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

Établissement des composantes linguales du son /r/ à l'aide d'ultrasons chez trois adolescents avec un implant cochléaire

Penelope Bacsfalvi

Abstract

Children with hearing loss frequently have difficulty learning North American English /r/. The purpose of the present study was to investigate the remediation of North American English /r/ by establishing its tongue movement components for three adolescents with recent cochlear implants (CIs) through the use of ultrasound as an adjunct to speech therapy. The three adolescents had all been diagnosed with severe-to-profound bilateral sensorineural hearing loss, and had recently received unilateral CIs. All three students wore a hearing aid in their other ear. Ultrasound was used to assist in establishing the gestural components of /r/ as a starting point for accurate /r/ production: tongue root retraction, retroflexion or bunching and midline grooving. A single subject design was used, with analyses of the gestural components of /r/ before, during and after intervention. All participants were able to learn the gestural components of /r/ with ultrasound. Furthermore, one of the participants gained accurate production of /r/ in isolation and at the word level.

Abrégé

Les enfants ayant une perte auditive ont souvent de la difficulté à apprendre le son /r/ de l'anglais nord-américain. La présente étude visait à examiner la correction de la production du /r/ de l'anglais nord-américain en établissant les mouvements linguaux nécessaires à sa production à l'aide d'ultrasons en plus de la thérapie orthophonique chez trois adolescents ayant un implant cochléaire. Les trois adolescents avaient eu un diagnostic d'une surdité neurosensorielle bilatérale sévère à profonde et avaient récemment reçu un implant cochléaire unilatéral. Les trois portaient un appareil auditif à l'autre oreille. Les ultrasons ont servi à établir les composantes gestuelles du /r/ comme point de départ pour la production adéquate de ce son : la rétraction, la rétroflexion ou l'épaississement de la base de la langue et la formation d'un creux médian. L'étude utilise une méthode à sujet unique où l'analyse des composantes gestuelles du /r/ a été effectuée avant, pendant et après l'intervention. Tous les participants ont pu apprendre les composantes gestuelles du /r/ à l'aide des ultrasons. De plus, un des participants a acquis une production précise du /r/ en isolation et dans un mot.

Key words: single subject design, hearing impairment, CIs, lingual gestures, speech therapy, and ultrasound

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Figure 1a: From rest position to retroflex North American /r/ as produced by author

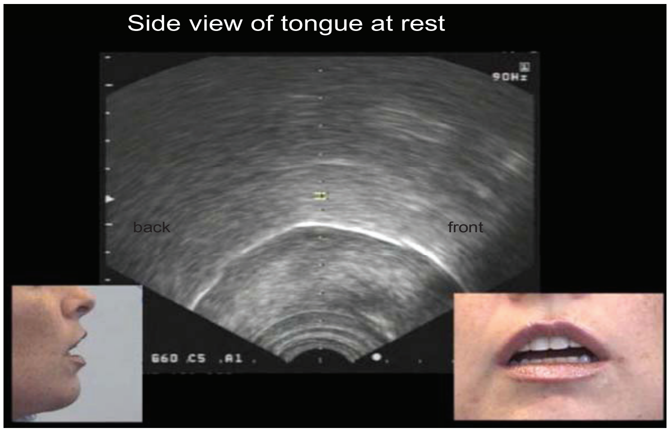


Figure 1b: Side view of tongue as it slides back into /r/ as produced by author.

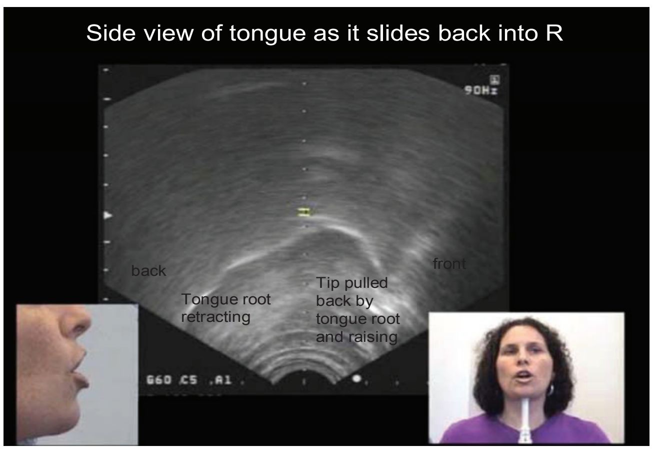


Figure 1c: Side view of tongue producing /r/ as produced by author.

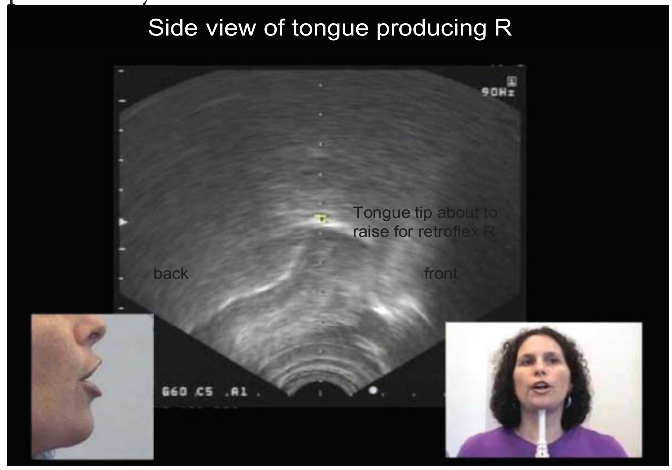
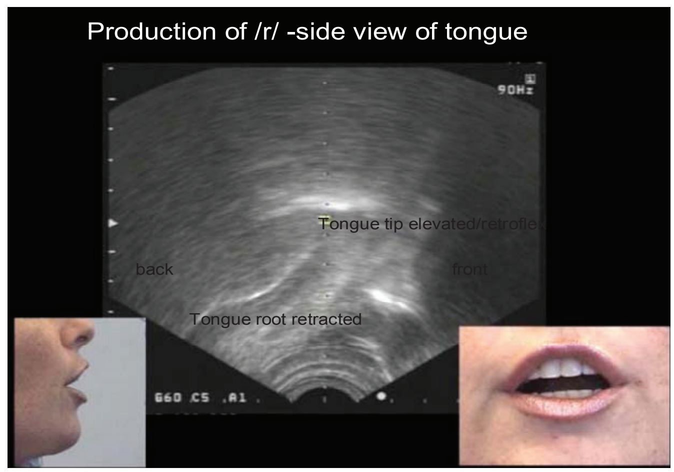


Figure 1d: Production of retroflex /r/ as produced by author



Note lip rounding for Figure 1 photos.

As cochlear implant (CI) 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 CIs for improving auditory perception, regardless of age at implantation, has been frequently reported in recent years (*Zwolan et al., 2004; Schramm, Fitzpatrick, & Seguin, 2002).* With this evolution, there has been an increased demand for CIs. Adults and children of all ages are taking advantage of the opportunity to have greater access to sound and speech through amplification with a CI. Many people now have an opportunity to hear what was unavailable to them previously (Svirsky, Robbins, Kirk, Pisoni & Miyamoto, 2000). Students with severe to profound hearing loss may obtain CIs as a final attempt to increase hearing and thereby improve speech production (Ertmer, Leonard & Pachuilo, 2002). Most of the research shows that children benefit the most in terms of speech, language and hearing outcomes when receiving their CI before the age of 5 (Flipsen & Colvard, 2006; Geers, 2004). However, older children and adolescents with congenital hearing loss are also receiving CIs in the region in which this study took place. For older children and teenagers, one of the primary aims is the potential for improvements in speech production. However, many of these later recipients of CIs continue to require speech-language therapy (Bernhardt, Loyst, Pichora-Fuller, & Williams, 2000). At the time of our study, a significant number of teenagers and older children were continuing to receive CIs. Contributing factors to this included newly established funding, technological advances of the CI itself, and changing candidate criteria.

The CI 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 & 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 CI 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, Leonard & Pachiullo, 2002). Studies of speech production of people with severe to profound hearing loss have revealed that, even years after receiving a CI, difficulties with speech production may continue, with clients showing limited tongue movement and reduced vertical range (Higgins, McCleary, Carney and Schulte, 2003). With more CI users receiving bilateral CIs speech production improvement may be greater for more people. While the hope is that there will be greater benefits, to date the research is showing mixed results (Litovsky et al., 2006).

Visual feedback technology has been shown to be a useful adjunct to speech therapy for people with a hearing loss (Bacsfalvi, Bernhardt & Gick, 2007; Bernhardt, Gick, Bacsfalvi & Ashdown, 2003; Dagenais, 1992; Fletcher, Dagenais, & Critz-Crosby, 1991). Ultrasound, in particular, is good for showing tongue shapes and movement (Bernhardt, Bacsfalvi, Gick, Radanov & Williams, 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 has been shown to be helpful in remediation of long-term persistent speech errors, such as /r/, in teenagers and young adults with normal hearing (Adler-Bock, Bernhardt, Gick & Bacsfalvi, 2007) and Down syndrome (Fawcett, Bacsfalvi & Bernhardt, 2008). The lingual components of North American /r/ 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 1).

Because our preliminary research with ultrasound revealed that it was useful in remediating North American English /r/ (Adler-Bock et al., 2007; Bacsfalvi, Adler-Bock, Bernhardt, & Gick, 2004; Bacsfalvi, Bernhardt & Gick, 2001; Bernhardt et al., 2003), a study was initiated with three recently implanted CI users with long-term speech production difficulties who did not yet produce /r/. Given that participants were all in their late teens and had received therapy for /r/ previously, this was considered to be a viable target. This paper brings forward a model of phonological therapy/speech habilitation that addresses the interaction of phonetic and phonological development through motor learning with auditory-visual feedback and a cognitive component that emphasises the functioning of the speech production mechanism. The objectives of the current study were to introduce the lingual components of /r/ through use of ultrasound to the three speakers. Based on previous research, establishing the components of /r/ leads to its production (Bacsfalvi et al., 2004; Gick, Iskarous, Whalen and Goldstein (2003). This suggests that targets are articulatory and that /r/ has several constrictions that are essential for production of an acoustically accurate /r/. Without audition, typically, a person cannot learn the necessary constrictions.

A single-participant design approach was used to evaluate the effectiveness of the ultrasound technology for teaching the components of /r/. Single participant research uses an approach that repeatedly and continuously measures the dependent variable from individual participants (Morgan & 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 /r/ during the treatment program, with the possibility that they might produce accurate /r/s after treatment. (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 [Bernhardt et al., 2005; Bernhardt et al., 2003; Ruscello, 1984].)

Methodology

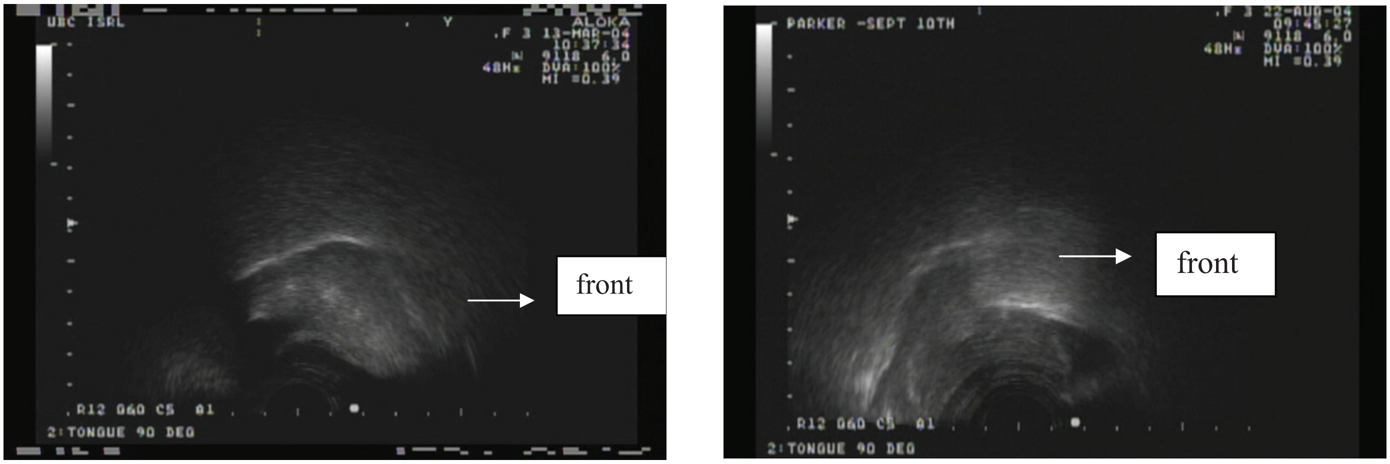
Participants

Three adolescents participated in this study. They all met the following criteria: (a) severe-to-profound bilateral sensorineural hearing loss; (b) congenital or early onset of hearing loss (< 3 years of age); (c) use of a CI unilaterally for more than three months (to allow mapping to be set and time for some auditory perceptual training), and consistent use of the CI; (d) the desire and motivation to improve speech productions; (e) past or current enrolment in an educational environment with an emphasis on an oral approach; and (f) access to speech therapy. All three students wore a hearing aid in their other ear for potential stimulation of the auditory nerve.

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 successfully treated with traditional methods. All participants used oral language on a daily basis to meet their communication needs. Speech intelligibility levels of participants were judged by two listeners, both practicing speech-language pathologists (S-LPs) familiar with speech of the hearing impaired.

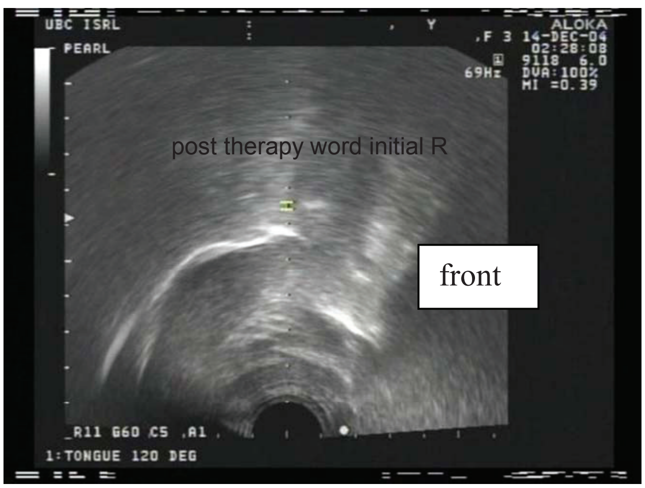
Participant 1 (pseudonym: Parker) was 15 years of age and presented with CHARGE syndrome. In this syndrome, tissues in various structures of the body do not develop completely. (CHARGE Syndrome Canada, 2010). Parker had a 3G Cochlear Nucleus behind-the-ear processor, which he had been using for 9 months when he joined the therapy project. His speech could be described as intelligible with careful listening, as judged by S-LP listeners. He had been in a signing program for most of his life and

Figure 2: Parker's productions of /r/ pre-treatment in word-initial position and post-treatment in isolation. Notice the tongue root retractions and tongue blade retraction in the post-therapy token.

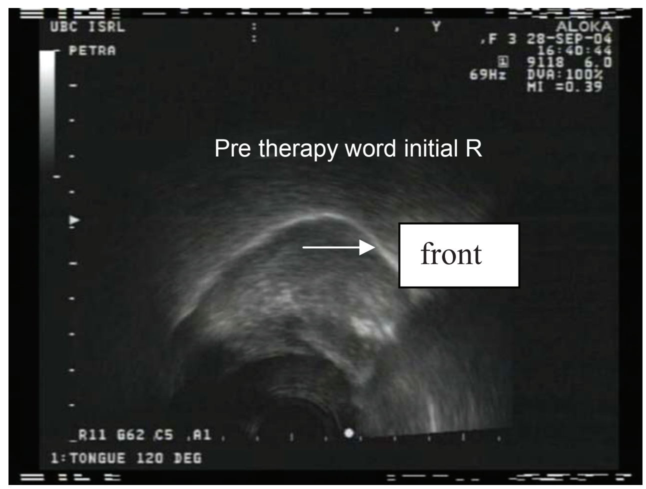


Figures 3a and 3b: Pearl's productions of /r/ pre (3a) and post-therapy (3b) in word-initial position. Notice the tongue root retractions and tongue tip curl in the post therapy token.

3a



3b



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.

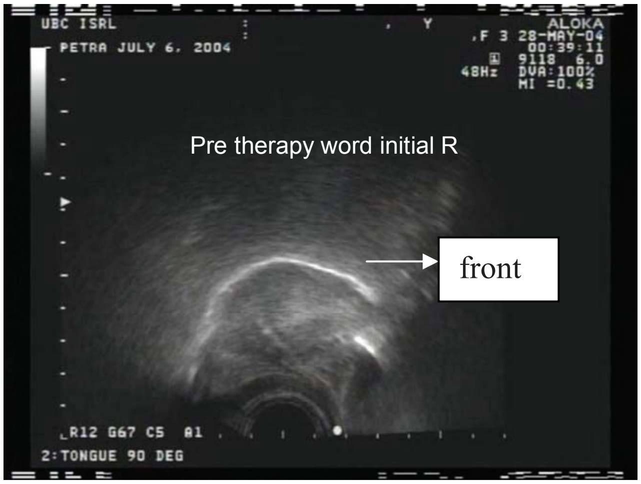
Prior audiology reports indicated a profound sensorineural hearing loss in the left ear and a moderate to severe sensorineural hearing loss in the right ear since birth. Parker was fitted with a unilateral hearing aid in the right ear at 1.5 years of age. At the age of 12, Parker's hearing began to degenerate 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.

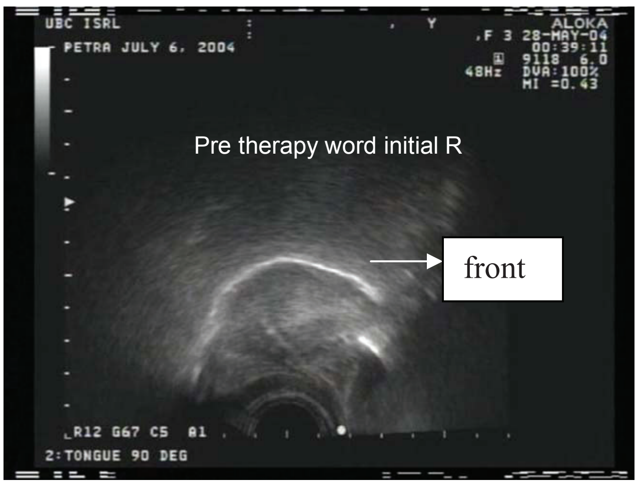
Initial speech evaluation with ultrasound, using a word list developed for ultrasound assessments at the speech laboratory (see Appendix 1), revealed some difficulty with the production of velars and none of the lingual components of /r/. For motivation, the participants were encouraged to add a couple of words they wanted to learn to the word list, which is why the lists were somewhat different. Parker had never used ultrasound technology and was unfamiliar with it. Figure 2a provides an example of Parker's /r/ attempt in word-initial position before intervention.

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. Her speech was described as unintelligible. She had been in oral programs her whole life, but communicated using a combination of written, oral and sign languages (with both English and Cantonese as input languages). 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.

Initial speech evaluation by the author revealed difficulty with the production of several consonants and

Figure 4: Petra's productions of /r/ pre and post therapy in word-initial position. Notice the tongue root retractions and tongue tip curl in the post-therapy token.





vowels, including /r/ (the /r/ portion of the word list is in Appendix 1). Pearl indicated that she wanted to focus on /r/ at the time of the study. Ultrasound images of her /r/ attempts pre-treatment showed none of the lingual components of /r/ (Figure 3a). Pearl had participated previously in therapy pilot work with ultrasound and was familiar with the equipment and the therapy process with visual feedback technology. She had previously acquired velars /k/ and /g/ using ultrasound.

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. Her speech could be described as intelligible 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 and was just starting to speak limited Cantonese at home with her family. She did use signing with some friends and acquaintances from the deaf community but used oral and sign communication at home and at school. 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. Petra had also participated in a pilot study with ultrasound and was familiar with the equipment. She had previously been introduced to the lingual components of /r/ and was able to produce all of the gestural components some of the time at the end of that pilot study before receiving her CI. Therapy research had been stopped to allow her time to adjust to the CI and the initial stages of learning to listen. Petra participated in the current study in order to re-learn the components of /r/ with her new and different auditory feedback. Figure 4a provides an example of Petra's /r/ attempt in word-initial position before intervention in the current study.

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 & Harmon, 2000; Morgan & Morgan, 2001). Due to past success with this approach, a componential approach to teaching /r/ was used (Bacsfalvi, Adler-Bock, Bernhardt, & Gick, 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 dependent variable was documented through a step-wise improvement in lingual component productions.

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 /r/ and one that is easy to demonstrate with this visual feedback tool. A componential approach 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. (See further details below on the intervention process.)

The dependent variables were the lingual components of /r/: tongue root retraction, tongue tip elevation or tongue blade bunching, midline grooving of the tongue, and lip rounding (see Figure 1). Accuracy of tongue components was measured two-thirds of the way through each session, after the client "warmed-up" and before fatigue began. When the participant produced 7 out of 10 accurate productions for a gesture in three consecutive sessions, the criterion was met and we moved on to the next component. A gestural component was considered established when the speaker could produce the gesture without prompts or cues from the clinician-researcher.

Equipment

An Aloka Pro-Sound SSD-5000 ultrasound machine with a 6 MHz transducer series M00196 was used for assessment and treatment, and a portable Sonosite 180 Plus ultrasound machine with a Sonosite C15/4-2 MHz

Table 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%
	Listener 3	4.17%	44.07%	39.90%
Pearl	Listener 1	27.78%	24.49%	-3.29%
	Listener 2	26.32%	30.61%	4.30%
	Listener 3	8.57%	10.64%	2.07%
Petra	Listener 1	34.78%	51.35%	16.57%
	Listener 2	39.13%	36.11%	-3.02%
	Listener 3	17.39%	25%	7.61%

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

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. Two machines were used because one was portable and one was not. The portable machine allowed the speech-language pathologist (S-LP, author) to work with the participants in the home or other rooms at the university when the need arose. All participants had equal time with both machines. Both machines provided the same level of detail to participants.

Intervention process

All students attended 45 minute weekly sessions to learn the lingual components of /r/, and to subsequently attempt /r/ 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 root 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 1d) was introduced as a backwards curl, but the students were also shown how the S-LP 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 as they found this easier to understand. Once these individual components had been established and the students could combine the components, voicing was added to attempt an [r]. Once a student was able to produce /r/ in isolation, /r/ 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 /r/ were decided in part with the students because they had words they wanted to learn to say accurately. Therefore, contexts reflected these personal goals for each student. Attempts were made to target words where /r/ occurred initially and finally with front, back, high and low vowels. Treatment sessions were typically 45 minutes long.

Evaluation of lingual components and speech samples

Evaluation of the treatment programme focused primarily on the lingual components of /r/. In addition, three speech-language pathologist listeners were asked to evaluate the /r/ sound files collected during assessments to evaluate whether change towards /r/ accuracy was underway. All three listeners had previous experience in clinical research and practice with ultrasound, to evaluate North American /r/.

The participants' lingual gestures were evaluated qualitatively by the author, with criteria developed in previous projects (Bacsfalvi et al., 2004; Adler-Bock et al., 2007) as in Figures 1a-1d). The gestures were recorded on DV tape with a Sony Mini DV Handycam (connected to the ultrasound, US) 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 speech-language pathology graduate student who was experienced in evaluating ultrasound images. She was blind to the chronological order of the ultrasound images and the identity of speakers. She viewed 10% of the ultrasound images of the /r/ gestures across sessions on video-tapes. The criterion for inter-observer agreement was 80% for gestural components accuracy, with the actual agreement between observers being 95% for all three participants.

To determine if generalization to the word level was occurring, short single word speech probes were taken every 2-3 weeks for evaluation of /r/ development. 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. Three S-LP listeners with normal hearing in the speech spectrum were invited to evaluate the /r/ productions. All three had worked with students who are deaf or hard of hearing in the past, and were experienced using ultrasound for therapy with /r/. Stimuli were presented through Kenwood Open Air Headphones KPM-110 and listeners rated between 75 and 100 tokens per speaker. To measure progress beyond the componential level, listeners were 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 /r/, but an attempt that included /r/-quality. There are different ways to measure (rate) outcomes. We chose rhotic quality as a factor to measure /r/ in isolation or at the word level. This type of rating provides the best opportunity to show changes in speech production, even if the participant has not yet completely mastered the target sound. This perspective followed that of Ertmer and Maki's (2000) speech habilitation study of children with hearing impairment; they state that there is an intermediate phase along the progress trajectory as the individual is learning. This phase can precede production of fully acceptable variants of the target (Ertmer & Maki, 2000). Mean intra-rater reliability for the three S-LP listeners was 92% (range 80% to 100% agreement). Inter-observer reliability was calculated for participants across all three listeners item by item (see Table 1).

Listener 1 was in agreement with listeners 2 (72%) and 3 (63%) for Parker. However, listeners 2 and 3 had a low level of agreement (48%) with each other for individual items in Parker's data. Although listener agreement was more divergent for Parker in absolute values, all three listeners agreed that he had improved in 'r' production by about 30%. Listeners had higher agreement levels for Petra (75%) and Pearl (69%). A greater range of inter-rater reliability agreements are acceptable when making judgments on speech production of people with a hearing loss, with the average agreements between 64% to 74% (Blamey et al., 2001; Shriberg & Lof, 1991).

A Chi Square analysis was used (alpha levels from .05 to .001) to determine if there were any significant differences between the pre- and post-treatment listener judgments for each participant (see results).

Results

Results are discussed within speaker because of the single subject design of the study. Results for the components of /r/ (the primary focus of the study) are presented in Figure 5.

In addition, ultrasound images of pre- and post-treatment /r/ attempts are shown in Figures 2-4. The listener evaluations of the /r/ word samples are presented in Table 1.

Participant 1: Parker

Three baseline measurements of /r/ production confirmed (Figures 2, 5) that Parker did not produce any of the gestural components of /r/: 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 /r/ in combination at the word level. Table 1 shows that listeners judged Parker's post-treatment samples to have significantly more /r/-like tokens (Chi Square Continuity Correction of 32.144, $p<.001$).

Participant 2: Pearl

Five baseline measurements of /r/ production confirmed that Pearl did not produce any of the gestural components of /r/ pre-treatment (Figures 3, 5). During the baseline period, speech therapy continued for Pearl with the author, including listening therapy, review of velars, and some attempts at /r/ without ultrasound. Once a stable baseline level was achieved for /r/ components, the introduction of one gestural component of /r/ 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 over two sessions. Once again Pearl was able to achieve accuracy during intervention and maintain this accuracy at follow-up. Listener ratings showed no significant difference in pre-post treatment word samples for /r/-like quality.

Participant 3: Petra

Petra produced the retraction and tongue tip gestures accurately when provided with visual feedback, but five baseline measurements of /r/ production confirmed that she did not produce the midline grooving component of /r/ (Figures 4, 5). Once a stable baseline level was achieved with the mid-line grooving component of /r/, the training for that final gestural component began. Petra learned tongue grooving over four therapy sessions, maintained it during the remainder of intervention, and continued to produce this gesture, as well as the others, at follow-up with 100% accuracy. Listener ratings for /r/ in words showed no significant change at this time.

Discussion

Overall Results

All three students made improvements in production of the gestural components of /r/. It is important to keep in mind that the goal of this study was to establish the components of /r/. Once the components of /r/ are established and voicing added, typically several weeks of therapy and practice are needed `to produce

/r/ at the word level, because the /r/ components need to be integrated both with each other and with surrounding segments (Bernhardt, Bacsfalvi, et al., 2005, Bernhardt, Gick, et al, 2005). All participants were successful in producing /r/-like segments post-treatment to varying degrees. Significant changes in /r/ production at the word level were seen only for Parker at this time, which was a desirable if not expected outcome (given the relatively short duration of the study).

Within-Participant Factors

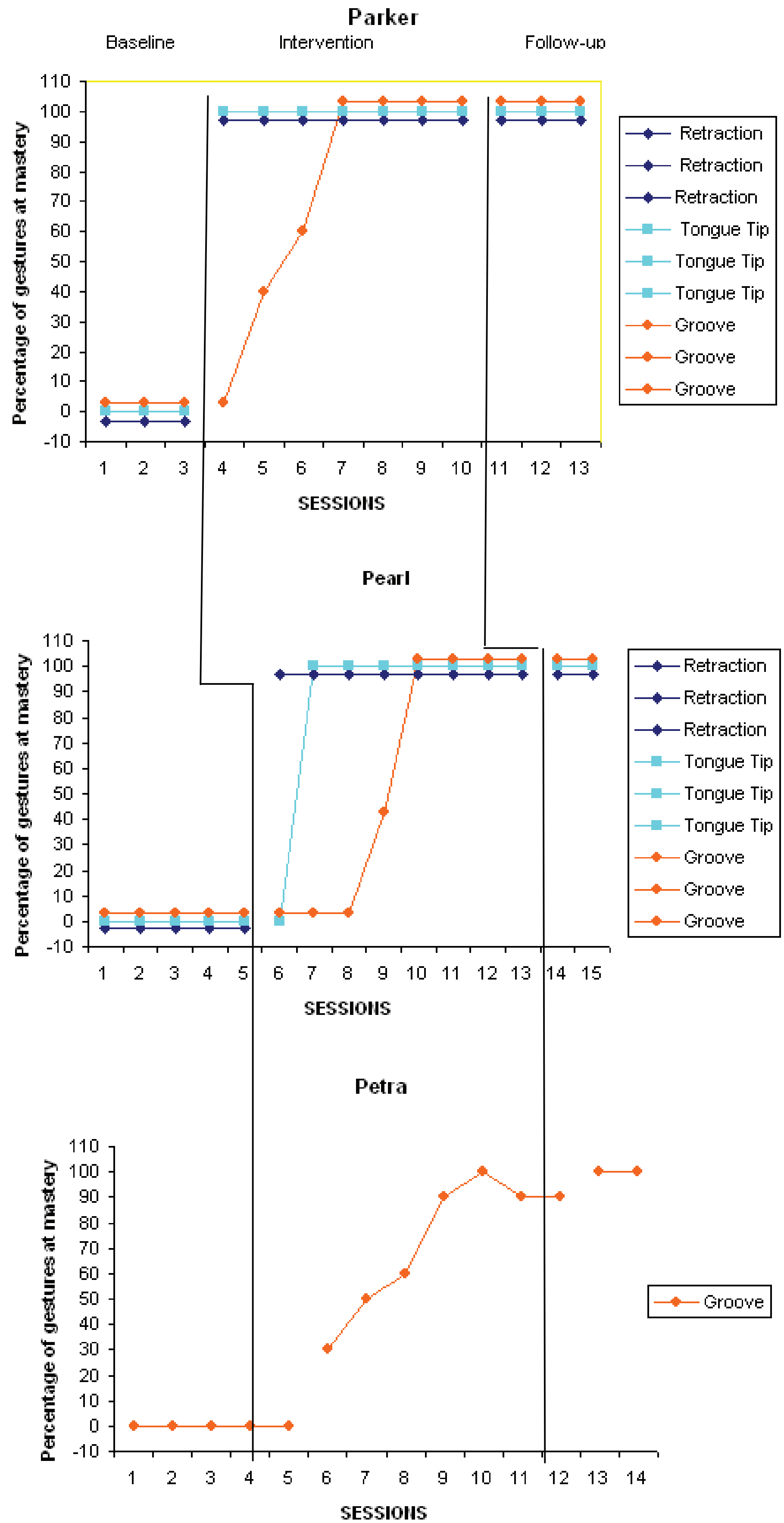
In evaluation of results, given a single-subject design, it is important to look at factors affecting varying outcomes for individuals in the study. Individual factors that can affect outcomes in speech intervention are motivation, practice opportunities, and for persons with CIs, auditory perception (McLeod & Bleile, (2004); Wie, Falkenberg, Tvete, & Tomblin, 2007). The following discussion describes the possible impact of those factors for each of the participants.

Participant 1: Parker

The main settings for Parker's habilitation were the home and the university. Parker was interested in learning speech and was very interested in and motivated by the ultrasound technology. Parker was always accompanied by his mother (a teacher) during the therapy sessions. In addition, Parker and his mother worked very hard on practicing and following through every step of the way during our ultrasound therapy project.

Prior to receiving his CI, Parker's audiogram had indicated a profound bilateral hearing loss. However, when we began therapy nine months post-implant, Parker was able to hear and identify most speech sounds, although he still presented with some r-w confusions. All of these factors may have facilitated his outcomes for the study, which included more /r/-like words in addition to mastery of the lingual components of /r/ within words.

Figure 5: Baseline, intervention and follow-up gestural /r/ components for Parker, Petra and Pearl.



Participant 2: Pearl

The main setting for Pearl's habilitation was the university. Prior to receiving her CI, she was minimally interested in speech practice and homework, but was more motivated upon receiving her new CI. Pearl did not have opportunity at home for consistent practice with English /r/ models (given the Cantonese/ESL home environment), although some of the time Petra would practice with her. Although her oral interpreter did attempt to provide some opportunities for her to practice at school, the curriculum was not designed to address her need to have scheduled practice sessions.

Prior to receiving her CI, Pearl's audiogram indicated a profound bilateral sensorineural hearing loss with very little benefit from amplification. However, while her audiogram looked similar to her sister's, her functional hearing was much lower. 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 CI. After three months of auditory perceptual training, she was still unable to hear all English consonants and vowels. The /r/ was still confused with /w/ some of the time.

Participant 3: Petra

The main setting for Petra's habilitation was the university and her community college. Petra had been diligent with schoolwork in high school and her first year of college. She 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 because she was very self-motivated.

Prior to receiving her CI, 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 before (/s/, /ʃ/ and /k/). She could also differentiate most of the English sound system by place and manner. However, she still had some difficulty discriminating between /r/ and /w/.

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, a formal study evaluation questionnaire was not used post-treatment. Instead, verbal comments volunteered by the participants are indicated here. All participants indicated that they believed they could produce /r/ more accurately and were better understood by family and friends. In addition, parents reported they were happy with the improvements during the course of the project, and all reported that participants were more intelligible.

Long-term follow-up

A follow-up evaluation of the ultrasound in treatment was completed 1.5 years later (Bacsfalvi, 2007), using perceptual judgments by trained listeners of randomized pre-post speech samples. All participants either maintained or improved their productions of target /r/ in the long term. All participants had access to traditional therapy for a couple of months post project.

Conclusion

This type of clinical research suggests the potential clinical usefulness of ultrasound as an adjunct to therapy, with a possibility of reducing the costs (years of therapy versus months) and time requirements for both the client and S-LP, and lessening the frustration for the client. The main objective of this study was to learn the gestural components of /r/. All three participants met this objective (Figures 2 to 5), with one moving beyond the objective to make a notable gain in production of /r/ or /r/-like segments as indicated by perceptual judgment (the other two also produced some /r/-like or /r/ segments during treatment, but showed no pre-post gain). All participants and the people in their lives reported that they were producing the /r/ with more rhotic quality by the end of this study. 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 the /r/ sound) suggests that this study was successful (McLeod & Bleile, 2004). This study was only the first step in the speech habilitation process, and looked at change in production predominantly at the level of the articulatory gesture. To facilitate production of accurate /r/ in conversation, continuing speech therapy with an S-LP experienced with acoustic phonetics, CIs and ultrasound was needed, with a generalization plan and sufficient practice opportunities. The longer-term outcomes evaluation (Bacsfalvi, 2007) showed either maintenance or continuing improvement.

The study 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, Stewart, Hardcastle, & Crampin, 1999). As a result, gestural components can be compared to these covert contrasts as positive prognostic signs in the process of learning /r/. This research reflects how /r/ has several constrictions that are essential for production of an acoustically accurate /r/, suggesting the necessity of learning these articulatory targets.

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

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References

Adler-Bock, M., Bernhardt, B., Gick, B., & Bacsfalvi, P. (2007). The use of ultrasound in remediation of English /r/ in two adolescents. *American Journal of Speech Language Pathology, 16*(2), 128-139.

Attanasio, J. (1994) Inferential statistics and treatment efficacy studies in communication disorders. *Journal of Speech and Hearing Research, 37*, 755-759.

Bacsfalvi, P.C.E. (2007). Visual feedback technology with a focus on ultrasound: The effects of speech habilitation for adolescents with sensorineural hearing loss. Unpublished Ph.D. dissertation, The University of British Columbia (Canada), Canada.

Bacsfalvi, P., Bernhardt, B., & Gick, B. (2007). Electropalatography and ultrasound in vowel remediation for adolescents with hearing impairment. *Advances in Speech Pathology, 9*(1), 36-45.

Bacsfalvi, P., Adler-Bock, M. Bernhardt, B., & Gick, B. (2004). Technology break-throughs for /l/ and /r/ treatment. Poster presented at the CASLPA Conference, May, 2004, Ottawa, ON, Canada.

Bacsfalvi, P., Bernhardt, B.M., & Gick, B. (2001). The new speech therapy for people with a hearing loss. Presented at Canadian Hard of Hearing Association (CHHA-BC) Conference, Richmond, BC, Canada, October 27, 2001.

Bernhardt, B., Bacsfalvi, P., Gick, B., Radanov, B. & Williams, R. (2005). Exploring the use of electropalatography and ultrasound in speech habilitation. Journal of Speech Language Pathology and Audiology, 29(4), 169-182.

Bernhardt, B., Gick, B., Bacsfalvi, P., & Adler-Bock, M. (2005). Ultrasound in speech therapy with adolescents and adults. *Clinical Linguistics and Phonetics, 19*(6/7), 605-617.

Bernhardt, B, Gick, B., Bacsfalvi, P., & Ashdown, J. (2003). Speech habilitation of hard of hearing adolescents using electropalatography and ultrasound as evaluated by trained listeners. *Clinical Linguistics & Phonetics, 17*, 199-216.

Bernhardt, B., Loyst, D., Pichora- Fuller, K., & Williams, R. (2000). Speech production outcomes before and after palatometry for a child with a CI. *Journal of the Academy of Rehabilitative Audiology, 33*, 11-37.

Blamey, P.J., Barry, J., Bow, C., Sarant, J.Z., Paatsch, L., & Wales, R. (2001). The development of speech production following cochlear implantation. *Clinical Linguistics & Phonetics, 15*(5), 363-382.

CHARGE Syndrome Canada (2010). What is CHARGE? Retrieved July 3, 2010, from http://www.chargesyndrome.ca/WhatisCHARGE.htm

Dagenais, P. (1992). Speech-training with glossometry and palatometry for profoundly hearing-impaired children. *The Volta Review, 94*, 261-282.

Eddington, D.K., & Peirschalla, M.L. (1994). CIs restoring hearing to the deaf. *The Harvard Mahoney Neuroscience Institute Letter on the Brain, 3*(4). Retrieved fall 1994, http://www.med.harvard.edu/publications/On_The_Brain/Volume3/Number4/Cochlear.html.

Ertmer, D.J., Leonard, J.S., & Pachuilo, M.L. (2002). Communication intervention for children with cochlear implants: two case studies. *Language, Speech, and Hearing Services in Schools, 33*, 205-217.

Ertmer, D.J. & Maki, J. (2000). Comparisons of speech training methods with deaf adolescents: spectrographic versus noninstrumental instruction. *Journal of Speech, Language and Hearing Research, 43*, 1509-1523.

Fawcett, S., Bacsfalvi, P., & Bernhardt, B.M. (2008). Ultrasound a visual feedback in speech therapy for /r/ with adults with Down Syndrome. *Down Syndrome Quarterly, 10*(1), 4-12.

Fletcher, S..G., Dagenais, P.A., & Critz-Crosby, P. (1991). Teaching consonants to profoundly hearing-impaired speakers using palatometry. *Journal of Speech, Language and Hearing Research*, (34), 929-943.

Flipsen, P. & Colvard, L. (2006). Intelligibility of conversational speech produced by children with CIs. *Journal of Communication Disorders, 39*(2), 93-108.

Gibbon, F., Stewart, F., Hardcastle, W.J., & Crampin, L. (1999). Widening access to electropalatography for children with persistent sound system disorders. *American Journal of Speech Language Pathology, 8*, 319-334.

Geers, A. (2004). Speech, language, and reading skills after early cochlear implantation. *Archives of Otolaryngology- Head & Neck Surgery, 130*(5), 634-638.

Gick, B., Iskarous, K., Whalen, D.H., & Goldstein, L.M. (2003). Constraints on variation in the production of English /r/. In S. Palethorpe & M. Tabain (Eds.) Proceedings of the 6ht International Seminar on Speech Production (pp. 73-78). Macquarie University: Sydney, Australia.

Gliner, J.A., Morgan, G.A., & Harmon, R.J. (2000). Single-subject design. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*(10), 1327-1337.

Higgens, M., McCleary, E., Carney, A., & Schulte, L. (2003). Longitudinal changes in children's speech and voice physiology after CIation. *Ear and Hearing, 24* (1), 48-70.

Litovsky, R., Johnstone, P., Godar, S., Agrawal, S., Parkinson, A. Peter, R., & Lake, J. (2006).

Bilateral cochlear implants in children: Localization acuity measured with minimum audible angle. *Ear and Hearing, 27*(1), 43-59.

McLeod, S. & Bleile, K. (2004). The ICF: a framework for setting goals for children with speech impairment. *Child Language Teaching and Therapy, 20*(3), 199-219.

Microsoft ® 2003. Part of Microsoft Office Professional Edition 2003. Power Point Presentation. Copyright © 1987-2003 Microsoft Corporation.

Morgan, D.L. & Morgan, R.K. (2001). Single-participant research design: Bringing science to managed care. *American Psychologist, 56*(2), 119-127.

Ruscello, D. (1984). Motor learning as a model for articulation instruction. In Costello, J. (Eds.) Speech disorders in children, recent advances. San Diego, CA: College Hill Press.

Schramm, D., Fitzpatrick, E., & Seguin, C. (2002). CIation for adolescents and adults with prelinguistic deafness. Otology and Neurotology, 23, 698-703.

Shriberg, L.D. & Lof, G.L. (1991). Reliability studies in broad and narrow phonetic transcription. *Clinical Linguistics & Phonetics, 5*, 225-279.

Svirsky, M. A., Robbins, A. M., Kirk, K., Pisoni, D. B. & Miyamoto, R. T. (2000) Language development in profoundly deaf children with cochlear implants. *Psychological Science 11*(2), 153-158.

WHO (2001). International classification of functioning, disability and health. Geneva, Switzerland: WHO.

Wie, O.B., Falkenberg, E.S, Tvete, O., & Tomblin, B. (2007). Children with a cochlear implant.

Characteristics and determinants of speech recognition, speech-recognition growth rate, and speech production. *International Journal of Audiology, 46*, 232-243.

Zwolan, T. A, Ashbaugh, C. M., Alarfaj, A, Kileny, P. R., Arts, H. A., El-Kashlan, H.K., & Telian, S. A. (2004). Pediatric CI patient performance as a function of age at implantation. *Otology & Neurotology. 25*(2),112-120.

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Appendix 1

Word and syllable probe lists for all participants

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 2

Speech Therapy Techniques with Ultrasound Biofeedback

The following appendix provides a short illustration how ultrasound biofeedback may be used to facilitate articulation therapy.

1. In the first step, we have found it useful to start with a verbal description of the anatomy of the tongue. We facilitate understanding by using as many means of illustration as possible. The following items may be helpful:

Anatomical drawings or pencil drawings of the midsagittal tongue and vocal tract are useful to orient the patient to the structures. Especially when working with pediatric patients, it is important to minimize distraction by choosing a drawing that is visually plain and clear.

EPG prints and clay models of the hard palate can be used to illustrate where and how the tongue touches the palate.

Mirrors can be used to help the patient relate the information from the drawing to his or her own mouth.

Tongue depressors can be used to provide the patient with gentle tactile feedback about the location of different intraoral structures.

Finally, pliable mouth models, often used by clinicians, or hand puppets with movable tongues can help to engage a child to learn in a play activity.

2. Following this, we provide a demonstration and verbal description of speech production with the ultrasound machine. The clinician demonstrates the midsagittal ultrasound image and demonstrates how the tongue attains different positions during the production of different speech sounds. We have found it useful to start the demonstration with the vowels /a/, /i/ and /u/, which are usually differentiated in the ultrasound image. The plosive sounds /t/ and /k/ produced in an /ata, aka/ sequence are useful to demonstrate front and back raising of the tongue for English. Depending on the therapy goals for the patient, a coronal ultrasound view may be used to illustrate grooving of the tongue. Here, it is useful to obtain a coronal scan of the posterior third of the tongue and to produce a sequence of /i/ and /u/, which will demonstrate an alternation of concave and convex tongue shapes in most speakers. The therapist should become familiar with the ultrasound image of his or her own tongue before attempting a demonstration to the patient.

3. We have found it beneficial to start tongue positions (gestures) without sound. These gestures must be stable and consistent before introducing sound. Each component of this oral motor work is underlying the exact movement needed in a speech sound. A componential approach to intervention is recommended.

4. Before giving homework, make sure the patient can do the movement without looking at the ultrasound display. The patient should practice the target tongue movement and speech sounds at least twice a day.

5. When using the ultrasound biofeedback, be mindful of patient fatigue and provide frequent breaks. While ultrasound is considered to be biological safe, it is prudent to limit the exposure duration in a session. Whenever the ultrasound display is not actively used in therapy, the machine should be put into the freeze mode.

How to teach velars

Suggested sequence for the differentiation and isolation of movements:

1. Place the transducer under the chin in the sagittal position.
2. Start with /u/ to demonstrate the high back tongue position and to ascertain that the patient can move his or her tongue towards the velum.
3. Ask the patient to push the tongue up against in the palate in the /u/ position (without voicing).
4. The clinician demonstrates the difference between /t/ and /k/ on the ultrasound.
5. Merge 'stopping' with /u/.
6. Begin with isolated productions. For example, you can move from /uku/ to other vowel contexts, and then to words.

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Bacsfalvi, P., Bernhardt, B., Gick, B. (2007). Electropalatography and ultrasound in vowel remediation for adolescents with hearing impairment. *Advances in Speech Language Pathology, 9(1), 36-45.*

Bacsfalvi, P. & Radanov, B. (2010). Ultrasound for Speech Training. [Video files]. Available from School of Audiology and Speech Science, University of British Columbia Web site, http://www.audiospeech.ubc.ca/partners/resources-for-practioners

Bernhardt, Gick, Bacsfalvi & Adler-Bock (2005). Ultrasound in speech therapy with adolescents and adults. *Clinical Linguistics and Phonetics, 19(6/7),* 605-617.

Fawcett, S., Bacsfalvi, P., Bernhardt, B.M. (2008). Ultrasound as Visual Feedback in Speech Therapy for /r/ with Adults with Down Syndrome. *Down Syndrome Quarterly, 10(1),* 4-12.