EFFICACY OF ULTRASOUND VISUAL BIOFEEDBACK FOR SPEECH SOUND REMEDIATION IN CHILDREN WITH HEARING LOSS

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Abstract

Auditory input is an imperative system in the development of speech sound production in children. Without a proper functioning auditory system, children are at risk for developing errors in speech sound production that can persist for years. There are multiple factors that contribute to the development of speech sounds with hearing loss such as age of onset, severity of hearing loss, type of hearing loss, and age of cochlear implantation, or access to other assistive technology. Even after intervention with assistive technology children can exhibit speech sound errors. Ultrasound visual biofeedback has been shown to be useful in speech therapy for a variety of etiologies including people with a hearing loss but has been used most with adults and adolescents. The purpose of this study is to investigate the effectiveness of ultrasound imaging visual biofeedback to remediate speech sound production errors in children with hearing loss, and the clinical implications.

Introduction

Hearing loss in children can have many implications for speech and language development. The inability for infants and children to receive auditory input of speech sounds can reduce the ability to perceive and produce intelligible speech, as the modality of learning spoken language is primarily auditory. Without proper auditory input, a mental representation of a speech sound segment—and consequently reproduction of the same acoustic feature during speech—will be affected. Thus, children with hearing loss can miss many aspects of speech that typically influence speech intelligibility (Bakhshaee, Ghasemi, Shakeri, 2007) which has been found to be a key factor in remediation of speech sound disorders in normal hearing children (Teraband, Brenk, van Doornik-van der Zee, 2014).

Significant factors contributing to language and speech development of children with hearing loss are age of onset, severity of hearing loss, type of hearing loss, and age of cochlear implantation, or access to other assistive technology. To increase auditory input of the speech signal, cochlear implants (CIs) and other assistive technology such as hearing aids (HAs), are used to heighten auditory perception regardless of the age of intervention (Zwolan et al., 2004). However, even after intervention, children with hearing loss can still exhibit speech sound distortions. Common errors that occur in those with hearing loss include errors between voiced and voiceless sounds, consonant deletions (especially final), substitution of stops for fricatives and liquids, distorted resonance and nasal consonants (ASHA). Speakers with a profound hearing impairment tend to produce visible, forward speech sounds more accurately than back or mid consonants which are less visible (Tobey, Pancamo, Stalle, Brimacombe and Beiter, 1991). Stelmachowicz, Pittman, Hoover, Lewis, and Moeller (2004), found that children with hearing loss showed delayed acquisition of all phonemes, the longest delay being with fricative sounds. This study also showed that children with hearing loss that had been identified and aided after the age 12 months of age showed significantly longer delays in acquiring these phonemes.

Children who receive cochlear implants are provided increased auditory input which facilitates an increase in speech perception, speech production, and phonemic inventory (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003). However, even children who receive intervention early still may have inadequate access to sound and certain frequencies or linguistic input. This combined with the potential of distorted sounds creates the possibility that children with hearing loss are at greater risk of developing issues with speech sound production (Ambrose et al., 2014). As early as ages 2 and 3, children who have hearing loss show consistently less accuracy in consonant production when compared to age matched children with normal hearing (Ambrose et al., 2014).

Speech sound disorders in those with cochlear implants have been treated with methods that require auditory feedback. One study (Pomaville & Kladopoulos, 2013) focused on behavioral therapy for speech sound production. The methods describe that the researcher would model the target and the client would repeat it in an imitative way. The targets as well as the feedback were based on the participant's ability to listen to the researcher and imitate the sounds.

Visual biofeedback methods, on the other hand, implement the use of technology to provide imaging that can display real time representations of the physiological area in focus. The display of the area of concentration allows for heightened awareness and eventually corrections. A variety of types of visual biofeedback have been implemented with the goal of remediating speech sound errors in people with hearing loss, including electropalatography, glossometry, and ultrasound visual biofeedback (U-VBF). Feedback technologies, such as glosseometry, electropalatography (EPG) and visible speech modeling have been explored as therapy options that are more visual, to assist those with hearing loss (Fletcher, Dagenais, & Critz-Crosby, 1991; Dagenais 1992) Bernhardt, Gick, Bacsfalvi and Ashdown (2002) found that the use of electropalatography shows significant improvements in speech production when used with adolescents who are hard of hearing. Glossometry, another form of visual biofeedback that displays changes in tongue height, has been used to teach vowels to children with profound hearing impairments and showed improvement in intelligibility of speech (Dagenais, 1992). These studies using EPG and glossometry suggest that therapy methods that are visually focused are beneficial to individuals with hearing loss.

U-VBF has been used to remediate speech sound errors with a variety of etiologies as well as various phonemic targets (Sugden, Lloyd, Lam & Cleland, 2018). U-VBF has shown improvement when used with speech sound disorders due to childhood apraxia of speech, acquired apraxia, total or partial glossectomy, and primary persistent SSDs (Preston, Leece & Maas, 2017). U-VBF can be an effective option in conjunction with other speech therapy, or with SSDs that have not responded to other methods of treatment.

U-VBF has proven to be a useful tool in speech therapy for people with a hearing loss (Bacsfalvi, Bernhardt & Gick, 2007; Bernhardt, Gick, Bacsfalvi & Ashdown, 2003), but has been used most commonly with adolescents with hearing loss. One study used U-VBF with adolescents with cochlear implants aimed to improve the gestural components of the /r/ sound. All of the participants were able to use the ultrasound to learn the /r/ components (Bacsfalvi 2010).

Ultrasound visual biofeedback when used in speech therapy provides live visualization of the tongue, which is an important articulator in most speech sounds. By holding a transducer beneath the chin, the client and speech-language pathologist are able to see the motion of the tongue within the mouth and is less invasive than other biofeedback methods that monitor the tongue. The increased visibility of the tongue allows for visual correction for tongue movement in errored speech sounds.

Correct production of speech sounds is important to language development and is also an expectation in educational and professional settings in the United States. A study established that as early as 2nd grade, teachers reported statistically significant differences in their expectations of children's academic, social, and behavioral performance when listening to a speaker with varying levels of intelligibility (Overby, Carrell & Bernthal, 2007). In an effort to assist children with cochlear implants and other assistive hearing technology and speech sound disorders, an alternative visual method of teaching could be very valuable to speech therapy, especially in a younger age group than has been explored. The purpose of this study is to investigate the effectiveness of ultrasound imaging visual biofeedback to remediate speech sound production errors in children with hearing loss. The effectiveness of this treatment will be assessed by looking at the functional relationship between the amount of correct production of errored sounds before and after the introduction of U-VBF.

Methods

This study will use a Single Case Design to assess the functional relationship of dependent and independent variables while using U-VBF for remediating speech sound errors in children with hearing loss.

Participants

Native English-speaking children between the ages of eight and twelve will be recruited for this study. Inclusion criteria include: 1) Have been diagnosed with a bilateral hearing loss. 2) Have auditory access to spoken language through the use of hearing devices (e.g. hearing aid or cochlear implant). 3) Use spoken language as their primary mode of communication. 4) Present distortion of speech sound in spoken language that can be assessed with ultrasound imaging. 5) Have no other disabilities that negatively impact language, cognition and/or vision. All racial, ethnic, and socioeconomic groups will be welcomed as long as they meet the inclusion criteria, and there will be no limit to balance for race or gender.

Participation in this study is voluntary. Participants can withdraw their participation at any time during the study. There are no penalties for withdrawing participation. All participants and their guardians will be informed of the purpose and procedures of this study. All children will provide their assent to participant before any study procedures (e.g. assessment and interventions) are initiated. Participant's guardian will provide his/her consent for the child to participate in this study before any study procedures commence. Guardians will be provided with a consent form that provides information on the research as well as the procedures for withdrawing participation on this study. Participants and their guardians will be allowed to ask questions regarding their voluntary participation prior to the study procedures

The COSD department and the Miller Speech and Hearing Clinic serves a population that may have potential participants. Individuals will be invited to participate through word of mouth. Invitation to participants will be purposely provided to individuals who have been previously identified as fitting the characteristics for participation and given information about the study and who have received speech-language remediation services at the Miller Speech and Hearing Clinic. Additionally, a flyer will be used for recruitment of participants outside the Miller Speech and Hearing Clinic.

Equipment

The equipment that will be used in this procedure includes the ultrasound machine and transducer. The research will use a Micro Sonospeech ultrasound scanner. The transducer will be a 4Hz convex transducer. The transducer will be used under the lower mandible for a mid-sagittal view of the tongue.

Assessments and target selection for treatment

Initial assessments will be done to gather information on each participant's speech-language skills and non-verbal cognition. For assessment of articulation errors Goldman-Fristoe Test of Articulation (GTFA-3) will be used. Based on results on GTFA-3, up to two sounds in error will be selected. One context from the selected sounds in errors will be randomly selected for treatment while another context will be untreated but monitored for generalization. For example, if /s/ and /k/ are selected, initial /s/ and final /k/ will be the treated contexts while word final /s/, word-initial /k/ will be the untreated contexts. The Kaufman Brief Intelligence Test (KBIT-2) will be administered to assess non-verbal cognition. For language skills, the Clinical Evaluation of Language Fundamentals, Fourth Edition (CELF-4) will be administered.

Baselines

Introduction of U-VBF treatment for each participant will be staggered. As such, baseline condition will vary across participants based on the following sequence. Five baseline data points will be gathered for the first participant, seven for the second participant, and nine for the third participant. This sequence will repeat as additional participants are recruited. Accuracy of sound production within the selected treated and untreated contexts will be collected during baseline as measured by a ten-word list containing the target sound and an image that represents the word (See appendix A). For example, for the concept of a house, an image of a house with the word “house” below it will be presented on a screen for the child to read. No model will be provided to the child. Sonographic tongue image during baseline will be gathered. Baseline data points will be rated for production accuracy of the target sound. A score of 1 for a perceptually correct production and 0 for incorrect. Baseline probes will be independently rated for sound accuracy by the student Co-PI as well as a naïve listener then compared for rating discrepancies. Percentage of rating discrepancies across baseline probes will be gathered. In the event of discrepant ratings, a third naïve rater will be used to make the final decision.

Within-treatment probes

To monitor changes in production accuracy for treated and untreated contexts, a list of 10 words (per context) will be used to monitor production accuracy within treatment sessions (See appendix B). These words will be different than words used for the baseline and words used during U-VBT. The treated context will be probed every two sessions, and the untreated contexts will be probed every three sessions. Scoring for production accuracy will be the same used during treatment baselines.

Treatment procedures

All participants will be scheduled for two 30-minute sessions per week, for a total of twelve treatment sessions. Only sound variants selected for treatment will be the target of all treatment sessions. Sessions will use a structured treatment protocol that allows for systematic practice through a variety of complexity levels and individualized feedback based on the sonographic tongue shape error. Treatment protocol will consist of practicing the sound variant through a top-down approach. That is, the participant will initiate practice at higher levels of complexity that are considered more functional levels of complexity (e.g. short phrase level, disyllabic words, monosyllabic words, and target sound in isolation). Each complexity level will provide five instances of production for the treated context. Accurate productions will be scored as 1 while error productions with 0. To move from one level of complexity to the next (e.g. from short phrase to disyllabic words), the participant must have a minimum of four accurate productions on the previous level. For example, if participant produced three correct productions of the treated context during disyllabic words, participant cannot move to monosyllabic words. In the event the participant scores three of less accurate productions after five practice instances during a level, the participant will be moved to the previous complexity level. Following the former example, where participant achieved three accurate productions at the disyllabic level, the participant will be moved to short phrase level for continuation of practice (See appendix C for treatment schedule). All treatment words will be unique from both the baseline words and within treatment probes. The unique treatment words will ensure that words are not learned, and data will show if the sound has truly been mastered in a variety of words (See appendix D for example of treatment words).

Feedback

Treatment protocol will allow for providing systematic feedback through all complexity levels based on the sonographic tongue image during production of the target sound. As participant moves through the various complexity levels, the amount and type of feedback will vary. The types of feedback include: Knowledge of Performance (KP), Knowledge of Results (KR), and no feedback. KP feedback will provide the participant with individualized information on their tongue shape during the practice attempt (e.g. *"that was a great /s/ because you raised both lateral sides").* Knowledge of Results (KR) will provide information on the clinician's perceptual judgment on the production of the treated context (e.g. *the /s/ sound did not sound good").* During instances of no feedback, the participant will not be provided with any information. To promote awareness of tongue configuration by the participant, instances of auto-monitoring (Au) will be included at the level of monosyllabic words. During auto-monitoring instances, the clinician will ask the participant about his or her opinion regarding tongue shape during the production attempt of the target sound. See appendix C for feedback schedule within treatment protocol.

Data Analysis

Data points from baselines and within-treatment probes will be plotted on a graph. Changes over time in our dependent variable will be analyzed by looking for changes in level, trend, and stability of the data points. The data will be interpreted using TAU-U to determine treatment effectiveness. This will control for potential increases in baseline data points and show the functional relationship between the independent and dependent variable.

Procedural fidelity.

A sample of the treatment sessions (20%) will be rated by a second rater trained on how to use ultrasound biofeedback for remediation of speech sound errors. The second rater will assess the accuracy of the clinician to adhere to the structured protocol.

Interobserver reliability.

All within-treatment probes will be rated independently by a second rater. Subsequently, ratings from the clinician and the second rater will be compared for instances of disagreement in the scoring of within-treatment probes. Differences in scoring will be discussed between raters to reach an agreement. If no agreement is made a third rater will be used to make the final decision.

Project Barriers

The completion of the recruiting, baselines and therapy for this project were set to happen between the spring and summer (April-August) of 2020. The outbreak of COVID-19 presented many barriers to allowing this to be completed. Beginning in mid-March, the TCU campus was closed, which included the Miller Speech and Hearing Clinic. As of August 19th, 2020, human subjects research on campus was only allowed to include TCU students, faculty or staff. These groups of people do not fit the age requirements to participate in the study, so research was not able to be conducted. In the current conditions, a clinician would not be able to stay six feet from the participant while administering this therapy. Due to the safety guidelines and procedure characteristics, the research was not able to be completed, and the project was finished as a prospectus.

Clinical implications

Improvement in speech sound production using therapy with U-VBF treatment would have many positive clinical implications within the field of speech pathology. Past research has indicated that individuals with hearing loss have responded positively to treatment with the use of ultrasound visual biofeedback. This method would allow those findings to expand into a younger age group.

Hearing loss is recognized as a risk factor for speech and language development. If the hearing loss is recognized early, preventative early intervention will often begin before the child reaches the age of three. Previous research with visual biofeedback for populations with hearing loss have been limited to adolescent age and older. Using U-VBF in a younger age group than previous research would allow for more treatment options for speech sound errors as children reach the ages of 8-12 years old. If a functional relationship between the dependent and independent variables are observed, there is opportunity for U-VBF to be more widely implemented into various treatment settings and practices throughout the field.

As the field of speech pathology will look to evolve as the world changes, this therapy could also be adapted to telepractice settings. Technology within telepractice is advancing as the need for it has increased. With the new technology, an ultrasound machine could be given to the family to use in their remote location. Once the family has the ultrasound machine, a parent or guardian would need to receive training over the same telehealth platform by the clinician. This training would ensure understanding and competency of the video platform, software and ultrasound technology (use and upkeep). During a session, the screen would be shared with the clinician so they can monitor the visuals of the tongue as the child is seeing them. Remote instruction would be given around positioning of the ultrasound probe, tongue positioning, production quality, etc. Feedback will be given on the same schedule over telehealth as it would be in person.

Appendices

Appendix A

Example of baseline word lists and scoring for a variety of potential target sounds.

Baseline # ________Date: ______________________

Score with a number one (1) for accurate production and zero (0) for incorrect productions.

Word-Initial /s/	**Scoring**	**Word-Final /s/**	**Scoring**	**/s/ Clusters**	**Scoring**
Sand		Class		Smell	
Santa		Tennis		Skunk	
See		Dice		Snow	
Said		Miss		Storm	
Sore		Yes		Sled	
Seed		Voice		Sponge	
Sack		This		Spoon	
Sign		Ace		Stamp	
Save		Peace		Space	
City		Price		Spider	

Word-Initial /r/	**Scoring**	**Word-Final /r/**	**Scoring**	**/r/ clusters**	**Scoring**
Red		Mother		Truck	
Room		Pear		Frog	
Radish		Zipper		Fries	
Rhino		Feather		Trash	
Ruler		Car		Drum	
Wrap		Guitar		Straw	
Root		Tiger		Green	
Rice		Helicopter		Grapes	
Radio		Dinosaur		Crayon	
Rectangle		Beaver		Grass	

Word-initial /l/	**Scoring**	**Word-final /l/**	**Scoring**	**/l/ Clusters**	**Scoring**
Leaf		Tall		Black	
Left		Wool		Fly	
Lime		Mail		Blue	
Lamb		Fall		Flag	
Laser		Owl		Blocks	
Lion		Bell		Gloves	
Lap		Tool		Glass	
Leap		Pool		Clown	

Leak		Wall		Glue	
Lock		Small		Clock	

Word initial /ʃ/	**Scoring**	**Word-final /ʃ/**	**Scoring**
Shape		Leash	
Sheet		Trash can	
Ship		Fish	
Shield		Sash	
Shout		Brush	
Short		Wash	
Sheriff		Mustache	
Shoulder		Cash	
Shadow		Push	
Shower		Wish	

Word initial /z/	**Scoring**	**Word-final /z/**	**Scoring**
Zebra		Keys	
Zipper		Nose	
Xylophone		Rose	
Zoom		Bees	
Zen		Elbows	
		Size	
		Shells	
		Toes	
		Beds	
		Sneeze	

Appendix B

Within-treatment probe

Example of within-treatment probe word lists and scoring for a variety of potential target sounds.

Treatment Session # ___________Date: ________________

Score with a number one (1) for accurate production and zero (0) for incorrect productions.

Word-Initial /s/	**Scoring (1 or 0)**	**Word-Final /s/**	**Scoring (1 or 0)**	**/s/ Cluster**	**Scoring (1 or 0)**
___Treated ___Untreated		___Treated ___Untreated			
Sword		Nice		Scale	
Sandwich		Erase		Spell	
Safe		Pass		Scared	
Sour		Bananas		Spot	
Sack		Prince		Skate	
Sock		Necklace		Slide	
Salad		Grass		Sleep	
Saw		Bus		Ski	
Simmer		Kiss		Stem	
Cereal		Cars		Smoke	

Word-Initial /r/	**Scoring (1 or 0)**	**Word-Final /r/**	**Scoring (1 or 0)**	**/r/ Clusters**	**Scoring (1 or 0)**
___Treated ___Untreated		___Treated ___Untreated		___Treated ___Untreated	
Ring		Door		Crib	
Rock		Jar		Three	
Roses		Weather		Bridge	
Roof		Pepper		Pretzel	
Rabbit		Sweater		Dragon	
Run		Bear		Cry	
Rocket		Deer		Frame	
Racoon		Flower		Broom	
Read		Star		Dress	
Ride		Paper		Gray	

Word-initial /l/	**Scoring**	**Word-final /l/**	**Scoring**	**/l/ Clusters**	**Scoring**
___Treated ___Untreated		___Treated ___Untreated		___Treated ___Untreated	
Lava		Shell		Clean	
Late		Ball		Planet	
Log		Peel		Sleeping	
Limo		Hole		Play	
Lamp		Mall		slow	

Light		Doll		clover	
Letters		Mail		Plum	
Lizard		Muscle		Cloud	
Lips		Tail		Blanket	
Laundry		Call		Floss	

Word initial /ʃ/	**Scoring (1 or 0)**	**Word-final /ʃ/**	**Scoring (1 or 0)**
___Treated ___Untreated		___Treated ___Untreated	
Shirt		Slush	
Share		Marsh	
Shake		Mesh	
Shave		Flush	
Shiny		Squish	
Show		Crush	
Shop		Finish	
Shampoo		Licorice	
She			
Shy			

Word initial /z/	**Scoring (**	**Word-final /z/**	**Scoring**
___Treated ___Untreated		___Treated ___Untreated	
Zigzag		Holidays	
Zookeeper		Knees	
Zillion		Jazz	
Zip code		Apologize	
Zap		Boys	
		Cookies	
		Prize	
		Sunrise	
		Flowers	

Appendix C

Treatment schedule with feedback levels.

Client Number: Clinician: Date: TX Session:
Score 1 for accurate production of target sound. Score 0 for inaccurate production of target sound.

Context:

CPhr:					T	Phr:					T	Disyllabic:					T	Monosyllabic:					T
KP	KP	KP	KP	KP		KR	KP	KR	KP	KR		KP	KR		KR					KR		A	
KP	KP	KP	KP	KP		KR	KP	KR	KR	KP		KR		KP	KR			KR		A			
KP	KP	KP	KP	KP		KP	KR	KR	KP	KR			KP	KR	KR			A				KR	
KP	KP	KP	KP	KP		KP	KR	KP	KR	KR			KR	KR		KP				A	KR		

Monosyllabic → One syllable words

Disyllabic → two syllable words

Phr → Prase CPhr → Cloze phrase. Tell the *patient "make up a phrase with the word (insert the word here)*. CPhr MUST comply with the positioning you are targeting during treatment.

KP-> Knowledge of Performance → *KR + a reason or explanation*

KR-> Knowledge of Results → *Yes, No, almost, not quite there, I see you are trying.*

A→Auto monitoring-> What do you think about that one?

Appendix D

Examples of treatment word lists.

Treatment Session # ___________Date: ________________

Score with a number one (1) for accurate production and zero (0) for incorrect productions.

Word Initial /s/	Scoring (1 or 0)	Word final /s/	Scoring (1 or 0)	/s/ Clusters	Scoring (1 or 0)
Sofa		Cactus		Snack	
Sun		Mice		Smile	
Seal		Slice		Sky	
Soup		Moose		Slug	
Soap		Mouse		Scar	
Sane		Octopus		Stop	
Syrup		House		School	
Salt		Juice		Slime	
Soda		Compass		Star	
Song		Vase		Stick	

Word Initial /r/	Scoring (1 or 0)	Word final /r/	Scoring (1 or 0)	/r/ Clusters	Scoring (1 or 0)
Rug		Vampire			Bread
Raisins		Four			Dream
Rain		Fire			Crane
Rake		Hair			Braid
Ribbon		Doctor			Track
Rattlesnake		Hammer			Friday
Race		Spider			Crab

Rope		Ear			Trumpet
Repeat		Floor			Brother
Reptile		Wire			Cricket

Word-initial /l/	**Scoring**	**Word-final /l/**	**Scoring**	**/l/ Clusters**	**Scoring**
Ladybug		Yell		Blackberry	
Love		Heel		Glitter	
Lemon		Hill		Close	
Llama		Pencil		Blink	
Lotion		Towel		Clam	
Lego		Wheel		Globe	
Lake		Nail		Claw	
Lunch		Apple		Plane	
Lollipop		Snail		Please	
Leg		Whale		Flute	

Word initial /ʃ/	**Scoring (1 or 0)**	**Word-final /ʃ/**	**Scoring (1 or 0)**
Shed		Flash	
Shark		Squash	
Shadow		Dish	
Sheep		Eyelash	
Sugar		Relish	
Shoes		Polish	
Sharp		Bush	
Shovel		Ash	
Shelves		Blush	
Shade		Rush	

Word initial /z/	**Scoring (**	**Word-final /z/**	**Scoring**
Zucchini		Close	
Zero		Hers	
Zoo		Fries	
Zombie		Breeze	
Zone		Toys	
Zany		Hose	
		Freeze	
		Bugs	
		Bears	
		Babies	

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