Visual feedback technology with a focus on ultrasound: the effects of speech habilitation for adolescents with sensorineural hearing loss

by

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Abstract

Developments in instrumentation offer new possibilities in habilitation for speech-language pathology. The series of studies in this manuscript-style thesis represents an investigation of two articulatory feedback instruments, ultrasound and electropalatography, in speech habilitation for adolescents with hearing loss and related speech impairments. The first study in the dissertation investigated the outcomes for vowel intervention for three adolescents with hearing impairment. Acoustic analysis and expert transcription with perceptual anchors showed positive outcomes for all participants (Bacsfalvi et al., 2007).The next study focused on three adolescent cochlear implant users with long-term speech errors secondary to deafness. All students were successful in learning the articulatory gestures components of the target phoneme /ɹ/, and one made significant progress in using the new phones in words. An additional finding of the first two papers concerned the tongue shapes and tongue-palate contacts of the speakers. Their tongue movements pre-treatment were similar to those of very young children (Green et al., 2000; Oh, 2005), who also show little or no differentiation of the parts of the tongue, lip and jaw during speech production. Post-therapy, these speakers showed a greater range of tongue movement, more similar to hearing speakers.

Two longer-term outcomes studies followed. The first study examined the speech of the seven former participants 2-4 years post intervention. Perceptual judgements by expert listeners suggested that six out of seven speakers either maintained or continued to improve their level of immediate post-treatment performance. A qualitative study based on interview revealed the experiences of therapy with visual feedback technology for five of the clinical investigation participants and five related stakeholders. Key themes that emerged were: "better speech", "improvement", "visual feedback is helpful", "remembering what was learned", and "new information".

The series of studies contribute to speech development research in speakers with severe hearing loss in addition to investigating advances in habilitation methods. The results show that ultrasound and electropalatography, as adjuncts to speech therapy, can increase speaker intelligibility, self-confidence and oral communication and have the potential to reduce treatment time and increase cost-effectiveness of treatment. Further large-scale investigation is warranted, for speakers with and without hearing impairment.

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Co-Authorship Statement

Together with my doctoral supervisor, Dr. B.M. Bernhardt, I planned the research programme in this dissertation. My contributions include: (i) selecting and designing the research studies, in consultation with Dr. Bernhardt and others where further consultation was required for specialized study designs (consultation with other professors included: Dr. B. Gick, Dr. J. Lucyshyn and Dr. J. Perry), (ii) recruiting participants and collecting data with minimal supervision (research assistants helped with some of the data collection), (iii) analysing and interpreting data in collaboration with Dr. Bernhardt, and (iv) preparing drafts of all of the dissertation chapters, with editorial comments from Dr. Bernhardt and committee members. Additionally, research assistants assisted with some of the data analysis or data management as noted in each chapter. Chapters 2 and 4 were co-authored for journal submission with Dr. Bernhardt and Dr. Gick, with my contributions as indicated above. Chapters 3 and 5 were solo-authored for journal submission.

CHAPTER 1 Introduction

Speech-language pathologists (SLPs) working with students with severe to profound bilateral sensorineural hearing loss encounter many students with unintelligible speech. A number of studies have reported that on average, only 20% of words of profoundly hearing-impaired speakers are intelligible (Brannon, 1966; Markides, 1970; Smith, 1975). Many deaf and hard of hearing speakers may have had little or no access to speech-language pathology services. Those who have had access to such services may not have had sufficient hours of practice to learn to produce intelligible speech, or may have practiced with paraprofessionals with insufficient training. A recent study of outcomes of 86 children with mild to profound congenital hearing loss and normal cognition suggests that therapists, educators and other professionals working in school systems are often failing children with hearing losses more generally (Wake et al., 2004). In their study, the children with hearing loss performed at lower levels than children without hearing loss in all areas: behaviour, speech production, language, reading and writing, adaptive skills and psychosocial quality of life scores. This is not to say that speakers with hearing loss cannot be successful in education or life skill development or, as is the focus in the current dissertation, develop intelligible speech. Yoshinaga-Itano (1998a) reported that the results of many past studies, including her own, have pointed to the difference in the development of speech versus language skills. She concluded that language requires intervention in the first year of life but that speech does not. Even if no speech skills are present in the first few years of life, a child with a hearing loss may be able to develop intelligible speech later. The studies in the following dissertation make and test the assumption that speech skills can improve in adolescence or later.

Purpose and Format of the Dissertation

As noted, the following dissertation began with the premise that adolescents may be able to improve their speech skills through speech habilitation. A series of studies is presented which investigated the effects of visual feedback technology as an adjunct to speech habilitation in adolescents with severe-to-profound bilateral sensorineural hearing loss. These investigations included an investigation of the effects of visual feedback technology, with a focus on ultrasound, in remediation of persistent speech issues including speech sounds requiring remediation (vowels, fricatives, and liquids). The first two studies focused on tense versus lax vowels (Chapter 2), and remediation of /ɹ/ for students with severe-to-profound bilateral sensorineural hearing loss (chapter 3: Bacsfalvi, 2007; Bacsfalvi et al., 2007). Two companion studies were completed to examine the quantitative and qualitative effects of ultrasound therapy on the main stakeholders (chapters 4 and 5 in this dissertation).

As a background for the manuscripts presented in this dissertation, this first chapter reviews literature relevant to the overall research program: (a) the speech and voice characteristics of persons with severe congenital hearing impairment, (b) speech habilitation approaches with persons with severe congenital hearing impairment, including people with cochlear implants and (c) methods in evaluation of outcomes in speech habilitation, including both quantitative and qualitative approaches and an overview of speech perception and listener studies. The literature review focuses particularly on intervention with biofeedback instrumentation, intervention for individuals with severe to profound hearing loss, and research methods for the following studies. There are many reasons for these foci: first, there has never been such a review, second, there are many relevant studies scattered across disciplines, third, many of the studies on biofeedback yield promising outcomes, and fourth, there have been limited success rates with traditional non-instrumental intervention strategies over the past fifty years.

Definitions Concerning Hearing Impairment

It is important to be aware that not all studies are clear about their definitions of degree of hearing loss. In general, hearing loss in decibels is described as mild if the pure tone average hearing threshold level (HTL) is 20-39 decibels, moderate if the HTL is 40 to 54 decibels, moderately severe if the HTL is 55-69 decibels, severe if the HTL is 70 to 89 decibels, and profound if the HTL is over 90 decibels (Katz and White, 1992). Hearing losses may also be symmetrical or asymmetrical. Wherever possible, severity of hearing loss is indicated for the people participating in the studies.

Reference points for the concept of deafness also need to be clarified when discussing habilitation services for people with differing degrees of hearing loss. A person who is deaf is someone whose hearing does not allow him or her to understand speech with or without a hearing aid. A person who is *hard-of-hearing* is someone whose disabled hearing allows them to understand speech with or without the use of a hearing aid (Moores, 2001). These definitions are used when possible. However, these definitions have not been used consistently by researchers.

Speech and Voice Characteristics of People who are Deaf and Hard of Hearing

The speech and voice characteristics of the deaf and hard of hearing vary according to severity of hearing loss, configuration of hearing loss (unilateral vs. bilateral; symmetrical vs. asymmetrical), age of onset, environmental factors such as family and resources and educational placement (Yoshinaga-Itano and Downey, 1996; Carney and Moeller, 1998; Yoshinaga-Itano, 1998a,b). Higgins et al. (1994) discussed the state of research aptly when they said that most studies of speakers with a variety of degrees of hearing loss had been primarily focused on perceptual or acoustic analysis or speech output studies. Studies of respiratory, phonatory, velopharyngeal and articulatory behaviours of speakers with hearing loss have characterized speech of deaf people as having abnormal voice quality, poor intelligibility, slow speaking rate and abnormal speech breathing. Vocal quality has been described as harsh (Monsen, 1987; Wirz, 1978), and breathy (Hudgins, 1934; Rawlings, 1935; Higgins et al., 1994) with abnormal oral-nasal resonance balance (Markides, 1970; McClean, 1973; Tatchell, Stewart and Lapine, 1991), glottalization, cul-de-sac resonance (Boone, 1966; Higgins et al., 1994), abnormal pitch (Smith, 1975; Wirz, 1979) and vowel prolongations and neutralisations (Osberger, 1987). The characteristics of "deaf speech" have been well-documented over the years (Hudgins and Numbers, 1942; Smith, 1975; Nickerson, 1975; McGarr and Osberger, 1978; Metz et al., 1990; Higgins et al., 1994, Yoshinaga-Itano, 1998a,b). Massaro and Light (2004) summed up the most common segmental difficulties of the deaf and hard of hearing populations as, "voiced-voiceless errors, omissions/distortions of initial consonants, omission of consonants in clusters, omissions/distortions of final consonants, nasalization, substitution of one consonant for another, and intrusive voicing between neighbouring consonants" (p.305). More detailed discussion follows in the subsequent sub-sections.

In terms of hearing impairment level, Yoshinaga-Itano and Downey (1996) found that better hearing corresponded to better speech intelligibility. The largest factor affecting intelligibility was severity of hearing loss. They reported further that little speech improvement was seen at any age. In their study (based on data collected in the 1970s and 1980s) they showed speech characteristics of this population to be very similar to the deaf and hard of hearing children populations in 1996. Very little had changed in that twenty-year period, in spite of a vast amount of research, teaching and clinical expertise into the education and study of speech and language development and learning for people with a hearing loss. Two years later, Yoshinaga-Itano (1998a) commented that there were some successful outcomes for speech learning later in life. Overall, however, she found that speech abilities of children with profound hearing loss generally remained poor regardless of the fact that families received 1 ½ hours a week of services related to developing speech, language and listening skills from time of diagnosis until age 3. This article was unclear, however, as to the kind of services offered and by which professional. Results of this study were mixed, with a variety of characteristics found in all children that were similar to those of many studies of speech and voice characteristics of the deaf and hard of hearing. That is, the speech of the participants contained vowel errors, consonant substitutions, word final deletions, consonant deletions in clusters, and phonetic distortions. An interesting finding of this study was the significant positive correlation between higher language production skills and speech production. While the study focused on a variety of language skills including speech, many other studies investigated speech alone.

In a study by Van Beinum and Doppen (2003) alternations of consonant- vowel (CV) movements were scarce when compared with those of hearing infants. The deaf infants were all raised in different communication environments: one in Total Communication (TC) (combination of oral method plus signing and finger spelling in this paper), two in Dutch Sign Language (DSL is a visual language with no oral counterpart) and two in oral environments (only spoken language is used). This investigation of ten mother-infant pairs (five infants with profound hearing loss and five hearing infants) revealed that CV structures were quite different when compared with early speech of hearing infants. The infants with hearing loss were found to produce more utterances "...with one articulation movement but without phonation than hearing infants" (p.47). The infants with hearing loss produced more utterances with vowel-like sounds, more labials in combination with central vowels, and more velars in combination with central vowels than hearing infants.

It is important to keep in mind the within-child factors that influence speech development in deaf and hard of hearing children. These factors include the age of onset of hearing loss, the age that intervention begins, when and if sensory aids are fitted, what type of educational programme is used for speech and language training, the degree of hearing loss, family involvement and any other psycho-social factors that may be relevant to the success of the child (Carney and Moeller, 1998). Whenever possible these factors will be clearly stated for each study in the current review.

Voice and Suprasegmental Factors Affecting Speech Intelligibility

Voice and suprasegmental factors affect speech intelligibility. The literature describes many vocal qualities that characterize the speech of deaf people, such as harshness, breathiness, abnormal oral-nasal resonance, cul-de-sac resonance, and abnormal pitch.

Harshness

Wirz (1992) found that 72.5% of the deaf speakers in their study showed harsh voice quality compared with 25% of their hearing speakers. This was discovered using the Vocal Profile Analysis (Wirz, 1992) with 40 profoundly hearing-impaired young adults, aged between 18 and 23 years, in tertiary education and with an average hearing loss of 85 dB (HTL). Wirz (1992) hypothesized that harshness was probably related to the high incidence of laryngeal tension observed in the speakers.

Breathiness

The speech of many deaf and hard of hearing speakers is characterized by breathiness, defined as having excessive airflow during voicing. Scuri (1935) reported that deaf speakers tend to use more breath while speaking than when not speaking, whereas hearing speakers use about the same amount in both cases. Higgins et al. (1994) also characterized the speech of the deaf speakers in their study as having a breathy quality, even in those speakers who had highly intelligible speech.

Abnormal Oral-Nasal Resonance Balance

Faulty control of the velum has long been recognised as a source of difficulty in the speech of the deaf. If the velopharyngeal port is opened when it should be closed, the speech may be perceived as hypernasal; if it is closed when it should be opened, hyponasality will result (Osberger and McGarr, 1982). Tatchell et al. (1991) studied 18 children with hearing impairment between 3 and 11 years of age. These children presented with hearing losses from mild to profound in severity. This study found no predictable pattern between degree of hearing loss and degree of nasality. However a higher degree of nasality was found in speakers with hearing loss than in speakers with normal hearing.

Cul-de-Sac Resonance

Cul-de-sac resonance is produced primarily by retracting the tongue toward the pharyngeal wall instead of placing it in a higher, forward position. Boone (1966) reported that cinefluorographic data showed deaf speakers to have less open space between the posterior tongue and the pharyngeal wall. Higgins et al. (1994) found that most of the participants in their study presented with cul-de-sac resonance.

Abnormal Pitch

Abnormal pitch can also contribute to poor intelligibility (McGarr and Osberger, 1978). Speakers who are deaf or hard of hearing may present with a great range of pitch use. Some speakers use monotone or flat intonation while others speak with an abnormally high pitch, and still others have erratic pitch fluctuations. Wirz (1992) reported results of application of a Vocal Profile Analysis scheme to 40 profoundly hearing impaired young adults with profound hearing loss between 18 and 23 as the following: 90% of deaf speakers compared with 27.5% of hearing speakers showed narrow pitch range, and 87.5% of deaf speakers compared with 7.5% of hearing speakers showed low pitch variability. Martony (1968) described pitch as having excessive variation, pitch breaks and erratic changes. The pitch of many speakers with deafness is often elevated when compared to hearing speakers of the same sex and age group. Higgins et al. (1994) found increased fundamental frequency (f0) for the group of speakers with hearing loss in their study. They indicated that this may be related to increased subglottal pressure, because all of the speakers in their study whose f0 was outside of the normal range, had above normal subglottal pressures. However, Ohala's (1978) study showed that subglottal pressures and air-flow rate can account for only a small part of pitch fluctuation. There are other factors such as muscle control, which account for bigger variations.

Overall pitch control causes considerable difficulty for speakers who are deaf, affecting speech intelligibility. Further study is needed to understand how these speakers are producing speech so that effective methods for habilitation may be put in place.

Articulatory and Voice Factors that Affect Intelligibility

As noted previously, articulatory factors reported in the literature include prolongations, voiced/voiceless errors, phonemic deletions, substitutions, omissions, phonetic 'distortions' (such as excessive nasalization), centralized tongue posture, tongue root retraction, abnormal vocal fold vibratory patterns and reduced control of vocal fold tension. Any of these factors may negatively affect intelligibility.

Articulatory Prolongations

Investigators have reported longer durations of words, sentences, vowels (Boone, 1966; Ling, 1976) and intraoral air pressures for individuals with moderate-to-profound hearing losses (Higgins et al., 1994). Higgins et al. (1994) indicated that in some deaf speakers prolongations occurred at the level of the larynx rather than the articulators, resulting in prolonged vocal fold articulatory gestures. Boone's (1966) spectrographic and cinefluorographic data suggested that deaf children take longer to say things, especially in terms of prolonged vowels and frequent pauses between words. In his study, vowels were often changed to diphthongs with upward or downward inflectional sweeps. Excessive pauses were found between words, resulting in no co-articulation between words.

Glottal Stop Insertion

Glottal stop insertion is the insertion of a glottal stop between syllables in a word or for other consonants. This greatly reduces intelligibility (Stevens, 1987). Osberger and McGarr (1982) reported that profoundly deaf children often substitute glottal stops for consonants produced in the centre and back of the mouth.

Voiced/Voiceless Errors

McGarr and Osberger (1978) found voiced-voiceless confusions were quite frequent in their study of fifty-seven 11-and 12-year-old profoundly deaf children. Calvert (1962) measured the durations of closure and release periods of consonants and found that when a plosive was intended to be unvoiced (e.g. /p,t/) and was heard as voiced (e.g. /b,d/), the duration of the release period was about the same as that of the voiced consonant when produced by a hearing speaker.

Consonant Deletions and Substitutions

Several investigators have reported irregular nasal productions substituted for an oral consonant, in the speech of persons who are deaf and hard of hearing (Markides, 1970; Stevens et al., 1974; Nickerson, 1975; Tatchell, et al., 1991). In Tatchell et al.'s (1991) study of 18 children with hearing impairment, irregular nasality (hyper- or hypo-nasality) was common but unpredictable in terms of hearing impairment level. The children who participated in their study demonstrated that nasality could be remediated. Hudgins and Numbers (1942), in their study of

192 deaf and hard of hearing children between the ages of 8 and 20, found excessive use of nasality in both consonants and vowels.

Other consonant deletion and substitution patterns have been found. Hudgins and Numbers (1942) found voice-voiceless errors were the most present overall, and many other consonant deletions and substitutions: for example, final consonant deletion, and substitutions of one consonant for another. Markides (1970) reported that children with mild-to-moderate hearing losses presented primarily with articulation mismatches for single consonants and consonant clusters. Stevens et al. (1974) found some lack of contrast between stop consonants and nasals in the speech of deaf persons. Bernhardt et al. (2003) indicated that the teen-aged participants in their study presented with difficulties with sibilant place contrasts, high frequency sibilants and lack of liquid and velar productions (non-visible consonants).

Vowel Substitutions

Angelocci at al. (1964) studied the vowel formants of teen-aged boys with hearing impairment and concluded that their vowels had higher fundamental frequencies and amplitudes for all vowels than those of hearing teenagers, and poor definition of formant areas. Gordon (1987) reported that substitutions for vowels typically were very close to the target vowel. Recent research by Bernhardt et al. (2003) confirms this finding with the adolescent participants showing neutralization of tense-lax contrasts for vowels of similar height and backness. Hudgins and Numbers (1942) characterized vowel production of children with hearing loss as neutral or more centralized, with frequent use of schwa. Monsen (1987) postulated that poor vowel production of the hearing impaired is due to the reduced visibility of articulatory gestures and distortion of second formant (F2) information in frequencies greater than 1000 Hz, where frequency sensitivity is often the poorest. Boone's (1966) data also showed a significant tendency toward a lowering of the F2, which is highly influenced by tongue position. F2 is related to the front-back tongue position as well as lip rounding (Ladefoged, 2001). The next section explores traditional speech training.

Traditional Speech Training

Therapy has been used for many years to ameliorate the voice and speech quality of the deaf and hard of hearing, with varied success. It is important to note that hearing aids have been used only relatively recently in history. It was not until the 1960s that hearing aids were accessible to the general public in North America. In addition, hearing aid technology was limited at that time. Hearing aid technology today is much more advanced and affords the user greater access to sound than in the past. However recent the advent of hearing aid technology, there is a long and rich history of speech teaching in both educational as well as medical settings for training speech. Many different speech teaching approaches were developed for schools for the deaf such as the Clarke School for the Deaf in the United States (Moores, 2001). Speech-language pathologists working with deaf people tended to use a more medical model, including deaf speech as disordered speech and clinical therapy visits. An extensive history of speech training and the similarities and differences between professions is beyond the scope of this paper. This paper investigates speech habilitation techniques primarily over the last forty years. In the following review, traditional therapy is defined as techniques that require no technology, but base intervention on some level of phonological and phonetic knowledge. For example, a phonological assessment may reveal word-final deletions as a phonologically deviant pattern for a person acquiring English.

The methodology of many speech teachers of the deaf and hard of hearing over the past forty years has been predominantly based on the teachings of Ling (1976). Ling proposed that specific speech sounds should not be taught to young children until they are able to produce pleasant vocal play patterns (1976, p. 114). Once these vocal behaviours are in place, then duration, loudness, and pitch need be established one at a time. At each level of segmental development suprasegmental structure also has to be taught. In addition, Ling (1976) espoused the importance of tongue movement and control development (p. 118). Once vowels have been taught then consonants can be taught – first teaching those consonants with the most visually salient cues and auditory cues (e.g., sounds that provide formant transitions in the lower frequencies). Next he recommended teaching consonant clusters based on whether they were produced by one or two articulators. Ling (1992) described in detail a step-by-step programme for teaching speech for children who were either deaf or hard-of-hearing.

Throughout the 1960s and early 1970s, a large number of aids and methods for speech training were implemented and tested (Strong, 1975). Wirz (1978) reported on a study of several centres throughout the United States about the different types of speech production training used with deaf and hard of hearing students. In the most successful programmes the Teachers of the Deaf and Hard of Hearing (TDHH), Speech-Language Pathologists (SLPs) and parents worked together as a team with the child. The most successful approaches included speech therapy and auditory training as taught together by SLPs, with teachers of the deaf and parents reinforcing speech instruction. Programmes that had excellent results, even for students aged 19, had a number of SLPs and involved speech training several times a week in a semi-intensive, highly structured speech therapy model.

Cued speech was also developed during this time, and was found to have some success by Wirz (1978). Cornett (1967) developed the cued speech approach to develop language, but found it had several other benefits: improved lip-reading abilities, improved generalization of speech production into spoken language and the development of spoken language before written language. The next section explores cued speech.

Cued Speech

Cued speech requires eight configurations and four hand positions to supplement natural speech, making speech production more easily understood. Each hand-cue represents a class of sounds (Strong, 1975). Cued speech hand configurations cannot be used on their own, but rather augment the information from the speakers lips (Cornett, 1967). Cornett (1967) described cued speech as an adjunct to lip-reading.

Since the cued speech approach was suggested in 1967 by Cornett, there has been a fair amount of research about its effectiveness (Nicholls, 1979). Advocates of cued speech believe that cued speech has an advantage over other communication approaches used by people who are deaf (Cornett, 1967; Nicholls, 1979; Lasensky and Danielson, 1987). Nicholls (1979) stated that sign language limits the communicator to communicating with the few people who sign, and oral language is too difficult due to an auditory signal that is too degraded and a visual signal that is too ambiguous to decode, leaving cued speech as the ideal balance. Nicholls (1979) also found in her study that speech reception involving audition and lip reading were closely related to speech production and intelligibility skills, but language attainments were more closely linked to reception through cued speech (p. 83). A study by LaSasso et al. (2003) also revealed the importance of cued speech for language and phonological development. The deaf participants in their study consisted of 20 deaf (severe to profound hearing loss) college and high-school students between the ages of 16 and 24. Except for two participants who became deaf at 36 months of age, all participants were either born deaf or became deaf before 18 months of age. Ten deaf students grew up and were educated with cued speech (CS group) and ten deaf students were not educated or exposed to cued speech (NCS group). These groups were matched for age and education to ten hearing college students enrolled in a sign language course. This study revealed that the CS group presented with better rhyming abilities than the NCS group, and these skills were comparable to hearing group peers. Their study supports their hypothesis that the CS group would have similar skills to their hearing peers, essential to language and literacy development.

Cornett (1967) reported that cued speech allows the speaking deaf the opportunity to be aware of their own pronunciations, and if errors are made, to eliminate them. In addition, an objective achieved through cued speech was that the deaf child could think in the phonemic equivalent of spoken English. Later, however, Cornett (1975) emphasized that cued speech alone was not sufficient for speech development nor auditory development, and that parallel programmes must be developed to address these areas. Cornett (1975) emphasized that cued speech does not reflect articulatory movements and therefore cannot help people who are deaf to produce sounds.

Cornett and Daisey (1992) emphasized that cued speech will not teach the hearing impaired child to produce good speech, but will facilitate the work of the SLP by reducing the time required to explain and clarify speech targets. They recommended that a qualified SLP work together with the parents to provide expert speech training in conjunction with the use of cued speech by parents, teachers and therapists. Their belief was that the deaf child would acquire a mental picture of the target speech when cued speech was used. In addition, the mouth and articulators are the focus of cued speech. Some children associate articulation patterns with the movements of cueing, thereby resulting in clearer speech. Cornett and Daisey (1992) also recommended auditory training in addition to cued speech in order to address issues of speech rhythm and vocal quality.

Ryalls et al. (1994a) studied the speech skills of 30 children between the ages of 7 years and 6 months to 12 years and 6 months, for Voice Onset Time (VOT), duration and fundamental frequency (f0). They found the cued speech hearing impaired group (CS) performed between the normally hearing group and the non-cued speech hearing impaired group (NCS) in accuracy for all of the above speech skills. All children with a hearing loss who participated in this study had hearing losses in the severe to profound range. However, these authors did not emphasize in their results that the CS group of children presented with less severe hearing losses then the NCS group of children. The NCS group had hearing levels between 105 dB to 120 dB (average of 115 dB) while the CS group showed hearing levels between 89dB to 110dB (average of 100 dB). Six children in the CS group had hearing levels between 89 and 99dB, while no children in the NCS group presented with levels less than 105 dB, the majority showing levels in the 110 to 120 dB range. These groups of children were not matched well for hearing loss. These differences may make the results more difficult to interpret because children with hearing losses of over 100 dB may not benefit from amplification.

An important issue that also needs to be considered is that while severity of hearing loss is a strong predictor to speech and language outcomes, it has its limitations. Two individuals with identical hearing loss configurations and severity may exhibit significantly different auditory abilities even if they are matched for other confounding factors such as age of onset, method of education and so forth. Issues such as cochlear dead regions and auditory neuropathy may need to be considered.

Overall, cued speech appears to be quite useful in language and literacy development for children who are deaf. However, these references indicate that while cued speech may be an extremely important tool for language learning, its role in speech production is much less. Overall it fares poorly compared with other approaches used for speech habilitation as seen in the following review. The next section will focus on biofeedback as a therapy tool, the main focus of this review.

Biofeedback in Speech Habilitation

Biofeedback technology has been used since the 1920s as a therapeutic tool in speech habilitation (Gault, 1924; Boone, 1966; Wirz and Anthony, 1979; Shawker and Sonies, 1985; Keller, 1987; Fletcher, 1989; Fletcher, Dagenais, and Critz-Crosby, 1991a/b, Dagenais, 1992; Plant, 1998; Bernhardt et al., 2000; Massaro and Light, 2004). McGillivray et al. (1994) claimed the underlying concept of biofeedback to be as follows: "...a subject can learn to exercise some control over a physiological process if information regarding that process is immediately available" (p. 348). In 1975, Strong completed a review of the literature to that point concerning biofeedback aids for speech habilitation of people with hearing impairment, noting that aids were used for assessment, speech habilitation and perception. Most were tactile or auditory in nature, and primarily addressed the speech parameters of fundamental frequency and intensity. Other parameters addressed included nasality, spectra, frication and rhythm. Strong (1975) postulated that a wearable reception speech aid with automated cued speech, formant coded speech and phoneme/syllable speech that could be worn on an everyday basis would be the ideal for persons with profound/severe hearing impairments.

The biofeedback studies discussed in the following review include those that were conducted in schools, clinical and research settings. The first section discusses tactile feedback, and the second, visual feedback. Studies are grouped within each section by age, hearing status, whether service was direct or indirect and according to clinical versus research applications.

Use of Tactile Feedback

Tactile speech perception devices have been used to help the deaf and hard of hearing since the 1920s (Gault, 1924). While most studies of tactile feedback devices have been designed to measure the perceptual performance of their users, many studies have also investigated the impact on speech production, or designed studies with tactile aids as speech production tools. Tactile aids offer information on voicing, manner, and the more sophisticated frequency cues (Plant, 1998).

By the 1980s, tactile aids that convert sound into vibratory patterns were being used regularly. A number of studies were done to investigate the effectiveness of tactile aids for both speech perception and production in people with hearing impairment. Advances in technology have since increased the potential of tactile aids and have allowed them to become portable and usable in everyday life, not just the laboratory (Lynch et al., 1989; Weisenberger, 1989; Galvin, et al., 1995; Reed et al., 1992; Reed and Delhorne, 2003). There are many types of tactile aids with the chief differences being: (a) whether they are vibrotactile versus electro-cutaneous in transmission, (b) the type of speech information that is transmitted, (c) the number of channels and (d) the body site where they are worn. Tactile aids may be useful for those whom hearing aids do not provide much information, and who are not candidates for cochlear implants (Reed and Delhorne, 2003). The following studies investigated electro-tactile devices such as the Tickle Talker, Tactaid and Portapitch to evaluate improvements in articulatory accuracy.

Child participants: Deaf and hard of hearing

Galvin et al.'s (1995) study assessed the use of on-line tactile feedback (the multi-channel electro-tactile Tickle Talker) as an aid to articulation accuracy for six children with hearing impairment. This supplementary approach to speech therapy had the benefit of providing on-line feedback in daily communication. They had mixed results, with only three of six children improving their articulatory accuracy. Nevertheless, it was helpful to some students who did not benefit from traditional speech therapy without any kind of biofeedback device. Weisenberger (1989) studied the effects of different numbers of multi-channel tactile feedback. Her research investigated five versus sixteen channels on speech perception of the Queen's aid for three children. Results revealed higher performance levels for two of the three participants with the 16-channel model in more complex tasks. For simpler tasks, such as minimal pair perception, the 5-channel model was also sufficient. In addition, Weisenberger (1989) investigated the speech production of the participants. Teachers were asked to rate the speech production of these participants while wearing their tactile aids (TC-1600) and while not wearing their aids. These participants, in conjunction with their tactile aid, continued to receive regular speech classes as before. Results suggested that using the TC-1600 led to improved speech production even though an additional tactile-aid speech training programme had not been implemented.

Another study, Youdelman et al. (1989), compared the use of a vibrotactile aid with a visual aid or no aid for improving monotonous production. Sixteen children aged 7 to 18 years with severe-to-profound hearing impairment participated in the study. The results indicated that a vibrotactile aid (the Portapitch, a multi-channel vibrotactile sensory aid) was better suited to training intonation and pitch than a visual aid (the Visipitch from Kay Elemetrics Corporation). They asserted that visual aids were more effective for remediating the more static aspects of speech.

Plant (1998), in his case study of an 18-year-old male, used tactile aids to train speech production. His participant used two multi-channel tactile aids simultaneously, the Tactaid VII and the Tactaid 2000+. The results of his speech training programme using these tactile aids was positive, despite the fact that the young man had very limited speech skills and communicated primarily in Signed English. A listener's panel was able to identify CVC productions post-therapy 25% more than pre-therapy. In addition, there was great improvement on the voiceless high frequency consonants: /t/, /s/, /ʃ/, and /ʧ/. Overall, this participant was more successful receiving speech therapy with the addition of tactile information than without it.

Overall the results of these studies revealed mixed success in speech therapy with the addition of tactile information than without it.

Adult participants: Deaf

It is important to determine which techniques, methods and devices offer the most benefit to the deaf and hard of hearing in both speech perception and production. A study by Reed et al. (1992) contrasted three supplementary tactile devices in conjunction with the Tadoma method for perception of speech. The Tadoma method consists of the 'listener' placing his/her hands lightly over the face and neck of the talker, following lip and jaw movements, airflow on the lips and vibration on the neck. They described the Tadoma method as highly successful, resulting in the same performance as that of hearing people listening to speech in background noise. The three supplementary devices consisted of: (1) a tactile display representing the tongue and palate contact points, (2) a multi-channel speech spectrum display and (3) a tactual analog of cued speech that was created for the study. These studies were completed with the assistance of one or two adult participants taking part in each subsection of the investigation. The results revealed that the most successful model was the Tadoma Cued Speech combination where one participant achieved nearly perfect discrimination. In the other two methods tried, two participants performed best in the augmented Tadoma conditions (approximately 6% higher than on either system alone). However, it is difficult to discern from this study if improvements were due to experience with Tadoma and a tactile-modality based approach or whether visual cues were more difficult to integrate with a tactile-based method. It would be interesting to compare and contrast these three supplementary devices for speech production. While there is general agreement that speech perception should occur before production, good perceivers are not always able to produce accurate speech without training; therefore, further study of the effects on production would be informative.

In Galvin et al. (1999) comparing the Tactaid II and the Tactaid 7, the subjects reported no subjective improvement in their speech production or perception with either model. The researchers concluded that a Tactaid is not the ideal device to improve communication in adults with profound hearing impairments, and that cochlear implantation might have better results.

Tactile aids and methods, while somewhat successful, appear to have limitations. For one, the user would have to always take another piece of equipment with them; secondly these devices, while somewhat successful for children, were not the ideal device to improve speech for adults, and lastly some methods such as the Tadoma method were not very realistic in terms of functional communication. Placing one's hands on the neck and face of the talker is not practical and may be uncomfortable in some settings for both the speaker and the listener.

Use of Visual Biofeedback

A number of investigators have studied the outcomes of therapy with visual biofeedback tools such as the voiscope, electropalatography, glossometry and ultrasound (Boone, 1966; Wirz and Anthony, 1979; Shawker and Sonies, 1985; Keller, 1987; Fletcher, 1989; Fletcher et al., 1991a,b; Dagenais, 1992; Reed et al., 1992; Plant, 1998; Galvin et al. 1999; Bernhardt et al., 2000; Bernhardt et al., 2003; Massaro and Light, 2004). Since the 1980s and early 1990s, technological advancements have resulted in the development of better access to tools and advances in the design and accuracy of the tools themselves. These factors have contributed to the ease of use for client, SLP and researcher, and together with reduced costs have offered greater accessibility. Massaro and Light (2004) discussed the additional reasons for success with visual feedback as an adjunct to therapy. They discussed the growing understanding by researchers of the value of visual and auditory information together and described it as 'superadditive', meaning that the value of the two together far outweighs each modality alone. Several programmes have been developed over the last two decades to address the many issues related to abnormal speech production. Essentially there are two types of programme aids: feedback on what the client produces compared with the normally hearing model, and feedback on just what the client is doing. Software programmes such as 'Dr. Speech' (Huang, 2007), 'The Rosetta Stone' (Rosetta Stone, 2007) and 'Speech Viewer' (Pratt et al., 1993) have become more user-friendly and accessible to SLPs and their clients, and fall into both of these categories. These programmes offer visual feedback information on pitch, loudness and formants. In addition, acoustic analysis freeware over the internet has allowed access that was unavailable a decade ago, e.g., PRAAT (Boersma and Weenink, 2005), showing analyses of pitch, loudness, phonatory timing and speaking rate. Electropalatography (EPG) studies provide information on lingua-palatal contact patterns, addressing issues of place and manner (Fletcher et al., 1991a; Dagenais, 1992; Bernhardt et al., 2000; Bernhardt et al., 2003). Tongue palate contact information is displayed on a computer screen via an acrylic palate with embedded electrodes that record the data (Bacsfalvi et al., 2007, chapter 2). The newest advance in biofeedback for speech habilitation is ultrasound (e.g., Bernhardt et al., 2003, 2005a,b). Studies using visual biofeedback in speech-language pathology are described in the next section by decade.

Biofeedback in the 1960s

Child and adult participants: Deaf and hard of hearing

In the 1960s, Boone (1966) advocated the use of a pitch meter that gave a dial reading of fundamental frequency with deaf and hard of hearing children. He indicated that the pitch meter could help the child explore vocal range. This was a simple biofeedback tool, but one that he claimed to be effective.

Bridges (1964) experimented with an acoustic type visual biofeedback apparatus. While these early inventions were helpful, their usefulness was limited and the speech of deaf speakers continued, for the most part, to be unintelligible.

Biofeedback in the 1970s

In the 1970s, some researchers started using electropalatography (EPG) and other palatal appliances to explore the articulatory characteristics of language (Tudor and Selley, 1974; Boothroyd, et al., 1975; Fletcher et al., 1975; Wolf, et al., 1976). EPG allows the research and speaker to see palato-lingual contacts, information that was previously unavailable. Other researchers continued to experiment with spectrographic information, e.g., Bridges and Huckabee (1970).

Child and adult participants: Hearing and deaf

Bridges and Huckabee (1970) developed and experimented with a visual feedback apparatus that gave a display much like a simplified speech spectrogram. The experimenters found that their three participants, two children and one adult, were all successful in learning target phonemes with this visual biofeedback. Only two 45-minute sessions were required to gain these new speech skills. Their pilot study of oscilloscope traces showed success with acoustic-based visual feedback.

Tudor and Selley's (1974) speech training aid combined a visual and tactile aid. This speech aid was not developed specifically for the deaf and hard of hearing person, but rather for individuals with velopharyngeal insufficiency. The tactile portion was a palatal appliance with a wire loop that trained the patient to become aware of the movement of the soft palate and aided in the control of the soft palate. The visual portion consisted of a light that went on when the soft palate was elevated to enable the client to monitor his palatal movements visually. Clients were all able to lift their palates voluntarily after using it. Both adults (9) and young children (15) were successful with the training appliance, although adults took longer to achieve success. The authors suggested that this type of treatment programme might also be appropriate for babies. Such an appliance could prove useful for the deaf and some hard of hearing because they also have frequent lack of coordination of the soft palate and articulators and poor velopharyngeal control, resulting in inappropriate nasality in speech.

Another acoustic speech training aid developed by Nickerson and Stevens in conjunction with a team of SLPs and TDHHs was a computer-based feedback system (Boothroyd et al., 1975). This system addressed the parameters of loudness, pitch, voicing, nasality, tongue positions in vowels, aspiration, and combinations of some of these parameters. The programmes included a speech spectrum and simple time-based line indicators for voicing presence and nasality, with the capability to compare the client's speech with speech of the instructors. The ability of the clients to compare their productions with that of the target was considered a great advantage, and superior to feedback systems that do not demonstrate what the participant is doing in comparison to the target model. The 42 participants, ages 8 to 18, found some success, particularly in the area of suprasegmental aspects of speech rather than articulatory features. These clients were provided with a daily speech programme over a 2-year period. They found that clients with less severe speech problems were more successful. The research team stressed the importance of teachers acquiring greater knowledge of acoustic phonetics and physiology to be able to do sophisticated speech training. It should be noted that this exploration of a computer-based system with several important parameters of speech was hampered in large part by the technology of the day.

Another tool, the 'Voiscope', was investigated by Wirz and Anthony (1979). The purpose of the tool was to provide information about the suprasegmental aspects of speech of profoundly deaf children. The Voiscope consisted of an oscilloscope screen that displayed pitch patterns (fundamental frequencies) of the client and interventionist. This tool allowed students to compare and copy the target productions of the interventionist with that of their own. The Voiscope was helpful in the modification of airstream control, pitch control, pitch movement and rhythm within an utterance (Wirz and Anthony, 1979). It appears as if many software programmes used today have used the Voiscope as a base: Dr. Speech (Huang, 2007), Speechviewer (Pratt et al., 1993), Baldi (Massaro and Light, 2004), to name a few.

Biofeedback in the 1980s

By the 1980s, progressively more sophisticated forms of technology became available. For example, preliminary explorations of tongue movements and speech impairments with ultrasound technology began during this time (Shawker and Sonies, 1985; Keller, 1987; Klajman, et al., 1988). Ultrasound allowed researchers a view of dynamic tongue movement from both sagittal and coronal perspectives that was safe and relatively noninvasive. An ultrasound transducer may be hand held or placed on a microphone stand and then held pressed below the chin. Gick (2002) comments that "...two-dimensional cross-sections of the superior surface of the tongue can be imaged from root to blade....likewise, by turning the transducer 90 degrees, any coronal or transverse section of the tongue may be imaged" (p. 115). Refer to chapters two and three for figures with ultrasound. Another method that continued to be studied fairly extensively was EPG (Fletcher and Hasagawa, 1983; Gibbon and Hardcastle, 1987; Yamada et al., 1998).

Child participants: Hearing

Shawker and Sonies (1985) used ultrasound biofeedback in speech therapy with one 9-year-old hearing child who substituted [w] for /ɹ/. Their study did not indicate whether one- or two-dimensional ultrasound was used. Results revealed that this single participant was able to produce /ɹ/ in single words and in open-ended sentences with 88% accuracy. This case study suggested that further study should be done using this type of biofeedback for a larger number of clinical participants.

An example of a case study with EPG was Gibbon and Hardcastle (1987). A programme of four-one hour weekly sessions with EPG was completed successfully for lateralized [sˡ], a pronunciation which is often resistant to traditional speech therapy. There were several studies during this decade with EPG in the areas of deaf speech (Fletcher at al., 1991a), cleft palate speech (Gibbon, 1988; Gibbon and Hardcastle, 1989) and functional articulation disorders (Gibbon and Hardcastle, 1987).

Adult participants: Hearing

Fletcher (1985) continued to explore the uses of electropalatography (EPG) for speech production. In one study he explored the articulator roles of EPG in stops and fricatives in the speech production skills of an adult with an unrepaired palatal cleft. His findings revealed compensatory strategies of the speaker in creating intelligible speech and supported the hypothesis that language is shaped by oral motor capabilities and limitations. In addition, this investigation gave insight into lingua-palatal contacts of speech.

Keller (1987) used ultrasound to investigate vertical tongue dorsum movements in several cases of motor disturbance such as Parkinsonism, senile dementia, stuttering and traumatic brain injury. His main goal in the study of tongue movements in dysarthric patients was to identify the control and impairment variables. His study found ultrasound to be very useful in collecting quantitative information for speech motor disturbances. Some important findings were variability in movement amplitude, variability in duration and insufficient coordination in his subjects.

While the studies outlined above were completed with hearing participants, ultrasound and EPG were also potentially useful for deaf and hard of hearing participants who often have difficulty acquiring /ɹ/ and /s/, as the next section shows.

Child participants: Deaf

Klajman et al. (1988) investigated the articulatory setting of vowels and use of ultrasonograpahy as a visual biofeedback adjunct to training. They reported that the majority of a group of 21 congenitally deaf children was able to improve their tongue shapes during the vocalization of vowels. Most children were successful (16/20) in partially or completely matching the teacher's target vowels in one session. The researchers commented that it was very important for the instructor to have specific knowledge and the ability to give precise help based on this knowledge.

While each of these studies offered an important insight into the use of biofeedback with children and adults with speech disorders, it was the combination of all this knowledge that was beginning to show the efficacy of visual biofeedback.

Biofeedback in the 1990s

Biofeedback in the 1990s addressed a wide range of speech issues: articulatory accuracy, voice habilitation and control, appropriate breath support for speech and coordination of voicing and phonation using a broad range of biofeedback instrumentation. Some of the instruments developed and used during this time included electromagnetic articulography, 'EMMA', (Katz and White, 1999), electropalatography (EPG), 'ALBERT' (Howard and Rossiter, 1996), glossometry (Fletcher et al., 1991a), 'Respitrace' (Murdoch et al., 1999), ultrasound imaging (U/S), and 'SNORS' (Main et al., 1999). Electropalatography continued to be used in the assessment and remediation of speech disorders by a number of researchers (e.g., Fletcher et al., 1991a; Hardcastle et al., 1991; Dagenais, 1992; Gibbon et al., 1999).

Child participants: Hearing

During this time period, several studies using visual biofeedback were confirming the use of this technique as an adjunct to speech therapy across many types of speech impairments. Although not used exclusively with deaf persons, they could also prove beneficial for deaf persons working to improve speech production.

Hardcastle et al. (1991) explored the use of EPG as an assessment tool that informs therapy, and as a therapeutic tool. One important finding in their investigation was a raised awareness in diagnosing speech difficulties. Traditional transcriptions even by expert transcribers can fail to detect "...clinically relevant features of speech because some of these events may not have auditory consequences" (p.57). EPG data offered quantitative data that were often missing in their assessments. In their investigation of three participants each with a different speech disorder (phonological disorder, acquired dyspraxia and cleft palate) they discovered that a motor-phonetic approach to remediation might be more appropriate than traditional approaches used to that point. For example, in their investigation of a 4-year-old girl diagnosed with a phonological impairment, EPG showed that two phones that sounded the same were actually produced in two distinct places of articulation. The child misplaced her articulators for the release of the phone. EPG feedback could then help this child see where her tongue placement needed to be for target release. Their study revealed that the use of such a tool was effective for a range of disorders and etiologies. All of the implications and uses of Hardcastle et al.'s (1991) study are beyond the scope of this paper; however, this example brings to light how EPG could be an important visual feedback device.

Other feedback methods for suprasegmentals and respiration described in the 1990s included a vocal intensity feedback system (McGillivray et al., 1994) and Respitrace (Murdoch et al., 1999). In the former, McGillivray et al. (1994) successfully used vocal intensity biofeedback to reduce excessive vocal intensity in a 4-year-old girl. Murdoch et al. (1999) used real-time continuous visual biofeedback to treat speech-breathing disorders in a 12-year-old with traumatic brain injury. The Respitrace supplied biofeedback of chest wall movements during breathing to help the participant coordinate his abdominal musculature. Similar to other biofeedback methods discussed, this also required the participant to match a target trace provided on the computer screen. The focus of therapy was to establish coordinated voice onset and decrease the amount of air wastage prior to voice onset. This study found that biofeedback as an adjunct to therapy was again superior to traditional therapy techniques, successfully modifying speech-breathing patterns of this child. These authors advocated for the development of more accessible technology to the SLP that could easily be used on-line to improve every day therapies. Because of a lack of coordination in voice onset and breath support in deaf and hard of hearing speakers, this type of device might also prove beneficial for them.

Gibbon et al. (1999) described their EPG network, which was designed to provide access to EPG technology throughout Scotland. Four clinic centres across Scotland were set up with EPG systems and each centre was provided with a number of portable training units (PTU) that could be loaned out to SLPs. At the hub was an EPG specialist who advised the local SLPs on strategies and ideas for treatment and provided technical support and training. The role of the specialists declined as SLPs became familiar with the biofeedback capabilities and techniques. In their case study, a young boy's SLP took advantage of the EPG network to address long-term backing of alveolar stops and affricates. The child had received extensive traditional speech therapy for these articulatory targets, but with no success. With the adjunct of EPG to therapy, he was successful in producing the targets in spontaneous speech (Gibbon et al., 1999).

Adults: Hearing

Two additional studies in the late 1990s confirmed the effectiveness of biofeedback in speech therapy for treatment of both articulation and velopharyngeal insufficiency, another area that is relevant for deaf and hard of hearing speakers. Katz et al. (1999) used electromagnetic articulography (EMMA) treatment for an adult with aphasia and apraxia of speech. As with the other forms of biofeedback, this method of treatment resulted not only in improved accuracy, even though speech difficulties were motorically based, but took minimal time for therapy gains to be made (five sessions within one month). While the discussion of their results revealed that there was greater improvement in non-speech than speech tasks (e.g., greater accuracy for silent and humming tasks) they argue that this may have been due to the greater complexity of the speech motor tasks requiring a longer programme of treatment. This is quite probable because Adler- Bock et al. (2007) found in their study of visual biofeedback treatment with two hearing teenagers that the speakers required a minimum of 15 weeks to be able to produce North American English /ɹ/.

Howard and Rossiter (1996) developed real-time visual feedback (acoustic and laryngeal) for use by those developing their voices professionally, ALBERT. Their studies focused on the efficacy of ALBERT with non-professional voice users and the need for further research on a variety of speech disorders.

Main et al. (1999) used SNORS (the super nasal oral radiometry system) to measure nasal and oral airflow during speech to treat hypernasality due to velopharyngeal insufficiency in their case study. SNORS provides an online display of nasal and oral airflow providing the patient with biofeedback. Once again this study compared conventional therapy with therapy using biofeedback and found the latter far superior. While conventional therapy provided some results, as it has in the other studies, this client was able to proceed much further with biofeedback as a therapy adjunct. Again, this might prove beneficial to persons who are deaf and working on speech skills.

Child participants: Deaf

In the 1990s, EPG was also being used in habilitation studies with deaf children. Fletcher et al. (1991a) used EPG to teach consonants to five profoundly hearing-impaired children between 10 and 16 years of age. All of their students were able to change their speech productions significantly using EPG. Following the brief 3-4 week period of daily therapy, all participants produced many more consonants than they were able to produce with traditional therapy. The authors report that their training principles followed some of Ling's (1976) procedures, such as teaching stops first, while others were adapted to better suit the technology and the participant. In addition, they reported that the success obtained supports the notion that teaching new segments to this population may have a greater impact on speech intelligibility than teaching suprasegmentals. However, ideally both would be addressed. They suggested that this conclusion further confirmed Maassen and Povel (1985).

In another study, Fletcher et al. (1991b) taught vowels to six profoundly hearing-impaired children ages 4 to 16 using glossometry. Glossometry displays the location of the tongues surface in the oral cavity through LED photosensors that are embedded into a pseudopalate similar to the EPG pseudopalate. In this study the participants received two weekly 50-minute training sessions for four weeks. While glossometry is similar in apparatus to EPG, the visual feedback shown to the participants on a monitor during glossometry training is more similar to formant-like feedback displays. Participants were trying to match lines representing the target positions. The results were mixed, with each participant producing some vowels significantly differently. All participants used an expanded use of oral space with greater between-vowel differentiation post therapy. The results of this clinical research investigation were less obviously successful, and researchers hypothesized that a longer therapy period may have been needed. Nevertheless the results of this study were encouraging, with all speakers making some gains.

Dagenais (1992) used both glossometry and palatometry as an adjunct to traditional speech training in a long-term study of four profoundly deaf children over two school-year periods, with the summer off for the traditional break. His past studies with visual biofeedback had shown a lack of generalization to spontaneous speech. As a result Dagenais believed that a combination of traditional and biofeedback approaches would best serve students. Students improved all targeted speech sounds with a dip in performance after the summer break and then continued improvement once school and services resumed. The results revealed that visually based speech training was a viable adjunct to traditional auditorily based training.

Another study compared traditional speech therapy (the Ling method) to the use of computer assisted speech training (IBM's Speech Viewer) for remediation of vowels (Ryalls et al., 1994b). Speech Viewer is a software programme that includes vowel spectra in order to monitor vowel formant frequency. The participants in the computer therapy group played games in a videogame format to reach their target sounds. Vowel training was half an hour per week for seven weeks for the vowels /i/, /u/ and /a/. The students in both groups (with or without computer therapy) were trained with a SLP. The results of their study revealed no difference between groups pre- and post-therapy. They did see a trend in improvement for both groups. However this study was very short in length, with a limited amount of speech training per week. It is difficult to draw a conclusion from these results. Most other studies that were successful had much longer training periods before they saw significant change. Another possibility is that the kind of feedback provided by the IBM Speechviewer may not have been specific enough.

A variety of visual feedback devices from the 1990s were beginning to show success. By the late 1990s, many speech and language specialists had experimented with great success with visual biofeedback devices. Although the outcomes of these investigations were all positive, most small centres or centres without a research institute usually did not have access to these technologies or therapeutic techniques.

Biofeedback in the New Millennium

Spectrography (Ertmer and Maki, 2000), ultrasound (Bernhardt et al., 2003; Bacsfalvi et al., 2004; Bernhardt et al., 2005), electropalatography (McLeod, 2007), and newer software such as Baldi (Massaro and Light, 2004), based on information incorporated from various visual biofeedback devices, are the state of the art at the current time for speakers with and without hearing impairment.

Child participants: Hearing

Adler-Bock et al. (2007) addressed long-term misarticulation of North American English /ɹ/, using ultrasound as an adjunct to traditional therapy. This study was conducted in a laboratory that was set up to be a clinical setting for the 15 hourly sessions with two hearing adolescents. The participants had attended years of traditional speech therapy before trying ultrasound. Both were successful in learning to produce /ɹ/ at the word level after 15 weeks of training with ultrasound.

Child participants: Deaf

Ertmer and Maki (2000) compared spectrographic biofeedback with noninstrumental instruction with four deaf adolescent middle school participants. These participants communicated primarily in sign language and wore their hearing aids intermittently. The target sounds for production were /t/ and /m/ and the training procedures were identical with the exception of the spectrographic displays. The spectrographic training allowed for immediate feedback of the participants' productions and a comparison to a correct target production. Therapy was provided in an intensive model of four times per week by an experienced SLP. A strength of this study was the emphasis on maintenance of improvement and generalization. Listener ratings were performed by three SLP students who had a background in phonetics, and little exposure to deaf children. This study did not control for some important factors across subjects, such as oral-motor abilities and cognitive skills. Both of these factors may have contributed to lower scores in one participant. Nevertheless, all participants' speech production improved. The other three participants all achieved generalization of the speech targets with the spectrographic display therapy model.

Bernhardt et al. (2000) found success in their case study of a child with a cochlear implant and the use of EPG as an adjunct to therapy. The child in their study made more and faster gains with visual feedback therapy than in two previous intervention programmes without visual feedback.

Baldi (Massaro and Light, 2004) offers all the acoustic information available in programmes like IBM Speech Viewer (Pratt et al., 1993) or Dr. Speech (Huang, 2007) plus more articulatory information for the speech learner that was previously available only from ultrasound, electropalatography or other such instrumentation. Baldi consists of a computeranimated talking head (Baldi) that has interactive speech and language training modules. Users of this programme can watch what is happening when Baldi talks from either the outside or inside. The skin can be made to be transparent so that students can view what is happening on the inside of the mouth and neck. This programme is very comprehensive and offers a range of information including a view of what is happening during co-articulation, timing for affricates versus fricatives, vocal fold vibrations for voicing distinctions and the ability to slow down the rate of speech being produced. Currently Baldi is being used primarily with the deaf and hard of hearing populations. Massaro and Light (2004) investigated the effectiveness of Baldi with seven students aged 8 to 13. The participant's aided hearing threshold levels were all within the mild-to-moderate range. As with traditional speech therapy, students participating in this study were asked to complete speech perception and identification tasks prior to speech production training. Training was over 21 weeks at twice a week for 45 minutes. Students worked mostly on their own with Baldi as their trainer, and then were provided with a tutoring session during which they received direct instruction from the SLP. Linguistics students with phonetics training were used to rate the students' speech from pre-test to post-test. Each participant's data were individually analysed to evaluate performance outcomes. Statistically significant increases in speech production were found for each participant. The percentage of change overall, in consonant matches, for each participant was: S1= 25% gain, S2= 76% gain, S3=58% gain, S4=33% gain, S5=46% gain, S6=57% gain, and S7= 23% gain. One weakness of this programme is the inability of students to compare what they are doing with a model. Nevertheless, Baldi appears to be a significant contribution to speech therapy and visual biofeedback technology.

Bernhardt et al. (2003), a background study for the current dissertation, evaluated short-term speech outcomes of EPG and ultrasound for four adolescents (Purdy, Palmer, Pamela and

Peran) with moderate to severe sensorineural hearing losses. The participants attended speech therapy sessions twice a week, once with technology, and once without, for 14 weeks. An examination of individual results showed treatment gains similar to those for Baldi in a shorter time period. Average percentage gains for consonant accuracy were: Purdy = 58% gain, Palmer = 54% gain, Pamela = 47% gain, and Peran = 29% gain. Average percentage gains for vowel accuracy were: Purdy = 30% gain, Palmer = 25% gain, Pamela = 17% gain, and Peran = regression of 1%. The authors noted no apparent advantage of one technology over the other.

Adult participants: Deaf and hard of hearing

Few studies have been conducted with adults. McGarr et al. (2004) investigated sibilant (/s/ and /ʃ/) and vowel productions (/i/ and /u/) of eight adult speakers with severe-to-profound hearing loss and without hearing loss using EPG and perceptual evidence. This study found differences in contact points for speakers with a hearing loss and those without. For the most part perceptual judgements matched the differences that were found in the articulatory placements. The differences included slower segmental tongue movements, less differentiation of contacts across segments and reduced segmental influences on co-articulation. Their data contribute to our knowledge about differences in speech production between hearing individuals and hearing impaired speakers. A strength of this study was in the comparison of perceptual information and EPG data. It is important for researchers and SLPs to understand the relationship between articulatory, perceptual and acoustic data to better understand speech production.

Overall Outcomes of Biofeedback Studies

One common outcome of the biofeedback intervention studies has been the significant reduction in the amount of time required for therapy participants to learn a speech target. Some common criteria for success in treatment programmes with visual feedback have been intensity, well-trained SLPs providing therapy and feedback, and motivation on the part of the participants. Limitations include lack of availability of equipment due to cost.

Up to this point, the focus has been on external visual or tactile feedback. Another technology that is changing the way deaf and hard of hearing speakers are learning speech is the cochlear implant. With the advent of the cochlear implant, intervention has shifted from production-focused to perception-based methods. Because three of the participants in the dissertation studies had cochlear implants, a discussion of outcomes of cochlear implant use is included, again focusing primarily on speech production.

Cochlear Implants

While cochlear implants are just another type of hearing device, much of the literature appears to be quite separate from research about communication and hearing of deaf individuals using hearing aids. The use of hearing aids implies that there is aid-able residual hearing which allows a hearing aid to amplify hearing to a damaged cochlea. A cochlear implant circumvents the natural cochlea stimulating the afferent nerve ending directly. As a result, this paper discusses cochlear implants separately. With the arrival of the cochlear implant came many questions. How beneficial is it? Is it ethical? Can people born deaf really learn to listen and speak like people born hearing? How much can you hear with a cochlear implant? Who should obtain a cochlear implant?

Eligibility criteria for cochlear implants are quite inconsistent in the literature and over the web (Zaidman-Zait and Jamieson, 2004). Children and adults with severe-to-profound hearing losses with appropriate medical, physical and psychological health as judged by the assessment team may be candidates. In addition, child candidates must have family members or caregivers willing to be part of the rehabilitation process for many years. If families are unable to commit to assisting a child after cochlear implant surgery, a child would not be a candidate in the west.

Over the past two decades there have been many studies documenting the speech perception and production, language and literacy development of children and adults implanted with cochlear implants (e.g., Osberger et al., 1991, 1993; Tye-Murray et al., 1995; Ertmer and Mellon, 2001, Rhoades and Chishom, 2001; Geers, 2002; Uchanski and Geers, 2003). Some recent studies report great success in speech intelligibility and conversational fluency formerly unattainable by profoundly deaf children (Pisoni et al., 1999; Geers, 2002). In addition, several approaches to (re)habilitation have developed with cochlear implant technology. These approaches vary from the strictly oral approach to the total communication approach. Some believe that the best chance for deaf individuals in a predominantly hearing society is to learn to hear and speak (Rhoades and Chisholm, 2001). This school of thought is found predominantly in the oralist approach and the auditory-verbal approach to speech and language habilitation (Pollock, 1997; Rhoades and Chisholm, 2001; Ling 2002).

Interestingly, school success has often been linked to speech development. The link between speech, reading and writing has been well researched (Vygotsky, 1978; Catts and

Kahmi, 1998; Catts et al., 1999). Vygotsky (1978) believed that reading and writing originated with speech and therefore the three were interdependent. Much of the research on speech and language development has been done concurrently for children with cochlear implants. Language development is discussed briefly; however, because the paper has a speech production focus, most of the discussion concentrates on speech. A large number of cochlear implant studies have concentrated on early implantation and speech and language outcomes, and are discussed in the next section (Tye-Murray et al., 1995a; Ertmer et al., 2002b; Geers, 2002; Tobey et al., 2003; Yoshinaga-Itano, 2003).

Speech Outcomes for People with Cochlear Implants

Cochlear implants, while primarily a hearing device, are also an important aid in the development of speech production for people who are deaf (Osberger, 1989, 1990; Osberger et al., 1993; Osberger et al., 2003; Van Lierde et al., 2005). Ertmer and Mellon's (2001) case study of a 20-month-old child implanted with a multi-channel cochlear implant found that the child learned to vocalize speech-like utterances through maximizing the auditory modality with a family-centred approach to listening habilitation. This child received therapy once a week pre-implantation and for the 4 months following activation of the cochlear implant, and then twice-weekly auditory, speech and oral language training. The child understood 240 oral words and spoke 90 words after one year using the cochlear implant.

However, many studies continue to show considerable variability between language and speech outcomes post-implant (Geers, 2002; Connor et al., 2000). Often this variability is due to the large number of factors that play a part in a cochlear implant user's success rate: age at time of implant, education method, type of cochlear implant device used, electrode array implanted, preoperative aided speech detection thresholds, cognitive levels, language levels, family support other personal-social factors and more recently bilateral cochlear implants. Studies now attempt to tease apart variables that contribute to or detract from the success with cochlear implant technology (Tye-Murray et al., 1995b; Pisoni et al., 1999; Connor et al., 2000).

Tye-Murray et al.'s (1995b) study investigated speech acquisition, the variables of age at implantation and the influence on speech acquisition, how speech production and perception skills relate, and the impact of a total communication language background on speech production. Their study revealed that children implanted before the age of 5 were more successful in acquiring intelligible speech than children implanted after the age of 5, but that improvement of speech intelligibility did occur after two years of implantation even in children implanted after the age of 5. In addition, phoneme production accuracy exceeded that of children with similar degrees of hearing loss using hearing aids. Furthermore, there appeared to be a perception and production link; children with greater speech perception produced more intelligible speech.

However, the results of other studies have produced mixed reviews when it comes to speech intelligibility and the relationship between speech perception and production. It appears that, while many cochlear implant users may develop good perception skills, this does not always translate to good production skills (Tye-Murray et al., 1995a; Te, et al., 1996; Mondain et al., 1997).

Some studies have revealed success for cochlear implant users past the early childhood years. Schramm et al. (2002) completed a retrospective study of open-set speech recognition to investigate 15 adolescent and adult patients with prelinguistic deafness who received cochlear implants after the age of 12. Speech perception data and qualitative data were collected from the participants. Their results demonstrated that later implanted individuals could achieve open-set speech perception. However, adult scores were noticeably lower than adolescent scores. Results were variable, as were the factors contributing to the variability of speech perception outcomes. Nevertheless Schramm et al. (2002) concluded that all participants had access to auditory information that was not available to them with other technology. In a subsequent study, Fitzpatrick and Schramm (2006) revealed that outcomes may not be adequately measurable by current measurement tools. In this qualitative investigation SLPs reported that success of cochlear implant usage is not always able to be accurately measured by standardized tools. Qualitative results revealed that the majority of adults with prelingual deafness reported satisfaction with their cochlear implants, even though tests may have shown they had no speech recognition skills. Their ability to function and quality of life were improved. They found that cochlear implants facilitated communication for these adults in the domains of communication abilities and social functioning. Their study confirms the need for speech perception tests and instruments that more accurately document outcomes. Overall outcomes for cochlear implants have been improving and continue to improve as newer technology offers increased capabilities. Van Lierde et al. (2005), in evaluating past studies, reported that all studies indicated an increase in size and diversity of consonant production overall. However, few studies had investigated the speech characteristics of deaf individuals using hearing aids (HA) versus cochlear implants (CI) as their hearing devices. Van Lierde et al. (2005) investigated six HA children and nine CI children, between the ages of 5.10 and 13.8, and made a complete analysis of speech and voice characteristics of each of these groups. They concluded that overall the CI group had better speech production than the HA group. They concluded that of the consonant mismatches observable in each group, substitutions and deletions occurred more frequently in the HA group while the CI group tended to show slight phonetic aberrations only. The overall intelligibility of the HA group was categorized as moderately impaired in terms of speech, while the CI group was categorized as mildly impaired. Both HA and CI support development of speech production skills. However, in this study the transcriptions were completed by two SLPs who knew to which group each child belonged. This may have impacted the results, plus individual child factors. While the use of cochlear implants continues to offer ever-increasing benefits, speech production continues to be challenging for many people who are deaf.

Speech Perception and Production Outcomes and Cochlear Implants

Tye-Murray et al. (1995a) stated that good speech recognition skills do not necessarily lead to good speech production skills. The purpose of their study was to investigate the relationship between speech perception and production in 23 prelingually deafened children with an average age of 34 months post-implant. Their participants ranged in age from 2 years 7 months to 14 years 2 months, and had a range of speech production skills (poor to very good). The study evaluated the participants' ability to produce voicing, nasality, duration, frication, and place of articulation in vision-only, audition-only and vision-plus-audition conditions. The participants' speech production and perception skills were assessed by an SLP in each of these conditions with a test comprised of seven letters of the alphabet and three common words. While this limited data set compromised generalizability of results, they felt that due to time constraints and short attention spans of the child participants, they could not administer more assessment tests. Consonants with the highest level of visible information (/p,b,m/) were produced with the highest accuracy and fricatives (/s, z/) were produced with the lowest, which is no different from other children with hearing loss. Other areas of difficulty were voicing distinctions, duration and frication in general. Relationships between production and audition-only perception conditions were significant for place, nasality and voicing. The investigators also reported that there was a significant relationship between children producing target place of articulation features and longer periods of CI use. However, the investigators did not mention the role of speech therapy and auditory training in their consideration of speech production levels. It is unknown if they all had no training, or training of speech was variable for each participant over the 34-month period.

Other factors affecting speech outcomes are length of time using the implant, habilitation/teaching method and age of implantation, discussed in detail in the next sections.

The Effects of Years with an Implant and Age at Time of Implantation

Tye-Murray et al. (1995b) investigated the speech of 28 prelinguistically deafened children who had used a Nucleus 22 cochlear implant for a minimum of two years post-implant (with an average of three years use). The participants were divided into three groups based on age at implantation: 2-5 years, 5-8 years and 8-15 years. Their goals were to determine: (a) speech intelligibility post-implantation, (b) whether age of implantation was an important factor in speech intelligibility, (c) the relationship of speech production to speech perception skills and (d) whether sign language disappeared or continued. As in other studies they found that visible consonants were more likely to be correct across age groups: bilabials were most often produced correctly while fricatives were produced most often incorrectly. Tye-Murray et al. (1995b) interpreted pre- and post- implant scores of younger implanted children as faster than that of older implanted children for speech production progress. However, it is unclear that the normal acquisition of speech sounds was accounted for in children under the age of six. In particular the 2-to-4 year-old group would be expected to progress the most because they had the most improvement to make in speech overall. Also, the results of this study indicated that participants in the middle and older age groups continued to improve in their speech production skills. The participants' abilities to perceive were significantly correlated with their abilities to produce speech in this study. The investigators examined the story retell task and asked parents to complete a questionnaire in order to determine degree of signing in use. They found that signing was still used to communicate with the SLP, but that families reported less use of sign in the home. Participants may have continued to sign to their SLPs and teachers due to habitual patterns of communication. Meanwhile family and friends may have begun to sign less because it was not needed as much. In cases where speech perception is more difficult (e.g., noisy classrooms), more reliance on sign language may be necessary.

Mondain et al. (1997) found great variability in the speech intelligibility levels of prelingually deaf children after four years of cochlear implant use. All children in their study had received implants under the age of 5. A range of intelligibility levels was found with the average intelligibility level at about 70% correct. Te et al. (1996) reported mixed results depending on the area of speech production. They studied the speech of each child each month after implantation for a year. They reported vowel production to be the easiest task to master and the quickest. The most difficult tasks to master included place and manner of consonant production.

Pisoni et al. (1999) investigated the outcomes of cochlear implant effectiveness in prelingually deafened children four or more years post implantation. They found that all children improved their scores over time; however, there was great variability in the amount of improvement. They also found a correlation between speech and language; children with higher language scores, attending oral only education programmes (a requirement of the study), and implanted at younger ages produced better speech. These authors stated that their results are suggestive of issues that are central rather than peripheral in processing, and that further research in the areas of perception, attention, learning and memory is warranted. However, it is important to be aware that it is difficult to compare methods where oral-only is the requirement for the participants. At the time of their study research had not shown significant differences between implant devices or programming strategies. Since that time, investigators have discovered that different devices, changing technology, implant devices and programming strategies can make a significant difference (Tobey et al., 2003). Thus, while some of the information in these studies is relevant, due to newer technology and programming possibilities, some may no longer be applicable.

A study that investigated the phonological systems of a 5 years 8 months old CI user two years post-implant provided descriptive information about the development of a child's phonological system (Chin and Pisoni, 2000). The reason they cited for choosing a case study design was to avoid losing individual variability. In addition, they did not find averages of broad-based descriptions reliable. The child in this study attended speech therapy session twice weekly after her CI (a Nucleus 22-channel Multi Electrode cochlear implant) was switched on. Results of data collection over five speech therapy sessions revealed a wide range of segmental productions including all place, manner and voicing features of English. In addition, she produced sounds not produced in English, especially an over-production of frication. Despite a hearing age of just under two years, she was already producing consonant clusters and word-final consonants, and was able to produce all segments in her inventory in any syllable position. Though her speech inventory did not fully match that of English, she produced a variety of speech sounds and word shapes. The authors indicated that she did not produce /ɹ/ but that a child of her age should be producing /ɹ/. If they had counted hearing age rather than chronological age, this may not have been appropriate. The English /ɹ/ is a very complex sound composed of a number of articulatory components (Adler-Bock et al., 2007). This study would have been more informative with more participants. In addition, ultrasound or EPG would have provided us with greater detail on which to base phonological development in new cochlear implant users (Oh, 2004). However, it is not clear if the improvement is due to the CI itself, the SLP intervention or a combination of the two.

In a more recent study, Uchanski and Geers (2003) studied the acoustic characteristics of speech in young cochlear implant users to compare them with those of typically hearing children. Speech was analysed from 181, 8- and 9-year-old children four years post-implant. The results of their study revealed that children with the newer cochlear implants were producing speech with acoustic characteristics similar to those of children with normal hearing. While there is some correlation between the acoustic characteristics of speech and speech production, this does not completely account for articulatory accuracy. So, if children are able to hear more information in higher frequencies like frication, recent processing strategies provide more speech perception and therefore lead to better production. For example, a child may realize that frication is needed and produce a fricative-like sound, but one that does not match the language target. Uchanski and Geers (2003) considered the children's production of sounds with the category of manner as accurate, even it the child produced a /b/ for a /d/. While this means the child's speech is more accurate in term of manner, the child may continue to need articulatory training including visual biofeedback technology such as ultrasound or electropalatography to produce truly intelligible speech (see Bernhardt et al., 2003). Nevertheless, the ability of new cochlear implant users to perceive and produce speech sounds within manner of articulation is no small feat.

Higgins et al. (2003) looked at factors that contributed to intelligibility and fluency in a semi-longitudinal study of seven children. These children were implanted between 5 years and 3 months and 10 years and 7 months of age. Their speech and communication skills were judged for intelligibility 5 to 6 years post-implantation. This study offered a valuable contribution to understanding the interaction of the many variables that contribute to speech intelligibility and fluency: voice onset time (VOT), intraoral air pressure, oral and nasal airflow, and fundamental frequency (f0). Higgins et al. (2003) found that these children had great variability in speech production outcomes. Their observations of speech/voice patterns typical of speakers with hearing impairment resulted in mixed reports with some improving, and some showing new patterns typical of deaf speech. For example, in most children, f0 had either remained inappropriately high or had increased by the end of the study. The authors warn, however, that by the time this research had been published speech processor coding had changed, and many children were being implanted at younger ages. In addition, all of these children were educated in a total communication environment. They warn not to assume that delayed or disordered speech/voice patterns will improve without appropriate intervention. It would be important to investigate these variables in children implanted with the newest cochlear implant technology in younger children.

Another study that investigated the speech intelligibility of deaf children six years post-implantation (Cochlear Ltd. 22-electrode cochlear implant) found the number of intelligible utterances and syllables per utterance increased for nine children with profound hearing loss (Blamey et al., 2001). In addition, they found the percentage of words produced without error continued to rise. Analysis of the participants' speech intelligibility revealed a significant downward trend in unintelligible speech over time. However, unintelligibility did not fall to zero. Speech remediation was still necessary for all participants 6 years post-implant. Their study found that neither speech perception performance nor age of implantation was correlated with the rate of speech production improvement, which they claimed differs from several other studies. In addition, two participants in their study did not improve their speech intelligibility – supporting their claim that this study showed no evidence for a difference between speech intelligibility in participants implanted at very young or older ages. They emphasized that there may be many factors that contribute to the success of cochlear implants that were not investigated in this study, such as nonverbal intelligence and family support.

Ertmer and Mellon (2001) and Ertmer et al. (2002b) studied vocal development and intervention techniques for children with cochlear implants implanted before age 2. These descriptive studies give us insight into the variability of new cochlear implant users implanted at early ages. In Ertmer and Mellon's (2001) study of a deaf toddler, Hannah, implanted at 20 months, showed a great increase in canonical and post-canonical utterances in the first five months post-implant. Hannah's perception and speech production continued to grow, and after one year of implant experience she had a spoken vocabulary of about 90 words. Hannah had been receiving twice a week therapy for listening, speech and language. In Ertmer et al. (2002b), two toddlers aged 10 and 28 months were implanted and their vocal development was followed. In this study, the 28-month-old progressed more quickly, increasing canonical babbling and her vowel and consonant inventories, and later in the study, jargon and CVC syllable shapes. The 10-month-old developed speech quite slowly and atypically for hearing children, did not develop much canonical speech productions, but increased vowel and diphthong productions. In addition, the child implanted at the younger age developed vocalizations much more slowly than the older implanted child. Based on these results the researchers stated that early speech intervention plus auditory training is sometimes necessary for young children with cochlear implants. The authors presented a therapy approach that focused on modelling of speech sounds at the early stages of vocal development to assist the child in developing speech. Their programme used a family-centred approach to early speech and language therapy, not unlike the Hanen Early Language Programme (Watson and Weitzman, 2000). As predicted, all three children increased the complexity of their vocalizations over time, albeit at different rates. In these studies, it was not possible to tease apart the effects of cochlear implant versus habilitation and family support versus individual child factors. This is an important caveat for many studies of young deaf children across domains, not only speech. The authors recommend further research in these areas with a larger number of research participants.

Age of implantation plays a significant role in the outcomes of speech production for children with cochlear implants. This range of studies investigated children at different ages or different amounts of time, with different habilitation programmes, leaving confusing results. Overall it appears that children made gains in speech but continued to need habilitation post-implantation. More systematic studies investigating the same issues at different ages would be beneficial. However, because technology changes so rapidly, results may become quickly obsolete. The next section will explore the habilitation methods used by speech and hearing specialists to date.

Habilitation/Teaching Methods

As noted previously, habilitation/teaching methods are also relevant in speech production outcomes for people with cochlear implants. Cochlear implant habilitation is an important issue that continues to be contentious. Over the years various groups have formed their own ideas regarding best practice for education and training of children with hearing loss, each believing that their approach is best practice (Nevins and Shute, 1996; Connor et al., 2000; Ertmer et al., 2002; Chute and Nevins, 2003; Tobey et al., 2003). Some important questions to contemplate when considering the habilitation debate include: (1) how can we predict which children will do well, and (2) how can we know which approaches are best for each child and family at different points in time? This is important because developmental needs and learning are dynamic. Habilitationists and teachers need to be aware of the changing needs of the CI users throughout the learning process.

A positive side of this heated debate is the amount of research that has been done to prove or disprove a position. The main habilitation approaches with regard to deaf education are auditory-verbal, total communication, and the bicultural-bilingual approach. It is important to note that although the term Total Communication was coined to refer to a philosophical approach to educating children who are deaf, it is commonly used to describe a method of instruction which combines both spoken and sign languages (Garretson, 1976). The review touches on each of these approaches with a few examples from the vast literature in these areas.

Tye-Murray (2003), and Higgins et al. (2003) investigated changes in children's speech, voice and conversational fluency post CI. The result of Tye-Murray's (2003) study lead her to recommend programmes with an emphasis on communication therapies, i.e., speech and language therapy and communication breakdown strategies. In a comparison of cochlear implant users with typically hearing children, they discovered that the CI users communicating through simultaneous communication (oral and signed language together) had more communication breakdowns and dysfluencies than CI users in the oral communication group. The factors that impeded successful communication the most were speech intelligibility and language comprehension abilities. Higgins et al. (2003) found continued speech issues on at least two of their measures 5 or 6 years post implant.

Connor et al. (2000) examined the differences between an oral (OC) and total communication (TC) approach for speech, vocabulary and education of children using cochlear implants. In particular, they focused on consonant production accuracy and vocabulary development. This study included 147 children who had been implanted between 6 months and 10 years, all with profound sensorineural hearing loss. They found that overall children benefited from either approach, and improvements were made using both approaches. However there was a complex relationship between children's age at implantation, educational approach used and functioning with the cochlear implant. In their literature review, Connor et al. (2000) found mixed results, some research clearly supporting OC while others supported TC for greater language learning. All of the studies they examined supported OC for superior speech perception scores. Their study improved on past studies by controlling for age of implantation, preoperative aided speech detection thresholds, type of cochlear implant device used, knowledge of active electrode array successfully implanted, newer technology or an older device and number of years of experience with CI. For speech production accuracy they found the OC approach to be more successful with greater achievement and faster growth rates. When they controlled specifically for length of cochlear implant use to expected speech growth curves, they found no significant difference between OC and TC for children who received their implants during preschool. However, when they compared early and middle elementary school aged children, the OC children's speech production scores were significantly higher, with greater growth rates over time. This was a complex study, with a great deal of information, which adds to our knowledge when making decisions on programmes for children with CIs. They cautioned that quality of educational programmes, family factors and children's motivation are all important components that lead to success with cochlear implants.

Wilkins and Ertmer (2002), and Teagle and Moore (2002) introduced oral approaches in different school-based programmes that they claim led to educational success. However, it appears that neither of these recommendations was based on critical studies of these approaches. Wilkins and Ertmer (2002) advocated for education in an oral school with small classes and small group activities to help learn speech, language and listening skills. In addition they emphasized the use of trained professionals such as SLPs and teachers of the deaf working together to provide comprehensive services. Teagle and Moore (2002) advocated for an inclusive approach to habilitation with the child in his/her neighbourhood school, but supported by SLPs and educational audiologists who provide intervention with an emphasis on listening therapy, and speech and language training. Both programmes advocated for thorough assessments by SLPs, family training and support, family commitment to an oral approach, a home practice component, classrooms with appropriate acoustics for the hearing impaired and an interdisciplinary approach to habilitation. They also promoted the gradual change from signing to oral language rather than an auditory-verbal approach that promotes audition only. Interestingly, Teagle and Moore (2002) did not see the need for a teacher of the deaf, nor a specialized school. Wilkins and Ertmer (2002) supported a special oral school education, including daily speech perception and production training, with listening and speech reinforced throughout the day. However, they also included weekly reading activities with hearing children to act as models from a neighbouring school, mimicking a hearing environment. They claimed that the goal of their programme was to assist children in graduating to their neighbourhood schools. In the end, both approaches have the ultimate goal of placing children using CIs in their neighbourhood schools.

Uchanski and Geers (2003), in their study of over 150 children CI users, found that these children produced speech that closely resembled that of hearing children in terms of acoustic characteristics. They compared the acoustic characteristics of speech in children using CI's with those of children with normal hearing abilities. Their research revealed that a significantly greater number of children from an oral education setting produced speech that more closely matched the acoustic characteristics of normally hearing children's speech productions than those in total communication settings. However, once again we do not know what this meant in terms of articulatory accuracy.

In addition to the larger group studies, some case study research has also been done. Ertmer et al. (2002) described intervention programmes in two case studies for children with very different profiles. These examples highlighted the vast array of intervention needs by children with new cochlear implants. One child lost his hearing at age 3 (P1) and received a cochlear implant only at age 7 years and 6 months when he lost his remaining residual hearing. This child received a combination of auditory training, speech production training and language therapy with a focus on vocabulary comprehension and production twice a week. P1 was very successful with this approach to remediation. As the authors commented, having had hearing until the age of 3 was probably a factor in his quick success. At the time of the study, he continued to use both audition and signing to be successful in school. He was attending age-level appropriate classes with a signing interpreter when learning new information, and wearing an FM system. He no longer required speech production therapy because he had attained all English phonemes and had intelligible speech. This child was very successful with a total communication approach.

The second case study (P2) was of a younger child who had lost his hearing at age 5 months due to spinal meningitis, and suffered some neurological complications. This child received his cochlear implant at age 3 but because of ossification of the cochlea could only have 11 of 22 electrodes inserted and activated. Up until the age of 4 years and 2 months, P2 had received services that were insufficient for the amount of language, hearing and speech training that he required. They were neither specialized, nor intensive enough for his needs. At 4 years and 2 months he started speech therapy with the author and his team, and received therapy once a week for 90 minutes with a family-centred approach. Their assessment revealed that P2 had poor discrimination abilities with speech perception scores at chance, and that 80% of his vocalisations were still in the pre-canonical stage. He did, however, consistently produce five vowel sounds and three consonants. Most of his communication was through single signs, gestures and eye gaze. Speech and language therapy was a typical combination of structured auditory stimulation activities, speech production, language and play development activities, and a total communication approach. P2 developed speech, listening and language skills very slowly. At the end of two years, P2 was just able to discriminate between sounds and could identify a few words, initiated spoken language very minimally (although he was good at repetition), and communicated in one-word signs. It appears that P2 would have benefited from a much more intensive schedule of auditory and speech-language training. In addition, P2 did not have a certified teacher of the deaf managing his educational needs in the school, nor instruction in ASL from a fluent adult. Rather, he received instruction from an interpreter in a special needs classroom in manually coded English. This child required a much more intensive programme with additional intensive language therapy and training for the parents. These two cases demonstrate the extreme ends of the spectrum for outcomes with cochlear implants in young children. This study highlights the need for appropriate programmes that are run by professionals with specialized training, and the need for ongoing comprehensive evaluations so that additions and changes to programme plans can be implemented as soon as necessary.

Yoshinaga-Itano's (2003) also presents two case studies, putting forth the view that without sign language intervention, two profoundly deaf children since birth would not have developed speech and language. The sign language gave them a lexical bootstrap to speech. Both of these children were implanted at 22 and 30 months of age. Prior to receiving cochlear implants, neither of these children appeared to benefit from hearing aids used for amplification. However, neither of these children received an auditory-verbal or oral approach to habilitation where the focus was on residual hearing and audition. Therefore it is difficult to determine if these children would have been successful given this other approach. Instead, both children were provided with sign language expert instructors through which they learned language. After cochlear implantation, both of these children were successful with a total communication approach, using both oral and sign language. It remains important to compare the auditory-verbal and total communication approaches with a large number of children to determine if either approach is more powerful.

From these studies it appears that there is more than one approach that is successful for children with cochlear implants. Perhaps there is a constellation of elements that must be present for children to be successful, or perhaps there is considerable within-child and between-child variability. Further research is warranted with careful research designs that take into account the many factors that play a role.

Summary: Factors Contributing to Success with Cochlear Implant Use

While many of the factors contributing to the success of cochlear implant use have been touched upon with regard to successful outcomes and educational placements of children with cochlear implants, a large body of studies has attempted to determine exactly what the contributing factors may be (Gordon et al., 2001; El-Hakim et al., 2002; Kirk et al., 2002; Moore, 2002; Preisler et al., 2002; Tobey et al., 2003).

In a recent study, Tobey et al. (2003) investigated speech production outcomes and the factors influencing those outcomes with 181 children who had received a multi-channel cochlear implant by the age of five (between 1 year and 8 months and 5 years and 4 months). All the children in this study had been using a cochlear implant between four and six years. The participants in this study were all 8 or 9 years of age and implanted with the most current cochlear implant technology -- the Nucleus 22 electrode array. Judges of speech intelligibility were three hearing adults with limited exposure to hearing impaired individuals. Recordings were narrowly transcribed by SLPs. The results of this study revealed a number of interesting findings. Tobey et al. (2003) discovered that female participants had significantly higher speech intelligibility scores than male participants, with more variability of scores in male participants. Children who had the newer speech processing strategy, more active electrodes, a greater dynamic range and good loudness growth also had higher speech production scores. In terms of education, once again, auditory-oral education resulted in higher speech production scores, especially for children in regular classrooms. Finally, this study found that age of onset of deafness and age of implantation (although they were all implanted before age 6) did not appear to contribute significantly to oral communication abilities. It is important to note that the children in this study were implanted within a close time span of each other. This study presented very positive outcomes for families deciding to use cochlear implants. As technology continues to advance, with newer technology and programming strategies, outcomes will probably continue to improve. Fewer studies have investigated the outcomes of teenagers and adults with the latest cochlear implant technology; it would be interesting to explore the outcomes with this population. Will newer technology offer new possibilities to prelingually deafened adults? Researchers are considering every aspect of cochlear implants and the interplay between factors in their studies. While many more studies are needed, a good foundation has been laid.

Overall this sub-section highlights the importance of trying to determine cause and not just correlation. Many factors contribute to the success or failure of cochlear implants, and it is important for us to examine all the factors carefully. These factors include age of onset of hearing loss, age of implantation, habilitation/education programme and years of cochlear implant use. In addition, we still do not know exactly how cochlear implants work. With continued research and improving technology we are, it is hoped, coming closer to understanding the intricacies of this technology.

Summary

The literature has shown us that deaf and hard of hearing speakers need better amplification systems for greater speech perception initially. They then need good sound habilitation with an auditory-oral focus for good speech production outcomes. In addition, visual biofeedback, which focuses on articulatory information, appears to be beneficial because it offers direct information and shortens the habilitation time. It is quite striking from this review of the literature that while study after study over the last four decades has reported great success with visual feedback, it does not appear to be a key intervention tool. Perhaps in the past there was little access to these technologies due to availability or cost. Technologies were more cumbersome and difficult to use in real life, clinics and school settings. Nevertheless, the majority of these studies took place in schools, hospitals and clinical settings, often in partnership with universities.

There is now greater access to technologies that are portable and manageable in everyday settings. For example, ultrasound machines are smaller and lighter weight than many current laptops, and EPG systems can be installed onto a laptop. Speech therapy can continue to improve through clinical research on newer technologies and the interactions between perception technologies (newest hearing aids, cochlear implants, and FM systems) and biofeedback production technologies. In addition, a team approach to therapy can be utilized that allows for the best of all possible areas of expertise.

Major Question for the Dissertation

This literature review provides us with an in-depth look at the history of the use of visual feedback technologies for speech habilitation. The literature has shown the great potential of visual feedback as an important piece in the habilitation toolbox. With changes in technology and greater possibilities in terms of portability and affordability, it was a logical next step to explore the possibilities of ultrasound for speech habilitation with persons with hearing and speech impairments. The major question for this dissertation was to investigate the effectiveness of ultrasound as a tool (with and without EPG) in the short term and long term for adolescents with hearing impairment in speech therapy. In the next section, issues on methodology in outcomes evaluation will be discussed before giving an overview of each study, including specific questions for each.

Outcomes Evaluation: Combining Qualitative and Quantitative Approaches

A spectrum of methods can be more powerful than a collection of studies using the same method (Mosteller, 1990). The four studies presented in this dissertation provide a range of information on speech habilitation and the impact of visual feedback technology using a variety of research methods. This series of studies investigates speech intervention outcomes using quantitative pre-test/post-test designs, single subject design and qualitative methods.

There are different conceptual frameworks that attempt to define outcomes along a continuum of the consequences of disease, disorder, injury or active pathology (Frattali, 1998). The WHO (2001) classification divides functioning into three levels: the level of the body's structure and function (for example, the phonological system), a person's activities (e.g., communication with others) and a person's participation in society. With appropriate rehabilitation and intervention a disorder may or impairment may not result in a handicap. Mixed methodology including both qualitative and quantitative research may add to our further understanding of the impact of habilitation on functioning in society. "Methodological triangulation involves the use of both qualitative and quantitative methods and data to study the same phenomena within the same study or in different complementary studies…" (Tashakkorie and Teddlie, 1998, p. 18). Quantitative research uncovers the impact of an intervention on a variable under clinical investigation. Qualitative research allows the process to be discovery-driven, permitting the investigation to follow what emerges as important to understanding the area under investigation (Morse and Field, 1995; Simmons-Mackie and Damico, 1999). Qualitative studies can also address issues of social validity. Treatments that result in meaningful changes in clients' lives are considered to be socially valid (Olswang, 1998). "Knowing/proving the relationship between the treatment and the 'real-world' changes for the client is critical as we attempt to understand the nature of communication and the ways in which intervention can alter the effects of disorders" (Olswang, 1998, pp. 137). Because speech-language pathology focuses on human communication and social interactions, qualitative research is uniquely oriented toward uncovering the details of these social phenomena (Simmons-Mackie and Damico, 2003). There are different conceptual frameworks that attempt to define outcomes along a continuum of the consequences of disease, disorder, injury or active pathology (Frattali, 1998). Qualitative research may add to our further understanding of the impact of habilitation on functioning in society. Qualitative research allows the process to be discovery-driven, permitting the investigation to follow what emerges as important to understanding the area under investigation (Morse and Field, 1995; Damico and Simmons-Mackie, 1999).

Quantitative investigations can take different formats. Two of the quantitative investigations in this study were in the pre-post-test design format, designed to investigate the impact of an intervention strategy (in this case speech therapy with visual feedback) by judging the difference between pre-treatment and post-treatment measures (Silverman, 1998). The pre-post-test design is an improvement over the single case study, because treatment is applied to more than a single individual. This allows a point of reference so that the post-test scores can be compared to pre-test scores. However, limitations still exist, including effects of history, maturation and testing (Ventry and Schiavetta, 1986).

The other type of quantitative investigation used was single-subject design. A single-subject design to measure the efficacy of ultrasound technology for visual feedback is an appropriate and powerful design. Single-subject design research repeatedly and continuously measures the dependent variable from individual participants (Morgan and Morgan, 2001). "...The characteristics of single-subject and small-n approaches that may be found in the literature ...lend themselves to investigations of treatment efficacy while remaining true to ...the purposes of scientific research: replication, the discovery of causal relationships, the establishment of the generality of relationships, the discovery of new knowledge, and the use of formal codified knowledge as the basis for research" (Attanasio, 1994, p. 758). The major components of single subject design (SSD) are the same as in other quantitative research, i.e., the concepts of independent and dependent variables. Concepts unique to SSD include baseline, intervention and follow-up phases (Richards et al., 1999). Advantages of this design include the monitoring of behaviour throughout the treatment with withdrawal of an effective treatment not necessary to demonstrate change. Multiple-baseline design research lends itself well to clinical research.

Small-scale studies can provide valuable insights information for clinical investigations. "Using large groups of subjects or adding subjects to groups has an effect on the mean and standard deviation and would increase generalization, but only to the aggregate data; nothing is gained in our understanding of the individuals in the groups (Robinson and Foster, 1979)."

These small-scale studies for this dissertation will give us more detailed information about the successes and limitations of visual feedback technology for seven participants. Although the participant numbers are small, the studies also provide an opportunity to compare performance informally between the participants with cochlear implants and those with hearing aids. These studies further have the strength of evaluating short-term outcomes and also long-term outcomes. Outcome studies are important for evidence-based practice, which leads to better patient care (ASHA, 2005; Coyte, 1992; RCSLT, 2007). Long-term outcomes provide information about effectiveness of intervention as well as insight into predictors of successful outcomes (Felsenfeld and Broen, 1994; Bernhardt and Major, 2005; Glogowska et al., 2006).

Important to the quantitative investigations in this study are listener issues. Listening to difficult speech is extremely difficult, and therefore lower levels of inter-rater reliability are expected and have been found in past studies (Blamey et al., 2001). Efforts were made in the dissertation studies to decrease difficulty by using expert listeners (all studies), providing training (study 3), limiting listening time to prevent fatigue (studies 2 and 3), and using visual anchors (study 3-in the form of formant information and sliding scales) or auditory anchors (study 1-using Ladefoged's [2001] CD as a reference for comparison) when selecting phonemes. These issues of listener evaluation will continue to be addressed throughout the manuscript, and will are discussed further in the next section.

Outcomes Methods in Speech Production Studies

An important factor in outcomes studies in the area of speech production is deciding how to measure outcomes. There are a variety of possibilities: transcription (everyday and expert listeners), acoustic analysis and tongue movement measures (EPG contact points, ultrasound measurements). As noted above, outcome measurement using listeners requires careful attention to important factors such as listener factors (age, hearing ability, first language, experience with type of speech, expert versus everyday listeners) and transcription method (with anchors, without anchors, biased, forced choice, training versus no training). Because different types of analysis yield different information, it was challenging to select the best analysis for each study. Two types of measurement that may be useful to these investigations include tongue measurements and acoustic analysis. Currently tongue measurement using ultrasound is a difficult task that requires further investigations before accuracy can be claimed. We do not yet know how to measure tongue movement changes accurately and many hours of interdisciplinary research has taken place in the last decade in this area. In addition, it appears that this type of analysis is not necessary for clinical intervention to be successful. However, qualitative tongue shape information was found to be important for the SLP and client in these intervention studies. As a result the SSD study (chapter 3) used both listener evaluation and tongue shape evaluation to measure change in speech productions. EPG tongue-palate contacts, however, may be used to measure change in tongue-palate contact placement (as in study 1).

While acoustic analysis of formants for the hearing population is relatively straightforward and quite accurate (Hillenbrand et al., 1995), it is extremely difficult to interpret formant information for the speech of a person who is deaf or hearing impaired. Formant data are often difficult to read and take many hours of lab work to interpret. In addition, this may not always be adequate for people with speech impairment because some information may not be observable through formant values. Hardcastle et al. (1991) study indicated that tongue contact information is also valuable because it shows different information that may not be heard. Covert differences may not be able to be heard all of the time, but may contribute to speech issues. As a result acoustic analysis may not be adequate alone for disordered speech productions.

Different types of analysis were chosen for each study in this thesis to try and improve on the limitations of past studies and to account for differences in study design and technologies used. The major method was transcription by expert listeners. Our initial studies (Bernhardt et al., 2003; Bernhardt et al., 2005a) revealed essentially the same results for most targets with everyday listeners. Expert listeners, however, should be able to do fine transcriptions that everyday listeners do not have the training to do. This may allow researchers to see smaller changes in addition to the overall changes made by speakers. The first study (chapter 2), which investigated intervention outcomes of vowels for deaf and hard of hearing HA users (Bacsfalvi et al., 2007), relied on expert SLP transcriptions with perceptual anchors (comparisons with a recorded speech) plus acoustic analysis and tongue-palate contact point counts. This study attempted to improve on transcription methods used in an earlier investigation (Bernhardt et al. 2003) by using the Ladefoged (2001) CD as an anchor for each vowel transcription. The next study, which investigated three CI users and habilitation of 'r', enlisted expert listeners not directly involved in the study. These three SLPs were very experienced with both 'r' habilitation studies and ultrasound. Limitations of this study were limited experience with the speech of the deaf in two of the three listeners, perhaps reducing accuracy of transcriptions, and also perhaps creating difficulties in obtaining high listener agreement levels. However, inter-rater reliability of people with unintelligible speech is known to be challenging (Shriberg and Lof, 1991). Articulatory gestures were also examined as an additional outcomes measure to evaluate potential differences post-treatment that were not audible.

One of the two long-term follow-up studies (study 3) again used expert SLP listeners. In this study, listeners were provided with a chart that included a visual scale of phonemes for the consonants and formant values for men, women and children for each vowel. See chapter four figures 4.1-4.3 for a visual display of the selection screen. This was designed in order to reduce their selection bias. In addition, listener variability was reduced by randomly assigning one listener to each speaker. This also reduced comparisons of listeners between speakers, a possible biasing factor in the other listener studies.

An overview of each study is provided in turn. A more in-depth discussion of the purpose, methods and results of each study are presented.

Brief Overview of Each Study in the Thesis

Study 1

The purpose of the first short-term outcomes study was to investigate the impact of visual feedback technologies (electropalatography and ultrasound) as an adjunct to therapy, on the vowel productions of three students with severe-to-profound hearing loss with hearing aids. Vowels have received considerably less attention than consonants in phonological development and intervention research for children with and without hearing impairment (Bernhardt and Stemberger, 2000). Based on studies by Dagenais and Critz-Crosby (1992), Ryalls et al. (1994b) and Bernhardt et al. (2003), it was hypothesized that:

(1) acoustic correlates for vowels would be closer to those of speakers with normal hearing levels for formants F1 and F2,

(2) there would be improvement as perceived by expert listeners, and

(3) there would be changes in tongue-palate contact points for all vowels.

Untrained vowels might also change due to generalization effects, frequently seen in therapy. This study was the next step in the investigation of visual feedback methods for intervention, bringing together three areas previously not combined: vowels, visual feedback technology using both EPG and ultrasound and intervention. The study used a quantitative pre-post design for evaluation and revealed that the vowel /i/ changed significantly across all variables. Other vowels were also measured to have changed significantly across at least one variable, but not across all variables (Bacsfalvi et al., 2007).

Study 2

The purpose of the second short-term outcomes study was to investigate the effects of therapy with ultrasound only in conjunction with traditional speech therapy for three adolescent cochlear implant users on the articulatory components of North American English /ɹ/, and its production in isolation and words. While restoring at least some hearing to individuals who are deaf has been relatively successful, the spontaneous development of speech after surgical implant has not always occurred, as the literature review above indicates. Many cochlear implant recipients continue to need extensive speech therapy to become intelligible speakers, often for years. Others never quite develop intelligible speech, though they have recovered their hearing. Many deaf students obtain cochlear implants as a final attempt to increase hearing and thereby improve speech production (Ertmer et al., 2002). Bernhardt et al. (2003) revealed positive effects in production of /ɹ/ and other targets for adolescents with severe to profound hearing losses and hearing aids, in a study that used EPG and ultrasound independently.

The question for the current study was whether adolescents with new cochlear implants would be able to master the components of /ɹ/ and produce this phoneme in isolation. Past intervention studies have indicated that mastery at one level, i.e. the level of the phoneme or gestural components of a phoneme, can be viewed as positive prognostic indicators of learning during treatment, but are not the end product, which requires further practice (Gibbon et al., 1999). It was hypothesized that the participants in this clinical investigation would be able to learn the articulatory components of /ɹ/ and once established, be able to generalize the phoneme into spontaneous speech (Dagenais, 1992). In Dagenais's (1992) long-term clinical intervention study, teachers reported correct sound productions to be more stimulable once the target sound had been established, allowing for learning to take place without the use of equipment in the later stages of learning. (Another study, reported in chapter 3, revealed that the participants did show increased generalization over time.)

Because Bacsfalvi et al. (2001) and Bernhardt et al. (2003) studies revealed no apparent difference between either visual feedback tool for overall effectiveness, the present study investigated speech therapy in conjunction with ultrasound only as the sole visual feedback device. A single-subject design was used. The dependent variables were the articulatory movements and actual production of the target to be learned: the consonant /ɹ/. All participants wanted to learn /ɹ/ and were unable to produce it.

The outcomes differed slightly. Judgments from the clinical investigator revealed attainment of all articulatory gestures for all participants. Three listeners judged /ɹ/ at the word level. Improvement, at this level, was noted in the pronunciation of /ɹ/ for one of the participants. One listener noted improvement for a second speaker. The listeners noted minimal change for the third speaker, even though her articulatory gestures had changed.

Study 3

The purpose of the third study was to investigate the long-term outcomes of intervention with visual feedback technology on speech production. An expert listener study design was used. Questions were:

(1) Were these former students able to maintain changes?

(2) If they did lose some of the change, was it completely?

(3) Were any of the participants able to continue improving their speech through practice over time, now that they had more knowledge about speech segments?

Predictions, based on past studies (Dagenais, 1992; Bernhardt et al., 2003), were that participants would be able to maintain components of speech sounds established with visual feedback. With further practice these speech sounds would be generalised at the monosyllabic word level, multi-syllabic word level and so on up to conversational speech depending on continued therapy and practice without technology.

Results from this investigation of seven speakers by seven expert listeners revealed improvement or maintenance on at least one target for six speakers. While one speaker was judged to have not maintained improvements in speech production (at least for multisyllabic words), the qualitative assessment for the participant and that of the stakeholders disagreed (study 4), with the speaker and stakeholders believing that there had been continued improvement.

Study 4

The purpose of the final study was to investigate the outcomes of intervention with visual feedback technology over the long term using qualitative methodology. Quantitative results of these investigations with visual biofeedback are very important to our knowledge of the efficacy of visual feedback technologies as adjuncts to therapy; equally informative are qualitative approaches to evaluating the effectiveness of new intervention approaches. "…qualitative data acknowledges that the variables surrounding particular behaviours are complex, interwoven, and difficult to measure, and thus quantitative data alone are inappropriate or insufficient" (Olswang, 1998, p. 143). A qualitative descriptive study was chosen because descriptive studies remain close to the data.

The question for the current study was to determine the experiences of the participants and other related stakeholders through interviewing. These results would provide further outcome evidence to contrast and compare with findings in quantitative designs. Overall learning, generalization of speech targets and enjoyment of the methodology were important themes that emerged from this study.

Summary: Research Questions

The major question for the dissertation was:

Is ultrasound, with or without EPG, effective as a tool in speech therapy in the short and long term for adolescents with hearing impairment?

Each individual study asked the following questions:

Chapter 2: Are electropalatography and ultrasound effective tools for vowel remediation in the short term for adolescents with hearing impairment?

Chapter 3: Is ultrasound an effective tool for establishing the gestural components of /ɹ/ in the short term for adolescents with hearing impairment?

Chapter 4: Was ultrasound, with or without electropalatography, an effective tool for speech habilitation in the long term for adolescents with hearing impairment as judged by expert listeners?

Chapter 5: Was ultrasound, with or without electropalatography, an effective tool for speech habilitation in the long term for adolescents with hearing impairment as evaluated by the experiences of the stakeholders?

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CHAPTER 2

Electropalatography and ultrasound in vowel remediation for adolescents with hearing impairment

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The present study investigated the use of electropalatography (EPG) and ultrasound imaging in vowel remediation for three adolescents with severe hearing impairment. There are relatively few reports on vowel development and remediation, possibly because vowels tend to be more quickly acquired than consonants, even by children with hearing impairment (Osberger and McGarr, 1982). However, several studies have reported vowel production difficulties in speakers with hearing impairment. Stoel-Gammon and Otomo (1986) noted that 8-month-olds with hearing impairment produced fewer vowel distinctions than age-matched hearing babies. In their study of 192 speakers with hearing impairment (aged 8-20 years), Hudgins and Numbers (1942) described a number of vowel mismatches: substitutions (their example, J*a*ne for J*o*hn), splitting of diphthongs into two separate vowels, diphthongization (their example, *do you' as 'do-ee you-ee'*), and nasalization. Using EPG, Dagenais and Critz-Crosby (1992) observed that the tongue movements and positions for vowels in 10 children with normal hearing differed significantly from those of 10 children with hearing impairment, with speakers with hearing impairment showing less vertical range, less distinctive between-vowel tongue shapes and more within-vowel variability than the hearing speakers. Ryalls and Larouche (1992) also observed greater variability in vowel production in speakers with hearing impairment.

Few studies have been conducted concerning vowel remediation in speakers with hearing impairment. Because the present study utilized visual feedback, only those studies evaluating visual feedback displays are discussed here. Most earlier studies evaluated the impact of acoustic displays on speech habilitation (treatment), reporting generally positive results (e.g., Bridges and Huckabee, 1970; Boothroyd, et al., 1975; Houde, 1980; Stevens et al., 1983). Researchers have also used articulatory visual feedback in speech habilitation for vowels, using a number of different tools, such as, glossometry, ultrasound and EPG (e.g., Tudor and Selley, 1974; Shawker and Sonies, 1985; Klajman et al., 1988; Fletcher et al., 1989; Fletcher et al., 1991a,b; Bernhardt et al., 2003).

With glossometry, the client wears a custom-fit acrylic pseudopalate, much like a dental appliance, that has four pairs of light-emitters and receivers (diode photosensors). Hardware and software outside the speaker's mouth calculate and display distances between the tongue and the sensors during articulation. Fletcher (1989) evaluated the use of glossometry in a 3-week study with a 12-year-old with profound hearing loss. After daily practice with the glossometer, the client showed greater differentiation of tense-lax vowel pairs, although tongue placement remained variable. Fletcher et al. (1991b) targeted the four point vowels (/i, æ, u, ɑ/) in a one-month (15-20 session) glossometry study with six students aged 4 to 16 years with profound hearing impairment. Results were mixed but suggested that glossometric feedback could facilitate improvement in tongue position and vowel accuracy.

To view tongue position and movements with ultrasound, an ultrasound transducer is placed against the underside of the chin, above the larynx. Dynamic two-dimensional ultrasound displays a series of relatively strong white successive images that approximate the tongue's position and movements on a screen in real time. The images are a result of the refraction of ultrasound waves when they pass from tissue into air just above the tongue's surface. The transducer can be turned to allow imaging along either the mid-sagittal or coronal planes. In a study using 2-dimensional ultrasound, Klajman et al. (1988) evaluated vowel remediation in 18 deaf children aged 8-17 years. One to four vowels were targeted per child for up to 10 minutes per vowel. Post-treatment, six children produced the vowels accurately, ten showed closer approximations and two showed no change.

EPG requires the user to wear a custom-fit pseudopalate. The palate contains electrodes that record the timing and location of the tongue's contact with the palate. This allows display of tongue-palate contact patterns for the majority of English lingual phones on a computer monitor (Hardcastle et al., 1991). For vowels, EPG shows lateral tongue margin contact in the palatal and velar regions of the oral cavity. Lax vowels generally have less contact overall than tense vowels, and appear retracted in comparison (compare /u/ and /ʊ/ in Figure 2). The tense vowels are higher, and show a more advanced tongue root than their lax counterparts (compare /u/ and /ʊ/ post-treatment in Figure 2 for Purdy). Most EPG studies have focused on consonants. However, Bernhardt et al. (2003) targeted English high vowels in four adolescents with severe hearing impairment during three of 14 treatment sessions, using EPG or ultrasound independently in different sessions. Three participants showed significant gains in vowel production, although had not yet mastered the vowels.

The few studies using articulatory feedback for vowel remediation suggest that such feedback can have positive treatment effects. However, studies have been limited in terms of treatment time, participant number and evaluation measures. The present study was undertaken to investigate more in-depth the effects of EPG and ultrasound use in speech habilitation for vowel production in three speakers with hearing impairment by focusing only on vowels in treatment and by using three types of measures to evaluate results: phonetic transcription, acoustic analysis and EPG tongue-palate contact patterns. It was predicted that, post-treatment, vowels would be closer to the target acoustically, in terms of EPG tongue-palate contacts and in terms of phonetic transcription, with greater gains for trained than untrained vowels. Based on the Dagenais and Critz-Crosby (1992) study, it was expected that vowels might also show less variability post-treatment. Because none of the three participants had learned all high vowels, particularly the tense-lax distinction, these were treatment targets, with the lax vowel /ɛ/ being an untreated comparison target.

Insert Figure 2.1 about here

Insert Figure 2.2 about here

Method

Participants with hearing impairment

Three 18-year-olds from an oral program for the deaf and hard of hearing participated in the study. All three participants (pseudonyms Pamela [female], Purdy [male] and Peran [male]) were diagnosed with severe- to-profound sensorineural hearing loss before the age of 2;6 years. Aided thresholds for the three participants were in the moderate to severe range (sloping downwards towards the high frequencies). Although all three participants came from families that speak English as a second language, only Pamela speaks the family's mother tongue. All participants speak western Canadian English, which is similar to Standard American English with the exceptions of (a) /u/, which is produced as a high round central vowel, (b) /ɔ/, which is produced only before the consonant /r/ and (c) the limited appearance of "Canadian raising" (in which the onsets of the diphthongs /aʊ/ and /aɪ/ become mid vowels when they precede voiceless obstruents). These students had participated in the Bernhardt et al. (2003) study, and thus were familiar with EPG and ultrasound. Pre-treatment transcriptions (Table 1) by the first two authors showed relatively accurate production of /ɛ/ and /ɪ/ by Pamela, /u/ and /ʊ/ by Peran, and /ɪ/ by Purdy.

Insert Table 2.1 about here

Reference speakers with normal hearing

Speech samples were collected from two young adults in the local area (one female, one male) to gain acoustic reference data. In addition, EPG data were collected from one male and one female adult from the area. These data were collected as basic age-matched reference information for Canadian speech for the region, as recommended by Hillenbrand et al., (1995), who note that speech production can change over a period of several decades and can vary by geographical region. The reference data are included in Tables 3-5 and represent the average of ten tokens for each vowel, a similar amount to that collected for the study participants.

Equipment

A WIN-EPG (2002 version) system was used for EPG assessment and training with a Dell Computer and Windows 1998. The WIN-EPG is designed for use on a Windows operating system and uses Articulate Assistant 1.10 as the built-in EPG software. Both the participants and their two SLPs had custom-fit artificial palates. Two kinds of ultrasound machines were used in the study. An Aloka Pro-Sound SSD-5000 ultrasound machine with a 6 MHz UST-9118 180-degree convex array EV transducer was used for both assessment and treatment. A portable

Sonosite 180 Plus ultrasound machine with a Sonosite C15/4-2 MHz MCX convex array transducer was used only for treatment, i.e., when the larger machine was unavailable or when an ultrasound machine was taken to the participants' school. (The two machines provide very similar images.) Clarity of the image was enhanced on ultrasound by adjusting the range and gain (e.g. range of 11, gain of 60 on the Aloka Pro-Sound) and coating the transducer with water-soluble ultrasound gel. During EPG data collection, speech was audio-recorded using the WIN-EPG with a table-top Radio Shack microphone (model 33-3009) placed four inches from the mouth. During ultrasound data collection, audio and video data were recorded onto digital videotape using a Shure microphone (model SM58) placed 10 inches from the mouth.

General assessment and treatment procedures

Vowels were elicited in real CVC words collected pre- and post-treatment during both EPG and ultrasound data collection. Data were collected independently for EPG and ultrasound in order to reduce interference in speech production from having a simultaneous palate and ultrasound probe during assessment. This also provided a means to determine whether speech production would differ in the two conditions. Consonants in the words were chosen so as to limit co-articulatory influence on tongue position for the vowels (/h/, /p/, and in one case, /t/, as in *heap, hip, hoop, put, pep*). These monosyllables were produced in the carrier phrase *I'm a* *hoop*, which the participants could pronounce easily, and which contained a neutral vowel schwa as the last vowel before the vowel of interest. Each sentence was read ten times in a row, with the EPG palate in the participant's mouth for the EPG recording and with the ultrasound probe on a stand beneath the chin for ultrasound recordings. Sentence stimuli were not randomised in order to reduce the need to re-instruct the speakers frequently about the intended vowel target and to increase the speed of a very tedious task for speakers with a disability. (Unfortunately, the speech sample data for Pamela's pre-treatment /i/ were lost prior to analysis and, in addition, Peran's /ɪ/ data were lost due to technician error after analysis.)

Treatment took place twice a week for 6 weeks, and was conducted by the first and second authors of the study, both certified speech-language pathologists (SLPs). One of the weekly treatment sessions was at the Interdisciplinary Speech Research Laboratory (ISRL) at the university for 1 to 1.5 hours, and the other 45-minute session took place in the participants' high school. The first author took the portable ultrasound into the school for some of the school therapy sessions. All sessions had some individual and some group instruction. Each session began with an awareness component, i.e., the participants were given phonetic instruction about the vowel quadrilateral, the differences between tense and lax vowels and the articulatory components of the vowel targets. The SLPs then demonstrated the vowels using either ultrasound or EPG separately, with both still and moving images. Each student was asked to explain the articulatory parameters of the vowel and the differences between his or her production and the target. The vowels were practised first in isolation and then in syllables, words and phrases, with focus on the tense-lax distinction within sessions, using for example, minimal pairs or functional vocabulary. Home practice with a family member or school assistant and without visual feedback was encouraged for targets achieved within sessions (although the homework was not completed each time by all participants). (For further information on treatment procedures, see Bernhardt et al., 2003, 2005a, 2005b.) Following the treatment, acoustic, EPG and phonetic transcription analyses were conducted as described below. No ultrasound measurements were made, because of the difficulty in obtaining stable measurements for that technology (Stone, 2005). In addition, it was difficult to find an adequate method of head stabilization for the participants at the time of data collection.

Acoustic analysis

The audio-recordings of the vowels were transferred from the ultrasound recordings to a Macintosh computer using Adobe Premiere 1.0 (2004) as the video editing software and stored on the hard drive. Only ultrasound recordings were chosen for the acoustic analysis. Although there can be some noise from the scanner, it was considered that the ultrasound recordings might have less distortion than recordings using EPG pseudopalates. The waveforms of the vowels were extracted into Praat (version 4.2.05, Boersma and Weenink, 2005). Each vowel was analysed by a research assistant who had training on Praat and who was unconnected with the study. Vowel formant frequencies were obtained by first displaying the waveform of each vowel in Praat on the computer. Using the cursors from Praat, the target vowel was selected from each word and marked by hand. Once this was completed, Praat scripting was used to find the first three formants in each vowel. The 50% point was selected. All of the vowels were checked by the first author to determine that Praat scripting was accurate and that no incorrect formant choice had been made. Where discrepancies arose, these were corrected manually by the research assistant or first author. Average F1 and F2 values over the 10 tokens were calculated at each measurement location for each vowel pre- and post-treatment for the participants. Ten percent of all formant values were re-evaluated by the first author to assess inter-observer reliability. There was 85% exact agreement between the assistant's F1, F2 and F3 values and the first author's. Areas of disagreement (within a margin of error of 75 Hertz) were primarily due to weak signals in several audio files, making formants difficult to see. Disagreements were arbitrated by a phonetician unconnected with the study.

For acoustic analyses shown in Figures 3-5, F2-F1 x F1 was plotted because this method is reported to be a better mapping to spatial locations in the oral cavity (Ladefoged and Maddieson, 1996).

Insert Table 2.2 about here

EPG analysis

For purposes of tongue-palate contact analysis, the WIN-EPG analysis software (Articulate Assistant v1.10) was used. This system provides quantitative information on contact patterns in alveolar, palatal and velar regions (see Wrench, 2006, for more information). In general, the alveolar region represents the two upper rows, the palatal region, the middle three rows and the velar region the bottom three rows, with the black squares indicating tongue contact (see figure 2.2). A second research assistant unconnected with the study extracted the target vowels, and selected the point of maximum tongue-palate contact. The numbers presented by the program were checked visually by the first author and research assistant with 100% agreement between observers. Average values were calculated for each vowel for each participant pre- and post- treatment.

In terms of reference data, velar contact for the hearing male EPG reference data showed the highest percentage for /i/ and /u/, followed by /ɪ/, with very little for /ɛ/ and /ʊ/. Vowels /ɪ/, /i/, and /u/ also had observable palatal contact, while /ɛ/ and /ʊ/ had none (see tables 4-6).

Phonetic transcription

Speech sample data for transcription came from recordings conducted during both EPG and ultrasound assessments. Trained transcribers were used (the first and second authors of the paper), in keeping with the finding of Assmannn et al., (1982), that untrained listeners can have orthographic and labelling difficulties in evaluating vowels. Although the two transcribers were also the SLPs for the study, bias was reduced by using Ladefoged's (2001) phonetic training CD as a reference for comparison with each of the vowels of the participants. Reliability between transcribers was 88%. Differences in transcriptions related to degree of /ɹ/-colouring, raising, lowering, fronting or backing. Consensus transcriptions were arrived at by referring to the Ladefoged (2001) CD. These consensus transcriptions were then coded on a 3-point scale for quantitative analysis (as opposed to a 2-point measure indicating accurate versus inaccurate). The three-point scale (as utilized in Ertmer and Maki, 2000 Bernhardt et al., 2005a) provided a means to show partial matches with the target (a rating of '2'). A score of '1' reflected accurate articulation of the vowel (phonetically acceptable match). A score of '2' was given for broad transcription phonemic matching, i.e., narrow phonetic deviation was considered acceptable, e.g., /i/ realized as [ɪ]. A score of '3' indicated that the phone produced was not perceived as a match in either broad (phonemic) or narrow (phonetic) transcriptions, e.g. /i/ -> [ɪ]. Average ratings were calculated for each vowel pre- and post- treatment for each speaker. Ultrasound and EPG transcriptions are reported separately because of concern that speech produced with EPG palates may sound more unnatural.

Insert Figure 2.3 about here

Results and Discussion

Observations are presented and discussed within speaker, and then followed by a general summary. Note that Table 2.2 also includes acoustic data from the post-treatment recordings of a previous study (Bernhardt et al., 2003) as an indication of observable change over time across participants. These earlier data are for reference only and are not discussed in the current paper.

Pamela

All of Pamela's vowels except /i/ (for which EPG data were lost) showed change on some dimension in the present study, although no vowel showed changes on all measures. (There were also notable and in some cases, greater changes from Time 1 to Time 2.) The most-improved vowel appeared to be /u/, which showed improvement in both transcription (Table 2.1) and acoustic data (Table 2.2). A scatter plot (Figure 2.3) mirrors the change in tongue position when measured with formants. The higher F1 post-treatment reflects movement of the tongue away from the central pre-treatment position. The EPG contact data, however, did not show notable change for /u/. Pamela's artificial palate appears relatively short (i.e., does not extend very far back into the oral cavity), meaning that the tongue-palate contact may not have been visible for post-treatment /u/.

Reduced variability was one of the expected changes for /u/ and /i/. The standard deviation decreased for /u/'s F2 from T1- 93Hz to T2-68Hz to T3-50Hz. Results of acoustic variability were mixed across all other vowels from T1 to T3 for Pamela.

For Pamela, limited changes had been expected for the lax vowels, because pre-treatment transcriptions showed a high degree of accuracy, and /ɛ/ was untreated. Minimal or no changes were noted in transcription or acoustics in accordance with that prediction, although EPG contact data showed notable change (see Table 2.3 and Figure 2.2). The /ɪ/ and /ɛ/ velar contacts and the /ɪ/ palatal contacts approximated the adult target more closely post-treatment, but the /ʊ/ contacts varied more from the adult target post-treatment. The tongue placement changes for /ɛ/ were negligible post-treatment, and may have reflected random variation, i.e., no generalization effect. Overall, for the front lax vowels, results were in keeping with expectations. For the back vowel, /ʊ/ pre-therapy, there was little or no EPG contact (similar to the adult reference participant) and the EPG recordings matched the adult target (rating of "1"). However, the ultrasound recordings showed deviation from the adult target (Table 2.1), suggesting the vowel might show some post-treatment improvement overall. Post-treatment, changes in acoustics and transcription were insignificant, but there was a negative change in terms of EPG contacts; the consonant /t/ in the word *put* may have caused her tongue to move forward for the vowel as she was trying to make a difference in production.

The divergence in results between EPG contact patterns and transcription/ acoustic results occurred across all measurable vowels in Pamela's data. Contact pattern changes thus do not necessarily imply a change in the acoustic signal.

Insert Table 2.3 about here

Inset Figure 2.4 about here

Peran

Peran showed change on some dimension (transcription, EPG, acoustic) across all vowels, with /i/ showing improvement on all measures. Among the front vowels, transcription data for both EPG and ultrasound recordings revealed notable changes for /i/ and /ɪ/ (see Table 2.1) but not for the untrained vowel /ɛ/. Acoustic data (Table 2.2) appeared to converge with transcription data for /i/ but not for /ɪ/ or /ɛ/. Figure 4 reflects the change in tongue position for the vowel /i/. The lowering of F1 reflects a higher tongue body and movement of the tongue away from a more central position as expected. In terms of EPG contact (see Table 2.4 and Figure 2.2), changes in palatal and velar contacts were observed for only one front vowel (/i/) plus the two back vowels, /u/ and /ʊ/. Furthermore, less variability in range of contacts was seen for each of these vowels post-treatment. However, these changes were not necessarily mirrored acoustically, where minimal change was seen.

Acoustic formant data revealed reduced variability from T1 to T3 for vowels /I/, /u/ and /ɛ/. Overall there was a trend toward reduction of variability (standard deviation) across F2 values for Peran post- intervention. For example, /u/ standard deviation values decreased from T1- 113Hz to T2 – 96Hz to T3 – 47Hz.

Pre-treatment expectations were that Peran's front vowels /i/ and /ɪ/ would improve, with some possible generalization to the untrained vowel /ɛ/. Expectations were met for transcription and to a certain extent for acoustic and EPG data. Peran's high back vowels, which were considered accurate pre-treatment, were not expected to show much change. However, both back vowels did show change in EPG contact, in the direction of the adult target, although these changes were apparently not sufficient to trigger perceptible acoustic differences. Overall, Peran's formant data changed in the expected direction. The exceptions were F2 for /i/ and /ʊ/, which appeared to change in the opposite direction, which was surprising in that the transcriptions and EPG data for /i/ showed notable improvement. The decrease in variability post-treatment was also in keeping with pre-treatment predictions concerning vowels of the hearing impaired.

Insert Table 2.4 about here

Insert Figure 2.5 about here

Purdy

Purdy also showed positive change across vowels (see Tables 2.1, 2.2 and 2.5). Transcription data for both EPG and ultrasound revealed changes, but for different vowels. The EPG transcription data showed change in the direction of the adult target for the vowel /u/, while ultrasound transcription data showed improvement for /i/ and /ɛ/. Formant changes in trained vowels /i/ and generalization target /ɛ/ matched the direction of change in the transcription data. Figure 2.5 displays the change in F2 that reflects a change in position on the front- back dimension for /i/. Among the back vowels, /u/ changed less than /ʊ/ for the acoustic data.

For EPG contact data (Table 2.5 and Figure 2.2), all of the noted changes were in the direction of the male reference data except for /i/, which showed a trend in the opposite direction for both palatal and velar contacts. However, the acoustic and transcription data showed improvement for /i/, suggesting that Purdy could approximate the acoustic quality of /i/ with an individual contact pattern. Overall less variability of the contacts was seen for his vowels post-treatment. Purdy's acoustic data revealed a trend of reduced variability for F2 values. Less variability was seen for the vowels /u/, /ɛ/, and /ʊ/. For example, variability for /ʊ/ (as measured by standard deviation values) decreased from T1 – 156Hz, T2 – 43Hz, to T3 – 53Hz, while /u/ changed from T1-122Hz to T2 – 52Hz to T3 – 55Hz. Changes were not expected for /ɪ/ as this vowel was accurate pre-therapy.

In summary, few changes were expected for Purdy's vowel /ɪ/, which was relatively accurate pre-treatment; change was observed only for EPG contacts, which were in the direction of the adult reference data, in keeping with expectations. Purdy's post-therapy productions of all other vowels showed expected change in terms of transcriptions, acoustics and in at least one tongue-palate contact change per vowel. The lack of similarity between Purdy's EPG contact patterns for /i/ and those of the adult reference speaker probably reflects the variability among speakers in terms of typical contacts for any target vowel. Purdy's productions post-therapy for these vowels, as expected, generally revealed less variability, although his production of /I/ was more variable post-intervention in EPG contacts.

Insert table 2.5 about here

General Summary

The current study was not designed as a comparison of EPG or ultrasound, but employed both equally, with the view that the complementary displays might be facilitative for vowel production. The six-week study incorporating visual feedback did appear to have at least a short-term impact on the vowel production of the three adolescents (see Tables 1-6 and Figures 2-5). Eight of the 15 vowels (five vowels across three speakers) showed gains, which suggests that outcomes were not spurious, but were at least in part influenced by the treatment methodology. Quantitative and qualitative data collection is currently underway to determine whether gains in this study were temporary or stable.

In terms of individual vowels, /i/ showed improvement for all three speakers, with prominent gains for Purdy and Peran across all measures. For many speakers with sensorineural hearing impairment, vowels with high second and third formants such as /i/ are challenging; thus, the improvement for /i/ was noteworthy. All three participants also showed changes in EPG contact patterns for /ʊ/, although none of those changes matched transcription ratings or acoustic measures (except for F1 for Purdy). The untrained /ɛ/ generally showed less gains than other vowels across speakers, but this was not a remarkable difference. Overall, changes across vowels might reflect an increased awareness of the whole vowel space, and the need to use greater tongue movements in the oral cavity.

Variability in vowel production was noted to be another key issue for speakers with hearing impairment (Dagenais and Critz-Crosby, 1992; Ryalls and Larouche, 1992). In the present study, variability changes were noted for some vowels, usually in the direction of reduced variability post-treatment, another positive change, especially when coupled with improvement in accuracy.

Because the SLPs for the study were also the transcribers, it was important to have instrumental measurements undertaken by assistants external to the study, i.e., EPG and acoustic data, to compare with the phonetic transcriptions. For Peran, transcriptions accorded improvement to /ɪ/ whereas the other data did not confirm this, but for all other improvements noted in transcriptions across the three speakers, there were changes either acoustically or in terms of EPG, lending credibility to the transcription data. Some changes in EPG contacts and/or acoustic data did not reflect changes in transcriptions. Whether these were spurious, indicated incipient change or reflected real differences in evaluation methods cannot be known without follow-up studies. Differences among transcription, acoustic and EPG data have been reported previously. For example, Hardcastle, Gibbon and Jones (1991) reported that some speakers were able to produce consonants that were transcribed as accurate or near-accurate with tongue-palate configurations that were very different from typical productions. The use of different types of measures provided varying perspectives on the vowel production outcomes, with observation of possible subtle changes in EPG contact patterns that were not audible. However, more empirical studies are needed to learn about the articulatory and acoustic interactions of vowel production.

While EPG and ultrasound appear to offer valuable visual feedback, it is important to note that they are only one component of speech habilitation. Visual feedback cannot take the place of instruction based on knowledge of phonology and phonetics and speech-language pathology training and experience, but it does appear to show promise as an adjunct to treatment. Future clinical studies could vary the amount of type of time with and without different technologies to evaluate the effects of different types and intervals of treatment across different populations. Overall, the present case-based study suggests that further exploration of EPG and ultrasound is warranted, both independently and together, both to learn more about speech production from various perspectives, and to determine ultimate efficacy of such visual feedback approaches. Future research, eventually including randomized control trials may provide the field with more definitive answers on such technologies. In the interim, case data such as are presented here, provide insights into the potential of alternate treatments.

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Table 2.1: Transcription ratings for electropalatography EPG) and ultrasound (US) audio-recordings for all participants (Mean, SD)

	Tool	Pamela		Peran		Purdy	
Vowel		Pre	Post	Pre	Post	Pre	Post
/i/	EPG	n/a	n/a	2.3, .46	1.3, .23	2.9, .1	2.6, .49
	US	1.7, .48	1.4, 0.52	3.0, 0	2.4, 0.5	2.6, 0.1	1.7, 0.67
/ɪ/	EPG	1.2, 0.18	1.0, 0	2.7, 0.67	1.8, 0.66	1.0, 0	1.1, 0.1
	US	1.3, 0.7	1.0, 0	2.4, 0.97	1.3, 0.48	1.0, 0	1.0, 0
/u/	EPG	3.0, 0	1.6, 0.49	1.5, 0.67	1.1, 0.66	2.6, 0.47	1.8, 0.68
	US	2.6, 0.84	1.8, 0.65	1.0, 0	1.0, 0	2.7, 0.27	2.4, 0.49
/ʊ/	EPG	1.0, 0.18	1.3, 0.23	2.6, 0.5	2.0, 0.44	1.8, 0.18	1.3, 0.46
	US	2.0, 0	1.7, 0.48	1.0, 0	1.0, 0	1.8, 0.18	1.5, 0.28
/ɛ/	EPG	1.3, 0.23	1.8, 0.77	2.9, 0.1	2.9, 0.49	1.9, 0.84	1.5, 0.5
(un-trained)	US	1.3, 0.67	1.2, 0.4	2.6, 0.8	2.2, 0.91	2.7, 0.23	1.5, 0.72

Note. Vowels were pronounced in CVC words *heap, hip, hoop, put, pep* 10 times each in the carrier phrase *I'm a* ____. Transcriptions were coded using a 3-point scale: 1=phonetic match with adult target, 2= phonemic match, 3=non-match phonetically. Numbers represent averages and standard deviations over the 10 tokens.

Table 2.2: Average vowel formant values for the three participants 10 months prior (from Bernhardt et al., 2003) and pre- and post-treatment, compared with values for two hearing adults

Vowel		Pamela			Peran			Purdy			Hearing	Hearing
F1, F2		Prior	Pre	Post	Prior	Pre	Post	Prior	Pre	Post	female	male
/i/	F1	520	468	455	322	397	333	298	379	333	514	388
	F2	2119	2470	2480	1968	1966	1859	2005	1776	1930	2964	2233
/ɪ/	F1	463	605	609	339	347	329	374	464	420	914	633
	F2	2205	2101	2097	1943	1903	1868	1962	1716	1704	2251	1748
/u/	F1	576	430	503	314	389	450	316	356	346	621	435
	F2	1222	1018	1055	989	962	940	1584	817	1118	1418	1165
/ʊ/	F1	539	607	648	322	424	448	301	367	461	708	507
	F2	1131	1348	1299	932	1528	1615	1217	1430	1426	1796	1121
/ɛ/	F1	877	979	967	376	409	736	485	462	558	996	774
	F2	1920	1875	1913	1989	1775	1519	1794	1534	1406	1942	1596

Note. The values listed from the two young hearing adults were collected in the Interdisciplinary Speech Research Laboratory at the University of British Columbia as local acoustic reference data. Contact the author for further detail on the values, including standard deviation data.

Table 2.3: EPG tongue-palate contact data for Pamela

Vowel	Tongue contact area	Hearing female	Pre-Tx mean (SD)	Pre-Tx range	Post-Tx mean (SD)	Post-Tx range
/ɪ/	Palatal	.091	.034 (.026)	0-.083	0[a]	0[a]
	Velar	.408	.433 (.074)	.25-.5	.185 (.089)	.083-.292
/u/	Palatal	.054	0	0	0	0
	Velar	.454	0.017 (.029)	0-.083	.033 (.047)	0-.125
/ʊ/	Palatal	0	0	0	.731 (.123)	.583-1
	Velar	.142	0.046 (.041)	0-.083	0.496 (.172)	.375-.958
/ɛ/	Palatal	0	0	0	0	0
	Velar	.167	0	0	.12 (.252)	0-.083

Note. Palatal and velar contact numbers are mean maximum values for 10 pre- and 10 post-treatment (Tx) tokens. Vowels were analysed with WIN-EPG in words *heap, hip, hoop, put* and *pep* in the phrase *I'm a* ______. Data for /i/ were irretrievable. Reference data are included for one adult hearing female from the local area.

[a]Based on nine tokens.

Table 2.4: EPG tongue-palate contact data for Peran

Vowel	Tongue contact area	Hearing male	Pre-Tx mean (SD)	Pre-Tx range	Post-Tx mean (SD)	Post-Tx range
/i/	Palatal	.375	.196 (.127)	.042-.417	.475 (.069)	.375-.583
	Velar	.692	.583 (.075)	.417-.667	.646 (.066)	.542-.75
/ɪ/	Palatal	.091	.233 (.123)	.083-.417	.258 (.101)	.167-.458
	Velar	.408	.546 (.079)	.417-.667	0.454 (.108)	.333-.667
/u/[a]	Palatal	.054	0 (0)	0	.004 (.013)	0-.042
	Velar	.454	.170 (.127)	.042-.458	.314 (.065)	.125-.375
/ʊ/	Palatal	0	.554 (.127)	.333-.708	.013 (.028)	0-.083
	Velar	.142	.675 (.058)	.583-.792	.271(.141)	.042-.05
/ɛ/	Palatal	0	.188 (.087)	.125-.417	.208 (.076)	.083-.333
	Velar	.167	.375 (.1)	.25-.5	.375 (.098)	.25-.5

Note. Palatal and velar contact numbers are mean maximum values for 10 pre- and 10 post-treatment (Tx) tokens. Vowels were analysed with WIN-EPG in words *heap, hip, hoop, put* and *pep* in the phrase *I'm a* ______. Reference data are included for one hearing adult male from the local area.

[a]Based on 11 tokens.

Table 2.5: EPG tongue-palate contact data for Purdy

Vowel	Tongue contact area	Hearing male	Pre-Tx mean (SD)	Pre-Tx range	Post-Tx mean (SD)	Post-Tx Range
/i/	Palatal	.375	.025 (.029)	0-.083	.004 (.013)	0-.042
	Velar	.692	.525 (.040)	.458-.583	.496 (.053)	.417-.542
/ɪ/	Palatal	.091	0	0-0	.017 (.022)	0-.042
	Velar	.408	.441 (.029)	.417-.5	.358 (.069)	.25-.458
/u/[a]	Palatal	.054	.012 (.020)	0-.042	0(0)	0-0
	Velar	.454	.417 (.068)	.333-.5	.242 (.068)	.125-.333
/ʊ/	Palatal	0	.079 (.633)	0-.208	.025 (.040)	0-.125
	Velar	.142	.467 (.122)	.292-.667	.362 (.059)	.292-.458
/ɛ/	Palatal	0	.334 (.033)	0-.083	.029 (.02)	0-.042
	Velar	.167	.304 (.059)	.208-.375	.221 (.048)	.167-.333

Note. Palatal and velar contact numbers are mean maximum values for 10 pre- and 10 post-treatment (Tx) tokens. Vowels were analysed with WIN-EPG in words *heap, ship, hoop, put* and *pep* in the phrase *I'm a* ______. Reference data are included for one hearing adult male from the local area.[a]Based on 7 tokens for *hoop* pre-treatment.

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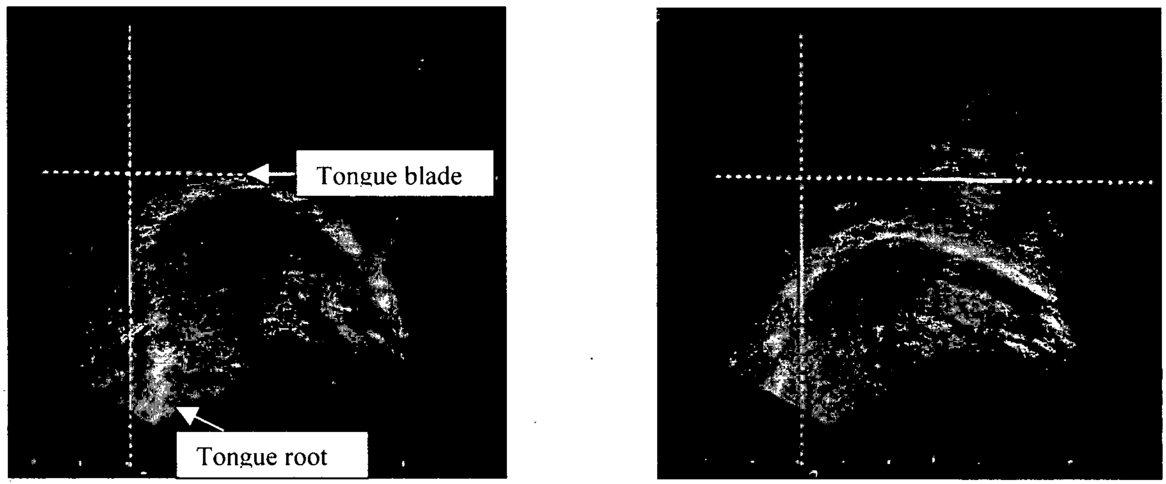

Figure 2.1. Mid-sagittal ultrasound displays of the English tense vowel /u/ (left), and /ʊ/ (right). The tongue tip is on the right of the image. Note the comparatively high tongue body and advanced tongue root of /u/ compared with /ʊ/.

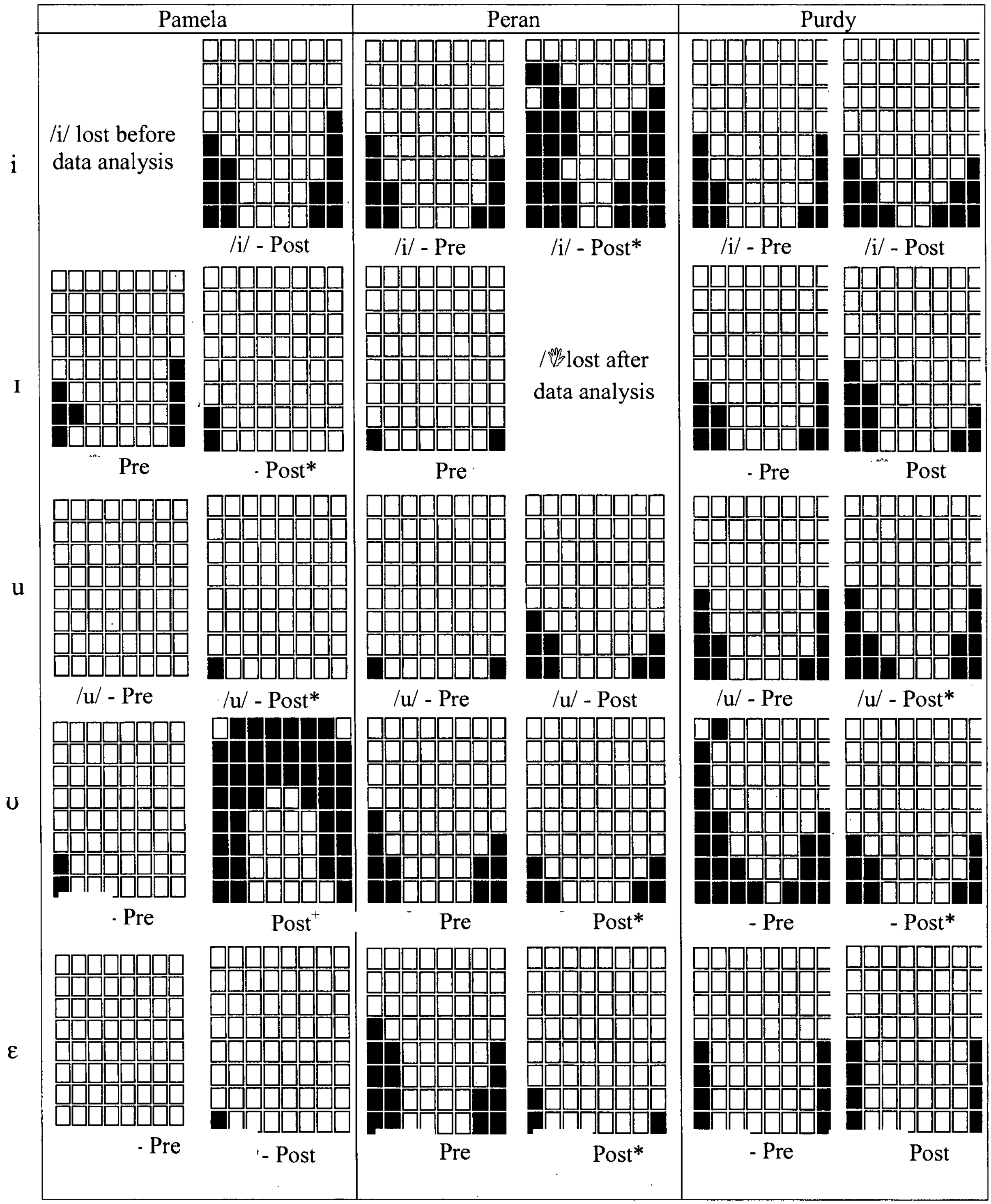

Figure 2.2. EPG contact patterns (black) for one sample vowel (maximum point) for each participant pre- and post-treatment. The upper two rows represent the alveolar region, the middle three rows the palatal region and the lower three rows, the velar region. *=notable improvement towards the adult target. += notable change away from adult target.

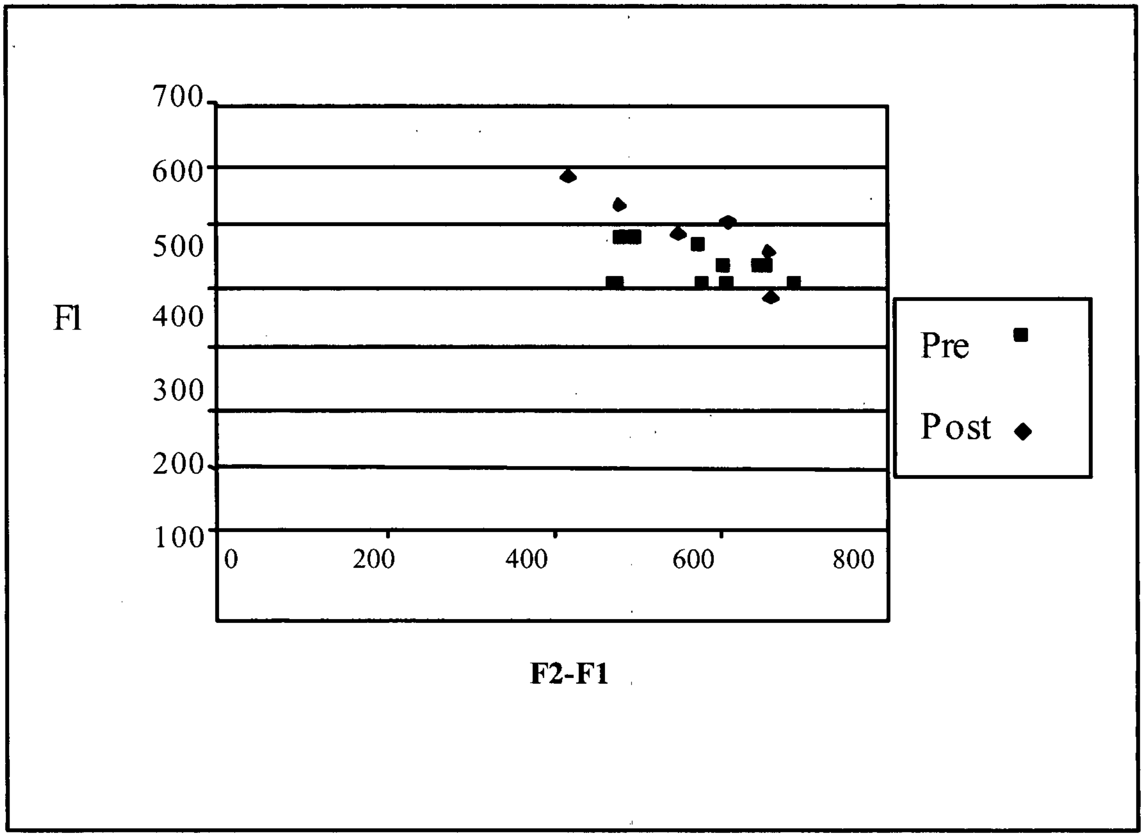

Figure 2.3. An acoustic plot of Pamela's /u/ (F2-F1 x F1). Note the higher F1 post-treatment.

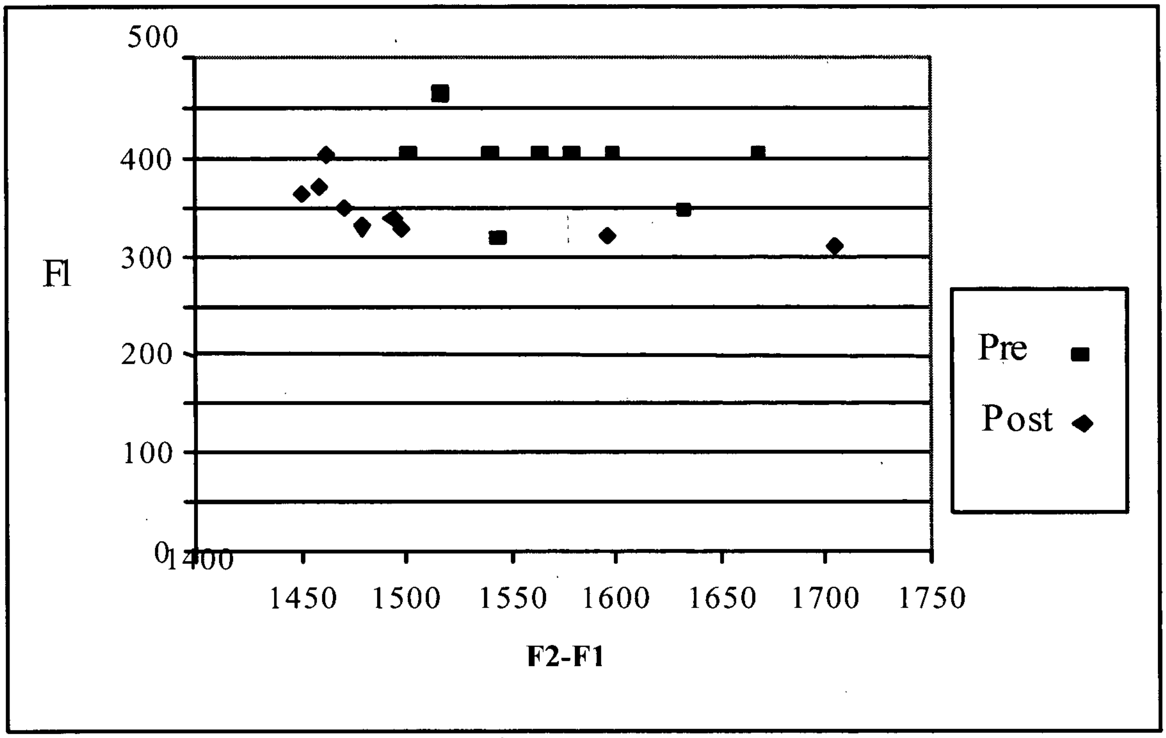

Figure 2.4. An acoustic plot of Peran's /i/ (F2-F1 x F1). Note the lowering of F1 and F2 and the reduced variability post-treatment.

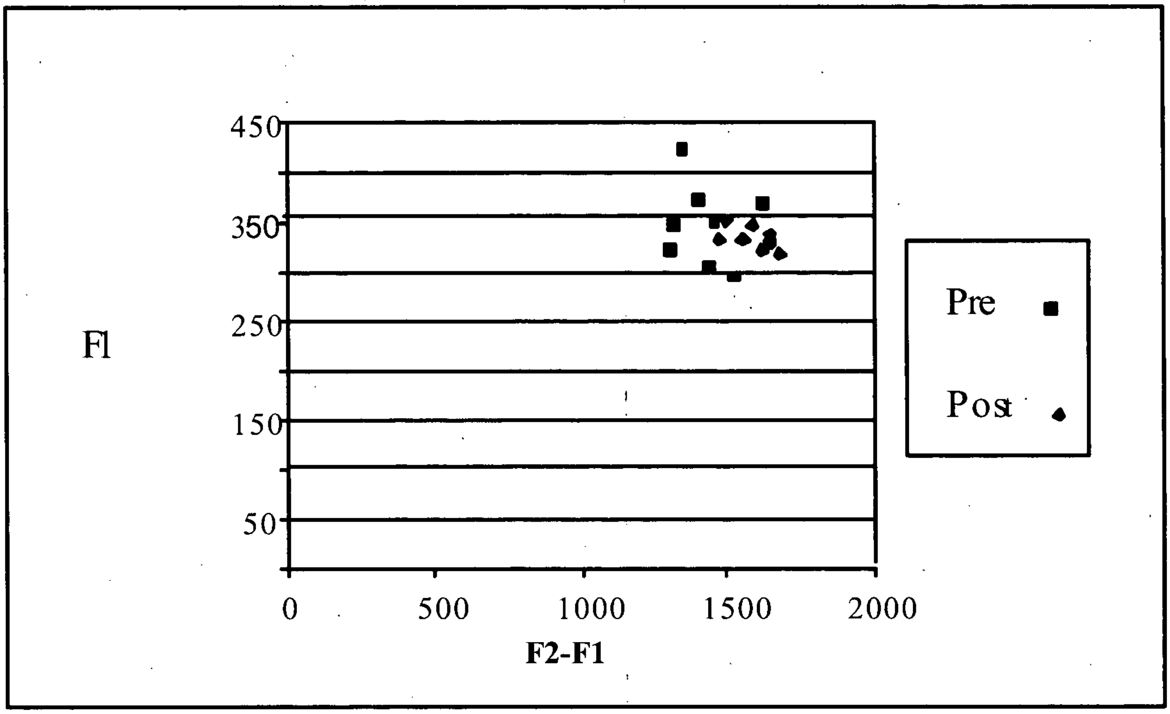

Figure 2.5. An acoustic plot of Purdy's /i/ (F2-F1 x F1). Note the change for F2 and reduced variability post-treatment.

CHAPTER 3

Attaining the lingual components of /ɹ/ with ultrasound for three adolescents with cochlear implants

A version of this chapter will be submitted for publication to the American Journal of Speech-language Pathology in June, 2007. Bacsfalvi, P. Attaining the lingual components of /ɹ/ with ultrasound for three adolescents with cochlear implants

As cochlear implant technology continues to evolve, greater access to the speech signal through audition is expected, and with it, potential for increased skills in speech production. The success of cochlear implants for improving auditory perception, regardless of age of implantation, has been frequently reported in recent years (Schramm et al., 2002; Zwolan et al., 2004). Students with severe to profound hearing loss may obtain cochlear implants as a final attempt to increase hearing and thereby improve speech production (Ertmer et al., 2002). Most of the research shows that children benefit the most in terms of speech, language and hearing outcomes when receiving their cochlear implant before the age of 5 (Geers, 2004; Flipsen and Colvard, 2006). However, older children and adolescents with congenital hearing loss are receiving cochlear implants in the region in which this study took place. Many of these later recipients of cochlear implants require speech-language therapy (Bernhardt et al., 2000).

The cochlear implant bypasses the external and middle ears by using electrical stimulation of electrodes implanted in the cochlea to reintroduce the signals carried by auditory nerve fibers to the brain. The goal of this technology is to elicit patterns of nerve activity that mimic those of a normal ear for a wide range of sounds. Ideally, such a system can enable people deafened later in life to recognize all types of sound (including speech) spontaneously, and can also provide input required for children deafened at a young age to acquire speech (Eddington and Peirschalla, 1994). However, while restoring hearing to individuals who are deaf has been quite successful, the spontaneous development of speech post-implant has not always occurred (Bernhardt, et al. 2000). Many cochlear implant recipients continue to need extensive speech therapy to become intelligible speakers. Others never quite develop intelligible speech, even though they have improved hearing ability (Ertmer et al., 2002). Studies of speech production of people with severe to profound hearing loss have revealed that, even years after receiving a cochlear implant, difficulties with speech production may continue, with clients showing limited tongue movement and reduced vertical range (Higgins et al., 2003).

Visual feedback technology has been shown to be a useful adjunct to speech therapy for people with a hearing loss (Dagenais, 1991; Dagenais, 1992; Bernhardt et al., 2003). Ultrasound, in particular, is good for showing tongue shapes and movement (Bernhardt et al., 2005). When an ultrasound probe is situated under the chin during speech, sound waves are reflected back from air just above the tongue back into the probe. The resulting waves are translated into images, which are presented on a computer screen, and show the outline of the tongue during speech production. Ultrasound alone has been shown to be helpful in remediation of long-term persistent speech errors, such as /ɹ/ (Adler-Bock et al., 2007). The lingual components of North American /ɹ/ that are visible on ultrasound include: tongue root retraction (into the pharynx), tongue tip retroflexion/curling or tongue blade bunching, and tongue midline grooving (see Figure 3.1).

Insert Figure 3.1 about here

Because preliminary research revealed that with ultrasound could be useful in remediating North American English /ɹ/ (Bernhardt et al., 2003; Adler-Bock et al., 2007), a study was initiated with three recent cochlear implant users with long-term speech production difficulties who did not yet produce /ɹ/. The objective of the study was to establish the lingual components of /ɹ/ to the three speakers through visual feedback as a basis for production of the phone /ɹ/. It was assumed that accurate tongue shape and articulator positioning is an essential first component in learning speech targets during treatment. Auditory perceptual judgments may not be able to detect covert contrasts that a client might be showing pre- or post-treatment for the targets in question (Gibbon et al.,1999), whereas the two views of ultrasound enable the clinician and client to evaluate tongue positioning during the treatment process.

A single-participant design approach was used to evaluate the effectiveness of the ultrasound technology for teaching the components of /ɹ/. Single participant research uses an approach that repeatedly and continuously measures the dependent variable from individual participants (Morgan and Morgan, 2001). "...The characteristics of single-subject and small-N approaches that may be found in the literature ...lend themselves to investigations of treatment efficacy while remaining true to ...the purposes of scientific research: replication, the discovery of causal relationships, the establishment of the generality of relationships, the discovery of new knowledge, and the use of formal codified knowledge as the basis for research" (p. 758, Attanasio, 1994). Predictions were that the students would attain the lingual gestures of /ɹ/ during the treatment program, with the possibility that they might produce accurate /ɹ/s after treatment in isolation and simple-syllable words. (It was recognised that further practice and speech therapy would probably be needed for accuracy in all positions in words, sentences and conversation, a process which was beyond the scope of the current project [Ruscello, 1984; Bernhardt et al, 2003; Bernhardt et al. 2005a; Bernhardt et al. 2005b].)

Method

Participants

Three participants were recruited for the study who met the following inclusion criteria: (1) severe-to-profound bilateral sensorineural hearing loss, (2) congenital or early onset of hearing loss (< 3 years of age), (3) use of a cochlear implant unilaterally for more than three months (to allow mapping to be set and time for some auditory perceptual training), and consistent use of the cochlear implant, (4) the desire and motivation to improve speech productions, (5) past or current enrolment in an educational environment with an emphasis on an oral approach and (6) access to speech therapy.

All the participants had received years of speech therapy and had had varying degrees of success with traditional approaches. While many phonemes were accurately produced, these students were interested in a new approach to speech therapy for remediation of the long-standing speech errors that had not been successful with traditional methods. All wanted to use speech as a primary mode of communication at the time of the study.

Participant 1 (pseudonym: Parker) was 15 years of age and had CHARGE syndrome. Parker had a 3G Cochlear Nucleus behind-the-ear processor, which he had been using for 9 months when he joined the therapy project. In terms of his hearing history, prior audiology reports indicated a profound sensorineural hearing loss in the left ear and a moderate to severe sensorineural hearing loss in the right ear since birth. Parker had been fitted with a unilateral hearing aid in the right ear at 1.5 years of age. At the age of 12 Parker's hearing began to degenerate and by 14 he had a profound sensorineural hearing loss bilaterally. At that time he appeared to receive no benefit from his hearing aids, and seldom wore them. Even prior to hearing degeneration, Parker's hearing aid was reported to have provided minimal benefit. His mother reported that throughout his childhood he wore his hearing aid at school but took it off as soon as he arrived home. When therapy began nine months post- implant, Parker was able to discriminate and identify most speech sounds.

Parker had been in a signing program for most of his life, but wanted to learn improve his oral communication. He communicated at school and with his peers and mother predominantly in sign language. Communication with his father, brother, family and neighbourhood friends was in spoken or written language. The author found his speech to be intelligible with careful listening.

The main settings for Parker's habilitation were the home and the university. Although he had never used ultrasound technology and was unfamiliar with it, Parker was very interested in and motivated by the ultrasound technology for improving his speech. Parker was accompanied by his mother (a teacher) during therapy sessions. In addition, Parker and his mother worked very hard on practicing at home during the ultrasound therapy project.

Initial speech evaluation with ultrasound by the author, using a word list developed for ultrasound assessments at the speech laboratory (see Appendix A), revealed some difficulty with the production of velars and none of the expected lingual components of /ɹ/. Figure 2.2a provides an example of Parker's /ɹ/ attempt in word-initial position before intervention. (Note: Pre-treatment status is indicated here as part of participant description.)

Insert Figure 2.2 about here

Participant 2 (pseudonym Pearl) was 15 years of age. Pearl had a 3G Cochlear Nucleus behind-the-ear processor, which she had been using for 3 months when she joined the therapy project. Prior audiology reports indicated a profound sensorineural hearing loss in both ears since birth. Pearl had been fitted with binaural hearing aids at 3 months of age. Audiology reports also indicated that the hearing aids were not providing Pearl with the auditory information that she needed. Aided response to warble tones revealed the range of moderate to severe hearing loss from 250-4000 Hz in the right ear. The left ear showed a moderate to moderately severe hearing loss from 250-1500 Hz with no response at 2000 or 4000 Hz. She had been in oral programs her whole life, but communicated in a combination of written, oral and sign languages. The author rated her speech as fairly unintelligible, even to familiar listeners.

The main setting for Pearl's habilitation was the university. She had previously been unmotivated for speech practice and homework at school, but was much more motivated upon receiving her new cochlear implant. Unfortunately due to lack of availability of practice partners at school, and English as a Second Language factors at home, Pearl did not have consistent practice with accurate /ɹ/ models. Some of the time her sister Petra (see below) practiced with her. (Note that both Cantonese and English were spoken in the home, however both girls used either English or a form of sign language to communicate.)

Initial speech evaluation by the author revealed difficulty with the production of several consonants and vowels, including /ɹ/ (the /ɹ/ portion of the word list is in Appendix A). Pearl indicated that she wanted to focus on /ɹ/ at the time of the study. Ultrasound images of her /ɹ/ attempts pre-treatment showed none of the lingual components of /ɹ/ (Figure 3a). Pearl had participated previously in informal pilot therapy with ultrasound and was familiar with the equipment and the therapy process with visual feedback technology. She had previously acquired velars /k/ and /g/, as her only targets, using ultrasound. (Note that voicing was worked on independently.)

Insert Figure 3.3 about here

Participant 3 (pseudonym Petra) was 18 years of age. She and Pearl are siblings. Petra used a 3G Cochlear Nucleus behind-the-ear processor, which she had also had for three months when she joined the therapy project. Prior audiology reports indicated a severe to profound sensorineural hearing loss in both ears since birth. Audiology reports also indicated that hearing aids (Phonak PPCL4 BTEs) provided adequate gain up to 1000 Hz but not above that frequency. The author rated her speech as intelligible for most listeners but with a quality typical of people with severe hearing impairment. She had been in oral programs throughout her schooling, and communicated predominantly in spoken English. She did use signing with some friends and acquaintances from the deaf community but used oral and sign communication at home and at school.

Petra had also participated individually in an informal pilot study with ultrasound and was familiar with the equipment. During treatment, she had previously been introduced to the lingual components of /r/ (the only treatment target) and was able to produce all of the gestural components some of the time at the end of that pilot period before receiving her cochlear implant. Therapy research had been stopped to allow her time to adjust to the cochlear implant and the initial stages of learning to listen in a new way. Petra participated in the current study in order to re-learn the components of /r/ with the new and different auditory feedback.

The main setting for Petra's habilitation was the university and her community college. Petra was diligent with school-work in the high-school and in her first year of college. Petra had the opportunity to practice her speech occasionally with an educational audiologist at the community college she was attending. However, she too, due to family circumstances, did not have the necessary support for consistent practice and feedback in the home. Nevertheless, Petra worked on her own to achieve her speech goals because she is very self-motivated. Figure 4a provides an example of Petra's /r/ attempt in word-initial position before intervention in the current study.

Insert Figure 4a about here

Research design

A non-concurrent multiple baseline across participants was employed in this single subject design study, with a changing criterion design for each participant. The design allowed for a sensitive assessment of developing repertoires, which is critical to clinical research (Gliner, Morgan and Harmon, 2000; Morgan and Morgan, 2001). A componential approach to teaching /r/ was used (Adler-Bock et al., 2007; Bacsfalvi et al., 2004). As each lingual component was established, the next one was added. The design had three major phases (a) baseline, (b) intervention and (c) follow-up. The functional relationship between the independent variable and the dependent variable was documented through a step-wise improvement in lingual component productions.

First the baseline of the target behaviours was established. When a stable baseline was established, training was initiated. Training began for each speaker with tongue root retraction because this is a critical element of /ɹ/ and one that is easy to demonstrate (Bacsfalvi et al., 2001, 2004). As mentioned, a componential approach was taken, which allowed the establishment of each lingual component before the next one was learned. Each component or gesture was learned first in isolation and, once maintained, then combined with others.

The dependent variables were the achievement of lingual components of /ɹ/: tongue root retraction, tongue tip elevation or tongue blade bunching and midline grooving of the tongue (see Figure 3.1). Note that lip rounding is also required, but ultrasound is not needed for demonstrating the lip gestures. Accuracy was measured two-thirds of the way through each session, after the client 'warmed-up' and before fatigue began. Based on the participant series for each trial, a summary percentage across the 10 trials was generated. Criteria were considered met when the participant produced 7 out of 10 accurate productions for each gesture. A gestural component was considered established when the speaker could produce the gesture without prompts or cues from the clinician-researcher. Criteria during the intervention phase were changed when the participant met the criteria for three consecutive sessions.

Equipment

An Aloka Pro-Sound SSD-5000 ultrasound machine with a 6 MHz transducer series M00196 was used for assessment (and treatment when available), and a portable Sonosite 180 Plus ultrasound machine with a Sonosite C15/4-2 MHz MCX transducer was used only for treatment. Clarity of the image was enhanced on all machines by adjusting the range and gain (e.g. range of 11, gain of 60 on the Aloka Pro-Sound) and coating the transducer with water-soluble ultrasound gel. The portable machine allowed the speech-language pathologist (SLP, author) to work with the participants in the home or other rooms at the university when the need arose.

Intervention process

All students attended weekly 45-60 minute treatment sessions to learn the lingual components of /ɹ/, and to subsequently attempt /ɹ/ in isolation and at the word level. Intervention sessions took place in privacy in the lab at the university or in the student's home with the portable ultrasound machine. Tongue tip retraction was demonstrated by the author, with an explanation that the tongue was being pulled back and kept low in the mouth. Tongue tip retroflexion was also demonstrated with the explanation that the end of the tongue is curling up and back. The tongue tip retroflexion (see figure 3.1d) was introduced as a backwards curl, but the students were also shown how the SLP used a bunched tongue blade, rather than a curled tip. They were instructed to try whichever one they found easier to learn. All three of the students began with the tongue tip curl because they found this easier to understand. Once these components had been established and the students could combine the components, voicing was added to attempt an [r]. After the student was able to produce /ɹ/ in isolation, /ɹ/ was incorporated into syllables and words in word-initial, -medial and -final positions as a singleton and in consonant clusters (e.g., /gr/, as in green).

Target contexts for /ɹ/ were decided in part with the students because they had words that they wanted to learn to say accurately. Therefore, contexts reflected these personal goals for each student. Attempts were made to target words where /ɹ/ occurred initially and finally with front, back, high and low vowels.

Evaluation of lingual components and speech samples

Evaluation of the treatment program focused primarily on the lingual components of /ɹ/. In addition, two speech-language pathologist listeners were asked to evaluate the /ɹ/ sound files collected during assessments to evaluate whether change towards /ɹ/ accuracy in single words was underway.

The participants' lingual gestures were evaluated qualitatively by the first author. The components investigated included the lingual gestures of tongue retraction, tongue tip curl and lateral margins raising. The gestures were recorded on DV tape with a Sony Mini DV Handycam (connected to the ultrasound) and/or recorded in a log-book after visual inspection of the frozen images. The hand entries were done either to shorten probe time for the speakers, or due to occasional equipment malfunctions during recording. For the computerized versions, the US recordings were transferred to a computer using Adobe Premiere 1.0 (2004) for video editing, and stored on the hard drive.

Independent observer agreement

Reliability measures were conducted by a graduate speech-language pathology student who was experienced in evaluating ultrasound images. She viewed 10% of the ultrasound images of the /ɹ/ gestures across sessions on video-tapes. The criterion for inter-observer agreement was 80% for gestural components accuracy; the actual agreement between observers was 95% for tongue gestures for all three participants.

Short single-word speech probes were taken every 2 to 3 weeks for evaluation of /ɹ/ development. (See Appendix A for word lists.) The sound files attached to the ultrasound recordings were extracted from the DV tapes and transferred onto a laptop computer in a PowerPoint format (Microsoft 2003), with stimuli organized in random order across evaluation points. One expert SLP listener with normal hearing in the speech spectrum was invited to evaluate the /ɹ/ productions. She had worked with students who are deaf or hard of hearing in the past, but does not work with this population on a regular basis. In addition, she was also experienced using ultrasound for therapy with /ɹ/, and thus had recent listening experience for /ɹ/. Stimuli were presented through Kenwood Open Air Headphones KPM-110 and the listener rated between 75 and 110 tokens per speaker. The listener was asked to rate the tokens as having some or no rhotic quality (yes-no judgments), i.e., where a 'yes' rating did not necessarily indicate an accurate /ɹ/, but an attempt that included /ɹ/-quality. The reason for this type of rating was to provide the best opportunity to show changes in speech production, even if the participant had not yet completely mastered the target sound. This procedure followed Ertmer and Maki (2000), who state that there appears to be an intermediate phase along the progress trajectory as the individual is learning that can precede production of fully acceptable variants of the target (Ertmer and Maki , 2000). A second listener then was recruited to rate the samples independently. This listener was less experienced overall in phonetic transcription, particularly of deaf speech. Both listeners had 82% intra-rater agreement. Inter-observer reliability was calculated between the listeners. Listeners had higher agreement levels for Petra (80%) and Pearl (77%). Listener 2 was in agreement with Listener 1 at 72% for Parker. Even though listener agreement was somewhat divergent for Parker in absolute values, the listeners agreed that he had improved in 'r' production by about 30% (see Table 3.1). Judgments are reported in Table 3.1.

Insert Table 3.1 about here

Results

Results are discussed within speaker because of the single subject design of the study. The results for the components of /ɹ/ (the primary focus of the study) are presented in Figure 3.5.

Insert Figure 3.5 about here

In addition, ultrasound images of pre- and post-treatment /ɹ/ attempts are shown in Figures 3.2-3.4. The listener evaluations of the /ɹ/ word samples are presented in Table 3.1.

Participant 1: Parker

Three baseline measurements of /ɹ/ production confirmed (Figures 3.2, 3.5) that Parker did not produce any of the gestural components of /ɹ/: tongue retraction, grooving or tongue tip curling/bunching. Parker quickly learned tongue root retraction, maintained it during intervention and continued to produce this gesture at follow-up with 100% accuracy. The tongue tip curl was introduced next. Parker was able to produce this by the end of the first session accurately, and was able to maintain this over the rest of intervention and at follow-up with 100% accuracy. The final tongue gesture taught was the tongue groove. Midline grooving proved to be more difficult for Parker and he took three therapy sessions to reach accuracy. Once again Parker was able to achieve accuracy during intervention and maintain this accuracy at follow-up. By the end of the intervention period Parker was able to produce all the components of /ɹ/ at the word level. Table 1 shows that listeners judged Parker's post-treatment samples to have significantly more /ɹ/-like tokens, although the two listeners disagreed on the absolute level of accuracy.

Participant 2: Pearl

Five baseline measurements of /ɹ/ production confirmed that Pearl did not produce any of the gestural components of /ɹ/ pre-treatment (Figures 3.3, 3.5). During the baseline period, speech therapy continued for Pearl with the first author, including auditory perceptual training with her cochlear implant, review of velars, and some attempts at /ɹ/ without ultrasound. Once a stable baseline level was achieved for /ɹ/ components, the introduction of one gestural component of /ɹ/ began. Pearl quickly learned tongue root retraction and maintained it throughout intervention, producing it at follow-up with 100% accuracy. The tongue tip curl was introduced next. Pearl was able to produce this by the end of the second session accurately, and was able to maintain this over the rest of intervention and at follow-up with 100% accuracy. The final component taught was the tongue groove. Midline grooving was learned again over two sessions. Once again Pearl was able to achieve accuracy during intervention and maintain this accuracy at follow-up. Listener ratings showed no notable difference in pre-post treatment single word samples for /ɹ/-like quality. Listener 1 rated slightly fewer tokens as having /ɹ/-quality, and Listener 2 slightly more.

Participant 3: Petra

Five baseline measurements of /ɹ/ production confirmed that Petra did not produce the mid-line grooving component of /ɹ/ (Figures 3.4, 3.5). Petra already had tongue tip curl and tongue root retraction (learned in the previous informal pilot work). During this time speech therapy continued with the first author for Petra, including auditory perceptual training with her cochlear implant. Once a stable baseline level was achieved with the last component of /ɹ/, the training for that final gestural component began (the grooving). Petra learned tongue grooving over four therapy sessions, maintained it during the remainder of intervention and continued to produce this gesture at follow-up with 100% accuracy. Listeners disagreed on the post-treatment single word samples, with Listener 1 hearing more /ɹ/-like tokens, and Listener 2, fewer.

Discussion

Overall results

The goal of this study was to establish the components of /ɹ/. The multiple baseline design, with staggered introduction of treatment to each participant demonstrated experimental control. Lingual gestures changed for the three participants only at the point of intervention. While all three students learned the gestural components of /ɹ/ in isolation, the perceptual matches were judged as having changed to varying degrees, with only Parker showing notable change in /ɹ/ production in words in the final test probe. Author observation revealed that Petra and Pearl could produce /ɹ/ in isolation and in words during treatment sessions, but listener ratings showed minimal use of /r/ for the two young women in the single word probes. Parker was more advanced in that he was able to retain what was learned in treatment sessions in the probe session. In order to integrate the newly established phoneme consistently into words, some speakers require more sustained practice.

Within-participant factors

Participant 1: Parker

At the time of our study Parker had been listening with his cochlear implant for 9 months and was able to discriminate speech sounds more accurately (as noted in informal observation) than either Petra or Pearl. These factors, plus his motivation and home support, may have facilitated his outcomes for the study, which included more /ɹ/-like words in addition to mastery of the lingual components of /ɹ/.

Participant 2: Pearl

Pearl's hearing history and lack of opportunities for practice may have impacted her ability to generalise her new knowledge quickly. Prior to receiving her cochlear implant Pearl's audiogram indicated a profound bilateral sensorineural hearing loss with very little benefit from amplification. Pearl struggled to listen with her hearing aids. As a result, she had a greater challenge in learning to listen and reduced speech intelligibility when she received her cochlear implant. After three months

of auditory perceptual training, she was still unable to discriminate all English consonants and vowels. The /ɹ/ was still confused with /w/ some of the time; this perceptual difference may have influenced her slower progress at the word level.

Participant 3: Petra

Hearing history and lack of practice opportunities may also have been relevant for Petra's slower progress at the word level. Prior to receiving her cochlear implant Petra's audiogram indicated a severe-to-profound bilateral sensorineural hearing loss. However, functionally, Petra listened well in conversational contexts, and used compensatory strategies very well. Within a few months of learning to listen Petra was able to hear all the high frequency consonants she had not been able to hear before; /s/, /ʃ/ and /k/). However, she still had some difficulty discriminating between /ɹ/ and /w/. This, along with reduced practice opportunities undoubtedly affected outcomes for her.

Qualitative commentary

Reports from participants and their families and friends add to the social validity of intervention research. Because of not wanting to place further demands on participants and their families at the time of the study, a formal study evaluation questionnaire was not used post-treatment (but see Chapter 5). Verbal comments volunteered by the participants are indicated here. All participants verbally indicated that they believe they could produce /ɹ/ better and be more understand by family and friends. In addition, parents reported that they were happy with the improvements during the course of the project. A follow-up study revealed that all participants were able to maintain the gestural components of /ɹ/ and produce /ɹ/ in monosyllabic words. In addition, Pearl and Parker were able to produce words and phrases that were more articulatorily complex (see chapter 5).

Clinical and research implications

The design of the current study did not allow for the follow-up evaluation of the ultrasound in treatment. However, it is probable that the students who were given support and guidance in their practice sessions in a consistent and on-going basis, either by school staff or a parent, would maintain their new way of approaching /ɹ/ production (see Chapter 5 for follow-up results). The degree of oral versus sign communication might also influence future outcomes for the students, those using oral communication more frequently possibly faring better over the long-term.

This type of clinical research suggests the potential clinical usefulness of ultrasound as an adjunct to therapy, reduced time requirements for both the client and SLP, and lessening the frustration for the client. All students and the people in their lives reported that they were producing the /ɹ/ with more rhotic quality by the end of this study and Figures 3.2-3.5 show that the participants were able to master the components of /ɹ/. This study was only the first step in the speech habilitation process, and looked at change in production predominantly at the level of the gesture.

The study also shows that perceptual and gestural components may not change at exactly the same time, or the early changes may not be perceptible. These well-known examples of speech productions that cannot be recovered by transcription alone have been called covert contrasts. Productive knowledge of covert contrasts has been viewed as a positive prognostic sign to facilitate learning of sounds in treatment (Gibbon et al., 1999). As a result gestural components can be compared to these covert contrasts as positive prognostic signs in the process of learning /ɹ/.

To facilitate production of accurate /ɹ/ in conversation, continuing speech therapy would be needed for clients such as those in the current study, with a generalization plan, and conducted by an SLP experienced with acoustic phonetics, cochlear implants and ultrasound. This program would include intervention once or twice a week until the student could produce the speech target at the paragraph level in a clinical environment. In addition, this plan would require the assistance of a family member or an educational specialist (e.g., a. speech assistant) to ensure correct practice of newly established speech patterns.

Further research is needed, with larger numbers of participants of different ages and disorder types, and over longer period of time to determine the optimal type of benefit of the technology and the course of change, as perceptual and gestural changes align.

Acknowledgments

I gratefully acknowledge the teenagers and their families who enthusiastically participated in this study. I am also very appreciative for the advice and guidance of Dr. J. Lucyshyn with Single Subject Design, and advice and assistance with the manuscript from Dr. B.M. Bernhardt. I would also like to acknowledge the assistance of the SLP listeners for volunteering their time. In addition, I would like to thank the University of British Columbia for funding through the University Graduate Fellowship programme.

Table 3.1: Listener judgments pre- and post-therapy.

Speaker	Listener	Percent 'yes'[a] pre-intervention	Percent 'yes' post-intervention	Percent change
Parker	Listener 1	43.14%	73.33%	30.20%
	Listener 2	61.22%	88.14%	26.91%
Pearl	Listener 1	27.78%	24.49%	-3.29%
	Listener 2	26.32%	30.61%	4.30%
Petra	Listener 1	34.78%	51.35%	16.57%
	Listener 2	39.13%	36.11%	-3.02%

[a]A "yes" judgment indicates perceptible /r/-quality, and includes accurate /r/s and tokens with some perceptible /r/-quality.

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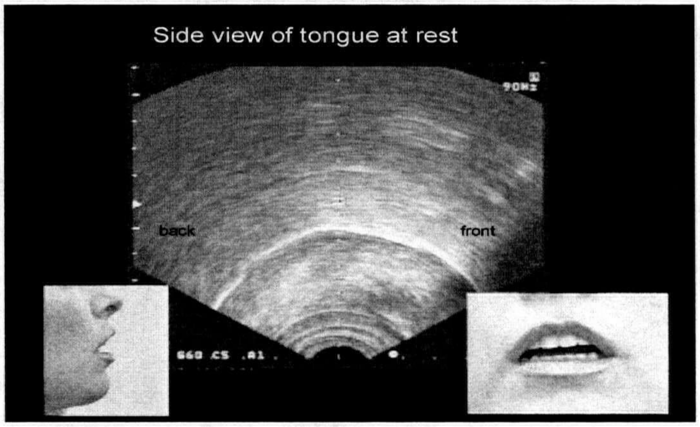


Figure 3.1a. From rest position to retroflex North American /ɹ/ produced by author.

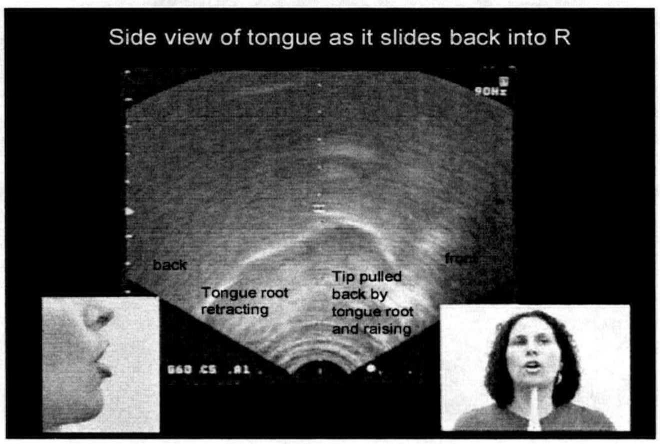


Figure 3.1b. Side view of tongue as it slides back into /ɹ/.

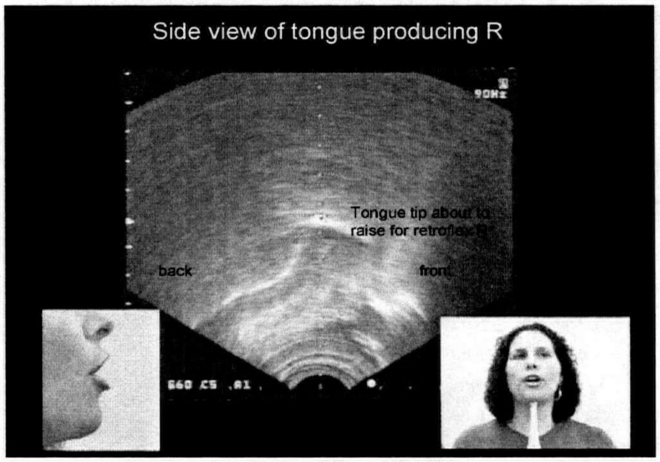


Figure 3.1c. Side view of tongue producing /ɹ/.

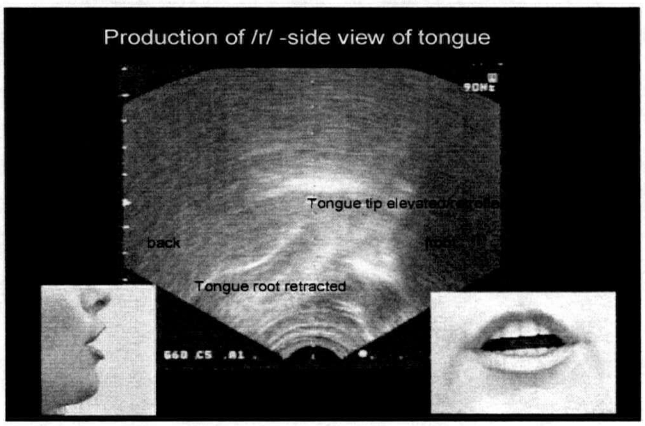
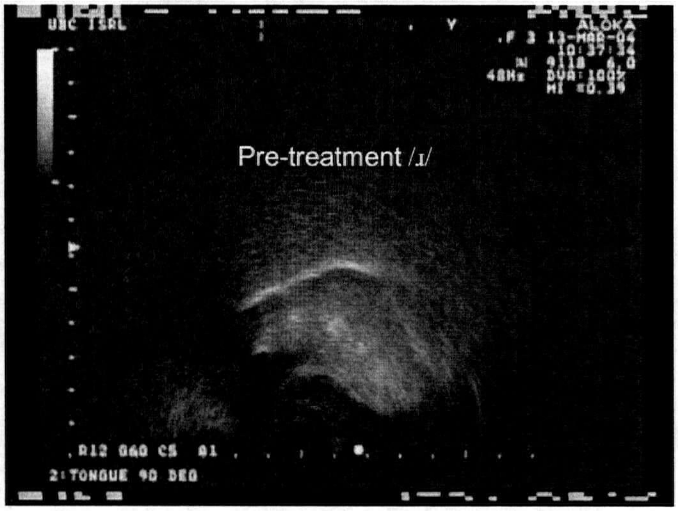


Figure 3.1d. Production of retroflex / ɹ /.



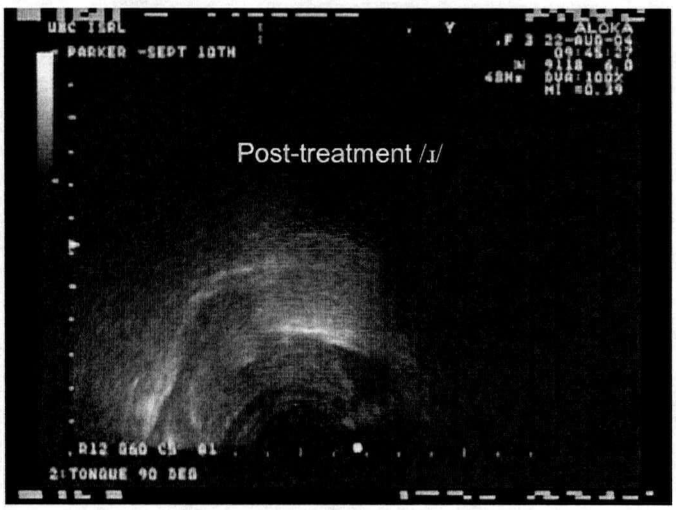


Figure 3.2. Parker's productions of /ɹ/ in word-initial position pre-and post-treatment in isolation. Notice the tongue root and blade retraction in the post-treatment token.

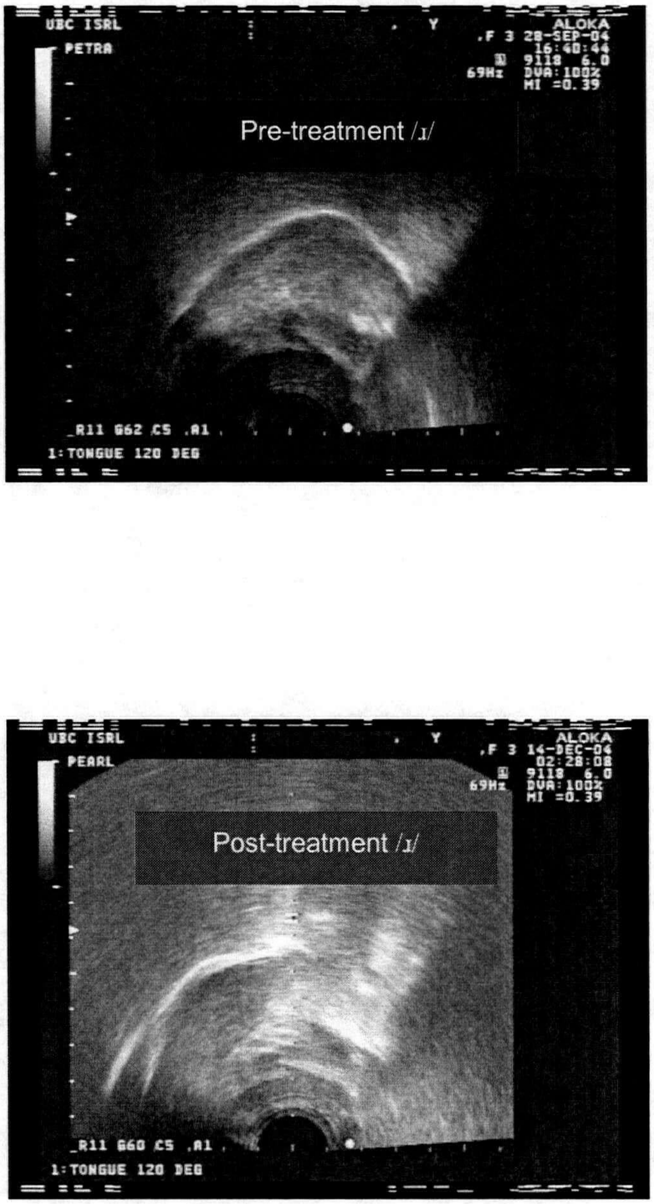
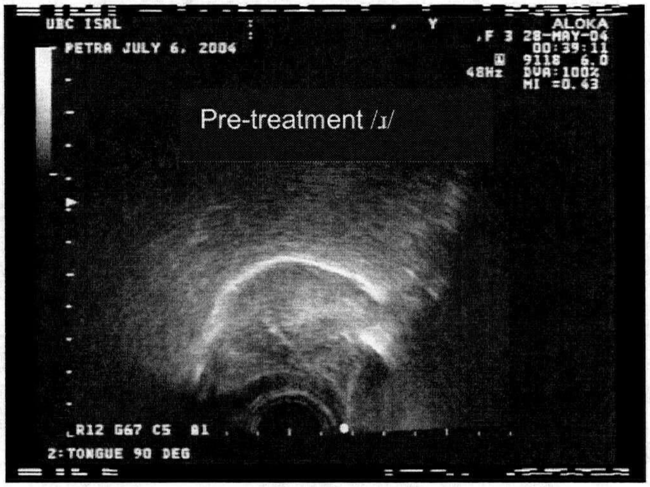


Figure 3.3. Pearl's productions of /ɹ/ pre- and post-treatment in word-initial position. Notice the tongue root retraction and tongue tip curl in the post-treatment token.



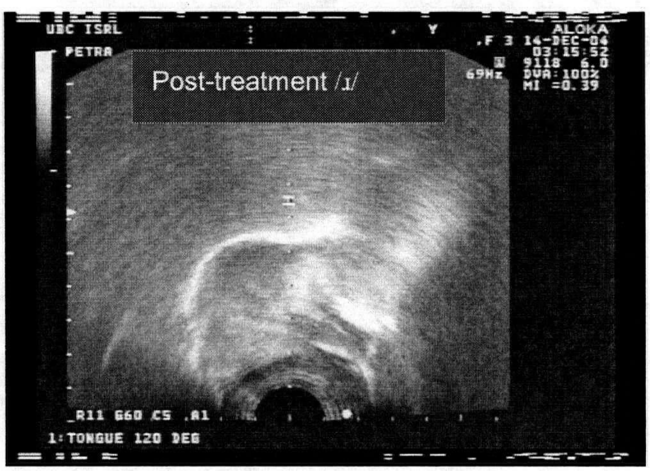


Figure 3.4. Petra's productions of /ɹ/ pre- and post-treatment in word-initial position. Notice the tongue root retraction and tongue tip curl in the post-treatment token.

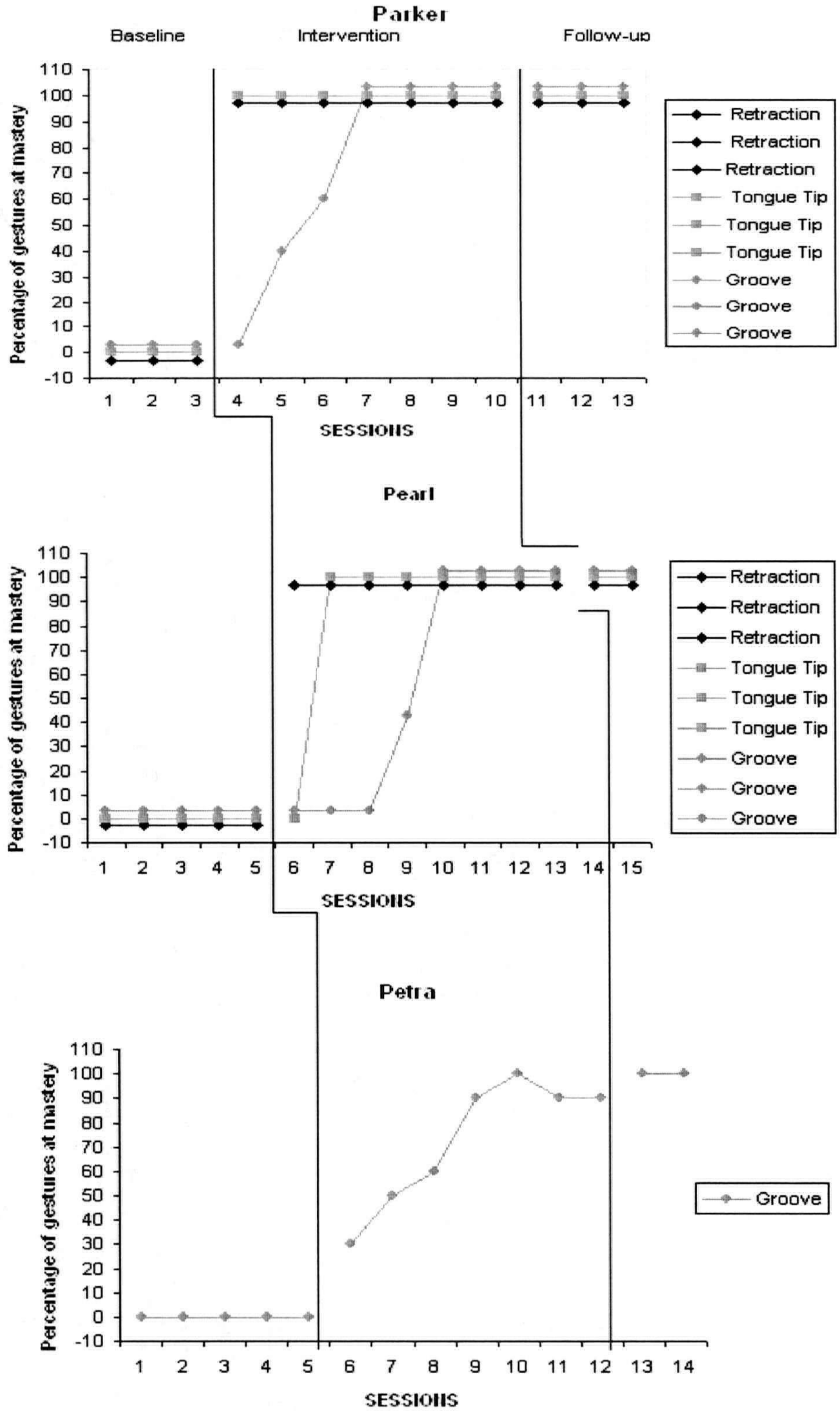


Figure 3.5. Graph of baseline, intervention and follow-up for Parker, Petra and Pearl.

CHAPTER 4

Long-term outcomes of speech therapy for seven adolescents with visual feedback technologies: ultrasound and electropalatography

A version of this chapter will be submitted for publication to the journal Clinical Linguistics and Phonetics in June, 2007. Bacsfalvi, P., Bernhardt, B.M. and Gick, B., Long-term outcomes of speech therapy for seven adolescents with ultrasound and electropalatography.

The use of ultrasound, (U/S) and electropalatography (EPG) in speech habilitation has been previously investigated and found to have short-term benefits for adolescents with hearing impairment (Bacsfalvi, et al., 2003; Bernhardt et al., 2003; Bacsfalvi et al., 2007; Bernhardt et al., 2000; Martin et al., 2007). Methods used to evaluate outcomes from past studies in the current team's investigations have included expert listener judgments (Bernhardt et al., 2003), everyday listener judgments (Bernhardt et al., 2005), formant frequency analysis (Bacsfalvi et al., 2007), palate contact tabulations (Bacsfalvi et al., 2007), qualitative reports from intervention participants and their stakeholders (Bacsfalvi, 2006), and the use of external anchors to improve reliability for listener judgments (Bacsfalvi et al., 2007). However, all previous studies evaluated short-term outcomes only. The goal of the current paper was to determine if speakers were able to maintain gains made using visual feedback technologies as an adjunct to speech therapy in the longer term. Expert listeners were used to evaluate those long-term outcomes.

The next section outlines the following background topics for this study: long-term follow-up studies, speech of people who are deaf or hard or hearing (DHH), and U/S and EPG technologies and speech perception issues as they relate to this investigation.

Background

Speech of people who are deaf and hard of hearing

People with severe to profound hearing loss often struggle to produce intelligible speech (Angelocci et al., 1964; Bernhardt et al., 2000). Segmental categories that are known to be particularly difficult include fricatives, vowels and liquids (Nickerson, 1975). Missing auditory information, both from others and self, contributes to difficulties in speech production for people with hearing loss. Fricatives contain high frequency information that may not be heard by people with severe and profound hearing loss; for example, a person with minimal hearing above 3500Hz would not hear the acoustic energy for /s/. Another issue causing difficulty for speakers with hearing impairment may be allophonic variations within segmental categories; for example, Ling (2002) notes that /ɹ/ in the word trap rarely if ever has vocal fold vibrations, while /ɹ/ in most contexts has voicing. Lack of acoustic information can have additional articulatory effects; during earlier studies it was discovered that all of the participants in the visual feedback studies had minimal tongue movement in any direction; for example, none were able to produce any of the gestural components of the /ɹ/ (Bernhardt et al., 2003). This reduced vertical range and singular flat shape was also found by Dagenais and Critz-Crosby (1992) in their investigation of vowels in speakers who are hearing and deaf. Low speech intelligibility may have disadvantages beyond speech production issues, i.e., reduced opportunities in the areas of educational goals and prospects, employment and social life (Bracket, 1997; Blackorby and Wagner, 2007). Thus, speech habilitation has the potential to enhance a person's participation in society in addition to improving intelligibility (McLeod and Bleile, 2004).

Intervention outcomes studies

The Royal College of Speech Language Therapists (RCSLT, 2006, from website: http://www.rcslt.org/resources/clinicaleffectiveness) and the American Speech and Hearing Association (ASHA) promote evidence-based practice in communication disorders as a way to maximize treatment effectiveness. ASHA (2005, ASHA Leader) states, "...current, high-quality research evidence is integrated with practitioner expertise and client preferences and values into the process of making clinical decisions" (p.23). Intervention studies provide us valuable information for evidence-based practice. Important considerations regarding evidence-based practice relate to the longer-term effects of treatment. Long-term follow-up studies not only provide information on the eventual effectiveness of intervention but also insight into predictors of successful outcomes (Shriberg et al., 1994; Shriberg and Kwiatkowski, 1988; Glogowska et al., 2000; Bernhardt and Major, 2005; Glogowska et al., 2006).

The outcomes of several studies in the area of speech habilitation with visual feedback technologies for people with hearing loss have been positive; however none of these studies to date have investigated long- term outcomes (Bernhardt et al., 2003; Panelemidou et al., 2003; Martin et al., 2007). Of 17 research papers reviewed concerning the use of EPG as a tool during intervention for people with hearing loss (Gibbon, 2006), none of them reported long-term follow-up evaluations. Without long-term follow-up studies any health profession cannot claim to have evidence-based practice. The following section provides background for visual feedback technologies used in our studies.

U/S and EPG technologies

EPG is a visual feedback system that supplies the speaker with tongue-palate contact information. The EPG consists of an acrylic pseudopalate implanted with electrodes that are connected to a computer. The computer monitor display reflects the tongue-palate contacts during speech. There is an extensive body of research that has been done using EPG for speech issues stemming from a variety of causes over the last 6 decades (Gibbon, 2006).

There has been far less research with the use of U/S in speech habilitation (Shawker and Sonies, 1985; Klajman et al., 1988; Bernhardt, et al., 2005). Ultrasound has been explored sporadically over the past three decades, but mostly in the domains of speech science and linguistics (Ostry and Munhall, 1985; Stone and Lundberg, 1996; Gick et al., 2005). When a speaker holds an ultrasound transducer under the chin, sound waves are reflected back from the air just above tongue; a monitor thus displays, in essence, the surface outline of the tongue (Stone, 2005). The user can observe tongue shapes from either a sagittal or coronal perspective by orienting the transducer in different directions under the chin. For a sagittal display the transducer should be oriented parallel with the nose, and perpendicular for a coronal display.

Both U/S and EPG displays can be dynamic, showing what is happening in real time. While both are very useful tools for speech habilitation, they offer somewhat different yet complementary information. U/S allows the user to see the shape of the tongue in 2-D, and where the tongue is placed in the oral cavity. EPG allows the user to observe precise tongue-palate contact points. Evaluation of results with visual feedback is still in the early stages. There are as of yet no fully developed methods for measuring articulatory outcomes with U/S and EPG. The following section briefly discusses some of the issues associated with other treatment outcome measures.

Treatment outcomes and listener studies: Issues of perception

The current study evaluated outcomes by using expert listeners. Issues in speech perception are relevant to that evaluation method. Many perception studies have been undertaken in the areas of linguistics (Wester et al., 2001), speech-language pathology (Gooch et al., 2001; Brunnegard and Lohmander, 2007), audiology (McCoy et al., 2005), psychology (Polka and Werker, 1994) and English as a second language domains (Flege et al., 1999).

Some key issues related to speech perception and listener studies include intra-observer and inter-observer agreement, listener differences (in terms of hearing status, language status, and education), speech presentation methods (block or random designs) and randomized data and assessment (Brunnegard and Lohmander, 2007).

Standards for intra-/inter-rater reliability are highly variable in the literature. Holm and Crosbie (2006) in their study of phonological disorders had intra-rater reliability levels at 73% for vowels and 77% for consonants. They reported these percentages to be within the acceptable range for reliability judgments for a hearing child with a phonological disorder. Adler-Bock et al. (2007) had intra-rater reliability levels between 93% and 100% for listeners evaluating /ɹ/ in hearing adolescents with a persistent /ɹ/ disorder.

In terms of inter-rater reliability, researchers have found a range of agreements to be acceptable. With a hearing child with phonological disorder, inter-rater reliability in one study was 86% for vowels and 83% for consonants (Holm and Crosbie, 2006). However, inter-rater reliability for evaluation of hearing speakers (with Shriberg and Lof [1991] reporting the average agreement to be 74%) appears higher than for speakers with hearing loss. In a study for children with impaired hearing acceptable inter-rater agreement ranged between 64% and 74% (Blamey et al., 2001).

A number of methods have been tried to increase inter-observer reliability. Yiu et al. (2007) found, in their recent study quality of voice judgments, that anchoring the data resulted in greater inter-observer reliability. Real speech was compared to synthetic anchors that could be created in the laboratory. These anchors were found be successful in helping the listeners make more reliable transcription decisions. Assmann et al. (1982) found in a series of listener studies that using phonetically trained listeners and the International Phonetic Alphabet (IPA, 2002) reduced orthographic interference in transcription. The same researchers also found that a blocked condition, where only one speaker's data were presented at a time, resulted in less listener identification error (Assmann et al., 1982). Several methods from Assmann et al. (1982) were incorporated into the present study, and will be discussed in the methods section.

Finally, to improve the validity and reliability of perceptual studies, Brunnegard and Lohmander (2007), in their studies of cleft palate speech, reported certain critical criteria for listening procedures: "(1) obtain judgments from multiple raters, (2) obtain judgments from recordings that are randomized and blindly assessed, (3) repeat a proportion of recordings to allow measurement of intra-rater reliability, (4) calculate and report intra- and inter-rater reliability, (5) use a narrow age span of the studied group, and (6) report the inclusion and exclusion of individuals with additional anomalies or cognitive delays" (p.34). All of these criteria that were applicable were used in our listener study with the exception of multiple raters for all speaker data. The current study design and use of raters will be discussed in the method section.

As noted, the purpose of the present study was to investigate the long-term outcomes of speech habilitation with U/S and EPG. After each of the earlier treatment studies, the speakers took away new phonetic knowledge about speech production. Improvement might occur because they had gained information that was not previously available to them. It was predicted that most students would maintain or improve their speech productions. However, such improvement or maintenance would only be possible if (a) participants continued to use speech as their main mode of communication and (b) they continued to have at least the same level of auditory input as during the studies. If any students chose to use ASL as their main mode of communication following the studies, then it was predicted that new productions learned would not be maintained due to disuse. Although this was not a between-subject study, it was also predicted that the participants with cochlear implants might maintain their speech productions more than the participants with hearing aids due to the greater amount of auditory information available.

Method

Speaker participants

All speakers were young men and women who had participated in speech intervention studies in the past in the same laboratory (Bacsfalvi, 2006; Bacsfalvi, et al. 2007; Bernhardt et al., 2003). (See Table 5.1.) Pre-treatment data concerning phonological targets are included below in the description of the participants. In addition, information about their pre-implant hearing status is included as background.

Insert Table 5.1 here

Of the seven speakers, four were male (S1, S4, S5, S6) and three were female (S2, S3, S7). All speakers had severe to profound hearing loss and had struggled to learn intelligible speech for many years. All participants were diagnosed with severe-to-profound sensorineural hearing loss before the age of three and were fitted with unilateral or bilateral hearing aids. Four of the participants had chosen to obtain cochlear implants (S1, S2, S3, S7). At the time of this study four speaker participants were using hearing aids (S4, S5, S6, S7) and three participants were using cochlear implants as their hearing devices (S1, S2, S3).

During the initial studies all students were in high school. All but one participant had attended oral programmes for the deaf. One participant (S1) had attended a school for the deaf where the language of instruction and communication was American Sign Language (ASL). At the time of follow-up two participants were still in high school, three participants were in college, and two were working.

Two speakers came from monolingual Canadian English speaking homes (S1, S5). All other participants came from homes where English was a second language. However, due to their hearing loss, all families but one (S7) chose to speak English with their child, making English the child's first language, and only oral language. This single bilingual speaker participant was a speaker of both Cantonese and English (S7).

Each speaker had participated in a different number of studies depending on their individual needs and time availability. Participant S5 participated in the earliest study (Bernhardt et al., 2003), and then graduated from high school and had the least amount of follow-up speech therapy to continue working on speech goals (less than one year). The current study took place 4.5 years after he finished treatment. Participants S1, S2 and S3 participated in a /ɹ/ study (Bacsfalvi, 2006; chapter 3) and then continued to have follow-up therapy in their school programmes. All three of these participants were continuing with auditory-oral therapy simultaneously because they had had their cochlear implants for less than a year. However, they had not had speech therapy for 1.5 years at the time of this follow up. Participants S4, S5 and S6 participated in two studies (Bernhardt et al., 2003; Bacsfalvi et al., 2007) and continued to receive speech therapy (on an intermittent weekly basis) in their school programmes collaboratively with our visual feedback study investigations, but they had not had speech therapy for four years at the time of follow-up.

The analysis for the current study was a listener evaluation. Due to ineffectual methods for ultrasound measurement as well as a qualitative evaluation, a perceptual analysis was used with expert listeners. The following section delineates the listener characteristics.

Listener Participants

All listeners were between the ages of 25 and 35. They were either SLPs or speech-language pathology graduate students who had finished their course work and had experience with listener data, specifically with a focus on /ɹ/ and vowels. All listener participants had worked on other perceptual and/or ultrasound experiments in addition to their clinical experience (although none with the participants in the current study). Prior to the experiment each listener confirmed hearing to be within normal limits for speech range. Listeners for this study included five Canadian native English adult participants, and two English as a second language adult participants. The two non-native English listeners were considered early, L2 (~age 7) and late, L6, (~age 16) bilinguals and had been speaking English for more than 15 years at the time of the study (see table 2). Both of these participants produced the phonemes for this study with native-like proficiency. According to the Speech Learning Model, phonetic segments can only be produced with native-like proficiency in the second language if they are perceived as a native speaker would perceive them (or native-like) (Flege et al., 1995). In Flege et al.'s (1999) study, neither the early or mid bilingual groups received significantly lower scores than those of the native speakers in vowels spoken. Flege et al. (1999) suggested that greater English language experience increases perceptual abilities to native-like proficiency. In addition, both bilinguals completed half or more of their high-school education in English. Both listeners had completed bachelor's and master's level education in the specialty area of speech-language pathology, with a focus on phonetics. For these reasons they were considered to be appropriate expert listeners for this study.

Study design

Within-subject evaluations

A within-subject design was chosen in accordance with the laboratory's past studies (Bacsfalvi, et al. 2007). In the present study, each listener transcribed the speech of one speaker. This design was chosen because of the small number of participants and the case study nature of the treatment. It also accommodated speaker and listener differences. Listeners did not have time to listen to all the data from all the speakers. In addition, by listening to one speaker only, contamination did not occur from one speaker to another within listener. Anecdotally, two listeners indicated that they might have made different judgments for their own participant, based on hearing the data for other participants at the inter-rater reliability listening session.

Data collection from the speakers

Three sets of data were included for each speaker: data before treatment with visual feedback (Time 1, T1), data immediately post-treatment (Time 2, T2) and follow-up data (T3). For data elicitation for the speakers during the T1 and T2 studies (Bernhardt, et al. 2003; Bacsfalvi, 2006, 2007), real or nonsense words had been collected in a phrase ('I'm an ____') or in isolation. Target phonemes that were recorded in a short phrase were presented that way to the listeners, if splicing acoustic data might have changed or damaged the data in some way.

Words for the follow-up experiment (Time 3) were collected in two ways. First, all speakers were administered the Computerized Articulation and Phonology Evaluation System (CAPES, Masterson and Bernhardt, 2001*)*; each word was repeated between one and three times. Sometimes, speakers chose to say some words more times of their own accord. Next a list of words and phrases were repeated between 5 and 12 times, depending on the fatigue of the speaker. Each speaker worked to his/her maximum capacity just before fatigue when repeating the word lists. (See Appendix B.)

Each speaker was recorded in the home or at the university laboratory. The speaker and assessor were comfortably seated around a table. The speech sample was recorded with a professional digital Marantz recorder, model number PMD670/U1B. The words or phrase lists were presented in a written form. An initial model was given by the experimenter if the participant did not appear to know the word, to prevent mispronunciation from lack of familiarity with a word. Speakers produced lists of words in a block design rather than a random mixed design to reduce chances of speaker difficulty with words, or the speaker forgetting pronunciations for words.

Listener procedures

As noted previously, each listener evaluated randomized data from one speaker only. This prevented cross-speaker contamination and reduced listener fatigue while allowing evaluation of all tokens from a speaker. Stimuli were presented to the listener in a blocked speaker condition, as in Assmann et al. (1982). Inter-listener differences in amounts of data reflected the number of targets elicited from the speaker. (See Table 4.2 for a list words and numbers of tokens by speaker/listener pair.)

Insert Table 4.2 about here

To determine inter-rater reliability, each listener also listened to 20% of the tokens of two other participants after rating his/her particular speaker. At the end of this session, the listener listened to the first 25 tokens again for intra-rater reliability, which took 5 to 10 minutes.

Digital audio signals were presented to the listeners in a quiet office at the university. The listener was first presented with 5 minutes of sentences and words in digital audio format on the Compaq Presario V3000. The listeners used Sennheiser PX 30 headphones. In addition, the HeadRoom Total BitHead Headphone Amplifier was used with the headphones. This processor was plugged into the laptop through a line-out port and then the headphones were connected to the preamp via a headphone jack. This preamplifier allowed the participants direct control over volume, and provided maximum fidelity to the input sound. (see http://www.goodsound.com/equipment/headroom_total_bithead.htm).

Both listening sessions began with a familiarization phase. The speakers have a range of speech intelligibility and therefore a familiarization period was used as a way to reduce listener fatigue and increase intra-observer reliability. Each listener was presented, by computer, with word and sentence lists from a speaker. The listener was instructed to "just listen to the words and become familiar with that person's speech". Nothing more was required during this 5-minute period. Speaker data included excessive nasalization, inappropriate stress placement plus untargeted inaccurate consonants and vowels. The listeners were instructed to ignore these speech differences and focus on the intended speech target (indicated in written form).

In the next part of the training session the first author reviewed the phonetic alphabet with the listener to determine whether any phone-symbol correspondence was unfamiliar. Each listener was also given a brief review of the vowel space in order to be comfortable with designating vowel substitutions for the vowels and /ɹ/ phonemes. At this stage training on use of the software programme (discussed below) was also completed.

The first listening session took between 2 and 2.5 hours. Each listener made judgments concerning his/her randomly assigned speaker for 45 minutes (see next section). At this time the experiment was stopped and the listener took a 20-30 minute break to avoid fatigue. S/he then continued listening to the same data from where s/he left off for up to 45 minutes or until completion.

The next session occurred within a week. In session 2, the listener was instructed to listen to two sets of speaker data for two other speakers to assess reliability of judgments between listeners. Listeners were again exposed to each speaker's speech for a few minutes for familiarization/training period before beginning the (same) transcription process.

Listener judgment methodology

Software was designed for the experiment to capture the listener judgments. The programme had three sections: /ɹ/, voiceless sibilants and vowels. The software for the experiment was designed jointly by the first author and Donald Derrick (computer programmer and doctoral student in Linguistics) and coded by Donald Derrick. Pilot work had been completed to identify the substitutions most commonly made by the speakers and these were then used in making the computer software created for this experiment. Testing software was developed using Java 1.4.2. Software uses Java Swing for the interface. The software uses vector drawings for the interface, which depend on a screen resolution height of 800 pixels. Resolution to height calculations for the vowel chart were within 10 Hertz accuracy. Precise calculations indicate an approximate difference of 4.48 hertz for F1 and 8.8 hertz for F2. The measurement method used is more precise than what a person with normal hearing can hear. In other words, the precision is higher than the accuracy.

The listeners were presented simultaneously with randomly selected written and oral words. Instructions were presented on the top of each screen as a reminder to the participant. The listeners were told to identify each phoneme by clicking in a graphical region representing a scale of accuracy for that phoneme as shown on the computer screen. These mouse click locations were captured by the software programme and written to a text file. (See Figure 4.1 for a picture display of the consonant selection procedure as presented on the computer screen.)

Insert figure 4.1 about here

For the vowels, an English vowel chart was presented and the listener was asked to click on the area that most closely represented what was heard (Figure 4.2). For example, if the listener heard /i/ but it was slightly lower then English /i/ s/he would click just below the /i/ on the vowel space. The vowels were matched to Peterson and Barney's (1952) formant data for F1 and F2 and to Fant's (1969) formant data from Swedish [œ] for F1 and F2 as this was judged by the author and research assistant to be one of the substitutions frequently used by speaker participants. For /ɹ/, a sliding graph was presented that indicated degree of 'r-ness'. If the /ɹ/ was judged to be completely accurate then the far right was to be clicked. As an example, if a listener participant clicked on a location near the 'r' end of the 'r' continuum (Figure 4.3) this might correspond with a recorded value of 80% accuracy.

Insert Figures 4.2 and 4.3 about here

However, if the phoneme produced was not /ɹ/-like at all, then the far left side of the screen was clicked and a vowel substitution was selected from the IPA vowel chart provided just below. In addition, if a combination of the two sounds was presented this could be indicated by clicking somewhere on the /ɹ/-sliding scale and then on a vowel.

For the fricatives, a chart was provided that allowed for the listener to select the consonant on a scale of stop to fricative to affricate substitutions. The software was designed so as to reduce any influence of the experimenter on the phoneme selections made by the expert listeners. For example, in other research designs, speakers may be offered a forced choice where the experimenters' biases already confine the choices of the listeners. In the study software the listeners were able to make judgments without bias from the experimenter. In addition, because the listeners were expert listeners, their knowledge of phonetics allowed for narrow transcription.

Reliability

Intra-rater reliability was measured by choosing randomly 10% of the speaker's words and having the listeners transcribe them twice during the listener evaluation. Reliability measures were between 83% and 95% accurate, except for L6 (an L2 listener) who had a lower level of accuracy at 63% (for speaker S6, Purdy).

Inter-rater reliability was estimated by randomly assigning three listeners to three speakers. All listeners rated 20% of the data from two speakers, other than the speaker for whom they listened to all the data. As noted, a number of the judges made verbal comments post-experiment about how they would have changed their judgments had they heard the speech of other speakers. Inter-rater reliability ranged between 62% and 81%. Table 4.3 shows the reliability ratings for each speaker by listeners. Note that L6 had fairly good inter-rater reliability with L1 and L2 (for S1 and S2: 73% and 70%, near the mean agreement for the listener sample) and that L3 and L5 had 73% agreement with L6 for S6. Thus, L6's data remain in the study even though the intra-rater reliability was lower. The lowest inter-rater reliability was for S4 and S5 and the highest was for S3 and S7 (81%).

Data analysis

Ertmer and Maki (2000) described the importance of intermediary steps on the road to speech accuracy in their speech intervention study with children with hearing impairment, a perspective followed by Bacsfalvi et al. (2007) and Bernhardt et al. (2005). Analysis in the present study also assumes an intermediary step as part of the learning process. All data percentages provided by the listeners for consonants were put into one of four categories: (1) less than 50% (<50%) accuracy (not acquired), (2) 51% to 69% accuracy (emerging), (3) greater than 70% (>70%) accuracy and (4) greater than 90% accuracy. All positions on the continuum in Figures 4.1-4.3 were linked to a percentage value; in this way numbers were not randomly assigned.

The vowel analysis required additional steps, with matches to reference data (see below). Vowels were analysed by first converting the Hertz to mels ($m=1127.01048 \log_e(1+F/700)$) and then using a simple Euclidian distance equation (SQRT ((C1-A1)^2 +(D1-B1)^2) to evaluate the distance from reference target values in a two-dimensional perceptual vowel space. Vowels within 149 mels were considered to be within the target vowel space. Each speaker participant who had vowel targets was matched with either male, female or child formant values based on their age at the time of each data collection point. As a result, S7's formants were compared with an adult female's formants, while the male speakers' formant values were compared with either child, male or female formant values based on their values from the 2007 study for vowels (Bacsfalvi et al.,2007, Chapter 2). Participants S4, S5 and S6 were considered to have adult male voices based on formant values of the local male hearing adult data collected for that study and the Peterson and Barney (1954) data.

Analysis

Consultation with statistician Dr. Bruno Zumbo revealed that there was no straightforward way to do statistical tests of the data. Statistical testing would have required many more raters and much more time but resources were minimal for the study. What was sacrificed in terms of statistical testing was gained in terms of lack of contamination from one speaker to another within listener. At this time, there is no known straightforward way to evaluate the data within-subject statistically given the individual speaker-listener design.

Results

Results are presented within subject in this section. Results for the Time 2 (post-treatment) versus the follow-up Time 3 data showed that the listeners rated five out of seven speakers as producing segments within the same range of accuracy at Time 3 as at Time 2.

Speaker S1 (Parker): Target /ɹ/

Tabulated results of /ɹ/ data (Table 4.4) revealed a decline from T1 to T2 and improvement from T2 to T3. Parker was able to produce with 70% or greater accuracy 68% of all tokens produced at T3 compared with 8% at T2 and only 29% at T1 as judged by the listener for this study. Inter-rater reliability was fairly good for this speaker (73%). Intra-rater reliability was good (95%) by the listener.

Insert Table 4.4 here

Speaker S2 (Pearl): Target /ɹ/ (target /k/ also investigated, as discussed below)

Tabulated results of consonant data (Table 4.5) revealed improvement from pre- to post-treatment (T1 to T2) and from post-treatment to follow-up (T2 to T3). Pearl was rated as producing with 70% or greater accuracy 59% of all tokens produced at T3 compared with 20% at T2 and only 5% at T1. Similarly, the percentage of tokens over 90% increased across the study. Inter-rater reliability was 73% for this speaker. Intra-rater reliability was irretrievable due to technical difficulties.

While the phoneme /k/ was not targeted experimentally, it is important to note that when assessment began with Pearl, she was unable to produce velars. The first author had often targeted velars in speech therapy but with little success. Pearl learned velars during the long assessment sessions, and as she was very motivated to learn them, was given practice words over several weeks following. At T3, Pearl was judged to produce velar /k/ in all word positions with 90% accuracy over 87% of all tokens.

Insert Table 4.5 here

Speaker S3 (Petra): Target /ɹ/

Tabulated results of consonant data (table 4.6) revealed a slight decline across the study. Petra was judged to produce 40% of all /r/ tokens with 70% or greater accuracy at T3 compared with 47% at T2 and 53% pre-intervention. Inter-rater reliability was relatively good for this speaker (81%). Intra-rater reliability was also good (83%), as judged by the listener.

Insert Table 4.6 here

Speaker S4 (Peran): /s/, /ʃ/, /ɹ/ and /i/

Tabulated results of consonant data (Table 4.7) revealed improvement from T1 to T2 and then again from T2 to T3. Peran was judged to produce with 70% or greater accuracy 65% of all tokens produced at T3, compared with 60% post-treatment and only 47% pre-treatment. Inter-rater reliability was low for this speaker (62%). While overall, Peran's consonant improved, investigating by phoneme, the biggest change noted was for /ʃ/. Peran improved from a rating of 30% at T1 to 55% at T3. The /s/ had been judged at T1 as 100% and was judged to have regressed at T3 to 58% accuracy. While the phoneme /ɹ/ was judged to have improved from T1 (78%) to T2 (100%), it regressed at follow-up to 80% accuracy. The accuracy of vowel production at follow-up also revealed a decline in production in the long term. Changes in accuracy were assessed by this listener as 100% at T1, 80% at T2 and 56% at T3. Intra-rater reliability was high (91%).

Insert Table 4.7

Speaker S5 (Palmer): /s/, /ʃ/, /ɹ/ and /I/

Tabulated results of consonant data (Table 4.8) revealed improvement from T1 to T2 and a decline from T2 to T3. Palmer was judged to produce with 70% or greater accuracy 53% of all tokens at T3 compared with 64% at T2 and only 14% at T1. The judged accuracy of vowel production at follow-up revealed no improvement from T1 (0%) to T2 (0%) and then greater gains post treatment from T2 (0%) to T3 (50%). Intra-rater reliability was good (85%) although inter-rater reliability was low for this speaker (64%).

Insert Table 4.8

Speaker S6 (Purdy): /s/, /ʃ/, /ɹ/ and /i/

Tabulated results of consonant data (table 4.9) revealed improvement from T1 to T2 and a small decline from T2 to T3 at the 70% or better accuracy level. Purdy was judged as producing 74% of all tokens at T3 with 70% or greater accuracy, compared with 82% at T2 and 75% pre-treatment. However, the rated accuracy level at 90% or better returned to the pre-treatment level at T3. The phoneme /ʃ/ was judged at above 90% accuracy for all three time points. The /s/ was judged to have improved from pre- (43%) to post-treatment (100%) and then to have slipped back by follow-up (76%). Phoneme /ɹ/ also dropped back at follow up: T1 (81%), T2 (100%) and T3 (75%). The accuracy of vowel production at follow-up revealed continued improvement from T1 (0%) to T2 (38%) to T3 (70%). Inter-rater reliability was fairly good for this speaker (73%) with intra-rater reliability low (63%).

Insert Table 4.9

Speaker S7 (Pamela): /s/, /ʃ/, /ɹ/ and /i/

Tabulated results of consonant data (table 4.10) revealed improvement from T1 to T2 and near-equivalent results from T2 to T3. Pamela was rated as producing with 70% or greater accuracy 74% of all tokens produced at follow-up compared with 74% post-intervention and only 22% pre-intervention. 90% judged accuracy declined slightly from post-treatment to follow-up. Inter-rater reliability was good for this speaker (81%). Intra-rater reliability was also good (91%) by the listener.

Insert Table 4.10

Summary of results

Overall, intra-rater agreements or the consistency with which the raters made their judgments were good, which contributes to the reliability of the results.

S1 (Parker): Target /ɹ/

This participant improved from post-treatment to follow-up. However it appears in this investigation that he performed more poorly pre-treatment to post-treatment. Reliability was fairly good between listeners and within listeners. Intra-rater reliability was high (95%).

S2 (Pearl): Target /ɹ/ (and /k/)

This participant improved from post-treatment to follow-up. Pearl also appeared to improve from pre- to post-treatment. Reliability was fairly good between observers. Intra-rater reliability was irretrievable.

S3 (Petra): Target /ɹ/

This participant appears to have changed minimally (slight decline over time). Reliability was good between listeners. Intra-rater reliability was high (83%).

S4 (Peran): Targets /s/, /ɹ/, /ʃ/, and /i/

Peran's speech steadily appeared to improve, including from post to follow-up. Reliability was low between observers, however. Intra-rater reliability was high (91%).

S5 (Palmer): Targets /s/, /ʃ/, /ɹ/, and /I/

This participant's speech was rated as improving from pre to post, although accuracy appears to have slipped over time. Again, inter-observer reliability was low for this speaker. Intra-rater reliability was high (85%).

S6 (Purdy): Targets /s/, /ʃ/, /ɹ/, and /i/

Purdy's speech appears to have improved from pre- to post-treatment, with a slight dip at follow-up. Reliability was fairly good between listeners, but not within listener. Inter-observer reliability was fairly good for this speaker (73%) with intra-observer low (63%).

S7 (Pamela): Targets /s/, /ʃ/, /ɹ/, and /i/

Pamela's speech appears to have improved from pre- to post and maintained at follow-up. Listener reliability was good between observers. Intra-rater reliability was high (91%).

Discussion

The main goal of this study was to determine if there had been maintenance or improvement since the post session until the time of long-term follow-up assessment. The purpose of this investigation had been to investigate the long-term outcomes of speech production years after habilitation with visual feedback. The results of this follow-up study were mixed. Listener judgments showed maintenance of accuracy levels (S7), improvement (S1, S2, S4), or a slight regression toward less accuracy (S3, S4, S5, S6). Five out of the seven participants' speech had improved on at least one target compared with before therapy with visual feedback. For the remaining two speakers, one (S6) was judged to have remained at the same level of speech accuracy, while the other (S3) was judged to have declined slightly in accuracy over time. The results of this study diverged in some cases with results of past studies in the laboratory. A number of factors were possibly relevant to the differences: differences in type and number of stimuli, between-listener differences and differences in study design for listening. Results are discussed below, both in terms of divergence from past studies and in terms of the individual factors.

S1 (Parker): Target /ɹ/

Listener judgments for the current study showed Parker to have improved from T1 to T3 but to have regressed from T1 to T2, a result that diverged from Bacsfalvi (2006; Chapter 2), in which he was shown to improve from T1 to T2. One factor (other than differences in listeners or listening tasks) that may account for the divergence between the studies was the reduced random selection of tokens for this study compared with Bacsfalvi (2006). Of the tokens that were randomly presented, seven words contained the target /ɹ/ in the initial position and 19 words contained the target /ɹ/ in the final position. Word-final position appeared to be more difficult for Parker and thus probably brought-down his overall score in this study compared with Bacsfalvi (2006), which included all the data, and had a more balanced sample in terms of word position (five word-initial /ɹ/s and six word-final /ɹ/s). A semi-random selection (balanced for word position) may have resulted in different judgments in the current study.

S2 (Pearl): Target /ɹ/

Pearl was judged to have improved across the study (T1 to T2 and again to T3). The T1-T2 data diverged from Bacsfalvi (2006, Chapter 2), in which she was judged not to have incorporated /ɹ/ into many words. No apparent stimuli factors appear to account for the differences in her case, and thus between-listener or between-study differences may have resulted in the divergent results. When the treatment study ended, Pearl did continue with both listening and speech therapy and thus the T3 results appear consistent with that intervention. Pearl was able to acquire /ɹ/ at the word level as has been revealed in this study, confirming the hypothesis in study 2 that word use with /ɹ/ would follow learning of the articulatory gestures.

S3 (Petra): Target /ɹ/

Overall, Petra was judged to have regressed slightly across time in terms of the >70% criterion. In contrast, Bacsfalvi (2006, Chapter 2), Petra was judged to have improved somewhat in production of /ɹ/ at T2 by one listener and not by the other. For words judged to be "r"-like at 50% or greater, there was a positive trend over time. The divergence in the results from T1 to T2, in light of the 50% or greater difference, possibly reflects the difference in study designs. In Bacsfalvi (2006) judgments were 'rhotic-like' or 'not rhotic-like'. A possibly greater range of 'yes' responses could be made in such a forced-choice design than in the more discriminate rating scale for the current study. The listeners in Bacsfalvi (2006), may have judged token that were somewhat rhotic (50% "r"-like) as 'yes' responses. In terms of the T3 data, the stimuli may have been too difficult for her overall; she wanted to attempt complex words in the follow-up sample that contained more syllables and clusters. In the pre- (T1) and post-treatment (T2) samples there were only monosyllabic words. An informal observation of her follow-up data without the complex word shapes revealed similar results to those of the previous study, i.e., maintenance of the T2 level.

In terms of personal factors, Petra was still learning to listen with her cochlear implant, but it is not clear that this was a contributing factor. Other issues related to a reduction in practice once she left high school were more likely impacting her lower accuracy rates. Note that Palmer, Peran and Purdy also showed slight declines reflecting lack of practice. The result of this is that while Petra's /ɹ/'s are better than they were at T1 and T2, she does not have stable production of all the new gestural components.

S4 (Peran): /s/, /ʃ/, /ɹ/ and /i/

This participant chose to participate predominantly in the Deaf world after graduation from high school and used American Sign Language as his main mode of communication. This lack of practice/use of speech undoubtedly had a major impact on speech production. These results are similar to our findings from 2003 (Bernhardt et al.), where Peran improved productions for consonants and /i/, and regressed on other vowels. Once exception is for /s/

where results diverge. In the 2003 study Peran's /s/ improved word finally and regressed word initially. In this study /s/ was judged to have regressed by T3 overall. This may be due to his difficulty with word initial /s/ or overall disuse of oral language.

S5 (Palmer) /s/, /ʃ/, /ɹ/ and /ɪ/

The T1-T2 consonant improvement for Palmer matches the Bernhardt et al. (2003) results. T3 results reveal some deterioration (51%) although not to T1 levels (19%). Vowels improved from T1 to T3 matching the Bernhardt et al. (2003) results. Palmer (the oldest participant) maintained most of what he has learned in spite of the follow-up occurring four years post treatment. This is with no speech intervention in the interim.

S6 (Purdy): /s/, /ʃ/, /ɹ/ and /i/

The T1-T2 results for consonants and vowels generally agree with Bernhardt et al. (2003) for tokens judged to be near-accurate (>70% accuracy). At T3, some individual tokens were maintained, while others slipped back.

For this participant, results are likely due to change in communication modality. For two years after high school he chose to use American Sign Language (ASL) as his primary mode of communication. He reported in an interview (Bacsfalvi, Chapter 5) that he thought his speech had "gone down" because he did not speak regularly. However he asserted that if he started speaking more regularly again, that he would be able to regain what he learned in the visual feedback therapy programme because he could remember all the gestures. In addition, it is possible that the fine differences made for /ɹ/ were more difficult to maintain than the bigger changes made when a phoneme is very poorly produced as for example /s/. Another factor may be the low intra-rater reliability of the listener, which may reflect his ESL status.

S7(Pamela): /s/, /ʃ/, /ɹ/ and /i/

Overall phoneme production changes match what was seen in past studies (Bacsfalvi et al., 2007; Bernhardt et al., 2003). It is important to note that this participant received a cochlear implant after our intervention programme. At this time she struggled to use the implant, but ultimately decided the cochlear implant was not for her. This struggle with learning to listen may have resulted in less improvement than would have been possible for this participant. While outcomes revealed maintenance, she may have continued to generalize and improve even more if she had not experienced difficulty with her cochlear implant for over a year.

Implications for future research and clinical use of visual feedback

The current study had a number of limitations: a relatively small speaker group, short intervention periods, perceptual analyses only and lack of access to a normative data bank for data comparison. In addition, a different tape recorder and in some cases, location, were used for the T3 recordings, which may have had some bearing on the acoustic signals for T3 compared with T1 and T2.

Concerning the listeners, data collection needed to respect availability of the unpaid listeners. Most listeners indicated that they did not have more time to participate than two scheduled meeting times. Because all listeners were working professionally, most listening sessions took place on weekends or during the evenings, which means that often the listeners were tired from having worked all day. Because listeners varied in efficiency and fatigue, some listeners were able to analyse more data

The listener study was very time-intensive, and thus time did not permit use of actual formant data from the region for comparison in construction of the listener templates. Future studies could include a normative data collection of vowels for comparison to speakers so that era, age, and regional comparisons are accurate as recommended by Hillenbrand et al. (1995).

Other design considerations for future studies imply a larger group of participants with a longer time frame for therapy so that phonemes are very well established at the sentence level before stopping therapy with visual feedback technology. This may give participants greater time to understand all the gestural components and the co-articulatory transitions needed for speech segment productions at the sentence level. It has yet to be investigated if people with hearing loss need continued practice with visual feedback technology to establish co-articulatory transitions between segments. Hearing speakers may take these transitions for granted, but a person with hearing loss may require more information to be able to make these transitions. During the time-limited exploratory investigations, there was very little time to address sentence-level production before the students were finished working with the visual feedback technology.

Future research would require the development of a normative formant data bank for the local area, a pool of trained, experienced listeners and a group of trained research assistants to assist with data management such as splicing, storing, organizing and tabulating the data. A future study with a large number of participants would require a large budget and possibly multi-site research team, including a statistician, so that a complex model could be used to analyse the data statistically, something that was beyond the scope of this investigation. In the interim, this investigation suggests that there is great potential for the use of visual feedback as part of the speech therapy toolkit for people with hearing impairment hoping to improve their oral communication skills.

Acknowledgments

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Table 4.1: Participant characteristics

Speaker	Age T1	Age T2	Age T3	Hearing Profile	Sex	Education, Language	Hearing Device
S1 (Parker)	15	16	17	Profound sensorineural hearing loss. Charge Syndrome	M	School for the Deaf, ASL	Cochlear implant All times
S2 (Pearl)	15	16	18	Profound sensorineural hearing loss	F	Oral programme, Mixed Sign language and oral English	Hearing aid, Time 1. Cochlear implant, Times 2 and 3
S3 (Petra)	17	18	20	Profound sensorineural hearing loss	F	Oral programme, Mixed sign language and oral English	Hearing aid, Time 1. Cochlear implant, Times 2 and 3

Table 4.1 (cont.)

Speaker	Age T1	Age T2	Age T3	Hearing Profile	Sex	Education, Language	Hearing Device
S4 (Peran)	16	18	22	Severe sensorineural hearing loss	M	Oral programme, Mixed sign and oral English	Hearing aid
S5 (Palmer)	18	19	24	Severe sensorineural hearing loss	M	Oral programme, oral English	Hearing aid
S6 (Purdy)	16	18	22	Severe sensorineural hearing loss	M	Oral programme, oral English	Hearing aid
S7 (Pamela)	16	18	21	Moderate to severe sensorineural hearing loss, Large Vestibular Aqueduct Syndrome	F	Oral programme, oral English and Cantonese	Hearing aid

Note. Pseudonyms in parentheses are used in Bacsfalvi et al. (2007) and Bernhardt et al., (2003).

Table 4.2: Tokens and targets at follow-up

Listener	Speaker	# of WI tokens	# of WM tokens	# of WF tokens	Total tokens before time cut	Targets
L1	S1 (Parker)	38	45	40	162	ɹ
L2	S2 (Pearl)	15 (20)	38 (7)	27(11)	206	ɹ,(k)
L3	S3 (Petra)	19	42	26	153	ɹ
L4	S4 (Peran)	55	29	48	182	ɹ,s,ʃ,i
L5	S5 (Palmer)	157	133	123	638	ɹ,s,ʃ,I
L6	S6 (Purdy)	34	77	50	320	ɹ,s,ʃ,i
L7	S7 (Pamela)	58	18	36	349	ɹ,s,ʃ,i

Note. WI=word-initial; WM=word-medial; WF=word-final.

Table 4.3: Inter-rater reliability for consonants

Speaker	Targets	Primary listener	Intra-rater reliability % agreement	Listeners for inter-rater reliability	Inter-rater reliability % agreement
S1	ɹ	L1	95%	L1, L2, L6	73%
S2	ɹ	L2	irretrievable	L1, L2, L6	70%
S3	ɹ	L3	83%	L2, L3, L7	81%
S4	ɹ, s, ʃ, i	L4	91%	L3, L4, L7	62%
S5	ɹ, s, ʃ, I	L5	85%	L1, L4, L5	64%
S6	ɹ, s, ʃ, i	L6	63%	L3, L5, L6	73%
S7	ɹ, s, , ʃ, i	L7	91%	L4, L5, L7	81%
Mean agreement			85%		72% (S.D. 7.44%)

Table 4.4: /ɹ/ ratings for S1 (Parker) as judged by an expert listener

Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
90%-100%	7/24 (29%)	1/24 (4%)	57/94 (61%)
70%-100%	7/24 (29%)	2/24 (8%)	64/94 (68%)
50 – 69%	2/24 (8%)	1/24 (4%)	13/94 (14%)
50%-100%	9/24 (38%)	3/24 (13%)	77/94 (82%)
0%-49%	15/24 (63%)	21/24 (88%)	17/94 (18%)

Table 4.5: /ɹ/ ratings for S2 (Pearl) as judged by an expert listener

Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
90%-100%	0/22 (0%)	3/30 (10%)	31/80 (39%)
70%-100%	1/22 (5%)	6/30 (20%)	47/80 (59%)
50 – 69%	0/22 (0%)	0/30 (0%)	9/80 (11%)
50%-100%	1/22 (5%)	6/30 (20%)	56/80 (70%)
0-49%	21/22 (95%)	24/30 (80%)	24/80 (30%)

Table 4.6: /ɹ/ ratings for S3 (Petra) as judged by an expert listener

Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
90%-100%	5/32 (16%)	2/32 (6%)	3/52 (6%)
70%-100%	17/32 (53%)	15/32 (47%)	21/52 (40%)
50% – 69%	0/32 (0%)	2/32 (6%)	13/52 (14%)
50-100%	17/32 (53%)	17/32 (53%)	34/52 (12%)
0-49%	15/32 (47%)	15/32 (46%)	18/52 (52%)

Table 4.7: Consonant and vowel results for S4 (Peran) as judged by an expert listener

Segment Type	Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
Consonants	90%-100%	11/34 (32%)	16/35 (46%)	62/114 (54%)
	70%-100%	16/34 (47%)	21/35 (60%)	74/114 (65%)
	50% – 69%	2/34 (6%)	5/35 (14%)	23/114 (20%)
	50%-100%	18/34 (52%)	26/ 35 (74%)	97114 (85%)
	0-49%	16/34 (47%)	9/35 (26%)	17/114 (15%)
Vowel /i/		5/5 (100%)	4/5 (80%)	5/9 (56%)

Table 4.8: Consonant and vowel results for Palmer as judged by an expert listener

Segment Type	Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
Consonants	90%-100%	6/88 (1%)	41/69 (59%)	102/277 (37%)
	70%-100%	12/88 (14%)	44/69 (64%)	146/277 (53%)
	50% – 69%	2/88 (2.3%)	9/69 (13%)	74/277 (27%)
	50%-100%.	14/88 (16%)	53/69 (77%)	220/277 (79%)
	0-49%	74/88 (84%)	16/69 (23%)	57/277 (21%)
Vowel /I/		0/9 (0%)	0/10 (0%)	1/2 (50%)

Table 4.9: Consonant and vowel results for Purdy as judged by an expert listener

Segment Type	Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
Consonants	90%-100%	29/61 (48%)	21/57 (37%)	43/90 (48%)
	70%-100%	46/61 (75%)	47/69 (82%)	67/90 (74%)
	50%–69%	2/61 (3%)	1/69 (2%)	7/90 (8%)
	50%-100%	48/61 (79%)	48/69 (70%)	74/90 (84%)
	0-49%	13/61 (21%)	21/69 (30%)	16/90 (18%)
Vowel /i/		0/8 (0%)	3/8 (38%)	25/36 (70%)

Table 4.10: Consonant and vowel results for Pamela as judged by an expert listener

Segment Type	Accuracy in %	Time 1 (Pre-Tx)	Time 2 (Post-Tx)	Time 3 (Follow-up)
Consonants	90%-100%	15/77 (19%)	66/95 (69%)	56/90 (62%)
	70%-100%	17/77 (22%)	70/95 (74%)	67/90 (74%)
	50%-69%	7/77 (9%)	4/95 (5%)	7/90 (8%)
	50%-100%	24/77 (31%)	74/95 (78%)	74/90 (82%)
	0-49%	53/77 (69%)	21/95 (22%)	16/90 (18%)
Vowel /i/		7/9 (77%)	10/10 (100%)	21/21 (100%)

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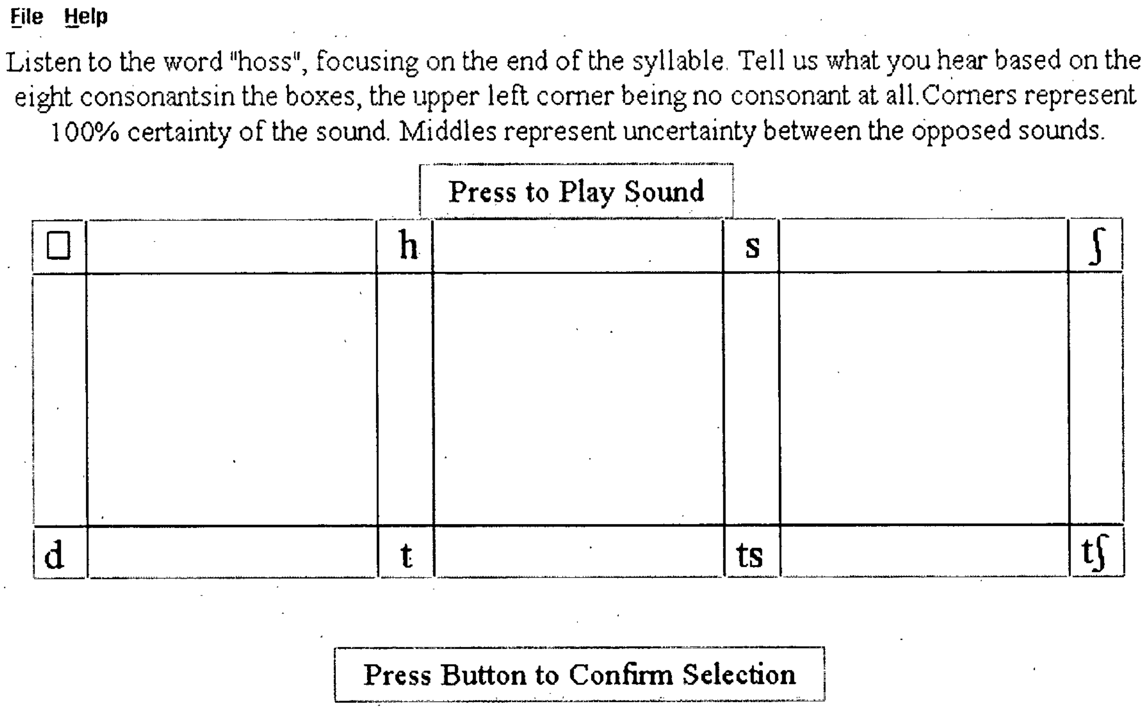

Figure 4.1. Fricative selection chart

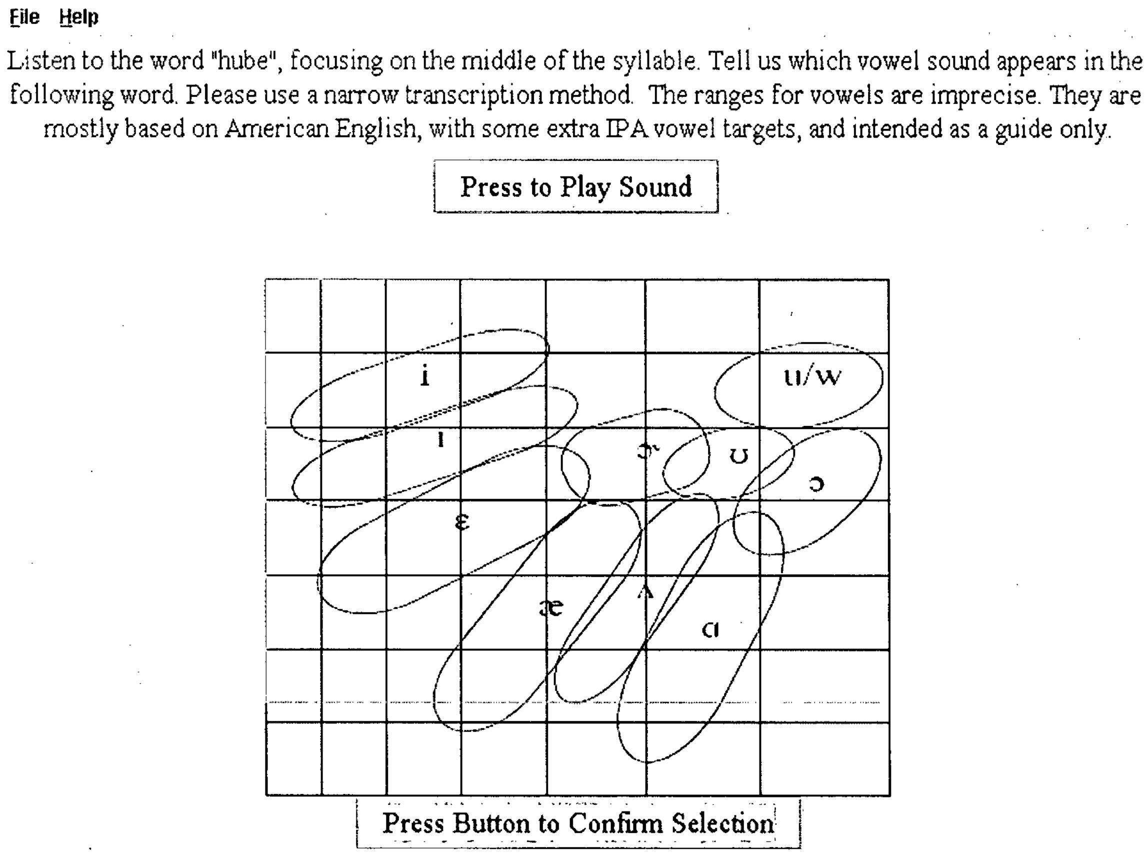

Figure 4.2. Vowel selection chart

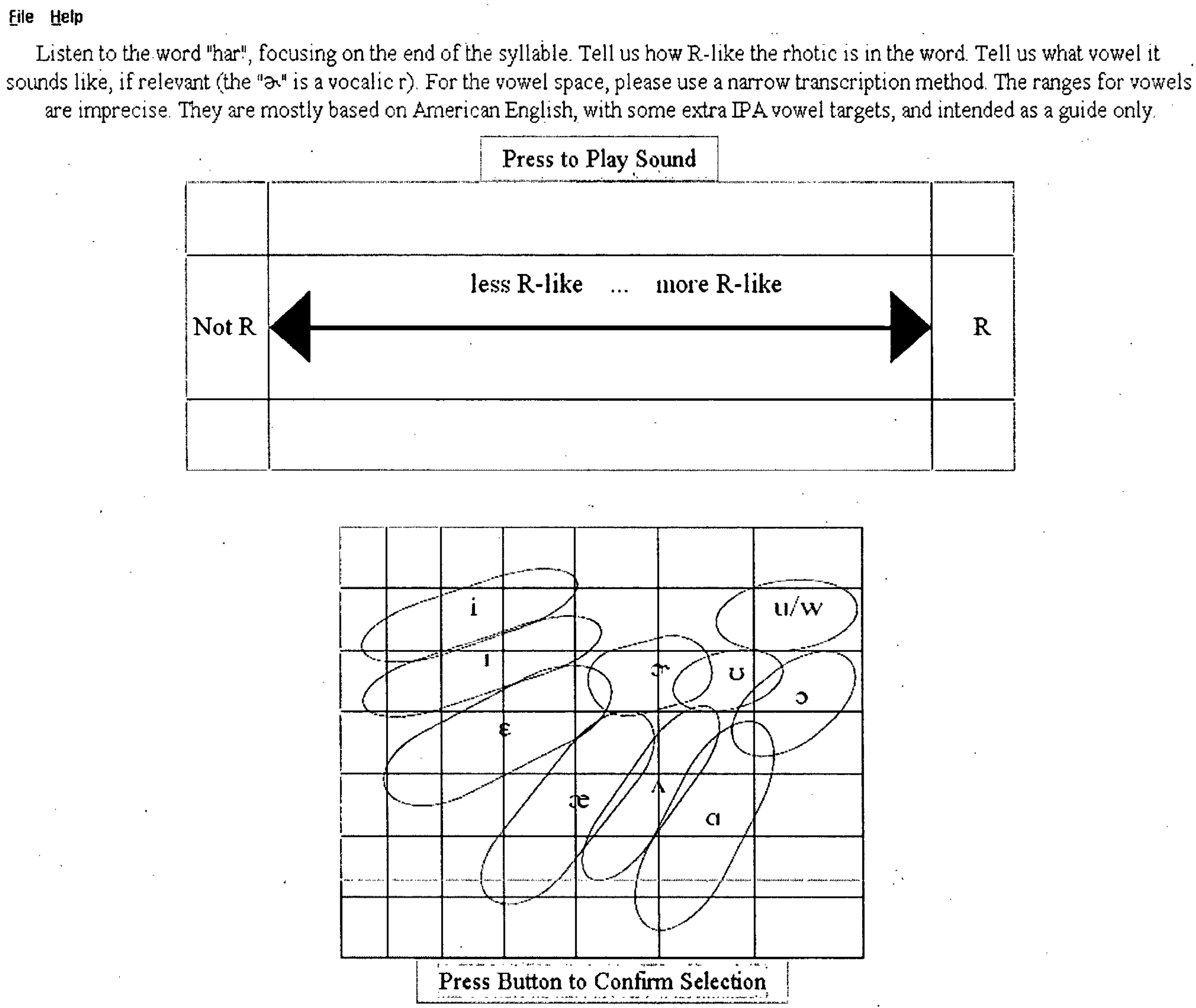

Figure 4.3. ‘r’ selection chart

CHAPTER 5

A qualitative follow-up study of the long-term outcomes of speech therapy for seven adolescents with visual feedback technologies: ultrasound and electropalatography

A version of this chapter will be submitted for publication to the journal Clinical Linguistics and Phonetics in May, 2007. Bacsfalvi, P., A qualitative follow-up study of the long-term outcomes of speech therapy for seven adolescents with visual feedback technologies: ultrasound and electropalatography.

Introduction

The speech of many people with severe to profound hearing loss is characterized as being unintelligible or difficult to understand (Hudgins and Numbers, 1942; Ling, 2002). The impact of unintelligible speech in the life of people with hearing loss has been often reported (Takala and Seppala, 1994; Skelton and Valentine, 2003; Blackorby and Wagner, 2007). These and other studies describe some of the negative effects of hearing loss in a hearing world, for example, the negative impacts on interpersonal relationships with family members and friends, performance in school, the ability to get jobs, and the ability to participate in society in general. Clear oral communication is one functional skill that may enhance the life of a person with or without a hearing loss. The World Health Organisation (WHO, 2001) emphasizes that the simplest requirement of health care is that there must be some beneficial change for the individual receiving treatment. One aim of speech therapy for persons with hearing loss is to assist them in improving their speech production and intelligibility, i.e., a beneficial change (Bernhardt et al., 2003). The ultimate goal of speech therapy is to improve the quality of life of individuals with communication impairments through enhanced social participation and self-esteem (McLeod and Bleile, 2004).

A number of studies were undertaken using visual feedback technology (ultrasound [U/S] and electropalatography [EPG]) to enhance speech production of a group of adolescents with hearing loss (e.g., Bernhardt et al., 2003; Bacsfalvi et al., 2007a). EPG portrays tongue-palate contacts during speech and U/S displays images of the tongue from either a sagittal or coronal perspective. For EPG, an acrylic pseudopalate implanted with electrodes converts the tongue-palate contacts to an image on the computer monitor. For U/S, a transducer pressed firmly under the chin transmits reflections of sound waves from air just above the tongue's surface to a monitor (for further detail, see Bernhardt et al., 2005b). Quantitative studies exploring the outcomes of speech therapy with U/S and EPG revealed positive results overall (Bernhardt et al., 2003; Bacsfalvi et al., 2007a; Bacsfalvi et al., 2007b). However, the views of the participants on the intervention process and results remained unknown.

Understanding the impact of intervention methods on the lives of clients is one of the goals of speech-language therapy, yet research on speech-language therapy has often only focused on the quantitative results of clinical intervention. Less is known about the experiences of clients and their families than about the intervention process and its effects. Qualitative research is becoming recognized as an important method for obtaining answers to clinical questions (Thorne et al., 1997). Qualitative description, used in this study, is a valuable and informative method of enquiry that stays close to the data and provides insight. Qualitative studies are able to illustrate benefits to clients that would not be available through quantitative analysis. For example, Fitzpatrick and Schramm (2006), in their qualitative investigation of the impact of prelingually deafened adult cochlear implant users, uncovered unexpected information about the impact of cochlear implants. The audiologists who participated in their study noted that patients often indicated that just a 'little bit more hearing' was able to improve their communication experiences. The current study was undertaken in order to gather information regarding the experiences of five former clients, their family members and members of their educational team concerning visual feedback technologies used in speech therapy, i.e., a descriptive qualitative approach to outcomes evaluation.

Method

The present study used semi-structured interviews as a means of collecting stakeholder information. The interview was chosen as the best method to learn about the participants' experiences. "…interviews are particularly suited for studying people's understanding of the meanings in their lived world describing their experiences and self-understanding, and clarifying and elaborating their own perspective on their lived world" (Kvale, 1996, p. 105).

Participants

Following procedures of the university's ethical process, individuals who had been associated with the previous visual feedback studies were provided with information on the qualitative study. If an individual indicated interest in participating, then written consent was obtained and an interview scheduled. The deaf community is fairly small in western Canada and as a result only very general information about the participants is included to protect individual privacy and confidentiality. No titles of institutions are used, nor are cities identified where individuals lived. The area is generalized to urban western Canada. Pseudonyms are used for the participants that are used in previous studies (Bernhardt et al., 2003; Bacsfalvi, 2007) in order to be able to cross-reference quantitative and qualitative outcomes.

The participants in this study had all been affected in some way by speech therapy with visual feedback technologies (US and/or EPG). Five of the participants in this longitudinal follow-up were the former students themselves (Speaker, S) who had participated in the clinical investigations. The speaker participants ranged in age from 17 to 24 years of age at the time of the current investigation. All have severe-to-profound hearing loss. All but two (S1 and S5) came from ESL backgrounds, although English was the main language of the household. The other four participants in the current descriptive study were stakeholders in the lives of the students (Related Stakeholders, RS): three parents (of Parker-S1, Palmer-S5, and Purdy-S6), one oral interpreter (OI) and one close family friend of Parker's (Parker's mother- M1, Palmer's mother-M5, and Purdy's mother- M6). All the participants in this study were chosen due to their direct or indirect experiences with these visual feedback technologies. The related stakeholders were asked to participate based on their close involvement with the speakers. The OI who participated in this study was selected because she had worked closely with several of these students during their participation in the clinical investigations. For a description of all participants refer to Table 5.1.

Insert Table 5.1 about here

Two former intervention participants who did not participate in the current study were also asked if they were interested in taking part in the qualitative study. One participant indicated that s/he was not interested in participating in any more studies. The other former participant indicated that s/he would be happy to participate; however, time and scheduling issues eventually resulted in non-participation.

Note on participant selection and the investigator

The interviewer knew all of the participants except the family friend because they had all worked together before. Familiarity was considered a benefit in the current study for the following reasons. The participants were all very comfortable with the interviewer. The S and two of the RS (M1 and OI) had worked quite closely with the interviewer during the period of visual feedback therapy. The author and the two related stakeholders had all worked closely together with the mutual goal of trying to improve speech therapy methods for people with hearing loss. As a result there was no discomfort or period necessary to establish rapport. Additionally, familiarity gave the participants the freedom to discuss what they liked and did not like and exactly what their experiences were because this is the kind of feedback and openness that was shared during the clinical investigation process. Also, in any cases where speech was difficult to understand, the interviewer's familiarity with the speech of the speaker was very helpful. The speech of two of the participants would have been difficult for an unfamiliar listener to understand and transcribe. A possible limitation of the researcher and the interviewer being the same person are that the participants may not have wanted to say anything negative about the past clinical research project. However, due to the fact that the investigator was not working directly with any of the participants at the time of the interviews, and because of the general atmosphere of openness, this was not believed to have been an issue. Furthermore, the main question was whether this experience was useful or not to further clinical practice for others. All participants in the interviews (interviewee and interviewer) had an investment together in being open and honest because this is the only way to improve clinical practice.

Interviewing procedures

All participants were interviewed either in their homes or at the author's clinical office, whichever was preferred by the interviewee, in comfortable seating either on a couch or at a table. The semi-structured interviews lasted from one to two hours with each participant. Interviewer and interviewee were alone in the room, although other family members or colleagues may have been in other rooms. A micro-cassette Sony M-677V (microphone built in) tape recorder was placed on the table or coffee table near to the seating location. During one recording the author requested that the participant speak directly into the tape recorder because the speaker's voice was extremely quiet. This was easily done with the small, light-weight palm-sized recorder. In addition, written memos were taken during the interview process or directly thereafter.

All interviews were conducted in the auditory-oral modality and on the rare occasion that there was a communication breakdown, then either oral repetition, or paper and pen were used. All participants use oral English as their main mode of communication even though several of the S also use some American Sign Language when communicating with people from the Deaf community.

The interviews consisted of a series of questions designed to generate candid descriptions of the S or RS experiences during and after therapy with visual feedback technology. Because the interviews were semi-structured, they took the course that the interviewee led. While the interviewer had some set questions that she wished to learn about, she was also interested in hearing about the experiences of the participants. Thus, the interview process was a combination of being led and leading the interviewee in a conversational style interview that was conducive to sharing an experience. Any questions or comments that could be interpreted incorrectly or misunderstood, as judged on-line by the interviewer, were paraphrased or reframed to the interviewee so that clarification could be made at the time of the interview. These clarifications in meaning became part of the interview process.

Each interview participant was reminded of the EPG and U/S projects that had taken place and was asked to indicate his or her experiences of the therapy, the whole process, the effectiveness and anything he or she would like to share. Participants were encouraged to include both negative and positive comments to determine if these visual feedback tools should be implemented into the mainstream school system and to determine from their perspective how they could be used in the best way possible. (See Appendix C for questions asked.)

Analysis methods

The interviews were collected over six months, and transcribed verbatim into a word document by the interviewer. Each transcript was listened to two to three times to make complete transcriptions. Each transcript was then read several times in the analysis procedure. The data were collected and preliminary analysis occurred simultaneously.

Theoretical framework for analysis

For analysis, a qualitative descriptive study was chosen because it remains close to the data. One benefit of a descriptive study is that it is much less likely to be influenced by inference and entails the presentation of the facts in everyday language (Sandelowski, 2000). The goal of the analysis was to inform the readers of the experiences of the participants rather than produce any particular theoretical rendering of the target phenomena, which is beyond the scope of this paper (Chow, 1998). Content analysis was used in conjunction with constant comparative analysis and line-by- line coding. Constant comparative analysis systematises the analysis by staying close to the data, being consistent and integrating information through constant comparison of data and their properties (Glaser, 1965). Qualitative content analysis is data-derived. Codes are systematically applied but generated from the data themselves. Reduction of data by uncovering uniformities in the original categories will occur throughout this process.

After the interviews were transcribed, they were read and re-read, and each transcript was open-coded (Glaser, 1965). Data were placed into categories and themes. First, the data were hand-coded by the interviewer for the main themes. Once the main themes had been established, then these were placed into categories. By constantly comparing and contrasting the codes, interpretations of similarities and differences within and between transcripts were developed. The codes were clustered to produce categories and their sub-categories. The author met with a doctoral candidate in speech-language pathology who was also doing qualitative research to discuss the coding and analysis of the data. The author and doctoral candidate separately completed preliminary coding for parts of two interviews. These analyses were in 100% in agreement for themes.

The analytic process was facilitated by referring to the written memos taken during the interview process or directly thereafter. These described the categories, properties and their relationships. Diagrams were developed to provide a graphic representation of relationships among the categories. (See Figures 5.1 and 5.2.)

Insert Figures 5.1 and 5.2 about here

Findings

Investigator responsibilities

As a researcher and an SLP reading through the transcripts and reviewing the field notes, the investigator and author became acutely aware of the level of trust that these participants had in the interview process. They trusted the interviewer enough to share their experiences and also trusted that there would be honest reporting of what they experienced. As a result the investigator felt a strong responsibility to share their stories as accurately as possible and to report any concerns or perceptions that they felt were important to recognise and bring to light. Through clarification, the investigator has attempted to reflect their perspectives as accurately as possible.

Data are first presented in the sequence of most prominent to least prominent themes that emerged from the interviews. Data are then presented by participant dyads or triads. The latter analysis provides a means of demonstrating triangulation of results by having the same or similar themes emerge from two or three different participants regarding the same intervention participant's experience.

Most prominent themes for speakers

As noted, the findings were grouped into themes and are presented in order of prominence. The most prominent themes were ones where four or five of the Ss mentioned a topic as important in their experience. The main themes were: "Good experience", "Therapy Method", "New Information", "Benefits", "Outcomes", and "Generalization".

Each theme was broken down into sub-themes, which are supported by quotations from the interviews. Every interview participant shared with me their belief that the speech of the Ss had improved and that overall they produced better and speech that was 'clearer'. Each of the major themes will be discussed below, with comments on sub-themes combined if the slightly different sub-themes overlapped. See Figure 5.1 for a diagram of the major themes and sub-themes.

S Theme 1: Good experience

Sub-themes S.1.1 and S.1.2. Enjoyed it, Successful

All of the speaker participants reported that they found this clinical investigation project a good experience. They spoke of enjoyment, fun, feeling pleased and being successful. For example, Parker indicated that this visual feedback technology was more fun than just traditional therapy alone. He said, "I like it…it help to talk clear… and it helps me to practice with that (the US)." Purdy said, "This way, I can be successful. I can pass- (*he means be understood by unfamiliar hearing speakers)*- now I can know how to talk."

Sub-theme S.1.3: Motivating

Palmer and Parker both indicated that working with this technology was very motivating for them. Palmer said, "…ya, it also helps you (to be) motivated…it tells you what you are missing with your speech-right?"

S Theme 2: Therapy methods

Sub-theme S.2.1. Hard work

A prevalent sub-theme that emerged from the data was "Hard work". Four of the five participants talked about the therapy and learning the gestural components of phonemes to be quite hard work. One participant, Parker, said, "Yes, it was *hard*- before, in the beginning, it was hard (work)…and then it got better and better, and *now* it is easy, I like it." He discussed how learning to use the ultrasound technology was initially difficult and how working on the gestural components was challenging, but that in the end, he learned the techniques and gestures and it became easy for him. He discussed how it was helpful to see what was happening to be shown <u>how</u> to produce the components that underlie a speech sound, the right way. Palmer also indicated that it was hard work, but then said, "No, this what I like to use because I will learn speech better (than without technology)." So even though it was hard work, he did not feel particularly negative about the hard work because the effort was worth the end result. Petra indicated that the practice time required was too much work, even though she believed the therapy was helpful overall. (In the quantitative study, she showed minimal improvement in terms of her principal target 'r', reflecting the issue with practice time. [Bacsfalvi et al., 2007b]).

Sub-theme S.2.2. Better method

All speaker participants reported that they had learned more with the visual feedback technologies than with traditional methods and that they believed that speech therapy in conjunction with visual feedback was the best method. Petra said, "The better way is to have ultrasound together with speech therapy". Parker preferred this method to therapy without visual feedback because it offered more information and he felt it was more advanced than traditional speech therapy. This could also fall under 'New information' as he found it not only more information but more advanced. He was able to learn more about the speech targets as well as learning how to say them correctly and more quickly.

Sub-theme S. 2.3. Whole package

Three of the speaker participants talked about the importance of having all pieces of the intervention programme in place for success. Palmer, Peran and Parker all talked about finding the combination of techniques important for the habilitation process. These included visual feedback technology for segmentals (EPG and U/S) and, visual feedback technology for suprasegmentals (visual feedback with acoustic phonetic software). This was not used experimentally, but used in therapy at the same time to address suprasegmental issues. Peran and Palmer indicated that they found the combination of technologies very helpful. Parker also talked about how he liked having aural rehabilitation plus the use of visual feedback technology to help him overall with speech, listening and overall communication. These speaker participants found all these components contributed to their success as speakers.

Theme 3. New information

S Theme 3 contained a variety of inter-related sub-themes such as: "Visual feedback is helpful (because of the information it provides)", "Know how to talk", "More information about speech", and "More advanced/deeper knowledge". The most talked about sub-themes were "Visual feedback is helpful (because of the information it provides)" and "greater knowledge" (discussed below).

Sub-theme S.3.1.Visual feedback is helpful (because of the information it provides)

Parker said, "It was helpful to see what happen(s), what's happening...to show how to do a 'r' the right way." Peran and Palmer talked about how it was helpful to have the visual feedback so that they knew where to place the tongue "properly". Peran said, "The picture for me is clearer- then I understand how to speak, I can speak". Palmer stated, "When I think about those equipments, like EPG and U/S....it tells you what you are missing with your speech, right?" Petra reflected, "I think it really important (for) improvement, because- um, some words they don't know what sound like....and then you can see it".

Sub-theme S.3.2. Greater knowledge

All of the participants discussed how the information from visual feedback about speech production was more in-depth than in speech therapy without visual feedback information. The Ss commented that they learned more about the various gestural components of speech. Purdy said that as a result of this deeper level of information he was more successful as an oral communicator. He said, "...that one [use of EPG or U/S] could tell me more deep...." Parker also stated that he liked using U/S because the knowledge gained was more "advanced".

S Theme 4: Short-term outcomes of therapy

Participants also commented on short-term therapy outcomes, i.e., the effect on speech production. The sub-themes of this section were "Better understood", "Speak more clearly" and "Recommend it". All the participants talked about how a direct outcome of participating in the visual feedback interventions studies was that they were better understood and that they spoke more clearly.

Because of their great success with speech therapy with this technology, they also recommended it for others struggling with their speech. Petra said, "I think ultrasound is great….because, some people (will) know how to say their words".

S Theme 5: Benefits

Sub-themes S.5.1. Improvement

The theme "Benefits" encompasses the overall benefits of speech therapy with visual feedback as experienced by the participants. All of the participants reported being pleased with their improvements in speech production. These improvements impacted their ability to communicate with family, friends and at work. They all felt that they were better understood by others post-habilitation. For example, Petra said, "Most of my friends or cousins, they told me they can't believe that I speak much better than before, and they can understand what I am talking about. *Before,* before they didn't understand. But now, they understand".

Purdy reported, The experience, "…at the university, that was really important for me- because this way I could talk with people…make people understand me, like most of the time- otherwise people don't have time to (have you) repeat, and try to understand what you say…again, again…they get tired. So that's why it was very important for me, for my life too".

Sub-theme S.5.2. Learn More

While the main theme of "benefits" encompasses benefits across learning, speech clarity and improvement in communication, the sub-theme "learn more" addresses specifically the experience of being able to learn more about speech and learning more than before in speech therapy. Palmer reported that he was able to learn about what was missing in his speech, "...it tells you what you are missing with your speech". He said that with visual feedback he had access to information that he previously had not had. Purdy said that before using visual feedback he had used his tongue in a different way that was not correct. He explained, if I don't know "how to say a word- I *guess,* how to say *that word.* With computer (EPG or US screens), you can know you say it.......how you say it, good or not, and I'm sure how to make (the correct gestures)". The sub-theme "learn more" represents the parts of learning rather than overall benefits under "improvement".

S Theme 6: Generalization (long term outcomes)

An important part of any treatment is that it is not only effective in the short-term, but in the long-term. All participants reported that they were able to remember the methodology and the gestural components of most of the phonemes that were learned. Four out of the five participants felt they still knew the gestural components of the speech targets that they had learned years previously (except for Petra which was basically consistent with findings of the quantitative study, Bacsfalvi et al., 2007b). As a result of this, they believed they still remembered what to do to produce intelligible speech.

Sub-theme S.6.1. Memory aid/Remembered gestures

Four out of the five participants commented that learning speech with visual feedback helped them to remember <u>how</u> to produce speech segments. For example, Peran said, "Because it helped me a lot get better, better...you can remember, you know?" He said that is was easier to remember once you saw the image then to try and remember how a gesture felt inside your mouth.

Sub-theme S.6.2. Maintenance of skills

Both Purdy and Peran indicated that once they finished high school, they had been immersed in ASL for a couple of years and they could tell that their speech proficiency had gone down because of lack of use. Purdy assured the author that he would easily remember his speech sound productions with just a little practice with ultrasound. He remembered the methods used for learning and was able to explain this methodology; however he indicated that he did not remember all of the gestural components and would need to review them. Being able to see what was happening aided in remembering in the long-term for him.

Less prominent themes for speakers

S Theme 7. Individual practice with hearing professionals

A theme that emerged for three of the five participants was "Practice with a hearing person". Purdy, Peran and Palmer all indicated that they thought it necessary and motivating to have a hearing professional with whom they could practice. These participants also indicated that they preferred one-on-one practice. Peran said, "One-on-one speech, this practice is the best- you know?" He apologized that he was just being honest by saying he preferred the focus to be on him, and that when there it is a group therapy and practice were not as good in his opinion. Purdy talked about how working with the oral interpreter was extremely helpful for him, and that that really helped him to consolidate and learn the new information. In addition, he thought working and having weekly practice with a speech-language pathologist was crucial for him to learn how to improve his speech. (While Petra did not mention this topic, she did have support while still in high school from the oral interpreter. Parker also did not mention this topic but had constant support and practice with his mother, who was an active participant in the process.)

S Theme 8. Discomfort of visual feedback technology

Three of the participants indicated that they found using the equipment uncomfortable at times. Peran said that his artificial palate for electropalatography was uncomfortable, while Petra and Parker indicated that the ultrasound transducer probe pushing under their chins made their jaw tired or a bit uncomfortable from time to time.

Most prominent themes for Related Stakeholders

Looking at the related stakeholder data were a bit more complicated because some of the stakeholders had been directly involved in the practice (parent M1 and the oral interpreter), some had been marginally involved (the two remaining parents, M5 [Palmer's mother)] and M6 [Purdy's mother]) and the family friend had not been directly involved at all, but had only witnessed the outcomes. Nevertheless, many themes emerged for related stakeholders that were similar to those of the speaker participants. In addition to this, the RS who were directly involved in practice with the Ss offered insights into the process. Both the oral interpreter and Parker's mother (M1) had been directly involved in assisting with speech practice during the intervention project. Once again the most prominent to the least prominent themes will be presented, followed by new themes and insights not previously mentioned.

RS Theme 1: Good Experience

All of the stakeholders reported that the students had enjoyed therapy (sub-theme RS.1.1), were excited about the project in general (sub-theme RS.1.2) and the possibilities of learning speech in a new way and showed increased motivation for speech improvement (sub-theme RS.1.3). The oral interpreter (OI) said, "…they always seemed so excited to go (to speech therapy) …- it was always positive from that aspect". Parker's mother (M1) indicated that he was "fascinated with the technology, with the seeing- he's a very visual learner…" M6 said, "…well, I think that was a wonderful programme for him- he benefited quite a bit out of it, and he was actually excited to do it". M5 also said that Palmer was excited, "…that it was something different to improve his speech, rather then just straight speech therapy".

RS Theme 2: Therapy methods

Sub-theme RS.2.1. Hard Work

Both the OI and M1 indicated that hard work was needed to be successful with this therapy method. The OI said, "…I saw a real improvement in the kids who had worked hard at what they were (learning)". While this theme was only mentioned by these two stakeholders, the other stakeholders were not actively involved in the practice and work components and therefore would not have known about the degree of work involved.

Sub-theme RS.2.2. New information

This is another topic area where only people intimately involved in the project would be able to know about the new information learned. In this area only M1 was working closely with her son and exposed to the ultrasound technology and so could comment on the intricacies of therapy. She said, "…well one of the benefits I could see for Parker was that you were able to give a full assessment and know exactly where you needed to work with him, and I really appreciated that. And the fact that you narrowed it down….was very fascinating for me because I mean, I don't have the technical expertise that you do so I wouldn't know that that was something that he even needed to work on. And then, to see you were able to break it down into such finite little bits…." She appreciated the precision of the assessment and the way speech goals were able to be made. Once again the technology provided more advanced/in-depth knowledge then had previously been provided to M1 and Parker. She added, "...there was a long time when he practiced it the wrong way....better late than never".

RS Theme 3. Practice

The "practice" theme is mentioned by both the stakeholders and some of the speaker participants, with sub-themes 'one-on-one' practice (RS.3.1), "practice at school" (RS.3.2) and "practice with professionals" (RS.3.3). Only the stakeholders who were closely involved in this area were able to reflect on the experiences of practice and offer insight into the issue of practice during the habilitation period.

The OI did practice with a few of the students, including the two students who participated in the speech intervention research, but not in this qualitative follow-up. She found that, "... all of them succeeded, some more than others, depending on how good their speech was to begin with, and they all enjoyed *practicing* more...." She also reported, "And I found that the kids that had that opportunity (time to practice during school), I think, improved more, because they had the input at school as well as off campus". She also indicated that these students benefited from one-on-one practice, where the focus was on their specific goals.

M1 also discussed the benefits of practice, in particular with the technology on a weekly basis. She said, "...when you brought the equipment to the house and he could see it....then you could tell after he was using the equipment- and even after he got the 'r'- then he would slip back and then he'd have to (learn it again)....and once he saw it again, it just helped. And now, now he knows it, he's learned it". The important points they brought up from their experiences were increased one-on-one practice, and the importance of regular practice within the schools at part of the habilitation programme.

While the theme "practice" touched on the issues of the importance of practicing with a speech assistant and working with professionals to make a difference, a strong theme that emerged was that of "practice/training in the school". M5 said, "Well, I think if it was in, especially at his school, for an oral deaf person, who is really working on speech and who really is, you know, you're really trying to use (speech)...I mean, it's not just schooling, its part of their *life*". M5, M1 and the oral interpreter brought to light the theme of speech therapy being an important part of the programme for these students, with adequate practice time incorporated into the school day with trained school personnel. This was a theme brought to light by RS who had been involved in the actual clinical intervention programmes.

RS Theme 4. Benefits

The OI, who had worked with Petra, Purdy and Peran said, "Well, I guess that I saw a definite improvement in the kids and that the programme really seemed to work where these kids were concerned, and I would kind of hope that that could happen for all the kids in the programme...." She added, "I had a reading programme set up in one block, so I read for ten to fifteen minutes with each one of the students, and um, I noticed a big improvement in their reading, and their speech capability from that.... "

M1 said, "And now, now he knows it- he's learned it. So, I think it's been really effective, and I'm positive that if you hadn't had this visual stimulus there for him to see, he would have given up long before; he would never have got where he got". The friend said, "Parker's always been a very friendly, out-going, very polite person, but he seems to be able to communicate more easily...." M6 said, "In terms of speech it was a long pay-off". As can be seen by these comments, the benefits of using visual feedback technology in the speech habilitation programme were readily apparent to the stakeholders in the lives of these young people with hearing loss.

RS Theme 5. Short-Term Outcomes

This theme speaks to short-term outcomes, rather than general outcomes as in the "benefits" theme. All the stakeholders reported observing "clearer speech", "more self confidence" and "speaking more" as the predominant sub-themes for outcomes.

Sub-theme RS.5.1. Speak more clearly

M1 stated, "And now, now he knows it- he's learned it. So I think it's been really effective...." M5 and the family friend stated that both young men were more difficult to understand before therapy. The family friend told me, "I know that his speech improved because we see Parker a fair bit." She added, "Before it used to be sometimes difficult to understand him..." M5 said, "...we did notice a difference in his speech....I really did think it did help...."

Sub-theme RS.5.2. Improved self-confidence in speaking situations

Three stakeholders (friend, OI, M6) all discussed a sub-theme of "improved self-confidence". While one of the S had touched on the theme of self-confidence (Palmer), it was mostly the observations of the more mature stakeholders who described this shift in behaviour for the speakers. Parker's friend said, "He is communicating more with more people". She also said, "...I think it does give him some confidence knowing he can be with a group of people for the afternoon and make himself understood". The OI had a more in-depth view of this because she worked with different students every day and was in the unique position to observe them interacting in their high school. She said, "....Peran and Purdy were in a class that I was the interpreter in, and they used to just sign to each other all the time; well [after this project] they were talking to each other, actually verbally talking to each other. So there to me was the biggest improvement you know". She added, "...and the other thing too in communicating with the hearing kids in the out classes, I think that they got more confident by being able to speak clearer and weren't so shy to speak to others...." M6 also talks about how Purdy's speech continued to develop post-therapy, making him feel confident that he could communicate with everybody.

Themes from dyads and triads

The last part of the analysis discusses themes that emerged from the data for each dyad or triad grouping. This was done to corroborate evidence and shed light, where possible, on a theme (Creswell, 1998). Table 5.2 outlines the dyads and triads.

Insert Table 5.2 about here

All dyads and triads in figures 5.3-5.7 revealed corroborating themes, providing triangulation of the data (Creswell, 1998). The experiences and perspectives of the speaker participants and their related stakeholders were overlapping, adding valuable insights. Themes that emerged repeatedly across speaker participants and their related stakeholders were "good experience", "benefits" "outcomes", and "practice". Overall speech therapy in conjunction with visual feedback technologies was a positive experience and all parties believed the speakers had improved and maintained changes in their speech production. Not only were they successful in terms of better speech, but increased self-confidence and increased oral communication also appeared as important themes from their experiences. All dyads and triads reported the same three themes of "good experience", "benefit" and "outcomes", leaving this to have been a successful overall learning experience for all the stakeholders.

Discussion

Nine stakeholders participated in a qualitative study to share their views on the experiences of the speaker participants in clinical investigations with visual feedback technology. All participants reported similar experiences that revealed themes and subthemes such as success, benefit, improvement, motivating, increased self-esteem, hard work and enjoyment. Overall, this qualitative investigation revealed that the past clinical investigations (Bernhardt et al., 2003; Bacsfalvi et al., 2007; Bacsfalvi, 2007) were a success in the eyes of the primary stakeholders in this study.

Limitations of the Study

Methodology

More information may have been obtained by holding focus groups with the participants in addition to interviews. Discussions from a focus group setting may lead the interviewees to remember more information leading to more in-depth discussion and information.

Investigator bias

There is investigator bias in all research. It is important to clarify any researcher bias so that the reader is aware of any assumptions that impact the inquiry (Creswell, 1998). For the current study, the author was not only the primary investigator, but also one of the primary researchers in the previous studies (Bernhardt et al., 2003, 2005; Bacsfalvi, 2007; Bacsfalvi et al., 2007;). As a result, the author of course would like these clinical methods to have been successful. However, the participants and investigators also worked as a team throughout the clinical investigation process, developing methods together. Trust and relationships were developed, built on honesty and openness. In this way, it is the author's belief that the participants were able to be truthful about their experiences and opinions on the effectiveness of visual feedback tools in conjunction with speech therapy.

Conclusion and Future Directions

The quantitative results of investigations with visual biofeedback are very important to our knowledge of the efficacy of visual feedback technologies as tools in therapy. Equally informative is an analytic qualitative study for evaluating the effectiveness of new intervention approaches. "…qualitative data acknowledges that the variables surrounding particular behaviours are complex, interwoven, and difficult to measure, and thus quantitative data alone are inappropriate or insufficient." (Olswang, 1998). Because speech-language pathology focuses on human communication and social interactions, qualitative research is uniquely oriented toward uncovering the details of this social phenomenon (Damico and Simmons-Mackie, 2003). Qualitative research allows the process to be discovery-driven, permitting the investigation to follow what emerges as important to understanding the area under investigation (Morse and Field, 1995; Simmons-Mackie and Damico, 1999).

Disseminating the findings may increase the awareness of parents, students, teachers and administrators of the impact of visual feedback as part of the speech therapy toolkit. The findings indicate that it may be important to provide students with opportunities to try visual feedback as a component of speech therapy and increased access for speech practice.

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Table 1: List of speaker and related stakeholder participants

Speaker participants	Occupation	Age	Sex	Related stakeholder 1	Related stakeholder 2	Previous studies
Parker (S1)	Student	17	M	Mother (M1)	Friend	Bacsfalvi (2007)
Petra (S3)	Student	21	F	Oral Interpreter		Bacsfalvi (2007)
Peran (S4)	Clerk	20	M	Oral Interpreter		Bacsfalvi et al., (2007a); Bernhardt et al. (2003)
Palmer (S5)	Student	24	M	Mother (M5)		Bacsfalvi et al., (2007a); Bernhardt et al. (2003)
Purdy (S6)	Tradesman	21	M	Mother (M6)	Oral Interpreter	Bacsfalvi et al., (2007a); Bernhardt et al. (2003)

Table 2: List of dyads and triads

Group	Speaker Participant	Related Stakeholder 1	Related Stakeholder 2
Dyads	Palmer	Mother (M5)	
	Petra	Oral Interpreter	
	Peran	Oral Interpreter	
Triads	Parker	Mother (M1)	Family Friend
	Purdy	Mother (M6)	Oral Interpreter

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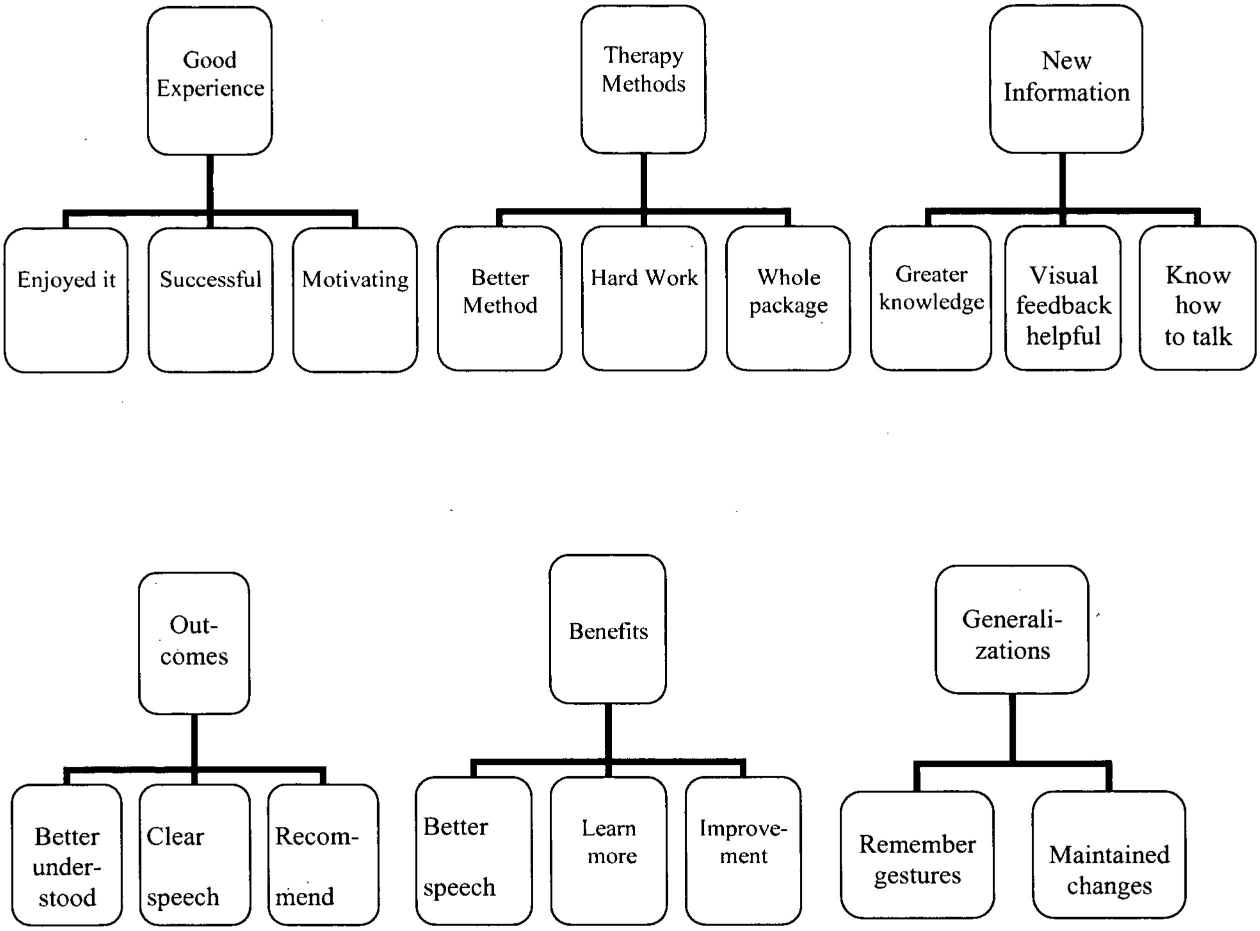

Figure 5.1. Major themes and sub-themes for speaker participants

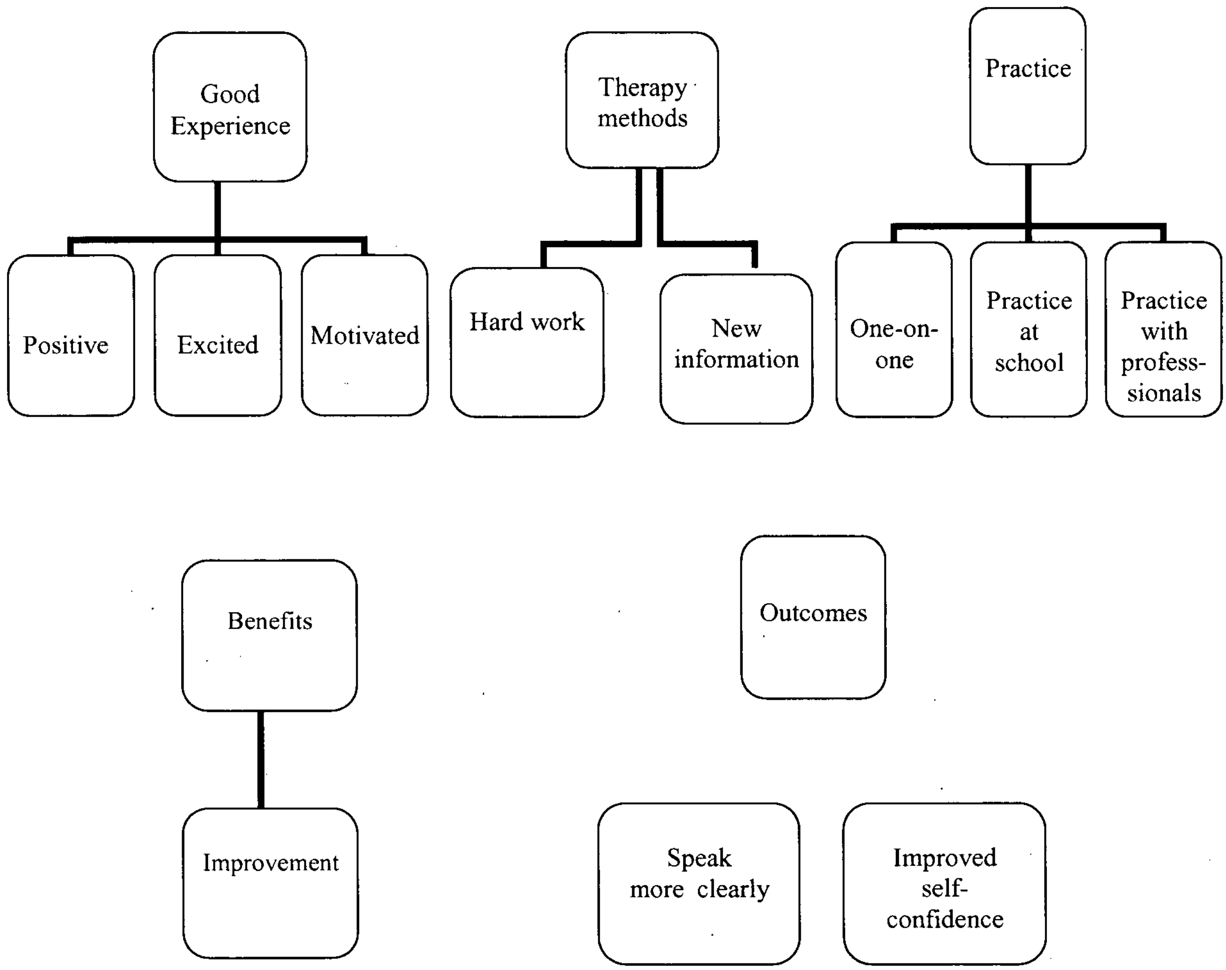

Figure 5.2. Major themes and sub-themes for related stakeholder participants

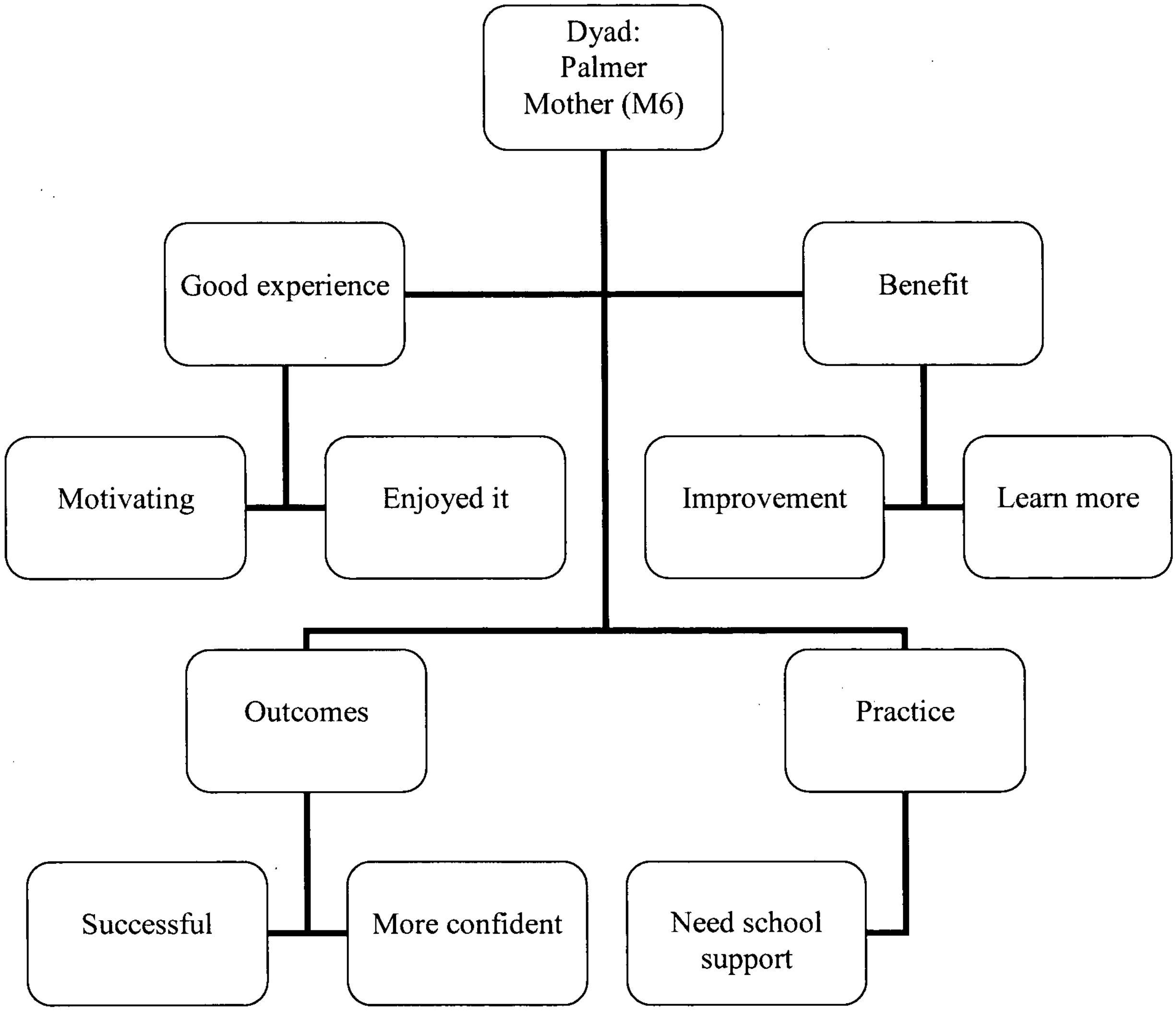

Figure 5.3. Corroborating themes: Experiences reported by Palmer dyad

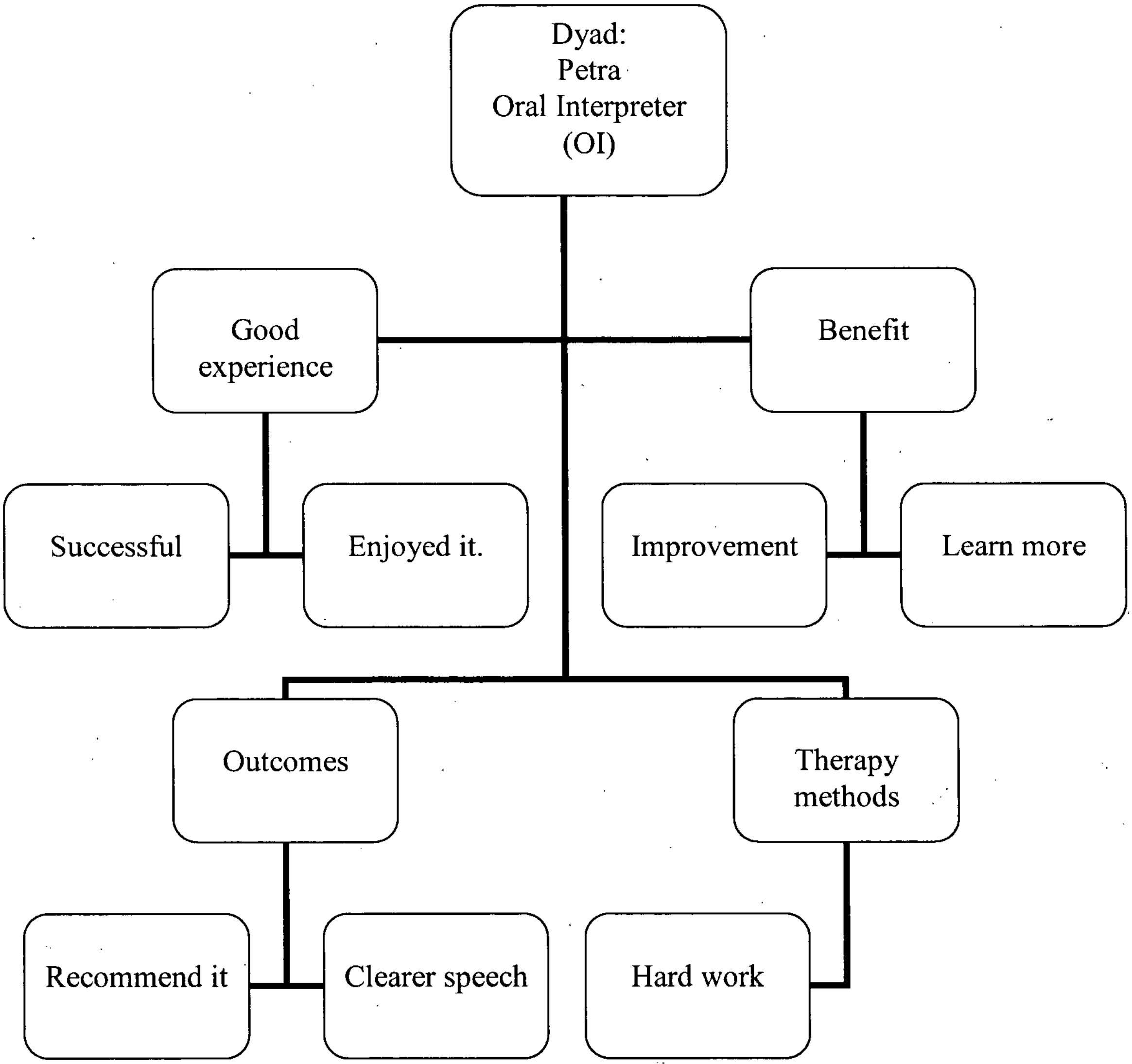

Figure 5.4. Corroborating themes: Experiences reported by Petra dyad

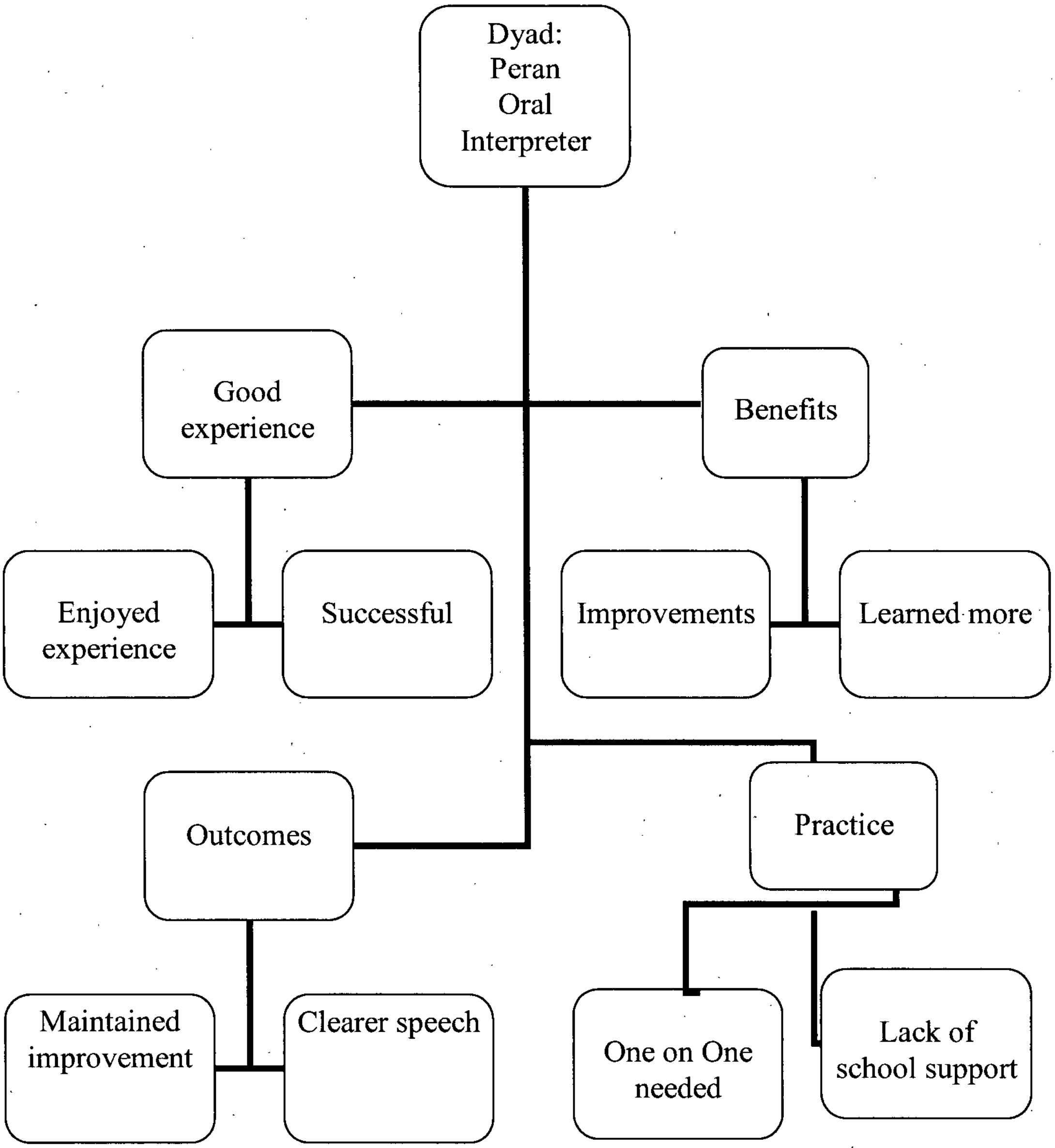

Figure 5.5. Corroborating themes: Experiences reported by Peran dyad

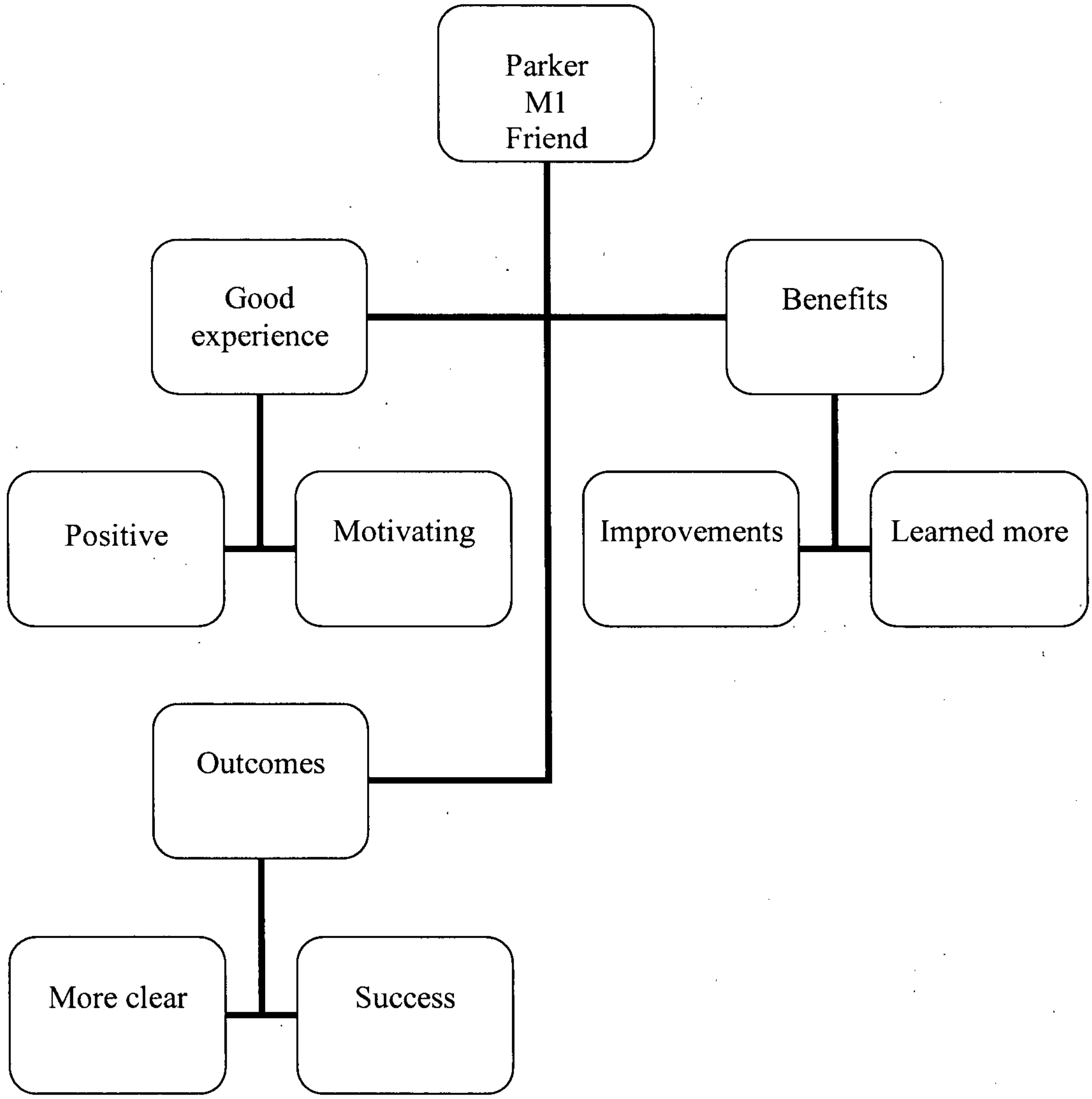

Figure 5.6. Corroborating themes: Experiences reported by all participants for Parker triad

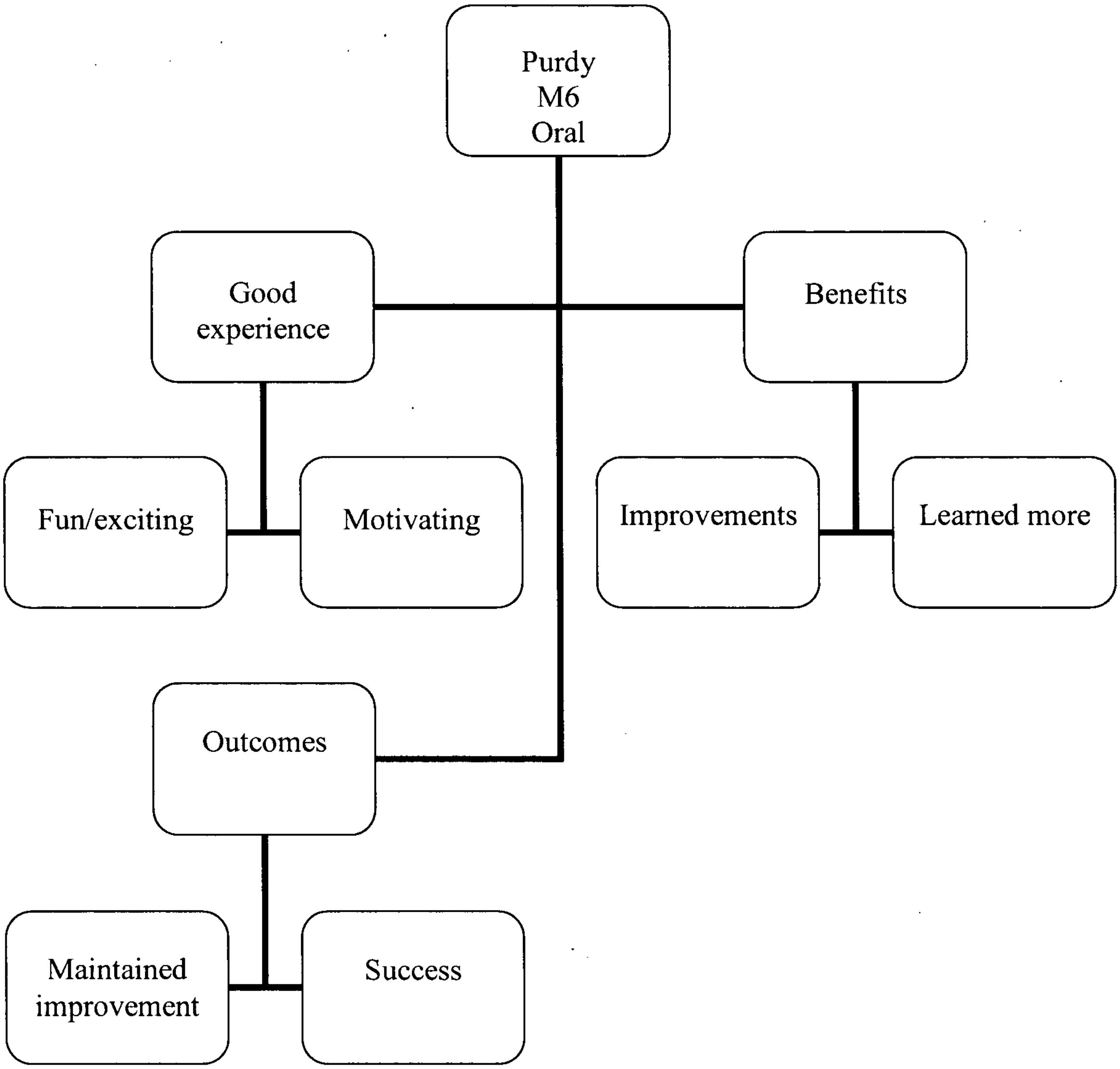

Figure 5.7. Corroborating themes: Experiences reported by all participants for Purdy triad

CHAPTER 6:

Conclusions and Clinical Implications

The body of research for this dissertation examined the outcomes of speech therapy with visual feedback technology (ultrasound and electropalatography) for seven hard of hearing adolescents with bilateral severe-to-profound sensorineural hearing loss. A broad scope approach to research design was used to investigate the results of short- and long-term outcomes. Triangulation of results was achieved through the use of different research designs and different data analysis methods. Different research designs included quantitative pre-test/post-test and single subject design methods and a descriptive qualitative investigation. Analysis methods included acoustic, perceptual and articulatory investigations to assess outcomes. These studies continued the long history of investigations with visual feedback technology and investigated the outcomes of speech therapy with EPG and U/S, opening the door to new methods for ultrasound. In this concluding chapter the most important findings of each chapter are discussed and the clinical implications are summarized. The theoretical importance, where warranted, is discussed.

Chapter 2

The first study of vowel remediation for three adolescents with severe-to-profound hearing loss, using hearing aids as their hearing devices, demonstrated the effectiveness of visual feedback technology (EPG and U/S) as an important component of the speech therapy toolkit. The results revealed notable changes for all vowels across all speakers. Past studies have shown that variability in vowel production is a key issue for speakers with hearing impairment (Dagenais and Critz Crosby, 1992; Ryalls and Larouche, 1992). Key findings in Chapter 2 (Bacsfalvi et al., 2007), revealed reduced variability in vowel productions and reduced intervention time (our study was only 6 weeks versus years of treatment with traditional methods). Interesting findings from this investigation were the divergence in results between

contact patterns, transcription results and acoustic results. It appeared as though contact pattern changes do not always imply a change in acoustic signal. These results may reflect a mid-point on the learning trajectory (Ertmer and Maki, 2000). We saw, however, reduced variability in vowel productions, a key issue for speakers with hearing impairment. Some questions arising from this study include major topics such as: (1) Which tool is more effective in therapy? (2) What is the length of time needed in therapy? (3) How can we best use visual feedback technology to enhance clinical practice? (4) Which clinical populations would benefit the most from these approaches? and (5) What are the implications for speech learning?
Sub-topics within each area include: (1) Which tool works best with various kinds of clients? and, Do these tools offer the same results or are they complementary? (2) How long should therapy be to reach generalization? and, How much intervention time is needed with ultrasound? (3) Is the role of visual feedback to establish speech to generalization or to establish the gestural components? and, How should these tools be used, at what part of the intervention process? (4) Does this tell us anything new about speech learning? and, Can this therapy replace what children with hearing impairment miss during development of speech?

The most important clinical implications that arose from this study were that ultrasound is an effective tool for use in speech therapy for people with long-term speech issues secondary to severe-to-profound hearing loss. Not only did these results corroborate past results of studies with visual feedback technology for speech learners who are deaf (Fletcher et al., 1991; Gibbon et al., 1999), but also introduced new technology (ultrasound) as a useful tool for therapy. The vowel study did not address qualitative aspects of the projects, however. Implications for research include a more in-depth investigation of the interactions between the articulatory, acoustic and perceptual information in the triangulation of results, which might offer greater insights into the speech learning process.

Chapter 3

The second study investigated an articulatory component approach to speech therapy using ultrasound for three adolescents. Unlike the first study, this study investigated the success of speech therapy with ultrasound alone. Differences in the design and focus in this study included single subject design, an articulatory component approach to therapy, and the participants using cochlear implants as their hearing device. Past studies (Bernhardt et al, 2003; Bacsfalvi et al, 2007) used U/S and EPG together as complementary visual feedback technologies for clients with hearing loss using hearing aids as their hearing devices. The focus of this second study was to investigate the efficacy of using ultrasound alone in developing therapy methods to address production of North American English /ɹ/ in students who were hard of hearing. These adolescent participants had all participated in traditional speech therapy sessions at various times for years with no success for acquisition of /ɹ/. None of the students had all the gestural components of /ɹ/ prior to beginning therapy with ultrasound. However, one student had started working on /ɹ/ in a previous study using ultrasound and continued intervention in this study. The goal of this study had been to teach the participants to establish the gestural components of /ɹ/ and produce /ɹ/ in isolation. As each gesture was learned, another gesture was added and then combined with the previously learned gesture. In addition, some work with /ɹ/ at the word level was initiated. It was not expected that the participants would be able to achieve /ɹ/ in all positions at the word and sentence level by the end of this study. Fully acceptable variants of a target take time to establish and were not the goal of this study. Ertmer and Maki (2000) state that there is an intermediate phase along the progress trajectory as the individual is learning speech. This phase can precede production of fully acceptable variants of the target (Ertmer and Maki, 2000). While these participants may have established the gestural components of /ɹ/, more practice was needed in establishing adult-like proficiency of /ɹ/ at the word and sentence level.

Because motor facility skills and phonetic contrasts depend on each other (Kent, 1984), it is not surprising that children not exposed to phonetic contacts through audition do not develop coordinated motor skills. This raises the question whether visual feedback can help to bypass the lack of acoustic cues and loss of coordinated motor development.

One limitation of this study had been the follow-up analysis post-therapy. Speech production stimuli were possibly too difficult for the participants. Follow-up measures should have only included gestures, /ɹ/ in isolation and /ɹ/ in phonotactically simple single-syllable words. The selection of words (due to speaker and investigator) at the word level in single and multi-syllabic words may have made listener judgments more difficult. In addition, development of methods for analysis of each separate gesture was warranted.

The clinical implications of this study were that ultrasound was a promising tool for remediation of long-term difficulty with North American English /ɹ/. These participants had been unable to learn /ɹ/ with traditional therapy over the years leading to this intervention programme. This was confirmed at baseline. In addition, even with the additional access to acoustic information, through the use of cochlear implants, these students had not been able to learn the production of /ɹ/. Visual feedback was necessary to overcome the lack of acoustic cues and long-term malformed productions of /ɹ/.

Research is needed, with larger numbers of participants of different ages and hearing disorder types, over longer periods of time to determine the optimal amount of therapy to ensure benefit of the technology and the course of change, as perceptual and gestural changes align.

Chapter 4

The goal of the third study was to investigate the long-term effectiveness of speech therapy with visual feedback technology. Any new method that is successful in the short-term must ultimately be investigated to determine if the short-term successes are maintained later. In this third study, the speech production of all seven participants was recorded and assessed by expert listeners two to four years post intervention.

Ratings by expert listeners (speech-language pathologists) revealed that six out of seven speakers either continued to generalize post-treatment or were able to maintain their level of post-treatment performance on at least one target. These results were encouraging. When we consider the personal and educational factors that were also at play in the lives of these participants -- from failed hearing technology, to periods of non-use of oral language and finally, jobs and educational training that led some of these individuals to function in environments where oral communication was not used frequently or consistently (e.g., studying computers, working in a factory and so on) -- these results were remarkable. Interestingly, there was no observable difference between the success rate of the hearing aid group versus the cochlear implant group for maintenance of speech production skills. One of the cochlear implant users showed minimal gain and a slight regression in the long-term. One of the hearing aid users similarly showed a lesser degree of maintenance in the long-term.

Strengths of this study included the use of expert listeners, offering a non-biased choice with anchors (formant data for vowels) during the listening judgment task, and listener training. Limitations included the use of Peterson and Barney's (1952) formant data rather than developing regional and era appropriate formant information for comparison (Hillenbrand et al., 1995). This occurred due to limited resources of time and money. This study was extremely time and labour intensive in terms of study set-up and design, data collection, analysis, and tool production. This then leads to another possible limitation. Perhaps formant analysis should have occurred for 20% of data randomly selected to confirm the listener data. However, a companion qualitative study did corroborate the results of this study. Future studies would benefit from having large multidisciplinary teams and substantial funding to expand and corroborate on the initial findings in the current study.

Chapter 5

A qualitative descriptive study was used as another way to investigate the long- term outcomes of visual feedback technology as part of the speech therapy toolkit. There are no prior studies of this nature for persons with hearing impairment as recipients of ultrasound habilitation.

Qualitative studies are rare in general in speech-language pathology, but currently gaining in popularity. Improving communication and social interactions is the ultimate goal of speech intervention, qualitative research is uniquely oriented toward uncovering the details of this social phenomenon (Damico and Simmons-Mackie, 2003). Olswang (1998) observes: "….– qualitative data acknowledges that the variables surrounding particular behaviours are complex, interwoven, and difficult to measure, and thus quantitative data alone are inappropriate or insufficient" (p. 143).

The qualitative commentary was extremely positive for the former students who had participated in this study and their stakeholders. The main themes that emerged from all the participants included "good experience", (good) therapy method", "new information", "benefits", "(long-term) outcomes" "improved self-confidence (when speaking)", practice (needed), "hard work" and "generalization". Not only did participants and stakeholders view the intervention as a positive learning experience, they also reported learning more about speech than previously and maintenance of these new skills.

Clinical implications include using a qualitative evaluation of speech therapy outcomes in addition to quantitative methods to provide a full look at clinical outcomes. Information on communication changes may be imperceptible or immeasurable by current technology and methodologies while qualitative analysis may provide information on the functional impact on the lives of clients and the important stakeholders.

Future research may involve interviewing more stake-holders in the lives of the speaker participants, and perhaps a more in-depth qualitative investigation that would offer theoretical findings. Alternate methods of interviewing, such as focus groups, may be used to offer a very different view of the phenomena than that which is collected during the qualitative interview (Morse and Field, 1995).

Summary and Conclusion

It is common for people who were prelingually deafened to demonstrate unintelligible speech (Osberger and McGarr, 1982). Historically speech therapy has been difficult and not always effective for people with hearing loss. Because many people with severe hearing loss continue to struggle in a predominantly oral society, visual feedback technologies may offer increased communication through greater intelligible speech in a shorter period of time.

The studies for this dissertation were very labour-intensive in terms of design set-up, data collection and analysis and the nature of the multiple levels of investigation. To address the many levels of issues relevant to this area of investigation requires a broad scope of knowledge in several areas: speech production and perception, linguistics, deaf speech, speech habilitation plus knowledge of computer software and programming was all needed in designing and developing these studies and analysis methods. Future studies would benefit from a team of investigators from a variety of complementary disciplines (speech-language pathology, linguistics, computer science, audiology, cognitive science, and engineering).

While the gold standard for research remains randomized controlled trial (RCT) studies, this type of study is seldom done for clients with complex conditions. There are many considerations such as the ethicality of randomly assigning clients, and the lack of clients with similar conditions for a study. In low incidence conditions, a multi-centre study is required for sufficient patient accrual (Peters et al., 2007). Single-subject design studies and smaller N studies offer the benefits of lending themselves well to clinical investigations, offering a detailed look at the results, and findings that they are more representative of the clinical setting. According to the International Classification of Functioning, Disability and Health (WHO, 2001) a reduction in speech patterns that are unusual (e.g., no movement of the tongue for production of a speech sound, unintelligible speech) suggests that these studies were successful (McLeod and Bleile, 2004). Future studies will need to illuminate the full potential of these visual feedback technologies as part of the toolkit for speech therapy.

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Appendix A: Word and syllable probe lists for all participants in Study 2

Parker	Pearl	Petra
raw	row	row
re	roo	roo
recycle	ree	ree
retire	or	or
ear	ear	ear
are		har
far		road
red		
bar		
car		

Appendix B: Word lists (for follow-up study #1, chapter 4)

Word list for Palmer

number	data collection	name	condition	token count	target	word
1	DC1	Palmer	mid	1	C	bleachers
2	DC1	Palmer	pre	1	C	cherries
3	DC1	Palmer	mid	1	C	fish
4	DC1	Palmer	mid	1	C	fishing
5	DC1	Palmer	post	12	C	hosh
6	DC1	Palmer	post	12	C	hoss
7	DC1	Palmer	mid	1	C	house
8	DC1	Palmer	post	1	C	paintbrush
9	DC1	Palmer	mid	1	C	parachute
10	DC1	Palmer	mid	1	C	receiver
11	DC1	Palmer	post	1	C	rich
12	DC1	Palmer	post	12	C	rush
13	DC1	Palmer	pre	12	C	saw
14	DC1	Palmer	pre	12	C	see
15	DC1	Palmer	pre	1	C	shark
16	DC1	Palmer	pre	12	C	shaw
17	DC1	Palmer	pre	12	C	she
18	DC1	Palmer	pre	1	C	shoe
19	DC1	Palmer	mid	1	C	slide
20	DC1	Palmer	mid	1	C	soap
21	DC1	Palmer	pre	1	C	spring
22	DC1	Palmer	pre	1	C	square
23	DC1	Palmer	pre	1	C	star
24	DC1	Palmer	post	1	C	stripes
25	DC1	Palmer	pre	1	C	stripes

26	DC1	Palmer	pre	12	C	sue
27	DC1	Palmer	mid	1	C	swimming
28	DC1	Palmer	post	1	C	toothbrush
29	DC1	Palmer	mid	1	C	watches
30	DC1	Palmer	mid	1	C	whistle
31	DC1	Palmer	mid	1	R	bleachers
32	DC1	Palmer	mid	1	R	break
33	DC1	Palmer	mid	1	R	bridge
34	DC1	Palmer	mid	1	R	broccoli
35	DC1	Palmer	post	15	R	car
36	DC1	Palmer	mid	1	R	cereal
37	DC1	Palmer	mid	1	R	cherries
38	DC1	Palmer	mid	1	R	circus
39	DC1	Palmer	post	1	R	computer
40	DC1	Palmer	post	1	R	cougar
41	DC1	Palmer	mid	1	R	crossing
44	DC1	Palmer	mid	1	R	cruise
45	DC1	Palmer	mid	1	R	crutch
46	DC1	Palmer	mid	1	R	drive
47	DC1	Palmer	post	12	R	ear
48	DC1	Palmer	post	1	R	feather
49	DC1	Palmer	post	1	R	finger
50	DC1	Palmer	mid	1	R	fireplace
51	DC1	Palmer	mid	1	R	garbage
52	DC1	Palmer	mid	1	R	gorilla
53	DC1	Palmer	mid	1	R	graduation
54	DC1	Palmer	post	1	R	guitar
55	DC1	Palmer	post	1	R	hanger
56	DC1	Palmer	post	1	R	helicopter
57	DC1	Palmer	mid	12	R	herb
58	DC1	Palmer	mid	1	R	kangaroo

59	DC1	Palmer	post	1	R	mother
60	DC1	Palmer	mid	1	R	paintbrush
61	DC1	Palmer	mid	1	R	parachute
62	DC1	Palmer	mid	1	R	present
63	DC1	Palmer	pre	1	R	rabbit
64	DC1	Palmer	pre	16	R	raw
65	DC1	Palmer	pre	1	R	razor
66	DC1	Palmer	post	2	R	receiver
67	DC1	Palmer	pre	2	R	receiver
68	DC1	Palmer	pre	14	R	ree
69	DC1	Palmer	pre	1	R	ribbon
70	DC1	Palmer	pre	1	R	rich
71	DC1	Palmer	pre	1	R	river
72	DC1	Palmer	post	1	R	river
73	DC1	Palmer	pre	12	R	robe
74	DC1	Palmer	pre	1	R	rock
75	DC1	Palmer	pre	1	R	roof
76	DC1	Palmer	pre	16	R	run
77	DC1	Palmer	pre	12	R	rush
78	DC1	Palmer	mid	1	R	shark
79	DC1	Palmer	post	1	R	soccer
80	DC1	Palmer	mid	1	R	spring
81	DC1	Palmer	post	1	R	square
82	DC1	Palmer	post	1	R	star
83	DC1	Palmer	mid	1	R	stripes
84	DC1	Palmer	mid	1	R	thirteen
85	DC1	Palmer	mid	1	R	toothbrush
86	DC1	Palmer	mid	1	R	tree
87	DC1	Palmer	mid	1	R	wreath
88	DC1	Palmer	mid	1	R	yard
89	DC1	Palmer	mid	1	R	zebras

90	DC1	Palmer	post	1	R	zipper
91	DC1	Palmer	mid	1	V	balloon
92	DC1	Palmer	mid	1	V	bleachers
93	DC1	Palmer	post	1	V	broccoli
94	DC1	Palmer	mid	1	V	canoe
95	DC1	Palmer	mid	1	V	cereal
96	DC1	Palmer	mid	1	V	cherries
97	DC1	Palmer	mid	1	V	chicken
98	DC1	Palmer	mid	1	V	computer
99	DC1	Palmer	mid	1	V	cougar
100	DC1	Palmer	mid	1	V	cruise
101	DC1	Palmer	pre	12	V	ear
102	DC1	Palmer	mid	13	V	feet
103	DC1	Palmer	mid	1	V	graduation
104	DC1	Palmer	mid	12	V	heel
105	DC1	Palmer	post	1	V	kangaroo
106	DC1	Palmer	post	12	V	lee
107	DC1	Palmer	mid	1	V	mommy
108	DC1	Palmer	mid	1	V	parachute
109	DC1	Palmer	mid	1	V	pig
110	DC1	Palmer	mid	1	V	queen
111	DC1	Palmer	mid	14	V	ree
112	DC1	Palmer	mid	1	V	roof
113	DC1	Palmer	post	12	V	see
114	DC1	Palmer	post	12	V	she
115	DC1	Palmer	post	1	V	shoe
116	DC1	Palmer	pre	1	V	soccer
117	DC1	Palmer	post	12	V	sue
118	DC1	Palmer	mid	1	V	teeth
119	DC1	Palmer	mid	1	V	thirteen
120	DC1	Palmer	mid	1	V	toothbrush

121	DC1	Palmer	post	1	V	tree
122	DC1	Palmer	mid	12	V	tube
123	DC1	Palmer	mid	1	V	TV
124	DC1	Palmer	mid	1	V	watch
125	DC1	Palmer	mid	1	V	zebras
126	Post	Palmer	pre	10	C	chaw
127	Post	Palmer	post	11	C	hosh
128	Post	Palmer	post	10	C	hoss
129	Post	Palmer	post	10	C	hotch
130	Post	Palmer	pre	10	C	saw
131	Post	Palmer	pre	9	C	shaw
132	Post	Palmer	post	10	R	hawr
133	Post	Palmer	mid	9	V	heeb
134	Post	Palmer	mid	10	V	hib
135	Post	Palmer	mid	10	V	hube
136	Pre	Palmer	pre	11	C	chaw
137	Pre	Palmer	post	9	C	hosh
138	Pre	Palmer	post	11	C	hoss
139	Pre	Palmer	post	12	C	hotch
140	Pre	Palmer	pre	10	C	saw
141	Pre	Palmer	pre	11	C	shaw
142	Pre	Palmer	post	10	R	hawr
143	Pre	Palmer	mid	20	R	raw
144	Pre	Palmer	mid	9	V	heeb
145	Pre	Palmer	mid	9	V	hib
146	Pre	Palmer	mid	11	V	hube

Word list for Peran

number	data col	name	condition	token count	target	word
1	DC1	Peran	pre	1	C	chicken
2	DC1	Peran	mid	1	C	fishing
3	DC1	Peran	post	9	C	hosh
4	DC1	Peran	post	7	C	hoss
5	DC1	Peran	post	1	C	house
6	DC1	Peran	post	6	C	rush
7	DC1	Peran	pre	12	C	shaw
8	DC1	Peran	pre	12	C	she
9	DC1	Peran	pre	1	C	slide
10	DC1	Peran	pre	2	C	soap
11	DC1	Peran	pre	7	C	sue
12	DC1	Peran	pre	1	C	swimming
13	DC1	Peran	post	1	C	watch
14	DC1	Peran	mid	1	C	watches
15	DC1	Peran	mid	1	R	burp
16	DC1	Peran	post	1	R	computer
17	DC1	Peran	post	1	R	ear
18	DC1	Peran	post	1	R	father
19	DC1	Peran	post	1	R	feather
20	DC1	Peran	mid	1	R	gorilla
21	DC1	Peran	post	1	R	har
22	DC1	Peran	mid	1	R	present
23	DC1	Peran	pre	1	R	raw
24	DC1	Peran	pre	1	R	ree
25	DC1	Peran	pre	1	R	ribbon
26	DC1	Peran	pre	1	R	run
27	DC1	Peran	mid	1	R	tree

28	DC1	Peran	post	1	R	zipper
29	DC1	Peran	post	1	V	canoe
30	DC1	Peran	mid	9	V	heep
31	DC1	Peran	mid	6	V	hoop
32	DC1	Peran	mid	2	V	queen
33	Post	Peran	pre	4	C	chaw
34	Post	Peran	post	4	C	hosh
35	Post	Peran	post	5	C	hoss
36	Post	Peran	post	4	C	hotch
37	Post	Peran	pre	6	C	saw
38	Post	Peran	pre	2	C	shaw
39	Post	Peran	post	5	R	hawr
40	Post	Peran	pre	4	R	raw
41	Post	Peran	mid	5	V	heap
42	Post	Peran	mid	5	V	hoop
43	Pre	Peran	pre	6	C	chaw
44	Pre	Peran	post	5	C	hosh
45	Pre	Peran	post	3	C	hoss
46	Pre	Peran	post	3	C	hotch
47	Pre	Peran	pre	3	C	saw
48	Pre	Peran	pre	5	C	shaw
49	Pre	Peran	post	4	R	hawr
50	Pre	Peran	pre	5	R	raw
51	Pre	Peran	mid	5	V	heeb
52	Pre	Peran	mid	5	V	hube

Word list for Pamela

number	data col	name	condition	token count	target	word
1	Pre	Pamela	pre	19	C	chaw
2	DC1	Pamela	mid	18	R	crow
3	DC1	Pamela	post	10	R	ear
4	DC1	Pamela	post	12	R	father
5	DC1	Pamela	post	12	R	har
6	DC1	Pamela	post	12	R	har
7	DC1	Pamela	post	12	R	har
8	DC1	Pamela	pre	13	R	raw
9	DC1	Pamela	pre	11	R	red
10	DC1	Pamela	pre	12	R	ree
11	DC1	Pamela	pre	12	R	run
12	DC1	Pamela	pre	13	V	ear
13	DC1	Pamela	post	12	V	ree
14	Post	Pamela	post	10	C	hosh
15	Post	Pamela	post	19	C	hoss
16	Post	Pamela	post	10	C	hotch
17	Post	Pamela	pre	10	C	saw
18	Post	Pamela	pre	10	C	shaw
19	Post	Pamela	post	10	R	hawr
20	Post	Pamela	pre	12	R	raw
21	Post	Pamela	post	10	V	heap
22	Post	Pamela	post	12	V	hoop
23	Pre	Pamela	post	9	C	hosh
24	Pre	Pamela	post	10	C	hotch
25	Pre	Pamela	pre	10	C	saw
26	Pre	Pamela	pre	10	C	shaw

27	Pre	Pamela	post	10	R	hawr
28	Pre	Pamela	pre	10	R	raw
29	Pre	Pamela	mid	9	V	heeb
30	Pre	Pamela	mid	10	V	hube

Word list for Purdy

number	data collection	name	condition	token count	target	word
1	DC1	Purdy	mid	9	C	saw
2	DC1	Purdy	mid	9	C	see
3	DC1	Purdy	mid	9	C	shaw
4	DC1	Purdy	post	8	C	hosh
5	DC1	Purdy	post	12	C	rush
6	DC1	Purdy	pre	10	C	she
7	DC1	Purdy	pre	17	C	sue
8	DC1	Purdy	mid	8	R	burp
9	DC1	Purdy	pre	8	R	rush
10	DC1	Purdy	mid	8	V	heap
11	DC1	Purdy	mid	11	V	heel
12	DC1	Purdy	mid	9	V	hoop
13	DC1	Purdy	mid	8	V	lee
14	DC1	Purdy	mid	7	V	loo
15	DC1	Purdy	post	9	V	she
16	DC1	Purdy	post	22	V	sue
17	Post	Purdy	post	7	C	hosh
18	Post	Purdy	post	10	C	hoss
19	Post	Purdy	post	11	C	hotch
20	Post	Purdy	pre	7	C	chaw
21	Post	Purdy	pre	6	C	saw
22	Post	Purdy	pre	9	C	shaw
23	Post	Purdy	post	5	R	hawr
24	Post	Purdy	pre	6	R	raw
25	Post	Purdy	post	8	V	heap
26	Post	Purdy	post	10	V	hoop
27	Pre	Purdy	post	11	C	hosh

28	Pre	Purdy	post	8	C	hoss
29	Pre	Purdy	post	8	C	hotch
30	Pre	Purdy	pre	7	C	chaw
31	Pre	Purdy	pre	6	C	saw
32	Pre	Purdy	pre	5	C	shaw
33	Pre	Purdy	post	8	R	hawr
34	Pre	Purdy	pre	8	R	raw
35	Pre	Purdy	mid	8	V	heeb
36	Pre	Purdy	mid	8	V	hube

Word list for Parker

number	data col	name	condition	token count	target	word
1	DC1	Parker	post	2	C	circus
2	DC1	Parker	mid	1	C	crossing
3	DC1	Parker	mid	2	C	cruise
4	DC1	Parker	post	1	C	paintbrush
5	DC1	Parker	mid	2	C	parachute
6	DC1	Parker	pre	3	C	shark
7	DC1	Parker	pre	1	C	soccer
8	DC1	Parker	pre	1	C	spring
9	DC1	Parker	pre	1	C	stripes
10	DC1	Parker	post	1	C	stripes
11	DC1	Parker	post	1	C	toothbrush
12	DC1	Parker	mid	1	R	bedroom
13	DC1	Parker	mid	1	R	break
14	DC1	Parker	mid	1	R	bridge
15	DC1	Parker	mid	1	R	brocolli
16	DC1	Parker	mid	3	R	carpet
17	DC1	Parker	mid	2	R	cereal

18	DC1	Parker	post	2	R	cougar
19	DC1	Parker	mid	1	R	cruise
20	DC1	Parker	post	4	R	door
21	DC1	Parker	mid	1	R	drive
22	DC1	Parker	post	5	R	ear
23	DC1	Parker	post	1	R	feather
24	DC1	Parker	post	1	R	finger
25	DC1	Parker	mid	1	R	fireplace
26	DC1	Parker	mid	1	R	garbage
27	DC1	Parker	mid	1	R	gorilla
28	DC1	Parker	mid	1	R	gorilla
29	DC1	Parker	mid	1	R	graduation
30	DC1	Parker	post	1	R	hanger
31	DC1	Parker	post	1	R	helicopter
32	DC1	Parker	post	2	R	mother
33	DC1	Parker	mid	2	R	paintbrush
34	DC1	Parker	mid	6	R	perfect
35	DC1	Parker	pre	1	R	rabbit
36	DC1	Parker	pre	2	R	rake
37	DC1	Parker	pre	1	R	raw
38	DC1	Parker	pre	3	R	razor
39	DC1	Parker	pre	2	R	receiver
40	DC1	Parker	pre	3	R	red
41	DC1	Parker	pre	4	R	ree
42	DC1	Parker	pre	4	R	retire
43	DC1	Parker	post	2	R	retire
44	DC1	Parker	post	1	R	ribbon
45	DC1	Parker	pre	1	R	rich
46	DC1	Parker	post	1	R	river
47	DC1	Parker	pre	3	R	river
48	DC1	Parker	pre	1	R	rock

49	DC1	Parker	pre	1	R	roof
50	DC1	Parker	pre	1	R	row
51	DC1	Parker	mid	1	R	shark
52	DC1	Parker	post	2	R	soccer
53	DC1	Parker	mid	2	R	spring
54	DC1	Parker	post	1	R	square
55	DC1	Parker	mid	2	R	thirteen
56	DC1	Parker	mid	1	R	tree
57	DC1	Parker	mid	1	R	yarn
58	DC1	Parker	mid	2	R	zebras
59	DC1	Parker	post	1	R	zipper
60	DC1	Parker	post	1	V	kangaroo
61	DC1	Parker	post	4	V	ree
62	DC1	Parker	mid	2	V	thirteen
63	Post	Parker	post	5	R	are
64	Post	Parker	post	7	R	car
65	Post	Parker	post	6	R	far
66	Post	Parker	pre	2	R	recycle
67	Post	Parker	pre	3	R	retire
68	Pre	Parker	post	5	R	bar
69	Pre	Parker	post	7	R	ear
70	Pre	Parker	pre	7	R	raw
71	DC1	Parker	mid	2	R	crutch
72	DC1	Parker	mid	5	R	parachute
73	Pre	Parker	pre	5	R	ree

Word list for Pearl

number	data col	name	condition	token count	target	word
1	DC1	Pearl	pre	3	C	candy
2	DC1	Pearl	pre	5	C	carpet
3	DC1	Pearl	post	4	C	coke
4	DC1	Pearl	pre	1	C	coke
5	DC1	Pearl	mid	1	C	crossing
6	DC1	Pearl	mid	1	C	fireplace
7	DC1	Pearl	mid	1	C	fish
8	DC1	Pearl	mid	1	C	fishing
9	DC1	Pearl	pre	1	C	goat
10	DC1	Pearl	post	1	C	house
11	DC1	Pearl	pre	5	C	kick
12	DC1	Pearl	post	4	C	kick
13	DC1	Pearl	mid	1	C	parachute
14	DC1	Pearl	mid	3	C	pickle
15	DC1	Pearl	pre	1	C	shark
16	DC1	Pearl	pre	1	C	soap
17	DC1	Pearl	pre	1	C	soccer
18	DC1	Pearl	pre	1	C	spring
19	DC1	Pearl	pre	1	C	square
20	DC1	Pearl	pre	1	C	star
21	DC1	Pearl	pre	1	C	stripes
22	DC1	Pearl	pre	1	C	swimming
23	DC1	Pearl	post	1	C	toothbrush
24	DC1	Pearl	post	5	C	truck
25	DC1	Pearl	post	1	R	bleacher
26	DC1	Pearl	mid	5	R	borrow
27	DC1	Pearl	mid	1	R	break

28	DC1	Pearl	mid	1	R	bridge
29	DC1	Pearl	mid	1	R	brocolli
30	DC1	Pearl	post	4	R	car
31	DC1	Pearl	mid	3	R	carpet
32	DC1	Pearl	mid	1	R	cereal
33	DC1	Pearl	mid	2	R	cherries
34	DC1	Pearl	mid	1	R	cherries
35	DC1	Pearl	post	1	R	cougar
36	DC1	Pearl	mid	1	R	cruise
37	DC1	Pearl	mid	1	R	crutch
38	DC1	Pearl	post	4	R	deer
39	DC1	Pearl	post	5	R	door
40	DC1	Pearl	mid	1	R	drive
41	DC1	Pearl	post	1	R	finger
42	DC1	Pearl	post	1	R	fireplace
43	DC1	Pearl	mid	1	R	garbage
44	DC1	Pearl	mid	1	R	gorilla
45	DC1	Pearl	mid	1	R	graduation
46	DC1	Pearl	mid	2	R	green
47	DC1	Pearl	post	1	R	guitar
48	DC1	Pearl	post	1	R	helicopter
49	DC1	Pearl	post	1	R	mother
50	DC1	Pearl	mid	1	R	present
51	DC1	Pearl	pre	1	R	rabbit
52	DC1	Pearl	pre	5	R	ray
53	DC1	Pearl	post	3	R	razor
54	DC1	Pearl	pre	1	R	razor
55	DC1	Pearl	pre	1	R	receiver
56	DC1	Pearl	post	1	R	receiver
57	DC1	Pearl	pre	2	R	ree
58	DC1	Pearl	pre	1	R	ribbon

59	DC1	Pearl	pre	1	R	river
60	DC1	Pearl	pre	1	R	rock
61	DC1	Pearl	pre	1	R	roof
62	DC1	Pearl	pre	3	R	run
63	DC1	Pearl	mid	1	R	shark
64	DC1	Pearl	post	1	R	soccer
65	DC1	Pearl	mid	1	R	square
66	DC1	Pearl	post	2	R	star
67	DC1	Pearl	mid	1	R	stripes
68	DC1	Pearl	mid	1	R	thirteen
69	DC1	Pearl	mid	1	R	toothbrush
70	DC1	Pearl	mid	1	R	tree
71	DC1	Pearl	mid	4	R	truck
72	DC1	Pearl	mid	3	R	try
73	DC1	Pearl	mid	1	R	wreath
74	DC1	Pearl	mid	1	R	yard
75	DC1	Pearl	mid	1	R	zebras
76	DC1	Pearl	post	1	R	zipper
77	DC1	Pearl	mid	1	V	again
78	DC1	Pearl	mid	1	V	book
79	DC1	Pearl	post	2	V	cage
80	DC1	Pearl	mid	1	V	canoe
81	DC1	Pearl	pre	1	V	chicken
82	DC1	Pearl	mid	1	V	computer
83	DC1	Pearl	post	4	V	deer
84	DC1	Pearl	mid	1	V	duck
85	DC1	Pearl	mid	1	V	glove
86	DC1	Pearl	mid	3	V	green
87	DC1	Pearl	mid	1	V	gum
88	DC1	Pearl	post	1	V	house
89	DC1	Pearl	mid	1	V	queen

90	DC1	Pearl	mid	1	V	receiver
91	DC1	Pearl	post	1	V	ree
92	DC1	Pearl	mid	1	V	thirteen
93	DC1	Pearl	post	1	V	tree
94	Post	Pearl	post	6	R	ear
95	Post	Pearl	post	7	R	or
96	Post	Pearl	pre	8	R	ri
97	Post	Pearl	pre	9	R	row
98	Pre	Pearl	post	6	R	or
99	Pre	Pearl	pre	7	R	ri
100	Pre	Pearl	pre	9	R	roux

Word list for Petra

number	data collection	name	condition	token count	target	word
1	DC1	Petra	post	1	C	fish
2	DC1	Petra	mid	1	C	fishing
3	DC1	Petra	post	1	C	house
4	DC1	Petra	post	1	C	rich
5	DC1	Petra	pre	1	C	shark
6	DC1	Petra	pre	1	C	shoe
7	DC1	Petra	pre	1	C	slide
8	DC1	Petra	pre	1	C	soap
9	DC1	Petra	pre	1	C	spring
10	DC1	Petra	pre	2	C	square
11	DC1	Petra	pre	1	C	star
12	DC1	Petra	post	1	C	stripes
13	DC1	Petra	pre	1	C	stripes

14	DC1	Petra	pre	1	C	swimming
15	DC1	Petra	post	1	C	watches
16	DC1	Petra	mid	2	C	whistle
17	DC1	Petra	mid	2	R	borrow
18	DC1	Petra	mid	1	R	break
19	DC1	Petra	post	4	R	car
20	DC1	Petra	mid	3	R	carpet
21	DC1	Petra	post	1	R	computer
22	DC1	Petra	mid	2	R	cruise
23	DC1	Petra	mid	1	R	crutch
24	DC1	Petra	post	4	R	door
25	DC1	Petra	mid	2	R	drive
26	DC1	Petra	post	1	R	feather
27	DC1	Petra	mid	1	R	gorilla
28	DC1	Petra	mid	2	R	green
29	DC1	Petra	post	2	R	here
30	DC1	Petra	mid	1	R	kangaroo
31	DC1	Petra	mid	1	R	present
32	DC1	Petra	pre	2	R	ray
33	DC1	Petra	pre	2	R	ree
34	DC1	Petra	pre	1	R	ribbon
35	DC1	Petra	pre	1	R	rich
36	DC1	Petra	pre	1	R	rock
37	DC1	Petra	pre	1	R	roof
38	DC1	Petra	pre	2	R	run
39	DC1	Petra	mid	1	R	shark
40	DC1	Petra	mid	1	R	spring
41	DC1	Petra	post	2	R	square
42	DC1	Petra	post	1	R	star
43	DC1	Petra	mid	1	R	stripes
44	DC1	Petra	mid	1	R	tree

45	DC1	Petra	mid	2	R	truck
46	DC1	Petra	mid	3	R	try
47	DC1	Petra	mid	1	R	wreath
48	DC1	Petra	mid	1	R	yard
49	DC1	Petra	post	1	R	zipper
50	DC1	Petra	mid	2	V	balloon
51	DC1	Petra	post	2	V	canoe
52	DC1	Petra	mid	1	V	chicken
53	DC1	Petra	mid	2	V	green
54	DC1	Petra	mid	1	V	mommy
55	DC1	Petra	mid	3	V	pig
56	DC1	Petra	mid	1	V	queen
57	DC1	Petra	post	2	V	ree
58	DC1	Petra	mid	1	V	teeth
59	DC1	Petra	post	1	V	tree
60	DC1	Petra	mid	1	V	TV
61	DC1	Petra	post	1	V	watch
62	Post	Petra	post	8	R	ear
63	Post	Petra	pre	9	R	ri
64	Post	Petra	pre	5	R	road
65	Post	Petra	pre	10	R	roux
66	Pre	Petra	post	11	R	ear
67	Pre	Petra	post	10	R	har
68	Pre	Petra	pre	5	R	raw
69	Pre	Petra	pre	6	R	ri

Appendix C: Semi-structured Interview Questions (for Chapter 5)

Introduction: Please tell me your impressions/experiences of speech therapy with ultrasound and electropalatography. I am interested in knowing what you thought about the whole process. I would like to know if you thought it was effective or not effective, what your experience of this whole thing was. Did you think it was good, did you think it was bad, did you think it was helpful or not...anything at all? You can say anything you want, positive or negative, it doesn't matter, I would rather know really what you thought about the whole experience and if it helped or if it didn't....just so I can learn how effective it really was.

The following questions were asked if the interviewee if s/he did not provide this information him/herself. Much of the information brought to light by these questions was spontaneously addressed by the participants talking about their experiences with ultrasound and electropalatography incorporated into their speech therapy programmes

Questions:

1. How was the overall experience with the equipment? What was your experience?
2. What kind of benefits did you get if any?
3. Did this experience affect you or your life in any way?
4. Did you notice a difference in your speech before and after using U/S or EPG?
5. Do you think this kind of therapy was better, worse or the same as other kinds of speech therapy you had before?
6. How do you compare U/S or EPG therapy with regular speech therapy?

7. Do you think your speech improvements stayed with you, got worse again, or improved even more? What do you think is the situation now?
8. Would you recommend visual therapy with U/S or EPG?
9. Do you have any other thoughts or memories that you want to share about your experiences with U/S or EPG?
10. Is there anything else people should know about ultrasound therapy?

Appendix D: UBC Research Ethics Review Board Certificates of Approval

Numbers: B02-0697

B03-0652

B04-0092

B04-0092 Amendment

B04-0092 Renewal