7	6.7	5.2	-0.769
Sample 8 (CA=95; PIA=60)	1.6	0	4.4	0.364
Velar Fronting - Final				
Sample 1 (CA=74; PIA=39)	5.5	0	10.9	0.505
Sample 2 (CA=77; PIA=42)	5.5	0	10.9	0.505
Sample 3 (CA=80; PIA=45)	5.5	0	10.9	0.505
Sample 4 (CA=83; PIA=48)	2.7	0	5.2	0.519
Sample 5 (CA=86; PIA=51)	2.7	4.5	5.2	-0.346
Sample 6 (CA=89; PIA=54)	2.7	0	5.2	0.519
Sample 7 (CA=92; PIA=57)	2.7	0	5.2	0.519
Sample 8 (CA=95; PIA=60)	1.6	0	4.4	0.364

Table 19. Z-Score Comparisons by Post-implantation Age: Participant 4.

Participant 4	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=65; PIA=42)	0.2	0	0.7	0.286
Sample 2 (CA=68; PIA=45)	0.2	0.4	0.7	-0.286
Sample 3 (CA=71; PIA=48)	0.1	0.3	0.6	-0.333
Sample 4 (CA=74; PIA=51)	0.1	0	0.6	0.167
Sample 5 (CA=77; PIA=54)	0.1	0	0.6	0.167
Sample 6 (CA=80 PIA=57)	0.1	0.4	0.6	-0.500
Sample 7 (CA=85; PIA=61)	0.1	0	0.6	0.167
Progressive Assimilation				
Sample 1 (CA=65; PIA=42)	0.2	0	0.7	0.286
Sample 2 (CA=68; PIA=45)	0.2	0	0.7	0.286
Sample 3 (CA=71; PIA=48)	0.1	0	0.6	0.167
Sample 4 (CA=74; PIA=51)	0.1	0.5	0.6	-0.667
Sample 5 (CA=77; PIA=54)	0.1	0	0.6	0.167
Sample 6 (CA=80 PIA=57)	0.1	0.5	0.6	-0.667
Sample 7 (CA=85; PIA=61)	0.1	0	0.6	0.167
Cluster Reduction - Initial				
Sample 1 (CA=65; PIA=42)	24.7	60.7	21	-1.714
Sample 2 (CA=68; PIA=45)	24.7	35.7	21	-0.524
Sample 3 (CA=71; PIA=48)	15.3	18.2	21.4	-0.136
Sample 4 (CA=74; PIA=51)	15.3	0	21.4	0.715
Sample 5 (CA=77; PIA=54)	15.3	17.9	21.4	-0.121
Sample 6 (CA=80 PIA=57)	15.3	20	21.4	-0.220
Sample 7 (CA=85; PIA=61)	9.7	8.3	15.6	0.090
Cluster Reduction - Final				
Sample 1 (CA=65; PIA=42)	24.7	12.1	21	0.600
Sample 2 (CA=68; PIA=45)	24.7	23.8	21	0.043
Sample 3 (CA=71; PIA=48)	15.3	15.2	21.4	0.005
Sample 4 (CA=74; PIA=51)	15.3	15.8	21.4	-0.023
Sample 5 (CA=77; PIA=54)	15.3	15.8	21.4	-0.023
Sample 6 (CA=80 PIA=57)	15.3	24.6	21.4	-0.435
Sample 7 (CA=85; PIA=61)	9.7	5.4	15.6	0.276
Final Consonant Deletion				
Sample 1 (CA=65; PIA=42)	4.9	5.7	8.4	-0.095
Sample 2 (CA=68; PIA=45)	4.9	7	8.4	-0.250
Sample 3 (CA=71; PIA=48)	3.2	3.6	6.5	-0.062
Sample 4 (CA=74; PIA=51)	3.2	8.1	6.5	-0.754
Sample 5 (CA=77; PIA=54)	3.2	8.9	6.5	-0.877
Sample 6 (CA=80 PIA=57)	3.2	14.3	6.5	-1.708
Sample 7 (CA=85; PIA=61)	2.4	1.9	3.3	0.152

Table 19. Continued.

Participant 4	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Liquid Simplification - Initial				
Sample 1 (CA=65; PIA=42)	8	10	9.3	-0.215
Sample 2 (CA=68; PIA=45)	8	16.7	9.3	-0.935
Sample 3 (CA=71; PIA=48)	4.7	6.3	9.2	-0.174
Sample 4 (CA=74; PIA=51)	4.7	0	9.2	0.511
Sample 5 (CA=77; PIA=54)	4.7	22.2	9.2	-1.902
Sample 6 (CA=80 PIA=57)	4.7	0	9.2	0.511
Sample 7 (CA=85; PIA=61)	4.5	9.1	8.7	-0.529
Liquid Simplification - Final				
Sample 1 (CA=65; PIA=42)	8	0	9.3	0.860
Sample 2 (CA=68; PIA=45)	8	4.3	9.3	0.398
Sample 3 (CA=71; PIA=48)	4.7	0	9.2	0.511
Sample 4 (CA=74; PIA=51)	4.7	0	9.2	0.511
Sample 5 (CA=77; PIA=54)	4.7	2.9	9.2	0.196
Sample 6 (CA=80 PIA=57)	4.7	0	9.2	0.511
Sample 7 (CA=85; PIA=61)	4.5	0	8.7	0.517
Palatal Fronting - Initial				
Sample 1 (CA=65; PIA=42)	5.5	0	10.9	0.505
Sample 2 (CA=68; PIA=45)	5.5	0	10.9	0.505
Sample 3 (CA=71; PIA=48)	2.7	0	5.2	0.519
Sample 4 (CA=74; PIA=51)	2.7	0	5.2	0.519
Sample 5 (CA=77; PIA=54)	2.7	0	5.2	0.519
Sample 6 (CA=80 PIA=57)	2.7	0	5.2	0.519
Sample 7 (CA=85; PIA=61)	1.6	0	4.4	0.364
Palatal Fronting - Final				
Sample 1 (CA=65; PIA=42)	5.5	0	10.9	0.505
Sample 2 (CA=68; PIA=45)	5.5	0	10.9	0.505
Sample 3 (CA=71; PIA=48)	2.7	0	5.2	0.519
Sample 4 (CA=74; PIA=51)	2.7	0	5.2	0.519
Sample 5 (CA=77; PIA=54)	2.7	12.5	5.2	-1.885
Sample 6 (CA=80 PIA=57)	2.7	0	5.2	0.519
Sample 7 (CA=85; PIA=61)	1.6	0	4.4	0.364
Stopping - Initial				
Sample 1 (CA=65; PIA=42)	2	43.1	4.1	-10.024
Sample 2 (CA=68; PIA=45)	2	52.4	4.1	-12.293
Sample 3 (CA=71; PIA=48)	1.9	65.1	3.3	-19.152
Sample 4 (CA=74; PIA=51)	1.9	72.1	3.3	-21.273
Sample 5 (CA=77; PIA=54)	1.9	29.3	3.3	-8.303
Sample 6 (CA=80 PIA=57)	1.9	57.9	3.3	-16.970
Sample 7 (CA=85; PIA=61)	0.8	0	1.9	0.421

Table 19. Continued.

Participant 4	Group Mean	Subject %	Group SD	Z-Score
Stopping - Final				
Sample 1 (CA=65; PIA=42)	2	0	4.1	0.488
Sample 2 (CA=68; PIA=45)	2	0	4.1	0.488
Sample 3 (CA=71; PIA=48)	1.9	3.3	3.3	-0.424
Sample 4 (CA=74; PIA=51)	1.9	0	3.3	0.576
Sample 5 (CA=77; PIA=54)	1.9	3.6	3.3	-0.515
Sample 6 (CA=80 PIA=57)	1.9	0	3.3	0.576
Sample 7 (CA=85; PIA=61)	0.8	0	1.9	0.421
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=65; PIA=42)	1.3	0	2.8	0.464
Sample 2 (CA=68; PIA=45)	1.3	0	2.8	0.464
Sample 3 (CA=71; PIA=48)	0.7	1.5	1.8	-0.444
Sample 4 (CA=74; PIA=51)	0.7	3.3	1.8	-1.444
Sample 5 (CA=77; PIA=54)	0.7	0	1.8	0.389
Sample 6 (CA=80 PIA=57)	0.7	1.2	1.8	-0.278
Sample 7 (CA=85; PIA=61)	0.5	0	1.5	0.333
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=65; PIA=42)	1.3	50	2.8	-17.393
Sample 2 (CA=68; PIA=45)	1.3	25	2.8	-8.464
Sample 3 (CA=71; PIA=48)	0.7	10	1.8	-5.167
Sample 4 (CA=74; PIA=51)	0.7	0	1.8	0.389
Sample 5 (CA=77; PIA=54)	0.7	0	1.8	0.389
Sample 6 (CA=80 PIA=57)	0.7	0	1.8	0.389
Sample 7 (CA=85; PIA=61)	0.5	20	1.5	-13.000
Velar Fronting - Initial				
Sample 1 (CA=65; PIA=42)	5.5	0	10.9	0.505
Sample 2 (CA=68; PIA=45)	5.5	0	10.9	0.505
Sample 3 (CA=71; PIA=48)	2.7	0	5.2	0.519
Sample 4 (CA=74; PIA=51)	2.7	5	5.2	-0.442
Sample 5 (CA=77; PIA=54)	2.7	0	5.2	0.519
Sample 6 (CA=80 PIA=57)	2.7	0	5.2	0.519
Sample 7 (CA=85; PIA=61)	1.6	0	4.4	0.364
Velar Fronting - Final				
Sample 1 (CA=65; PIA=42)	5.5	0	10.9	0.505
Sample 2 (CA=68; PIA=45)	5.5	0	10.9	0.505
Sample 3 (CA=71; PIA=48)	2.7	0	5.2	0.519
Sample 4 (CA=74; PIA=51)	2.7	0	5.2	0.519
Sample 5 (CA=77; PIA=54)	2.7	0	5.2	0.519
Sample 6 (CA=80 PIA=57)	2.7	0	5.2	0.519
Sample 7 (CA=85; PIA=61)	1.6	0	4.4	0.364

Table 20. Z-Score Comparisons by Post-implantation Age: Participant 5.

Participant 5	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=58; PIA=27)	0.1	0	0.5	0.200
Sample 2 (CA=62; PIA=30)	0.1	0	0.5	0.200
Sample 3 (CA=65; PIA=33)	0.1	0.5	0.5	-0.800
Sample 4 (CA=70; PIA=39)	0.1	0	0.4	0.250
Sample 5 (CA=74; PIA=42)	0.2	0	0.7	0.286
Sample 6 (CA=76 PIA=45)	0.2	0.3	0.7	-0.143
Progressive Assimilation				
Sample 1 (CA=58; PIA=27)	0.1	0	0.5	0.200
Sample 2 (CA=62; PIA=30)	0.1	0	0.5	0.200
Sample 3 (CA=65; PIA=33)	0.1	0	0.5	0.200
Sample 4 (CA=70; PIA=39)	0.1	0.5	0.4	-1.000
Sample 5 (CA=74; PIA=42)	0.2	0	0.7	0.286
Sample 6 (CA=76 PIA=45)	0.2	0	0.7	0.286
Cluster Reduction - Initial				
Sample 1 (CA=58; PIA=27)	67.7	9.1	21.4	2.738
Sample 2 (CA=62; PIA=30)	67.7	4	21.4	2.977
Sample 3 (CA=65; PIA=33)	67.7	44.4	21.4	1.089
Sample 4 (CA=70; PIA=39)	41.9	21.1	26.1	0.797
Sample 5 (CA=74; PIA=42)	24.7	0	21	1.176
Sample 6 (CA=76 PIA=45)	24.7	11.1	21	0.648
Cluster Reduction - Final				
Sample 1 (CA=58; PIA=27)	67.7	31	21.4	1.715
Sample 2 (CA=62; PIA=30)	67.7	21.6	21.4	2.154
Sample 3 (CA=65; PIA=33)	67.7	20.7	21.4	2.196
Sample 4 (CA=70; PIA=39)	41.9	19	26.1	0.877
Sample 5 (CA=74; PIA=42)	24.7	14.3	21	0.495
Sample 6 (CA=76 PIA=45)	24.7	21.6	21	0.148
Final Consonant Deletion				
Sample 1 (CA=58; PIA=27)	5.8	19.6	6.6	-2.091
Sample 2 (CA=62; PIA=30)	5.8	21.5	6.6	-2.379
Sample 3 (CA=65; PIA=33)	5.8	13	6.6	-1.091
Sample 4 (CA=70; PIA=39)	7.5	13.5	10.8	-0.556
Sample 5 (CA=74; PIA=42)	4.9	10.8	8.4	-0.702
Sample 6 (CA=76 PIA=45)	4.9	3.3	8.4	0.190
Liquid Simplification - Initial				
Sample 1 (CA=58; PIA=27)	24.5	13.3	17	0.659
Sample 2 (CA=62; PIA=30)	24.5	40	17	-0.912

Table 20. Continued.

Participant 5	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 3 (CA=65; PIA=33)	24.5	22.2	17	0.135
Sample 4 (CA=70; PIA=39)	11.7	0	12.9	0.907
Sample 5 (CA=74; PIA=42)	8	0	9.3	0.860
Sample 6 (CA=76 PIA=45)	8	0	9.3	0.860
Liquid Simplification - Final				
Sample 1 (CA=58; PIA=27)	24.5	6.3	17	1.071
Sample 2 (CA=62; PIA=30)	24.5	26.5	17	-0.118
Sample 3 (CA=65; PIA=33)	24.5	0	17	1.441
Sample 4 (CA=70; PIA=39)	11.7	5.9	12.9	0.450
Sample 5 (CA=74; PIA=42)	8	6.3	9.3	0.183
Sample 6 (CA=76 PIA=45)	8	0	9.3	0.860
Palatal Fronting - Initial				
Sample 1 (CA=58; PIA=27)	18.3	0	16.9	1.083
Sample 2 (CA=62; PIA=30)	18.3	0	16.9	1.083
Sample 3 (CA=65; PIA=33)	18.3	0	16.9	1.083
Sample 4 (CA=70; PIA=39)	8.1	4	12	0.342
Sample 5 (CA=74; PIA=42)	5.5	0	10.9	0.505
Sample 6 (CA=76 PIA=45)	5.5	0	10.9	0.505
Palatal Fronting - Final				
Sample 1 (CA=58; PIA=27)	18.3	0	16.9	1.083
Sample 2 (CA=62; PIA=30)	18.3	0	16.9	1.083
Sample 3 (CA=65; PIA=33)	18.3	0	16.9	1.083
Sample 4 (CA=70; PIA=39)	8.1	0	12	0.675
Sample 5 (CA=74; PIA=42)	5.5	0	10.9	0.505
Sample 6 (CA=76 PIA=45)	5.5	0	10.9	0.505
Stopping - Initial				
Sample 1 (CA=58; PIA=27)	9	14.3	15.1	-0.351
Sample 2 (CA=62; PIA=30)	9	35.3	15.1	-1.742
Sample 3 (CA=65; PIA=33)	9	75	15.1	-4.371
Sample 4 (CA=70; PIA=39)	3.9	41.5	7.7	-4.883
Sample 5 (CA=74; PIA=42)	2	12.8	4.1	-2.634
Sample 6 (CA=76 PIA=45)	2	39.3	4.1	-9.098
Stopping - Final				
Sample 1 (CA=58; PIA=27)	9	3	15.1	0.397
Sample 2 (CA=62; PIA=30)	9	0	15.1	0.596
Sample 3 (CA=65; PIA=33)	9	0	15.1	0.596
Sample 4 (CA=70; PIA=39)	3.9	0	7.7	0.506
Sample 5 (CA=74; PIA=42)	2	0	4.1	0.488
Sample 6 (CA=76 PIA=45)	2	3.3	4.1	-0.317
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=58; PIA=27)	2.8	3.5	3.4	-0.206
Sample 2 (CA=62; PIA=30)	2.8	3.5	3.4	-0.206

Table 20. Continued.

Participant 5	Group Mean	Subject %	Group SD	Z-Score
Sample 3 (CA=65; PIA=33)	2.8	1.3	3.4	0.441
Sample 4 (CA=70; PIA=39)	2.3	3	4.7	-0.149
Sample 5 (CA=74; PIA=42)	1.3	0	2.8	0.464
Sample 6 (CA=76 PIA=45)	1.3	3.5	2.8	-0.786
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=58; PIA=27)	2.8	0	3.4	0.824
Sample 2 (CA=62; PIA=30)	2.8	11.1	3.4	-2.441
Sample 3 (CA=65; PIA=33)	2.8	0	3.4	0.824
Sample 4 (CA=70; PIA=39)	2.3	28.6	4.7	-5.596
Sample 5 (CA=74; PIA=42)	1.3	0	2.8	0.464
Sample 6 (CA=76 PIA=45)	1.3	0	2.8	0.464
Velar Fronting - Initial				
Sample 1 (CA=58; PIA=27)	18.3	7.1	16.9	0.663
Sample 2 (CA=62; PIA=30)	18.3	2	16.9	0.964
Sample 3 (CA=65; PIA=33)	18.3	0	16.9	1.083
Sample 4 (CA=70; PIA=39)	8.1	3.8	12	0.358
Sample 5 (CA=74; PIA=42)	5.5	0	10.9	0.505
Sample 6 (CA=76 PIA=45)	5.5	0	10.9	0.505
Velar Fronting - Final				
Sample 1 (CA=58; PIA=27)	18.3	0	16.9	1.083
Sample 2 (CA=62; PIA=30)	18.3	0	16.9	1.083
Sample 3 (CA=65; PIA=33)	18.3	0	16.9	1.083
Sample 4 (CA=70; PIA=39)	8.1	0	12	0.675
Sample 5 (CA=74; PIA=42)	5.5	0	10.9	0.505
Sample 6 (CA=76 PIA=45)	5.5	0	10.9	0.505

Table 21. Z-Score Comparisons by Post-implantation Age: Participant 6.

Participant 6	Group Mean	Subject %	Group SD	Z-Score
Regressive Assimilation				
Sample 1 (CA=45; PIA=26)	0.1	0	0.5	0.200
Sample 2 (CA=49; PIA=29)	0.1	0.6	0.5	-1.000
Sample 3 (CA=52; PIA=32)	0.1	0	0.5	0.200
Sample 4 (CA=55; PIA=35)	0.1	0.6	0.5	-1.000
Sample 5 (CA=59; PIA=38)	0.1	0	0.5	0.200
Sample 6 (CA=62; PIA=41)	0.1	0.4	0.4	-0.750
Progressive Assimilation				
Sample 1 (CA=45; PIA=26)	0.1	0	0.5	0.200
Sample 2 (CA=49; PIA=29)	0.1	0	0.5	0.200
Sample 3 (CA=52; PIA=32)	0.1	0	0.5	0.200
Sample 4 (CA=55; PIA=35)	0.1	0.7	0.5	-1.200
Sample 5 (CA=59; PIA=38)	0.1	0	0.5	0.200
Sample 6 (CA=62; PIA=41)	0.1	0	0.4	0.250
Cluster Reduction - Initial				
Sample 1 (CA=45; PIA=26)	67.7	87.5	21.4	-0.925
Sample 2 (CA=49; PIA=29)	67.7	79.2	21.4	-0.537
Sample 3 (CA=52; PIA=32)	67.7	88.2	21.4	-0.958
Sample 4 (CA=55; PIA=35)	67.7	57.9	21.4	0.458
Sample 5 (CA=59; PIA=38)	41.9	55.6	26.1	-0.525
Sample 6 (CA=62; PIA=41)	41.9	40	26.1	0.073
Cluster Reduction - Final				
Sample 1 (CA=45; PIA=26)	67.7	71.4	21.4	-0.173
Sample 2 (CA=49; PIA=29)	67.7	69.2	21.4	-0.070
Sample 3 (CA=52; PIA=32)	67.7	75	21.4	-0.341
Sample 4 (CA=55; PIA=35)	67.7	38.5	21.4	1.364
Sample 5 (CA=59; PIA=38)	41.9	26.7	26.1	0.582
Sample 6 (CA=62; PIA=41)	41.9	30.3	26.1	0.444
Final Consonant Deletion				
Sample 1 (CA=45; PIA=26)	5.8	31	6.6	-3.818
Sample 2 (CA=49; PIA=29)	5.8	32.2	6.6	-4.000
Sample 3 (CA=52; PIA=32)	5.8	26.6	6.6	-3.152
Sample 4 (CA=55; PIA=35)	5.8	8.4	6.6	-0.394
Sample 5 (CA=59; PIA=38)	7.5	5.1	10.8	0.222
Sample 6 (CA=62; PIA=41)	7.5	25.9	10.8	-1.704
Liquid Simplification - Initial				
Sample 1 (CA=45; PIA=26)	24.5	0	17	1.441
Sample 2 (CA=49; PIA=29)	24.5	0	17	1.441
Sample 3 (CA=52; PIA=32)	24.5	20	17	0.265
Sample 4 (CA=55; PIA=35)	24.5	0	17	1.441

Table 21. Continued.

Participant 6	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 5 (CA=59; PIA=38)	11.7	40	12.9	-2.194
Sample 6 (CA=62; PIA=41)	11.7	28.6	12.9	-1.310
Liquid Simplification - Final				
Sample 1 (CA=45; PIA=26)	24.5	37.5	17	-0.765
Sample 2 (CA=49; PIA=29)	24.5	42.9	17	-1.082
Sample 3 (CA=52; PIA=32)	24.5	60	17	-2.088
Sample 4 (CA=55; PIA=35)	24.5	35.7	17	-0.659
Sample 5 (CA=59; PIA=38)	11.7	21.4	12.9	-0.752
Sample 6 (CA=62; PIA=41)	11.7	21.9	12.9	-0.791
Palatal Fronting - Initial				
Sample 1 (CA=45; PIA=26)	18.3	0	16.9	1.083
Sample 2 (CA=49; PIA=29)	18.3	0	16.9	1.083
Sample 3 (CA=52; PIA=32)	18.3	0	16.9	1.083
Sample 4 (CA=55; PIA=35)	18.3	0	16.9	1.083
Sample 5 (CA=59; PIA=38)	8.1	0	12	0.675
Sample 6 (CA=62; PIA=41)	8.1	0	12	0.675
Palatal Fronting - Final				
Sample 1 (CA=45; PIA=26)	18.3	0	16.9	1.083
Sample 2 (CA=49; PIA=29)	18.3	0	16.9	1.083
Sample 3 (CA=52; PIA=32)	18.3	0	16.9	1.083
Sample 4 (CA=55; PIA=35)	18.3	0	16.9	1.083
Sample 5 (CA=59; PIA=38)	8.1	0	12	0.675
Sample 6 (CA=62; PIA=41)	8.1	0	12	0.675
Stopping - Initial				
Sample 1 (CA=45; PIA=26)	9	50	15.1	-2.715
Sample 2 (CA=49; PIA=29)	9	35	15.1	-1.722
Sample 3 (CA=52; PIA=32)	9	55.8	15.1	-3.099
Sample 4 (CA=55; PIA=35)	9	16.4	15.1	-0.490
Sample 5 (CA=59; PIA=38)	3.9	56.6	7.7	-6.844
Sample 6 (CA=62; PIA=41)	3.9	63	7.7	-7.675
Stopping - Final				
Sample 1 (CA=45; PIA=26)	9	0	15.1	0.596
Sample 2 (CA=49; PIA=29)	9	0	15.1	0.596
Sample 3 (CA=52; PIA=32)	9	7.7	15.1	0.086
Sample 4 (CA=55; PIA=35)	9	0	15.1	0.596
Sample 5 (CA=59; PIA=38)	3.9	3.8	7.7	0.013
Sample 6 (CA=62; PIA=41)	3.9	0	7.7	0.506
Unstressed Syllable Deletion - 2 Syllable				
Sample 1 (CA=45; PIA=26)	2.8	5	3.4	-0.647
Sample 2 (CA=49; PIA=29)	2.8	2.4	3.4	0.118

Table 21. Continued.

Participant 6	**Group Mean**	**Subject %**	**Group SD**	**Z-Score**
Sample 3 (CA=52; PIA=32)	2.8	6	3.4	-0.941
Sample 4 (CA=55; PIA=35)	2.8	13.4	3.4	-3.118
Sample 5 (CA=59; PIA=38)	2.3	0	4.7	0.489
Sample 6 (CA=62; PIA=41)	2.3	10.7	4.7	-1.787
Unstressed Syllable Deletion - 3+ Syllable				
Sample 1 (CA=45; PIA=26)	2.8	25	3.4	-6.529
Sample 2 (CA=49; PIA=29)	2.8	0	3.4	0.824
Sample 3 (CA=52; PIA=32)	2.8	20	3.4	-5.059
Sample 4 (CA=55; PIA=35)	2.8	40	3.4	-10.941
Sample 5 (CA=59; PIA=38)	2.3	0	4.7	0.489
Sample 6 (CA=62; PIA=41)	2.3	6.3	4.7	-0.851
Velar Fronting - Initial				
Sample 1 (CA=45; PIA=26)	18.3	0	16.9	1.083
Sample 2 (CA=49; PIA=29)	18.3	40	16.9	-1.284
Sample 3 (CA=52; PIA=32)	18.3	0	16.9	1.083
Sample 4 (CA=55; PIA=35)	18.3	92.3	16.9	-4.379
Sample 5 (CA=59; PIA=38)	8.1	0	12	0.675
Sample 6 (CA=62; PIA=41)	8.1	64.7	12	-4.717
Velar Fronting - Final				
Sample 1 (CA=45; PIA=26)	18.3	0	16.9	1.083
Sample 2 (CA=49; PIA=29)	18.3	6.3	16.9	0.710
Sample 3 (CA=52; PIA=32)	18.3	0	16.9	1.083
Sample 4 (CA=55; PIA=35)	18.3	11.1	16.9	0.426
Sample 5 (CA=59; PIA=38)	8.1	0	12	0.675
Sample 6 (CA=62; PIA=41)	8.1	0	12	0.675

VITA

Rhonda Gale Parker was born in Wise, VA on December 31, 1973. She graduated with honors from J.J. Kelly High School in 1992. From there, she went to Virginia Tech and received a B.S. in Management Science in 1996. After a few years working as a software developer, primarily in a consulting role, she returned to college to pursue an interest in Linguistics. She then attended the University of Georgia, Athens, GA and received a B.A. in Linguistics in 2002. While at UGA, she further honed her interests to disordered communication. It was in the fall of 2003 that Rhonda began graduate work at the University of Tennessee, Knoxville. Soon after defending her master's thesis, Rhonda received a Master of Arts degree in speech pathology in December 2005.

VITA

[illegible] was born in [illegible], [illegible] 31, 197[illegible]. She graduated with honors from [illegible] High School in 19[illegible]. From there, she went to [illegible] and received a B.S. in [illegible] Science in 199[illegible]. After a few years [illegible], she returned [illegible]. She then attended the University of Georgia, Athens, GA and [illegible] in 2002. While at UGA, she [illegible] in the fall of 2003 that [illegible] began graduate work at the University of Tennessee, Knoxville. Soon after defending her master's thesis, [illegible] a Master of Arts degree in speech pathology in December 2005.