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Preliminary Case Studies Investigating the Use of Electropalatography (EPG) Manufactured by CompleteSpeech® as a Biofeedback Toolin Intervention

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Abstract

Purpose: This preliminary investigation examined the effectiveness of using electropalatography, manufactured by Complete Speech®, as a tool with three children diagnosed with articulation disorders. The participants produced the following phonemes in error: /ʃ/, /s/, /r/, r-colored vowels [ɚ,ɝ], and r-colored diphthongs [ɛr, ɪr, ɔr, ɑr] in different positions of words. **Method**: Speech and language skills were assessed prior to the intervention. A conversational speech sample was elicited and analyzed pre- and post-intervention. The intervention consisted of a 45-minute session once a week over a 10-week period. Perceptual data were recorded during each session. Three months post intervention two of the three participant's speech was analyzed to determine possible generalizationof therapy targets. No home practice program was provided to the participants. **Results**: The results revealed that each of the participants improved in their lingua-palatal contacts for the phoneme(s) targeted. **Conclusion:** Electropalatography manufactured by Complete Speech® was a useful intervention tool to improve the speech skills of three children diagnosed with articulation disorders. Positive improvements in articulation as indicated in this study show promise for use ofthis software to improve patient awareness of articulatory errors and ability to use visual feedback to effectively produce target sounds and generalize their correct speech productions.

Keywords: articulation, speech disorders, electropalatography, children, biofeedback and CompleteSpeech®

Introduction

According to the American Speech Language Hearing Association (ASHA, 2008), "speech sound disorders is an umbrella term referring to any combination of difficulties with perception, motor production, and/or the phonological representation of speech sounds and speech segments (including phonotactic rules that govern syllable shape, structure, and stress, as well as prosody) that impact speech intelligibility."

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The term is commonly used to refer to children who fail to develop their speech sounds at a typical age in the absence of an organic impairment (Gibbon, Stewart, Hardcastle & Crampin, 1999). As reported on the ASHA Portal (2015), Law, Boyle, Harris, Harkness, & Nye (2000) completed a systematic review and estimated the prevalence of speech sound disorders to range from 2% to 25% of children ages 5 to 7 years. More specifically, Dodd (1995) describes these children as having difficulty producing all sounds within a specific class of speech sounds, most commonly sibilants or liquid targets. According to Follent and McLeod (1997), children who present with speech sound disorders can continue to make progress and acquire sounds until the age of eight, due to maturation and progress made in therapy. However, some children often receive long periods of therapy with little to no success, and once children are older than eight years of age, their speech sound deficits become more difficult to treat and may take longer to generalize into connected speech (Follent & McLeod, 1997). Children with persistent speech sound disorders may not make significant progress towards their goals in speech-language therapy and due to insurance caps and school system regulations these children may be discharged from receiving speech-language pathology services. Currently, there are many evidence-based treatment techniques for treating speech sound disorders on the ASHA Portal (2015) including Contrast Therapy Approaches (Minimal Oppositions, Maximal Oppositions, Empty Set), Distinctive Features, Cycles Approach, Speech Sound Perception Training, however, often times these traditional intervention approaches fail to help children remediate their speech sound errors or generalize their knowledge outside of the clinical environment. When children's speech skills are not mastered through their own maturation or when traditional interventions are unsuccessful, alternate methods of evidence-based treatment must be explored. It is important for speech-language pathologists to be aware of alternative treatment options that may be the key to remediating their client's speech sound errors. Electropalatography (EPG)is another method for remediating persistent speech sound disorders.

EPG, also known as palatometry in the literature, is an instrumental technique that provides a biofeedback-based approach for treating avariety of communication disorders including articulation or speech sound disorders. EPG is a technique derived by phonetic scientists to examine the points of contact between the tongue and the hard palate. Static palatometry, which was used approximately 200 years ago**,** involved a mixture of cocoa and charcoal being applied to the tongue; photographs of the palate were taken after the production of a single phoneme. Dynamic electropalatography systems (which are used today) were developed in Germany and used electronic circuitry to capture the dynamic lingua-palatal contacts. Years later, Professor Fletcher (Logo Metrix Palatometer) and Professor Hardcastle in Edinburgh, UK (Reading University, EPG3 System) created their own types of EPG systems. In Japan, the Rion Company, developed the DP01 EPG System. All these systems differed in their designs of the artificial palates, including the number and arrangement of electrode contacts and materials used (Dagenais**,** 1995; Gibbon and Wood , 2010). A new Windows® version of the Reading System was developed at Queen Margaret University, Edinburgh in 2008 and is still in use there today (Gibbon & Wood, 2010). The Fletcher (Palatometer) and Rion systems were discontinued due to the high cost of manufacturing the systems. Following a restructuring of his company LogoMetrix in 2008 (The name was changed to Complete Speech®), Professor Fletcher modified his EPG system again to make it more affordable and user-friendly (Schmidt, 2007).

Electropalatography (EPG) is an option for clients who have persistent speech sound disorders and are not demonstrating improvements in their speech intelligibility with traditional speech therapy approaches (Carter & Edwards, 2004). EPG is a computer-based technique that records the tongue's contact against the palate during speech. The contact patterns are displayed on a computer screen, providing a visual display for the client. The aim of the current study is to investigate the use of an electropalatography system by Complete Speech® in conjunction with traditional articulation therapy with three children presenting with articulation disorders. Currently, this is the only EPG software available in the United States. EPG technology is different from other traditional intervention approaches because it allows the client and clinician to receive visual-feedback displayed on a computer screen. Fletcher (1992) views the following features of the articulator movement as the hallmarks of motor speech skill: speed, spatial accuracy, consistency of articulatory movement, and movement efficiency. EPG technology allows the clinician to observe these aspects of articulatory motor speech movements that cannot be easily observed through traditional therapy. EPG provides speech-language pathologists with the ability to monitor the location, contact patterns and the movement of the articulators as well as to describe where they occur in the oral cavity. Previously EPG technology has been used primarily for research purposes, however, it has been investigated as an approach to be used during the assessment and intervention of children with speech sound disorders (Cheng, Murdoch, Goozee, & Scott, 2007; Goozee, Murdoch & Theodoros, 2003; Hardcastle, 1987).

Before a clinician can begin to work with EPG, there are several critical steps that must be taken, including funding and obtaining the software, having a dentist make a mold for an electro palate, sending the mold to the company where the electro palate is manufactured. There are, also, some factors which are important to consider prior to recommending a client use EPG. First, it can be costly and time consuming as compared to traditional speech therapy. The clinician needs to consider the child's age and ability to follow directions. According to Degenais (1995), "children seven years and older are good candidates while children under five years of age are considered poor candidates" (p. 309). Children should have good receptive language skills as they have to understand what is viewed on the computer monitor and how they can make lingua-palatal contact adjustments. Also, using EPG clinically may require that new molds be taken for new electro palates to fit the palatal arches of growing clients. The financial constraints and amount of time it takes to obtain the EPG technology can be a deterrent for clinicians. According to Gibbon et al. (1999) clinicians may feel that an investment in EPG is not cost effective. It should also be noted that the electro palate can initially make speech sound more distorted as it takes time to adjust to the device in the oral cavity. Due to these factors, most studies have utilized EPG as a research tool, rather than implemented it in clinical practice (Cheng et al., 2007; Goozee et al., 2003; Goozee, Murdoch, Ozanne, Cheng, Hill, & Gibbon, 2007; Hardcastle, 1987). The International Classification of Functioning, Disability and Health (ICF) framework describes the impact of disease or injury on the body and its functions, as well as an individual's ability to participate in daily activities (Murray & Clark, 2006). EPG focuses on the Level of impairment of Body Functions, which includes the integrity of tissues and organs along with their function (World Health Organization, 2001). The inability to use the tongue to produce speech sounds accurately leads to difficulties with activities and participation in daily life. The use of EPG may help to enhance and improve speech intelligibility and overall life participation. Although there is an abundant literature about EPG, most of the articles are case studies or reports, which are Level IV and V evidence. The previous research has shown the efficacy of using EPG during intervention; however, many previous studies have employed different types of EPG systems, procedures and protocols for using it. Future research is warranted in order to demonstrate the effectiveness of EPG manufactured by Complete Speech®as a treatment tool, to be used as an adjunct to traditional therapy.

EPG has been used in the assessment and treatment of children with articulation disorders of unknown etiology and speech sound disorders (Schmidt, 2007; Carter & Edwards, 2004; Hardcastle, Gibbons, & Jones, 1991; Wrench, 2007). The children presented in the different studies have difficulty with fricatives, affricates, rhotic /r/, alveolar and velar phonemes (McAuliffe & Cornwell, 2008; Gibbon, Stewart, Hardcastle & Crampin, 1999; Gibbon & Wood, 2003; Carter & Edwards, 2004). Most research used case studies; however, there are different EPG systems employed in the different studies, different intervention protocols and procedures used in the studies. According to Gibbon and Wood (2010), EPG therapy can be beneficial as it involves the principles of motor learning as the clients are "given opportunities for repetitive and intensive practice" (p. 520) along with visual feedback. This technology has been reported to assist speech-language pathologists in working with clients who have difficulties with phonemes that are not easily visible, such as /r/. EPG provides visual feedback and can be used in conjunction with traditional articulation therapy for successful results. Generally, candidacy for using EPG is determined by the clinician. The child must be able to follow directions and understand the connection between the sensors on the electropalate and the image they are seeing on the computer screen (Dagenias, 1995). As suggested by Dent, Gibbon, and Hardcastle (1995), the age or maturity of the child, awareness, motivation and the presence of structural abnormalities such as cleft palate are important factors that may influence performance in therapy with EPG.

Several studies have reported using EPG with children who presented with speech sound disorders (Carter & Edwards, 2004; Dagenais, Critz-Crosby, & Adams, 1994; Dagenais, 1995; Gibbon, 1999). Nordberg, Berg, Carlsson, & Lohmander (2008) study reported on two participants diagnosed with dysarthria secondary to dyskinetic cerebral palsy. Each participant had received speech and language therapy for two-to-three years before beginning training with the EPG device. For eight weeks, EPG was used to remediate /t/, /d/, /n/, and /s/. After acclimating the clients to speaking with the electropalate in place, the therapy protocol progressed through several stages: Production of target sounds in syllables, word-initial position, all positions in words, two-word phrases, short sentences, and in stories containing the target sounds in all positions. Results revealed that the participants exhibited more accurate tongue placement for the targeted sounds after the EPG therapy. A study conducted by Gibbon & Wood (2003) focused on how EPG technology could remediate a moderate phonological delay in an 8-year-old with cerebral palsy.

The study focused on the production of velar targets [k, g, ŋ], which the participant was consistently producing as [t, d, n]. Over 15 sessions, the participant learned how to use the visual feedback provided by the EPG software to help execute the correct tongue-to-palate contacts for the target phonemes. The results of this study showed that prior to working with EPG technology, the participant was producing both alveolar and velar targets posteriorly in the oral cavity. After therapy with EPG, the participant began producing alveolar sounds more anteriorly. The findings of their study suggest that EPG technology is beneficial in training individuals how to produce sounds that are not currently in their phonetic inventory, as well as "kick start articulatory change" in a child with abnormal articulatory productions (Gibbon & Wood, 2003, p. 369). Several studies (Dagenais et al., 1994; Dent et al., 1995; Gibbon & Hardcastle, 1987; Gibbon, Hardcastle, & Moore, 1990; Hickey, 1992) have reported that EPG has aided in the improvement of specific speech sounds (e.g., improving articulation of /s/, /r/, and true palatal sounds) in children who arenot advancing with traditional speech therapy approaches (McAuliffe & Cornwell, 2008). Dagenais et al. (1994) examined the effects of EPG on the remediation of a persistent lateral lisp in two eight-year old typically developing participants. McAuliffe and Cornwell (2008) conducted a similar study and sought to determine if EPG technology would reduce the perceived "sloppiness" of the lateral /s/ phoneme in an eleven year old typically developing participant. Results of these studies revealed that after training with EPG, the participants were able to produce the targeted sounds more accurately. The ability to view the position of the tongue and its movements in real time during speech makes EPG an invaluable tool in therapy. Use of EPG helps children understand and develop conscious control of the internal cues used with tongue activity. Children may use biofeedback provided by the EPG in the early learning of specific sound patterns. As therapy progresses the clinician can withdraw the visual display and biofeedback and encourage the clients to relyon their own tactile and proprioceptive clues. A key component of motor learning is that there is multiple and repetitive practice-frequent repetitive drill activities. Therapy should progress to stimuli with a more complex syllable structure and different phonemic contexts. These drill activities can be used with EPG to increase awareness of articulatory placement.

There are identifiable articulatory patterns for different consonant phonemes. Typical speakers however, vary in the amount of overall lingual contact they produce. For example, there are varying patterns of contact for both the bunched and retroflex varieties of the /r/ phoneme. In order to better visualize tongue shapes and contacts during speech, researchers have investigated the use of ultrasound as a biofeedback tool to improve the production of the /r/ phoneme (Byun, Hitchcock, & Swartz, 2014; Klein, Byun, Davidson, & Grigos, 2013). Byun et al. (2014) performed two studies with eight children over an eight-week period using ultrasound as a biofeedback treatment for targeting rhotic sounds (e.g., the [ɹ] sound in the word red). The investigators proposed that ultrasound would allow participants to visualize varying tongue shapes, in order to find the most facilitative variant for each individual. In Study 1 participants were cued to match a "bunched tongue-shape target" while in Study 2 participants were cued to use a variety of tongue shapes to facilitate a perceptually correct rhotic sound. Results revealed that the group from study 1 had little to no improvement in their ability to produce rhotic sounds, while the group from study 2 made significant gains in production of rhotic sounds (~80% accuracy after several treatment sessions). In this study, ultrasound was useful in visualizing movements of the tongue surface; providing biofeedback about the posterior tongue to the speaker. Ultrasound may be beneficial to use in conjunction with EPG, which allows for more visualization of tongue tip and anterior lingual movements as compared to ultrasound. Both tools may be viable assessment and biofeedback treatment options for individuals with articulation and speech sound disorders. The current study is investigating the effectiveness of using software manufactured by Complete Speech® as a biofeedback tool for children with articulation disorders.

Method

This study, including the procedures, was approved by the Institutional Board at Adelphi University. Consent was obtained from one parent/guardian and assent from the child who participated in the therapy sessions. All the participants resided within New York City/Long Island area and spoke only English. Each participant had received traditional articulation therapy for their errors and made little to no progress within the past year. None of the participants were currently receiving speech therapy services in addition to the therapy provided. In addition, none of the participants were receiving any other types of therapy services. Each parent/guardian received a child intake form to complete prior to the study. The intake form provided information about the child's background including medical, social and academic history.

Instrumentation

Electropalatography (EPG)- Smart Palate System by Complete Speech®

The Smart Palate System by Complete Speech® consists of three different parts: a custom-fit Smart Palate mouthpiece equipped with sensors that capture tongue-to-palate and lip closure contact (See Figure 1 in Appendix), a microprocessor called a Data Link which syncronizes the palate data with audio feedback (See Figure 2 in Appendix), and the Smart Palate Software which displays the real-time palatal contact on a computer monitor (See Figure 3 in Appendix) (Printed with Permission by Complete Speech, 2014). The Smart Palate is a custom-made device that is similar to a retainer. The Smart Palate is embedded with 42 touch-sensor electrodes from the back molars to the alveolar ridge. The electrodes allow the speaker's tongue-to-palate contact to be observed on the Palate View software. The Smart Palate also has lip sensors, that register lip-closure on the computer monitor. As the participants speak, their tongue placement is displayed on a coordinating palate model on the computer screen. The clinician has the ability to model appropriate place and manner using a split screen function as well as to create custom articulation targets for students to practice specific phonemes. These targets, known as tongue targets, allow clients to practice placement consistently without relying solely on auditory cues. The tongue targets for the /r/ phoneme are illustrated in Figure 1. The Gold Standard feature within the software allows the participants to receive quantifiable scores on their productions based on their selected targets. The Oral Coordination feature allows participants to practice oral motor movements by touching individual sensors selected on the screen. Audio recordings synchronized with palate contact can also be captured and played back to monitor accuracy of productions of sounds both in isolation and conversation (Reprinted with permission from Complete Speech, 2014).

Figure 1: The Tongue- Palate Contact Targets for the Production of the Retroflexed [r]

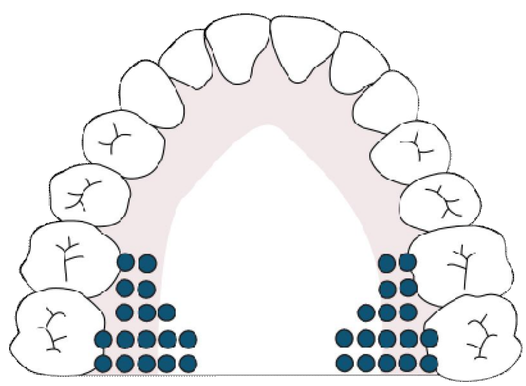
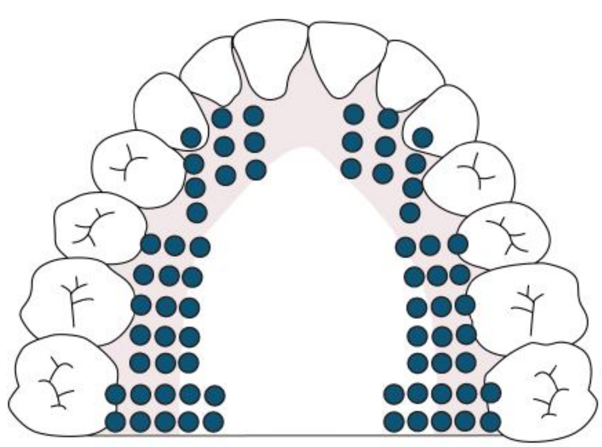


Figure 2: The Tongue-Palate Contact Targets for the production of the [ʃ]



Procedure

The participant's parent/guardian signed a consent form and the participants provided assent to participate in the intervention. Each participant's articulation and phonological skills were assessed to obtain a baseline measure prior to the EPG intervention. The principal investigator conducted an oral peripheral examination of each of the participants and elicited a conversational speech sample. In addition, the principal investigator conducted norm-referenced testing of two of the three participants (one participant had recently received a norm–referenced assessment measure). Each participant's parent/guardian was given a case intake form to provide the principal investigator with information about the participant's medical and developmental history. Therapy targets were determined based upon the assessment information. Afterwards, the participant's parent/guardian contacted their local dentist who took an impression of the participant's palatal arch to create the Smart Palate. The dentist sent the impression of the participant's palatal arch to Complete Speech's corporate headquarters where the artificial palate was created. The participant's dental visits and Smart Palates were covered by a faculty development grant awarded to the principal investigators by Adelphi University. The intervention began once the Smart Palate was received by the principal investigator. In addition, the investigators were fitted for Smart Palates, which were used during the therapy sessions. The study was conducted at the Adelphi University Hy Weinberg Center for Communication Disorders.

Participant #1

A female, age 9 years and five months, participated in this study. The participant's medical history was unremarkable with no known allergies or hospitalizations. Her mother reported that the participant suffered from recurrent ear infections, approximately five per year, between the ages of three through five that were treated with antibiotics. The participant's mother also reported that an audiological evaluation was completed earlier and the results revealed normal hearing. The participant's motor and speech and language milestones were achieved at age-appropriate times. The participant's mother indicated that she had received individual speech and language services both at school and at the university clinic for the past four years. Treatment had targeted both speech and language goals. In the past two years the participant had received traditional articulation therapy addressing only /r/ in all positions and did not make sufficient progress according to the Parent/guardian. The results of our initial assessment revealed that the participant had age-appropriate receptive and expressive language skills as evidenced by informal assessment. The oral peripheral examination revealed that structural or functional integrity of the articulators was within normal limits. Formal assessment employing the Goldman Fristoe Test of Articulation (GFTA-2) (Goldman & Fristoe, 2000) and the Khan Lewis Phonological Analysis (KLPA-2) (Khan & Lewis, 2002) revealed that her speech was age appropriate. The investigator elicited a conversational speech sample which illustrated that the participant had difficulty producing /r/ correctly in all word positions, the r-colored vowels [ɚ,ɝ] in the medial position of words, and r-colored diphthongs [ɛr,ɪr, ɔr, ɑr] in the medial and final positions of words.

Participant #2

The second participant was a male, aged 11 years 11 months. The participant had an unremarkable medical history and all developmental milestones were achieved within age expectations. The participant presented with no receptive or expressive language disorder at the time of this study. The participant's mother reported that he received traditional articulation therapy twice weekly for thirty minutes at his middle school. His mother also specifically requested EPG intervention. Formal testing was again conducted with the Goldman Fristoe Test of Articulation (GFTA-2) (Goldman & Fristoe, 2000) and Khan-Lewis Phonological Assessment-2 (KLPA-2) (Khan & Lewis, 2002) prior to initiating therapy. In addition, a conversational speech sample was elicited and revealed a speech pattern similar to the one revealed by the norm-referenced testing. The results revealed that the participant presented difficulty producing /s/, /ʃ/ and /r/ in all word positions. His production of /ʃ/ sounded like a lateral fricative. An oral-peripheral exam suggested no structural or functional abnormalities that would contribute to his misarticulations; however, he was hypernasal during speech production.

Participant #3

The third participant was amale, age 10 years and 1 month. The participant's medical history was unremarkable with no known allergies or hospitalizations. His mother reported that he suffered from ear infections and colds. She also reported that an audiological evaluation revealed that his pure-tone hearing results were normal. The participant's motor and speech and language milestones were achieved at age-appropriate times. She indicated that he had received individual speech and language services at school when he was enrolled in the 2nd and 3rd grade.

The participant began receiving speech therapy in the university clinic beginning in the summer of 2012. Initial goals targeted speech errors In the past two years the participant had received traditional articulation therapy addressing only the /r/ in all word positions and did not make sufficient progress according to the parent. The participant's mother and participant agreed to try EPG during the continued treatment. The results of our initial assessment revealed that the participant had age appropriate receptive and expressive language skills as evidenced by the Clinical Evaluation of Language Fundamentals (CELF-4). The oral peripheral examination did not reveal any evidence of structural or functional integrity issues. The results of the Goldman Fristoe Test of Articulation (GFTA-2) (Goldman & Fristoe, 2000) and Khan Lewis Phonological Analysis (KLPA-2) (Khan & Lewis, 2002) revealed that his speech was age appropriate except for one persistent error. The clinicians elicited a conversational speech sample which illustrated that he had difficulty producing /r/ correctly in all positions; however, he did not have difficulty producing /r/ in consonant clusters (as in the word "tree"). His productions of /r/ -> /w/ in the initial, medial and final positions of words.

Intervention Program

The investigator conducted the therapy individually once weekly for a 45-minute session over 10 weeks. The participant and investigator sat side by side during each session facing the computer monitor/screen. The investigator began the intervention explaining electropalatography and demonstrating how to use the electropalate. Perceptual data were recorded for each session of the program. In addition, a spontaneous speech sample was elicited and transcribed using IPA after the intervention was completed. The investigator also elicited a spontaneous speech sample 3 months post intervention. The first session consisted of a desensitization period, as suggested by McAuliffe and Cornwell (2008). A desensitization period was necessary because the electroplate can initially distort speech. For the first week, the participants were trained in wearing the electropalate while speaking. They also practiced making tongue-to-palate contacts for various lingual sounds with the Oral Coordination feature of the Smart Palate software. This feature allowed the participants to practice making tongue-to-palate contacts in succession in various positions on the palate with the aid of visual targets guiding the participant's tongue displayed on the computer screen. For example, while practicing with the Oral Coordination feature of the Palate View software, with the palate in situ, the participants would be instructed by the software to physically make the tongue-to-palate contact for a particular phoneme. There would be a highlighted dot on the computer screen instructing the participant where to place his/her tongue. The participant would then make the linguapalatal contact. Accuracy scores were kept to create a game-like feel. The oral coordination program for 2 and 5 contacts, was used in the beginning of each intervention session. The Gold Standard Module of the EPG software was used after the participant had established the correct or standard production for the phoneme being remediated. Afterwards, this program was incorporated into each therapy session until the end of the treatment program. The intervention program occurred from the 2nd to the 10th session. All the participant's speech was audio-recorded during each session. During the session, the investigator conducted a perceptual analysis of the participant's productions. A production was judged correct if it met 2 requirements: 1. It matched the lingua-palatal contact pattern and 2. A perceptual acceptable production of the target word. The Smart Palate was not worn during the connected speech portions of therapy.

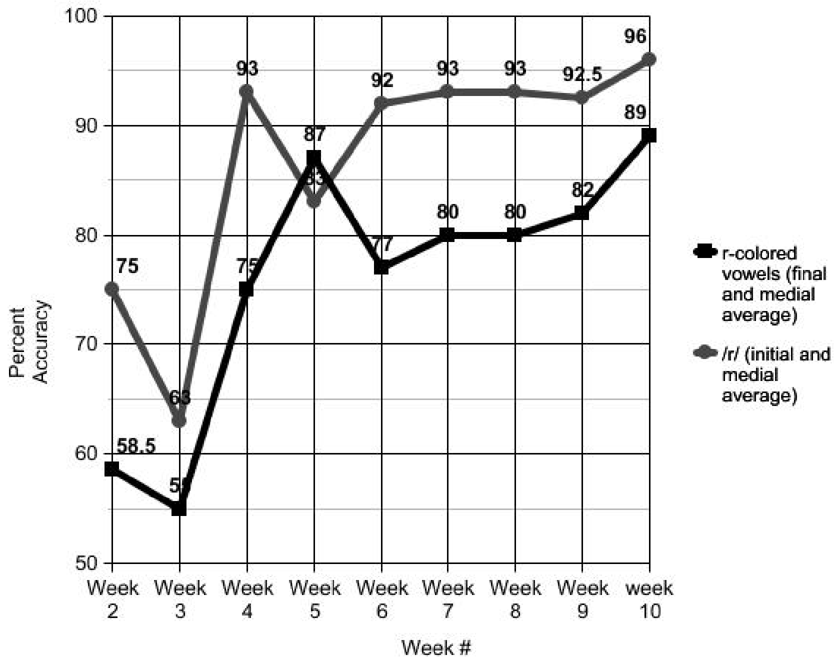
Teaching strategies were incorporated during the therapy sessions. Phonetic and tactile cues were provided to the participants during all sessions. Phonetic and tactile cues are supplemental ways to teach a child how to produce a specific sound. Phonetic cues were provided by explaining the placement of the tongue on the palate to produce /r/ while observing the articulators in a mirror. The investigators provided tactile cues by physically touching the area of the participant's alveolar ridge - with a gloved hand and/or tongue depressor in order to provide the participant greater awareness of accurate tongue placement. The investigators provided suggestions for self-monitoring and reminded the participants to be tactilely aware of tongue placement while matching the contacts patterns that appeared on the computer screen. This facilitated the production of those contacts again while the participant was wearing the palate. These phonetic and tactile cues also helped the participant with generalization of skills outside of the therapy room. These results will be discussed later in the paper. The investigators prepared therapy stimuli for each phoneme in each position based upon the child's age, gender, interests, and linguistic abilities. Ten to fifteen stimuli were prepared for each sound and the position. The investigator did not use all the stimuli for each session due to participant's fatigue, interest, and ability to sustain wearing the palate.

Results

Participant 1

The participant did not complete the oral coordination module consistently during the intervention program due to reduced cooperation and fatigue. Figure 3 illustrates the results of the intervention program for participant 1. Percent accuracy of /r/ in the initial and medial positions (initial and medial position average) increased from Week 2 (words) to Week 10 (connected speech). Percent accuracy of r-colored vowels (medial and final position average) also increased from Week 2 to Week 10 (connected speech).

Figure 3: Results of Intervention of /r/ and /r/ Colored Vowels (ɚ,ɝ)

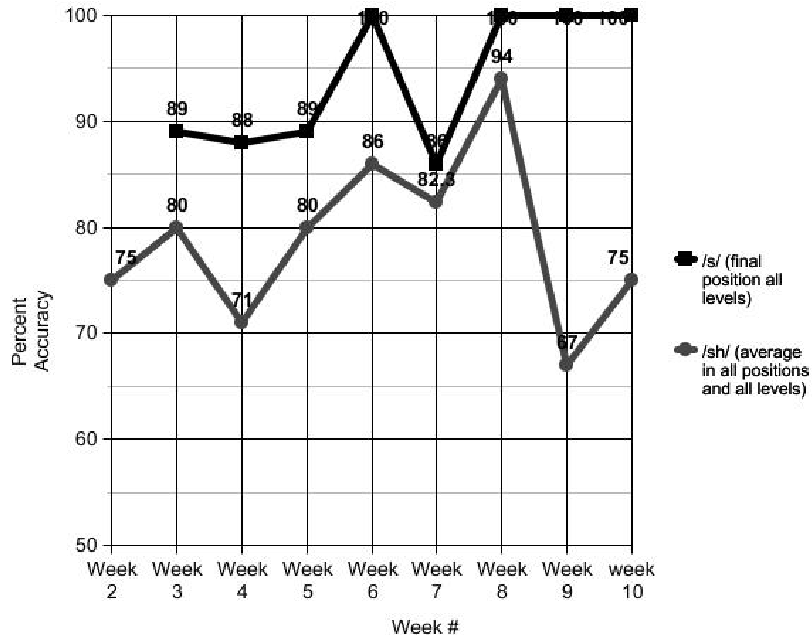


The investigator elicited a conversational speech sample from the participant after the intervention program. The participant's speech was transcribed using the International Phonetic Alphabet (IPA) and analyzed. The analysis revealed that the participant produced /r/ in connected speech with 92% accuracy and r-colored vowels [ɚ,ɝ] in the medial position with 80% accuracy and in the final position with 67% accuracy. Three months post-intervention the participant produced /r/ (including r-colored vowels) in connected speech with 40% accuracy, /r/ in the initial position of words at the sentence level with 100% accuracy, r-colored vowels in the final position of words at the phrase and sentence level with 90% accuracy, and r-colored vowels in the medial position of words at the phrase and sentence levels with 100% accuracy.

Participant 2

The participant completed the oral coordination module each session. The participant was asked to make 2 and 5 linguapalatal contacts three times each. Figure 4 illustrates the results of the intervention program for participant 2. Percent accuracy of /s/ in the final position increased from Week 2 (words) to Week 10 (connected speech). Percent accuracy of the /ʃ/phoneme (initial, medial and final position average) decreased from Week 2 (word level) to Week 4 (word level) then increased Week 8 (connected speech) and regressed again Week 10 (connected speech).

Figure 4: Results of Intervention of /s/ and /ʃ/

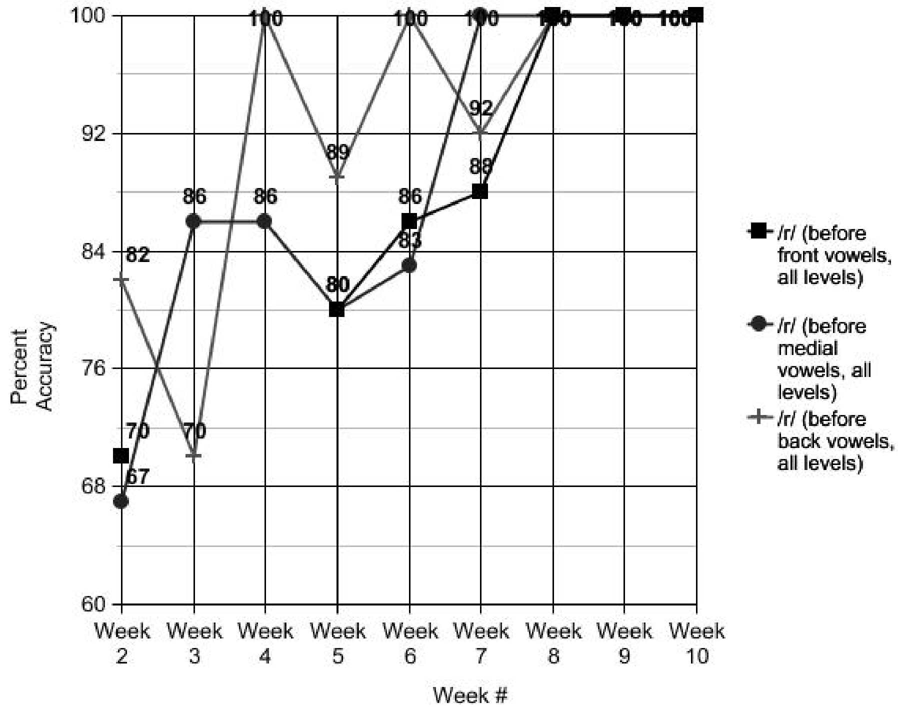


The investigator elicited a spontaneous speech sample from the participant. The participant's speech was transcribed and analyzed. The analysis of the participant's speech post-intervention revealed difficulty producing /s/ and /ʃ/in connected speech. He produced /ʃ/ correctly in a connected speech sample with 73% accuracy. Three months post-intervention the participant produced /s/ with 100% accuracy in connected speech, /ʃ/ in the initial position with 90% accuracy, (difficulty with medial vowels following it), 90% in the medial position, and 70% in the final position. Also, he had difficulty with /r/, specifically the r-colored diphthongs and vowels, in all positions was noted. The /r/ was not previously addressed in this intervention program because /s/ and /ʃ/ drastically reduced his intelligibility at the time.

Participant 3

The participant completed the oral coordination module during each session. The participant was asked to make 2 and 5 linguapalatal contacts three times each. The participant's oral coordination data was reported here for the first and last intervention session. During intervention session 1, the participant's average time (in seconds) for 2linguapalatal contacts was 3.4 seconds; for 5 contacts it was 12.4 seconds. During session 10, the participant's average time(in seconds) for 2 linguapalatal contacts was 1.5 seconds; for 5 contacts was 4.3 seconds. This exercise was a useful warm-up task helping the participant to adjust to wearing the Smart Palate and providing a variety of linguapalatal contact opportunities. Figure 5 illustrates the results of the intervention program for participant 3. Percent accuracy of /r/ in the initial position (before front vowels) increased from Week 2 (words) to Week 10 (connected speech), but regressed slightly during Week 6. Percent accuracy of r-colored vowels (before medial vowels) also increased from Week 2 to Week 10 (connected speech), but, accurate production decreased slightly during Week 6. Percent accuracy of r-colored vowels (before back vowels) increased after Week 4 to Week 10 (connected speech).

Figure 5: Results of Intervention of /r/ before Front, Medial, and Back Vowels



Intervention also addressed the r-colored vowels at the word, phrase and sentence levels. The participant accurately produced /r/ colored vowels 63% at the word level, 67% at the phrase level and 83% at the sentence level. As the intervention program progressed it was noted that the participant had difficulty with r-colored diphthongs (/ɛr/, /ɪr/, /ɔr/, and /ɑr/). The r-colored diphthongs were addressed for only three therapy sessions. Participant 3 produced /ɛr/ with 80% accuracy, /ɪr/ with 95% accuracy, /ɔr/ with 100% accuracy, and /ɑr/ with 60% accuracy. The investigator elicited a spontaneous speech sample from the participant immediately after the conclusion of the intervention program. The participant's speech was transcribed using the IPA and analyzed. The analysis of the participant's speech post-intervention revealed that he produced /r/ and r-colored vowels correctly in connected speech with 82% accuracy. The investigators did not have data 3 months post intervention program for this participant.

Discussion and Conclusion

The results of the three case studies reveal that the EPG instrumentation and software manufactured by Complete Speech® is beneficial as a visual biofeedback tool in addition to traditional therapy. The results concur with previous research studies which have found positive effects of using EPG in therapy (Gibbon, Stewart, Hardcastle, & Crampin, 1999; Carter, & Edwards, 2004; Dagenais, 1995; Gibbon & Wood, 2003; Gibbon, & Hardcastle, 1987). It should be noted that the investigators were only able to obtain data for two of the three participants 3 months post intervention. Participant 1 had regressed in her production of the /r/ phoneme in connected speech post intervention; however, not at the sentence level. Participant 2 produced /s/ and /ʃ/ with greater than 90% accuracy in connected speech three months post intervention. These results support the finding that EPG and traditional therapy provide a long-term solution to persistent articulation errors. It should be noted that the participants did not have access to an EPG system at home, therefore, home practice data were not taken. There were many positive predictive factors that should be noted. All the participants had age appropriate cognitive and language skills as indicated by formal and informal testing. The participants were cooperative and motivated to try an alternative intervention approach to help remediate their persistent speech errors. Also, each participant received an equal number of consecutive therapy sessions.

Limitations and Future Research

This preliminary investigation employed only three child participants, two males and one female of diverse backgrounds to investigate the use of EPG as a biofeedback tool. Even though this study provided an overview of the benefits of EPG by Complete Speech®, a larger participant group and statistical analysis should be employed in future studies. It should be noted that the lack of home practice might have contributed to the limited carryover of results three months post-intervention for one of the participants. Another factor to consider is that EPG is a tool which could be incorporated with traditional therapy approaches into the session. There is no standard procedure on how to implement the technology in the session; therefore, another factor affecting the clients progress is the clinician's experience with the technology and working with client's with speech sound disorders. Future research is warranted and should include a larger sample size, acoustical measures in addition to EPG, and comparison to different type of treatment techniques.

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Appendices (Permission provided by Complete Speech to use Pictures)

Appendix 1: Pictures of the Complete Speech Equipment

Figure 1: Mouthpiece from Complete Speech with Embedded Electrodes

Figure 2: Datalink from Complete Speech

Figure 3: Smart Palate System and Software Visual Display on Computer Monitor