Electropalatography: A Case Study

in APA format

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Abstract

Purpose: The aim of this study was to answer the following questions: 1) Through the application of EPG, can an individual with AOS improve speech sound production for /ʃ/ in the initial position and final position of words? 2) Can the improvement of sound productions be generalized to untreated words? 3) Is improvement only limited to the target phoneme? Initially, AOS is defined and characteristics and typical treatments for AOS are reviewed; also, the instrumental technique of EPG is defined and discussed.

Method: An ABA single- subject design combining EPG and an explicit motor learning framework was implemented on a 65 year-old male diagnosed with AOS and Broca's aphasia secondary to a left CVA 9 years prior. The participant received visual feedback provided by an EPG system for treatment of the target sound /ʃ/ in the initial and final position. The phoneme /r/ was used as an untreated control.

Results: The participant increased his production of the target sound /ʃ/ in the initial position of trained stimuli by 51.90% from pre- to post-treatment, and by 34.29% in the final position of trained stimuli. Also, generalization occurred in both positions: the participant increased his productions of the target sound /ʃ/ in the initial position of untrained stimuli by 47.62% from pre- to post- treatment and in the final position of untrained stimuli by 32.86%. However, the participant's improved production of /ʃ/ was not generalized beyond the word level. Effect Sizes (ES) utilizing a Cohen's *d* equation were calculated for all results and ranged from 1.92 to 5.84, which represent medium to large effect sizes.

Conclusion: The results indicate that an individual with AOS can improve speech production through the application of EPG as well as generalize those improvements to untrained words.

Introduction

Nature of AOS

AOS is a motor speech disorder resulting in impairment of the motor planning and programming of speech movements, which results in articulatory temporal and spatial segmental and prosodic distortions. McNeil, Robin, & Schmidt (2009) state, "it is not attributable to deficits of muscle tone or reflexes, nor to primary deficits in the processing of sensory (auditory, tactile, kinesthetic, proprioceptive), or language information" (p. 264). In studies reviewed by McNeil, et al., (2009), patients with AOS typically exhibit the following speech characteristics: 1) more consonant than vowel errors, 2) more substitution than distortion, omission, or addition errors, 3) more errors in the initial than the final position of words, 4) more errors of simplification (e.g. cluster reduction) than complication (e.g. addition of a phoneme or syllable), 5) more single feature than multiple feature sound substitutions, and 6) more place than manner or voicing errors. Some additional characteristics of individuals with AOS are variability in errors, effortful speech, articulatory groping, sequencing errors (e.g. "caktin" replaces the word "catkin"), reduced rate of speech, phoneme initiation impairments, and abnormal prosody (Hardcastle, MorganBarry, & Clark, 1985; Howard & Varley, 1995; McNeil, Doyle, & Wambaugh, 2000; McNeil et al., 2009). Anatomically, AOS results from unilateral and anterior lesions (McNeil et al., 2000) to the left cerebral hemisphere, including the parietal lobe, subcortical structures (e.g thalamus and basal ganglia), and the insula (Duffy, 2005).

Typical treatment methods for individuals with AOS

In a review of the treatment literature by Wambaugh, Duffy, McNeil, Robin, & Rogers (2006), the most commonly utilized treatment techniques for individuals with AOS can be placed into four categories: a) rate and/or rhythm approaches, b) methods involving alternative and augmentative communication (AAC), c) intersystemic facilitation/reorganization techniques, and d) articulatory/kinematic approaches. Rate and/or rhythm approaches are utilized with individuals with AOS for the treatment of timing issues, temporal patterning, and reduced rate of speech. Some techniques included in this approach are metronomic pacing, computerized control and/or feedback, and pacing or alphabet boards. For the second approach to treatment, the use of AAC techniques with an individual with AOS involves a device that serves as a communication medium to supplement and/or replace speech production for improved communication. The devices can range from no-tech to high-tech (e.g. no-tech consisting of a communication board with symbols and high- tech consisting of a computer system such as the Lingraphica), and must be individualized to meet the patient's specific daily needs for functional communication. The third approach, intersystemic facilitation/organization, involves the use of limb gestures for the reorganization of the framework for speech production. The most frequently used technique for reorganization with AOS is gestural reorganization. Gestural reorganization can include meaningful or nonmeaningful gestures (e.g. finger-counting or hand tapping).

Articulatory/kinematic approaches target correct articulation and sequencing of articulatory gestures for individuals with AOS. There are various techniques utilized for this approach; however, most and/or all studies reviewed by Wambaugh and colleagues (2006) incorporated a) motoric practice of speech targets, b) the use of modeling/repetition to obtain desired targets, and c) the use of integral stimulation, which involves providing the client with both auditory and visual modeling of targeted productions. Some other techniques for stimulation include direct instruction to the patient in terms of movement and placement of their articulators (e.g., prompts for restructuring oral muscular phonetic targets (PROMPT) approach).

Beside the different approaches to treatment, motor learning concepts are vital to the acquisition and retention of skills for individuals with AOS (Wambaugh, Kalinyak-Fliszar, West, & Doyle, 1998; McNeil et al., 2000; Wambaugh, et al., 2006; McNeil, Katz, Fossett, Garst, Szuminsky, Carter, & Lim, 2010; Yorkston, Beukelman, Strand, & Hakel, 2010). One principle is feedback, including amount and type. To increase acquisition of a motor skill, feedback should be provided after every trial. Once a motor skill is acquired, the amount of feedback should be reduced to increase retention and generalization of the skill. Type of feedback can be divided into knowledge of performance (i.e. specific feedback about what the client is doing…. "your tongue was too far forward") or knowledge of results (i.e. more general "that was good"). Knowledge of performance leads to improved acquisition of a motor skill while knowledge of results is suggested to lead to increased retention as well as the ability of the individual with a motor speech disorder to self-correct. A second motor learning principle is modeling. Frequent modeling should be utilized to assist the participant in acquiring new skills. This modeling should be provided visually and auditorily, both important aspects provided in traditional treatment approaches with the AOS population (Duffy, 2005; Wambaugh et al., 2006). As with feedback, modeling should be gradually withdrawn as speech sound production improves in order for new speech sound production skills to be generalized as the speaker with AOS uses their own internal model for correct sound production. A third motor learning principle is amount and specificity of practice. The amount of practice is a vital aspect of motor learning in that it requires experience. Speakers with AOS must practice speech movements repeatedly to make adequate progress. Specificity of practice simply means performing activities that are task specific (i.e., practicing linguistically meaningful material compared to isolated phonemes or non-speech tasks). The fourth motor learning principle is the order of practice of stimuli. Blocked practice (i.e., repeating a word or task a number of times before moving to the next word and following the same order of words/tasks throughout a treatment session) often leads to better acquisition, while randomized practice (i.e., producing each word one time before moving to the next word and randomizing the order of the words/task throughout a treatment session) often leads to better retention. The intent of treatment for acquired AOS is to adopt the appropriate treatment approach and motor learning principles in order to maximize therapeutic success.

Augmented Feedback of Articulatory Movement

As indicated in the review of treatment for AOS, feedback plays an important role. Auditory-based feedback is central to treatment; however, such feedback alone may not always be effective in improving speech sound production due to the complex movements underlying speech (Thompson-Ward & Murdoch, 1998; Katz, Bharadwaj & Carstens, 1999; Wood & Hardcastle, 2000). Supplementing or augmenting the auditory signal through instrumental techniques may lead to maximization of treatment. Recently, studies have focused on exploring the use of supplemental visual feedback of movement of the speech articulators in the treatment of adults with AOS (MorganBarry, 1989; Hardcastle, Gibbon, & Jones (1991); Howard & Varley, 1995; Katz et al., 1999; Katz, Garst, Carter, McNeil, Fossett & Doyle et al., 2007; Katz, McNeil, & Garst, 2010; McNeil et al., 2010). Two instrumental methods which have been used for the treatment of motor speech disorders include Electromagnetic Articulography (EMA) and Electropalatography (EPG). EMA is a noninvasive method of tracking articulatory movements through electromagnetic fields. A number of treatment studies have documented the successful augmentation of therapy through the use of visual feedback of tongue movement in the treatment of AOS (Katz et al., 1999; McNeil et al., 2010). When using EMA, an individual is wearing an articulograph helmet with a sensor attached to the tongue tip. Feedback results from investigators utilizing a mouse drawing tool to indicate a "target zone" for specific phoneme productions which is presented visually via a computer monitor (Katz et al., 2010).

EPG is a visual feedback system that records the location and timing of tongue contacts with the hard palate during speech through the use of a grid of sensing electrodes (Hardcastle & Gibbon, 1997; Hardcastle et al., 1991; Gibbon, Stewart, Hardcastle, & Crampin, 1999). There are different available versions of EPG systems. The general intent of the different systems is similar (i.e., visualization of tongue-to-palate contact); however, system features may differ such as: number of electrodes, arrangement of electrodes, construction/material of artificial palate, and specific hardware/software (Gibbon et al., 1999). All systems have the potential to provide some form of visual feedback to the participants regarding lingual contact with the palate (e.g. sensors lighting up, changing shape, changing color, etc.). These components of EPG systems are utilized to enhance feedback, therefore, the participant will not only receive auditory and proprioceptive feedback, but additional feedback regarding both temporal and spatial lingual contacts with the palate during both static and dynamic movements, a type of visual feedback for which traditional therapy methods cannot provide (Hardcastle et al., 1991; Howard & Varley, 1995).

Tongue-to-palate contact differences noted in individuals with AOS through the use of EPG

The adoption of EPG to the study of the underlying nature of the articulatory impairment in the speech of individuals with AOS, has led to an enhanced understanding of the disorder. Wood and Hardcastle (2000) reviewed and summarized the main tongue-to-palate differences detected in individuals with AOS compared to neurological normal speakers. Based on the original findings of Wood and Hardcastle (2000), and more recent work, individuals with AOS exhibit the following differences: 1) longer durations of lingual palatal contacts (Skenes, 1987**;** Wood, 1997; Howard, 1998; Bartle-Meyer & Murdoch, 2010), 2) increased variability of target gestures (Washino, Kasai, Uchida, & Takeda, 1981; Hardcastle & Edwards, 1992**;** Southwood, Dagenais, Sutphin, & Mertz Garcia, 1997; Wood, 1997; Bartle-Meyer, Murdoch, & Goozee, 2009), 3) increased number of lingual palatal contacts made (Washino et al., 1981; Howard, 1998), 4) misdirected articulatory gestures not perceived through auditory analysis (Hardcastle, 1985; Hardcastle et al., 1985**;** Sugishita, Konno, Kabe, Yunoki, Togashi, & Kawamura, 1987; Hardcastle & Edwards, 1992; Wood, 1997; Howard, 1998; Bartle-Meyer, et al., 2009), 5) errors in sequencing and selection (Hardcastle et al., 1985; Howard, 1998), 6) errors not being restricted to a single place or manner of articulation (Hardcastle et al., 1985; Hardcastle, 1987; Edwards & Miller, 1989; Hardcastle & Edwards, 1992; Wood, 1997), 7) disturbed temporal overlap in stop-stop sequences (Edwards & Miller, 1989; Ingram & Hardcastle, 1990; Hardcastle & Edwards, 1992; Wood, 1997; Southwood et al., 1997), and 8) syllable segregation (Howard, 1998).

Rationale for Agumenting Traditional Therapy for AOS with EPG

EPG has a long history of supplementing treatment in order to successfully treat a variety of communication disorders including AOS (Gibbon & Hardcastle, 1989; Morgan Barry, 1989; Hardcastle et al., 1991; Imai & Michi, 1992; Howard & Varley, 1995; Wood & Hardcastle, 2000). EPG can provide feedback for both static and dynamic movement errors not only visually but can also provide proprioceptive and tactile feedback to the patient (Edwards & Miller, 1989; Hardcastle et al., 1991). Hardcastle et al., (1985) suggest intact sensori-motor skills in AOS may benefit from improved tactile and proprioceptive awareness of tongue placement with EPG based feedback. Secondly, the character of errors as indicated by McNeil and colleagues (2009) (i.e., more consonant and than vowel errors; more substitutions than other consonant errors; predominance of place errors for consonants in the initial position) are conducive to benefit from EPG feedback based on previous studies (MorganBarry, 1989; Howard & Varley, 1995). The use of visual feedback may also be important for individuals with AOS because of the increased likelihood of auditory comprehension deficits associated with the co-occurring aphasia. The visual feedback provides them with a potentially easier means of identifying and understanding their speech errors to make the necessary changes (Duffy, 2005). The most beneficial part of incorporating EPG into therapy is the visualization of performance of tongue-to-palate contacts inside the oral cavity and association of the contacts with the auditory signal. Such a visual feedback system can provide the clinician with the ability to provide more adequate feedback consisting of knowledge of performance (e.g. “you’re tongue was too far back”) while also allowing the participant to visually observe the static and/or dynamic aspects of movement and the associated speech output. The unique information on articulatory activity provided by EPG is information that cannot always be accessed through perceptual judgment (Hardcastle and Gibbon, 1997; Wood and Hardcastle, 2000).

Given the success of EGP-based therapy with other communication disorders and the recent benefits of EMA-based feedback of articulatory movement in individuals with AOS, what is the effect of EPG-based treatment on apraxia of speech? The following section is a review clinical research studies on the use of EPG in treatment of both adults and children with a diagnosis of apraxia of speech.

Treatment studies adopting EPG as a form of visual feedback for treatment of acquired AOS

Research evaluating the influence of EPG on speech sound production in individuals with acquired apraxia of speech consisted of individual case studies. In a paper by Morgan Barry (1989), the author described a number of cases of individuals exhibiting a variety of communication disorders where EPG was adopted in treatment. One case involved a 49 year-old male exhibiting mild to moderate dyspraxia. Treatment included a visual feedback approach which targeted linking the typical linqual-palatal contact patterns for alveolar, velar, and palatal obstruents with both auditory and kinaesthetic feedback during non-speech activities "so that where a particular target sound was required, the appropriate placement was achieved at the first attempt" (p. 89). This was combined with a "slowed" speech approach. Visual feedback of tongue-to-palate contact was removed at the end of each session in order for the participant to achieve practice without EPG feedback. After treatment, the participant noted a slight improvement in speech sound production, but felt that his speech was still unpredictable (Morgan Barry, 1989). Objective pre and post-treatment measures were not reported by the author.

The only other case study involving an adult participant was completed by Howard and Varley (1995). The study investigated the use of EPG as an approach to treatment for a 47 year-old male with a diagnosis of severe acquired AOS. The authors indicated two reasons for the possible benefits of using EPG with individuals with acquired AOS: a) it is useful for providing necessary visual feedback to assist speakers in modifying their abnormal articulatory patterns, and b) it provides the SLP's with specific information on articulatory activity that cannot always be accessed through perceptual judgment. The participant, two years prior to participating in the study, had been diagnosed with a subdural empyema in the left sylvian fissure, and meningitis. Following a left temporal craniotomy, the participant suffered aphasic and AOS characteristics including highly unintelligible speech, with little to no improvement through weekly individual therapy for which the authors did not provide a description. EPG therapy consisted of two weekly 1-hour sessions, one with a speech-language pathologist and clinical phonetician, and one with minimal supervision by the authors to allow the participant to experiment and practice on his own. Initially, the participant completed an oral motor treatment phase which consisted of performing basic oral motor activities while receiving visual feedback regarding lingual contact of the palate. This included tongue tip/blade control activities through first making front and back contacts of the palate and then alternating between front and back contacts at different frequency rates.

The second phase of treatment focused on alveolar tongue-to-palate contacts. Therapy for this phase involved the use of minimal pair practice for the phonemes /d/ and /l/ (e.g., 'dough' and 'low') at both the word and phrase level. These speech sounds were chosen based on the distinct difference in the contact of the palate (i.e., /l/ was associated with a more lateral contact of the palate while the contact for the /d/ was more centralized). Production practice of the speech sounds first occurred without voicing by having the participant imitate static tongue-to-palate contact patterns modeled by the clinician. When the participant was able to achieve the patterns correctly, he was instructed to produce the speech sounds with voicing. This proved to be difficult for the participant, as individuals with AOS often exhibit more difficulty producing non-sense syllables or words (Yorkston et al., 2010). To remediate this, the speech sounds were introduced in minimal pair consonant-vowel (CV) words. Back, open vowels were chosen to help reduce co-articulatory effects on the participant's productions. As therapy progressed, stimuli increased to multisyllabic words, with some containing both target phonemes (i.e. 'ladder' and 'dollar').

The results of the study indicated the participant could produce words containing the phoneme /l/ before /d/; however, he revealed difficulty producing words containing the phoneme /d/ before /l/, and began exhibiting more lingual groping and sound searching than prior to EPG treatment. Quantitative outcome measures were not provided, which makes interpretation of the success of the study difficult to determine; however, the authors state based on their experience, EPG 'has been shown to be a valuable technique in apraxia therapy' (Howard & Varley, 1995; p. 255).

Treatment studies adopting EPG as a form of visual feedback for treatment of Childhhood Apraxia of Speech (CAS)

Two case studies to date adopted the use of EPG as a form of visual feedback for children with developmental apraxia of speech. Morgan Barry (1989) investigated the use of EPG for treatment of a case of a 9 year-old male participant exhibiting moderately severe oral and "articulatory dyspraxia" (p. 87). Therapy was implemented twice a week and targeted tongue-tip movements for non-speech activities, the phonemes /l/ and /s/, and alveolar stops. After "extensive" practice, the participant achieved a "reasonable /l/, some double articulation as well as good attempts at alveolar stops, and a slow release of the stop pattern which he was able to refine into an acceptable /s/" (p. 87).

A second study describing the application of EPG to a child with AOS was completed by Lundeborg & McAllister (2007). The study investigated the use of EPG and intra-oral sensory stimulation for a child with severe developmental dyspraxia. The participant was a five year-old female who had been receiving therapy since age 3 years, 6 months with no speech improvement (only oral motor skills and non-speech movements had improved). Intra-oral sensory stimulation treatment in the study included oral stimulation utilizing an electric toothbrush combined with EPG therapy consisting of non-verbal movement and precise articulation improvement, which aimed to improve the participant's lingual movements for the place and manner of her articulation. Treatment consisted of 2 steps. The first step involved 3 months (3-5 minutes daily) of general oral stimulation via an electric toothbrush on the surface of the tongue, the lips and the alveolar ridge of the participant. After a 3-month withdrawal period and a re-assessment of the participant, the second step was completed through three phases targeting the phonemes /k/, /t/, and /s/ utilizing minimal pairs. During the second step, EPG was used as a biofeedback method, utilizing a portable training unit, which allowed for visual feedback of tongue-to-palate contacts without the use of a computer. Each phase lasted 5 weeks (15-20 minutes daily) and between each phase there was a 5- week withdrawal period. Phase one consisted of non-speech movements of different parts of the tongue to increase the accuracy and speed of the participant's tongue movements. Phase two consisted of "two contrasting speech sounds (/t/ and /k/), first each in isolation, then each in sequences, then the sounds in minimal pairs" (Lundeborg & McAllister, 2007, p. 73). Phase three consisted of the introduction of the speech sound /s/. The previously learned /t/ was utilized as a starting point for the participant in this phase.

Results revealed significant improvement through a number of outcome measures: Percentage of Consonants Correct (PCC) increased from 9.17% to 58.23%, Percentage of Phonemes Correct (PPC) increased from 33.83% to 73.33%, Percentage of Words Correct (PWC) increased from 0% to 21.43%, and her intelligibility increased from 10.9% to 65.2% (when judged by an expert). Although the participant did not reach full age-equivalency regarding her speech sound production and speech intelligibility by the end of the study, she was still easier to understand, even when speaking spontaneously.

Purpose of the Study

In reviewing the literature involving the use of EPG to augement treatment for both adults and children with apraxia of speech, findings are indicative of Phase 1 clinical research based on the Robey & Schultz (1998) framework. This phase utilizes small sample sizes with no controls. According to Robey & Schultz (1998), the "primary objectives for Phase 1 research are: (a) to develop critical research hypotheses for later testing; (b) to establish the safety of the new treatment; and (c) to detect the activity of a treatment" (p. 792). EPG has been established as a safe treatment method for a large number of individuals with a variety of different communication disorders involving varied ages (Gibbon & Hardcastle, 1989; Morgan Barry, 1989; Hardcastle et al., 1991; Imai & Michi, 1992; Howard & Varley, 1995; Gibbon et al., 1999; Wood & Hardcastle, 2000). The four initial case studies involving the use of EPG are promising with respect to therapeutic improvement but the studies as a whole exhibit the lowest level of treatment evidence (Yorkston, Spencer, Duffy, Beukelman, Golper, Miller et al., 2001; Wambaugh et al., 2006). Some general limitations of the studies include: a) small number of subjects, b) only consist of case studies which do not control for cause and effect (not a rigorously controlled experimental design), c) limited description of therapy procedures which affects replicatation, and d) lack of valid and reliable outcome measures to document the success of treatment. Wambaugh and colleagues (2006) suggest with the increased availability of EPG systems, in concert with more experimentally rigorous designs, a better understanding of the type of candidate who may benefit from augmentative EPG therapy may emerge. Such research is warranted given the documented benefits of EMA-based therapy, a much more costly instrumentally based form of treatment which visually augments articulator movement (Hardcastle & Gibbon, 1997; Katz et al., 1999; McNeil et al., 2010).

The present study was completed to further investigate the effectiveness of EPG treatment, as well as incorporate necessary motor learning principles for an adult with AOS and Broca's aphasia nine years post strong while providing sufficient detail for replication. The current study attempts to detect therapeutic activity through the application of visual feedback of tongue-to-palate contact for the targeting of frequently occurring errored phoneme within a single-subject ABA research design with an untreated control phoneme. General steps were adopted and followed from previous studies carried out by Gibbon, Hardcastle, & Moore (1990); however, modifications were made to fit the specific participant's skill level and incorporate the principles of motor learning thought to be important to therapy success with AOS. The current study attempts to answer the following questions: 1) Through the application of EPG, can an individual with AOS improve speech sound production for /ʃ/ in the initial position and final position of words? 2) Can the improvement of sound productions be generalized to untreated words? 3) Is improvement only limited to the target phoneme?

METHOD

Participant

The participant was a 65-year-old male who sustained a left Cerebrovascular Accident (CVA) approximately 9 years prior to participating in the present study. He graduated high school and attended two years of college before joining the Merchant Marines for two years. He was drafted into the United States Army at age 22 and served for approximately four years. After his honorable discharge, the participant worked a number of jobs ranging from sales to building construction. Presently he is unemployed and lives in a Veteran Administration home within a small town. Since the CVA, the participant received individual speech-language therapy over several years focusing on speaking and writing.

An assessment of the participant's hearing, feeding/swallowing, cognition, speech and language, skills was completed. A standard hearing screening (i.e., impedance and pure tone hearing screening) resulted in the participant exhibiting normal middle ear functioning. The participant was administered a pure tone hearing screening at 1000, 2000, and 4000 Hz at 20 dB. He passed all three frequencies in his right ear, however, he did not pass 4000 Hz in the left ear, even when presented at 25dBHL. Even with the participant's reduced functioning, it was determined the participant displayed adequate hearing for the purpose of the study. Unimpaired feeding and swallowing skills were noted. The Mini-Mental State Examination (MMSE) was attempted (Folstein, Folstein, & McHugh, 1973). The participant achieved a score of 17/30 points. The MMSE has a normative mean of 27.6 with a standard deviation of 1.7, indicating a score significantly below the norm. These results are not too surprising given the participant's linguistic deficits (see the results of the Short Form of the Boston Diagnostic Aphasia Examamiantion (BDAE-3) in Table 1) and the adverse effects of linguistic deficits on the validity of cognitive screening results (see Pashek (2008) for a review). Observation by the first author indicated the participant exhibited adequate cognitive skills needed to participate in the experiment.

All aspects of the participant's voice (i.e., pitch. loudness, vocal quality, nasal and oral resonance) were found to be typical for his age and gender. The participant's prosody was also assessed utilizing the rating scale form for Deviant Speech Characteristics of Speakers with Dysarthria (Duffy, 2005). His prosody was reduced as a result of his slow speaking rate (2) and short phrases (2). Moderate impairment in articulation was noted in the form of both imprecise consonants (2) and prolonged phonemes (2). The articulation errors consisted of substitutions and distorted substitutions. The participant's word intelligibility score was 87% (Kent, Weismer, Kent, & Rosenbek, 1989). Disfluencies consisted mostly of hesitations, word fillers, and interjections.

The participant was administered a Physical Examination (PE) which evaluates structure and function of the jaw, lips, tongue, resonation, phonation and respiration, and observed symptoms suggesting impairment of these structures/subsystems of speech production (Yorkston et al., 2010). Evaluation of function involved the use of an equal appearing interval scale (0-normal; 1- mild impairment; 2- moderate impairment; 3- severe impairment) to measure range of motion and strength during non-speech tasks. Results indicated adequate range of motion and strength for the jaw, lips, with the exception of right labial asymmetry and velum. Results of the tongue PE revealed adequate function for both vertical and lateral range of movement; however, the participant displayed mild asymmetry and moderate impairment for elevation strength (2) and mild impairment for right and left lateralization strength (1). Further tongue strength testing with the Iowa Oral Performance Instrument (IOPI) revealed elevation and left lateralization tongue strength were below normal limits while the participant's right tongue lateralization was within normal limits. Results for tongue strength are presented in the following table:

Task	Participant score	Normative Range[a]
Elevation strength	38.3 kPa	52-72 kPa
Right lateralization strength	56.3 kPa	40-70 kPa
Left lateralization strength	19.6 kPa	40-70 Pa

a) Clark, O'Brien, Calleja, & Corrie (2009)

The PE exam also involved the evaluation of diadochokinetic rates. During diadochokinetic rates, the participant's repetition of the syllables was consistent (meaning if he was correct, he was correct for all repetitions and if he was incorrect, he was incorrect on the same phonemes across all repetitions). Syllable errors included the addition of the phoneme /k/ in the final position for /tʌ/ and /kʌ/ tasks (resulting in a CVC formation of either /tʌk/ or /kʌk/) and the substitution of /k/ for /t/ in the /pʌtʌkʌ/ task. All tasks were produced at a normal rate with the exception of a slow repetition rate for /pʌ/.

The participant's average maximum phonation time across three trials was 22.42 seconds (18.57-25.74). This valve was typical for his age and gender (Dagli, Mahieu, & Festen, 1997). The participant's's average vital capacity across three trials was 3.134 liters. This measurement was slightly below normal limits (Kent, 1994).

Based on the Short Form Boston Diagnostic Aphasia Examination (BDAE-3) (Goodglass, Kaplan, & Barresi, 2001), the participant exhibits mild to moderate Broca's Aphasia. Results from the Apraxia Battery for Adults (ABA-2) (Dabul, 2000) indicated the presence of a mild to moderate Aqcuired Apraxia of Speech (AOS) Table 1 displays assessment results from these standardized measures. As noted in the table, the client does not exhibit limb or oral apraxia.

Table 1

BDAE-3 and ABA-2 Results

Assessment Measure	*Score/Impairment Level*
Boston Diagnostic Aphasia Exam (BDAE)	
Articulatory agility	4/7
BDAE Phrase length	3/7
BDAE Grammatical form	3/7
BDAE Melodic line	4/7
BDAE Word finding relative to fluency	7/7
BDAE Auditory comprehension	91%
Apraxia Battery for Adults (ABA-2)	
Diadochokinetic rate	Moderate
ABA-2 Increasing word length	Moderate
ABA-2 Limb apraxia	None
ABA-2 Oral apraxia	None
ABA-2 Utterance time for polysyllabic words	None
ABA-2 Repeated trials	Moderate
ABA-2 Inventory of articulatory characteristics of apraxia	16

Experimental Stimuli

In order to identify the treatment targets for the study, the participant was instructed to repeat a list of 135 words based on a study completed by Wambaugh and collegues (Wambaugh et al., 1998). The original list from the Wambaugh and collegues study contained more than 135 words. However, for this study, words beginning or ending with bilabials (i.e. /m/, /n/, /w/, /b/, and /p/), interdentals (i.e. /θ/ and /ð/), and labiodentals (i.e. /f/ and /v/) were omitted due to lack of occurrence of lingual-palatal contact. The participant's word productions were recorded through a Crown Differoid Condenser[1] (CM-311A) head-mounted microphone attached to a digital recorder (TASCAM PS-D1). The words were judged by the first author using a two-way scoring system (Shriberg & Kent, 2003). From this list, the most frequent errors occurred for: /z/ in the initial position, /ʃ/ in the initial and final positions, /tʃ/ in the final position, /r/ in the initial position, & /l/ in the final position (refer to Appendix 1 for specific results). The target sound selected for treatment was **/**ʃ**/** in the initial and final position of words. This was selected based on frequency of the participant's errors (i.e. the treatment sound **/**ʃ**/** was produced correctly 0% in the initial position and 20% in the final position) and the degree of homonymy created by errors (i.e."same" for "shame"; "sin" for "shin"; (McNeil et al., 2000). This homonymy leads to reduction in word intelligibility; therefore, through targeting this sound, intelligibility should improve.

Experimental Design

The design used for this study was an ABA single-subject design with baseline, treatment and maintenance phases. Prior to each session across phases of the design, a list of 30 probe words produced by the participant was audio recorded. These words were acquired without the pseudopalate placed in the oral cavity. For each session the prove words were presented in a randomize order. For each word, the experimenter would present an orthographic representation of the word in a large black font on a white 4 X 6 index card about 12 inches from the participant. After the presentation of the card, the experimenter would provide the verbal presentation of the word .The participant was instructed to repeat the word immediately after the experimenter. The participant did not view the experimenter's face during the presentation of the words and moderately slow pace of word presentation was adopted. All probes were audio recorded in a quiet room.

The probe list consisted of 10 trained and 10 untrained words containing the target sound **/**ʃ**/.** The trained words were words targeted within a therapy session. The untrained words were adopted to measure generalization of learning. The 20 words were equally split between the target phoneme being in the initial and the final position of words. The probe list also included ten words with /r/ in the initial position to serve as an untreated control. The untreated control words were selected for the same reasons as the target sound **/**ʃ/, which was due to frequency of the participant's errors and degree of homonymy leading to reduction in word intelligibility. Each probe list was listened to by the experimenter within a quiet setting and judged for accuracy of phoneme production (i.e., **/**ʃ**/** & /r/) using a two-way scoring system (Shriberg & Kent, 2003). The words were perceptually judged by the experimenter as being correct or incorrect for each probe list, and a percent correct score was calculated for a) **/**ʃ**/** in the initial position of trained words, b) **/**ʃ**/** in the final position of trained words, c) **/**ʃ**/** in the initial position of untrained words, d) **/**ʃ**/** in the final position of untrained words, and e) /r/ for the untrained control words. Incorrect productions consisted of either substitutions, distortions or substituted distortions. Refer to Appendix 2 for a list of the probe words.

[1] A Sony Electret Condenser Microphone (ECM-44B) was adopted partway through the study due to malfunction of the first microphone.

Instrumentation

Both the acoustic signal and the palatal contact data were recorded through the CompleteSpeech Palatometer V 1.0 system (“Palatometer Details,” 2011). The CompleteSpeech Palatometer system consists of an artificial palate (i.e., SmartPalate), DataLink, a USB cable connect between the DataLink and computer and the associated computer software. The computer adopted for the study was a Dell Latitude E6400 laptop computer with a 14 inch monitor. The participant’s SmartPalate was a custom-formed retainer with a thin flexible printed circuit that conformed to the shape of the participant’s palate. The SmartPalate contained 126 gold-plated contacts, including 2 lip closure sensors and 2 gum contacts. The DataLink consists of a microcontroller processer (48 Mhz) and an integrated Omni directional microphone (20-16000 Hz) for combined acquisition of audio and palate data through a USB port. The sound pressure waveform was digitized at 44 kHz and the tongue-to-palate contacts were digitized at a rate of 100 Hz. Both tongue-to-palate contacts and the sound pressure waveform are provided as a visual display on a computer screen. The exact details of how the display was adopted to provide visual feedback to the participant are described in the next section.

Treatment Procedures:

After baseline measures were stable (i.e., the trend of the percentage correct of probe data were relatively stable for the target phoneme), EPG treatment was initiated.

Palatal Desensitization Procedures

Prior to the beginning of each therapy session, the participant was instructed to wear the pseudopalate for approximately 15-30 minutes for a desensitization period. Previous studies involving EPG suggest the use of a desensitization period where the palate or pseudopalate is inserted in the mouth prior to use of the device for assessment or treatment to minimize the influence of palate placement on articulation (Gibbon & Hardcastle, 1987; Gibbon et al., 1990; Hardcastle et al., 1991; Gibbon et al., 1999; Goozee, Murdoch, & Theodoros, 2003; Cheng, Goozee, & Murdoch, 2005). The allotted time for desensitization for the present study was reduced relative to other studies involving EPG. This was due to transportation scheduling limitations to and from the university clinic.

Basic Treatment Steps

Treatment procedures consisted of traditional steps using electropalatograpy in combination with motor learning principles. The study involved an adaptation of the treatment steps proposed by Gibbbon et al., (1990) for electropalatography treatment : a) introduction to the system, b) performing non-speech tasks using the system in order to understand the relationship between the palate computer display screen and the participant’s tongue to palate contact, c) producing /ʃ/ in isolation, d) producing target words containing /ʃ/ (initially, 3 in the initial position, and 3 in the final position and eventually moving to 5 in the initial position and 5 in the final position), and e) gradually fading visual and verbal feedback. In addition to these steps, motor learning principles were adopted for this study including feedback (type and frequency), modeling, task-specificity, and type of practice (i.e., block vs. random).

The first step consisted of an introduction to the CompleteSpeech palatometer system. During therapy, visual feedback of tongue-to-palate contact was delivered through the CompleteSpeech real-time program. The participant was seated in a room, wearing a pseudopalate, approximately 2-3 feet away from the 14 inch computer monitor of the Dell computer. Therapy began with the experimenter describing the palatal display screen to the participant. The CompleteSpeech software palatal display screen consists of two palate displays, one for the participant and one for the experimenter. Each palate contains 126 open circles, each circle representing a contact sensor (see Figure 1). The experimenter described how the palatal display related to the anatomy of the human palate and demonstrated what occurred when she made tongue-to-palate contact using her own SmartPalate. If no pre-recorded tongue palate contact pattern associated with a speech segment is not displayed on the palate display, and tongue-to-palate contact is made, the open circles representing the sensors changes to blue. However, if a pre-recorded target sound contact pattern is set on the palate display for pattern matching purposes, the target sound contact pattern to match is represented as green filled circles. When the tongue makes contact with a sensor associated with the contact pattern, the green circle turns blue. If tongue-to-palate contacts outside the expected pattern are made, those sensors are displayed as orange filled circles. This first step of therapy ended with the clinician producing a number of different lingual sounds and describing to the participant how each sound related to what was being displayed on the palate display screen.

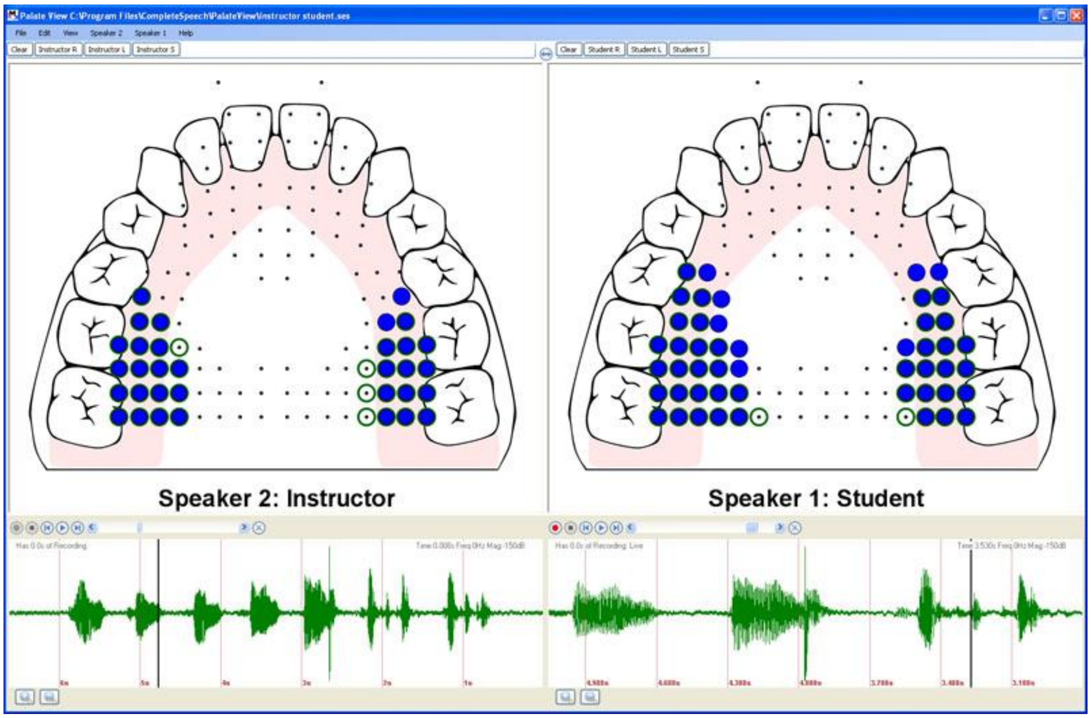

Figure 1: Palatal display on the CompleteSpeech system retrieved from www.completespeech.com. The green circles and blue sensors described above can be visualized on both the instructor and the student screens. The acoustic waves and audio-recording settings can also be viewed at the bottom of each screen.

The second step consisted of the participant performing non-speech tasks with the tongue with the participant's SmartPalate placed in his oral cavity. This step began with a series of non-speech movements involving the experimenter instructing the participant to make tongue-to-palate contact in the anterior, posterior, and lateral sections of his palate. During this step, the participant was instructed to either move his tongue between a front to back or right to left palate position. When a tongue-to-palate position was achieved, the experimenter indicated that the open sensor circles turned blue and the participant was instructed to hold the tongue-to-palate contact for approximately 10 seconds. After the 10 second period, the participant was instructed to move the tongue to the alternate position and hold the tongue-to-palate contact for that position for 10 seconds. This alternating sequence of movements was completed 3-4 times for each movement pair. This step ended with the experimenter randomly pointing to the palatal display on the computer screen and instructing the participant to make tongue-to-palate contact in that area of the palate.

The third step consisted of the participant producing target sounds in isolation while wearing the SmartPalate. This step was performed to help the participant to visualize the tongue to palate contact pattern for the /ʃ/. Perceptually, errors associated with a /ʃ/ exhibited a more high frequency fricative energy typically associated with a /s/. This suggested tongue placement was more anterior than needed for the /ʃ/ production[2]. First for this step, the experimenter instructed the participant to produce a number of different lingual sounds in isolation (e.g. k, g, t, and d) which the participant typically produced accurately. These sounds represented both anterior and posterior lingual contacts. After producing and discussing several productions of each isolated phoneme, isolated productions of the target sound /ʃ/ were practiced. For the first few sessions, this was first modeled by the experimenter while she was wearing a SmartPalate. Also, the target sound was first produced in isolation with no airstream. It has been found when using EPG in treating clients, initially clients acquiring a new articulatory pattern need to establish the pattern first without any other speech features present (e.g., voicing), and as a static posture (Hardcastle et al., 1991). This was completed to help simplify the task and direct focus toward lingual palatal contacts (i.e., enhance tactile and proprioceptive awareness). This step was also followed because placement of the tongue was thought to play a partial role in the difficulties producing this /ʃ/. Only the earliest stages in treatment utilized production of isolated sounds involving static posture until the participant moved into single word productions. The majority of the sessions of the treatment program focused on the production of /ʃ/ in words in order to target the instability of contact patterns associated with connected speech, a documented deficit in individuals with acquired AOS (Howard & Varley, 1985; Edwards & Miller, 1989; Wood & Hardcastle, 2000; Ziegler, 2005).

The fourth step consisted of the participant producing words containing the target sound /ʃ/. The vast majority of sessions the treatment phase involve only the procedures in this step. During all steps, the experimenter and the participant sat next to each other in order for both to visualize the palatal display on the computer screen. Both verbal and written presentation of the word was provided by the experimenter, followed by a request for the participant to produce the word. If the participant was successful at producing the word, he would be instructed to either repeat the word a few more times without a model by the experimenter or the next word would be presented (depending on how far into treatment he was-refer to Appendix 3). If the participant produced an incorrect production, the experimenter would verbally model the word and remind the participant to watch his tongue placement and round his lips. A mirror was utilized to provide feedback for lip rounding. Eventually, sessions consisted of only this final step, utilizing 10 words (5 with /ʃ/ in the initial position, and 5 with /ʃ/ in the final position) to increase practice productions for the participant.

The fifth and final step consisted of the gradual reduction of both verbal and visual feedback. This principle of beginning therapy with continuous knowledge of performance and eventually fading the amount and type of feedback was implemented with the participant in the current study. Approximately halfway through therapy, feedback from the experimenter became more variable (i.e. approximately every third to fourth production received verbal feedback). Also, this feedback shifted from mostly knowledge of performance to approximately 70% knowledge of results, while still providing specific feedback when necessary (i.e. the participant was having significant difficulty). The use of visual feedback was also gradually removed during the last 3-4 treatment sessions. Based on the participant's number of correct productions of a given word (i.e. 2 out of 3), visual feedback would be removed for the following set. Removal of the participant's SmartPalate was also implemented during the last 10-15 minutes of the final 3-4 sessions to monitor if success transferred into normal speech. For additional details regarding the treatment steps, refer to Appendix 3.

Motor Learning Principles

[2] After therapy began, it was noted the participant was not rounding his lips consistently. This could also result in higher frequency fricative energy because the tube anterior to the constriction for the /ʃ/ is shortened, leading to a high resonant frequency.

Different motor learning principles were incorporated into therapy to increase both acquisition and retention of the targeted phoneme production (Wambaugh et al., 1998; McNeil et al., 2000; Wambaugh et al., 2006; McNeil et al., 2010; Yorkston et al., 2010). The first principle was feedback, including amount and type. To increase acquisition of skills for the participant in the current study, feedback was provided after every trial initially (i.e. continuous feedback), and consisted of knowledge of performance (i.e. specific feedback about what the participant was doing "the right side of your tongue is no making enough contact" or "you aren't rounding your lips"). With improvement of trained stimuli, the feedback became less frequent (i.e. variable feedback) and consisted of knowledge of results which in the present case focuses on the achievement of the target speech sound. Knowledge of performance (e.g. "that was good" or "that sounded clear"/"that didn't sound like a clear /ʃ/") along with a reduction in the frequency of feedback was implemented to lead to increased retention of skills as well as self-corrective behavior by the participant.

A second motor learning principle incorporated was modeling. Frequent modeling should be utilized to assist the client in acquiring new skills. As indicated in earlier steps within the treatment program, the experimenter demonstrated and modeled with her own pseudopalate both non-speech and speech tasks for the participant to produce. This modeling was largely used when a new activity was introduced. The experimenter would perform the task, allowing the participant to observe and understand what was happening on the screen. The participant was then instructed to do the same and, depending on the amount of difficulty, the experimenter would perform the task along with him, or just provide verbal instructions. Modeling by the experimenter was also provided in the Goldstandard View on the CompleteSpeech system. This allowed the participant to make appropriate contact for a specific set target sound and the system would calculate the percent accuracy of the tongue-to-palate contact. The experimenter initially demonstrated how the Goldstandard View operated and explained the goal of striving for a high percentage. The modeling was tied closely to knowledge of performance feedback. This type of modeling was gradually eliminated and knowledge of performance feedback regarding the participant's contact patterns was used. The auditory modeling of the target sound in isolation and words was also gradually withdrawn. The experimenter modeled the target sound in isolation only the first 2-3 sessions. However, halfway through all sessions, production of the target sound in isolation was eliminated, and only words were being produced. The words were modeled for the participant until approximately the final 3-4 sessions. At that point, they were only modeled by the experimenter if the participant was having a large amount of difficulty with a particular word. As with feedback, modeling was withdrawn with improvement to enhance retention.

A third motor learning principle incorporated with the participant was amount and specificity of practice. To ensure an adequate amount of practice in the current study, the participant produced an average of between 250-300 practice words containing the target phoneme per session. Specificity of practice simply means performing activities that are task specific (in this case, using words with meaning more than non-speech tasks and phonemes in isolation). As indicated in the description of the stops of the therapy program, initially non-speech tasks and isolated productions were utilized for the participant to a) gain an understanding of the CompleteSpeech Palatometer system, b) understand the relationship between tongue movement and the palatal display and c) increase awareness of tongue movement, especially for the targeted speech sound. After this was achieved, these activities were withdrawn from therapy to focus practice on speech stimuli containing the target phoneme. After the initial introductory session, the following 4 sessions included 6 target words for practice (i.e. 3 with /ʃ/ in the initial position, and 3 with /ʃ/ in the final position. Session 5 until the final session (session 16), included the use of those same 6 target words with an additional 4 for a total of 10 target words for practice (i.e. 5 with /ʃ/ in the initial position and 5 with/ʃ/ in the final position). Additional words were added for session 5 because at that point, the number of non-speech tasks the participant was performing was greatly reduced, leaving more time for word practice. As stated earlier, task specificity is an important principle of motor learning, therefore, the current study strived to allow for maximal practice time with speech stimuli.

The fourth and final motor learning principle incorporated was the presentation of stimulus words. Blocked practice (repeated production of a word before moving to the next word and/or repeated production of words in the same order) often leads to better acquisition, while randomized practice (producing randomly ordered word lists) often leads to better retention. With the participant, a random-blocked order was utilized. This meant repeating the word 1-8 times (i.e. initially, the participant was instructed to repeat 8 times, and with every few sessions this number decreased) then moving to the next word in the randomized list of treatment words. After completion of each list of words, the words were randomized and practice was continued. The number of repetitions within a block decreased as the participant increased his ability to achieve more accurate word productions. As therapy progressed and the participant's accuracy level increased, the "blocked" component of practice was gradually faded out for purely random practice for many of the target words.

Reliability

As indicated, the first author made correct/incorrect judgments (i.e., two-way scoring system) of the target phoneme for both all probe words based on the audio recording. To calculate inter-judge reliability, a majority transcription method was adopted (Shriberg & Kent, 2003). The first step in this process involved the second judge evaluating all probes words for all sessions. A third judge listened to and judged any productions where there was a disagreement between the first two authors. The majority judgment for each disagreement was chosen as the correct response. Also, intrajudge reliability was calculated for 10% of the transcriptions for the three judges. The results were as follows: a) judge 1, 89%, b) judge 2, 68%, and c) judge 3, 87%. According to Shriberg & Kent (2003), these results fell into the average percentages of agreement for intrajudge reliability.

Data Analysis

Based on the majority transcription method, the percentages correct were calculated for the probe list words for each session. These results were visually graphed separately for: a) /ʃ/ in the initial position of trained words, b) /ʃ/ in the final position of trained words, c) /ʃ/ in the initial position of untrained words, d) /ʃ/ in the final position of untrained words, and e) /r/ for the untrained control words. A total of five graphs displayed percentage correct change for each session within the ABA design framework (i.e. baseline, treatment, and maintenance).

In order to document the change in the accuracy of phoneme production, comparisons were made between the baseline and the maintenance phase for each figure. The mean and standard deviation of all sessions in each phases were calculated. Due to the uneven number of sessions between the baseline and maintenance phase, statistical comparisons of the means could not be completed to identify a significant change in level. Instead the Two Standard Deviation Method (TSDM) was adopted (Satake, Jagaroo & Maxwell, 2008) For this method, a standard deviation confidence interval based on the baseline phase was used. If at least two consecutive percent correct session values within the maintenance phase fall above the 2 standard deviation baseline interval, then a significant change in treatment has occurred. In addition, the Cohen's *d* statistic was used as a measure of effect size (ES) in order to document the magnitude of change resulting from the supplemental EPG treatment. The Busk & Serlin (1992, pp. 197-198) formula for calculating a variation of the Cohen statistic (i.e., d_1) was used. This measure was selected based on the following reasons as outlined by Brossart, Parker, Olson, & Mahadevan (2006): 1) ES provides an index of the strength of association between intervention and outcome, from which the experimenter may infer how much of the outcome variable can be explained, controlled, and predicted by the intervention (Carver, 1978; Rosnow & Rosenthal, 1989), and 2) ES is not systematically affected by sample size, therefore, even short data series can be calculated into a strong ES. The ES in the current study was calculated based on all data points in the baseline and maintenance phases, and not on a certain number of points within each phase[3]. Given the lack of effect size results for motor-based treatment to use for comparison of ES as indicated by Katz et al., (2010a or b), the present study compared ES values to language intervention ES values provided by Robey, Schultz, Crawford and Sinner (1999).

RESULTS

The participant's performance on the percent correct production of the target sound /ʃ/ in the initial position of trained stimuli is displayed in Figure 2. As can be observed, the participant increased his productions of the target sound from a baseline mean of 26.67 (with a standard deviation of 10.33) to a maintenance mean of 78.57 (with a standard deviation of 16.57), resulting in a 51.90% increase in the accuracy of the target sound production from pre- and post-treatment. Plotting and calculation of the TMSD resulted in the magnitude of all the percent correct values for the session within maintenance phase being greater than the upper plus two standard deviation confidence interval. The Cohen's d resulted in an ES of 5.02, which reveals a large magnitude change between the baseline and maintenance phases (Robey et al., 1999).

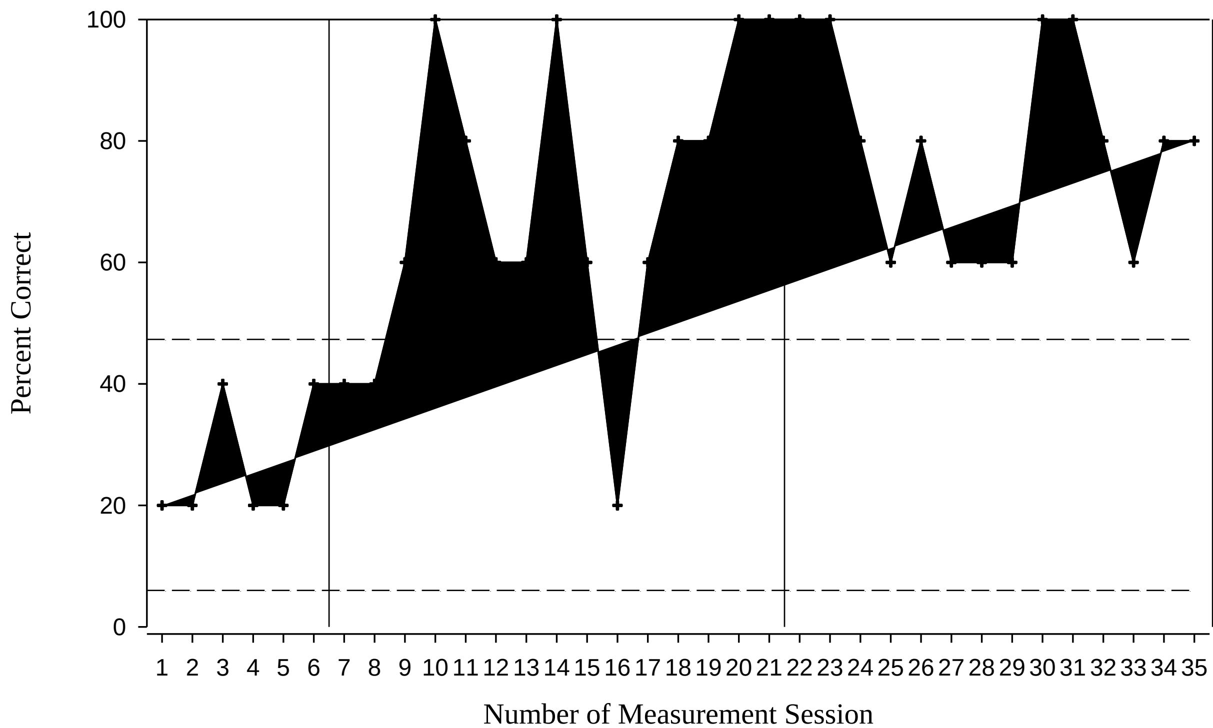

Figure 2: Percent correct values across all sessions for the "sh" in the initial position of trained words. The solid vertical lines separate the three ABA phases. The two horizontal dashed lines represent +/- 2 standard deviation confidence interval basedon the mean and standard deviation of the baseline sessions.

Figure 3 displays the participant's performance on the percent correct production of the target sound /ʃ/ in the initial position of untrained stimuli. The participant increased his productions of

[3] If there is no standard deviation, the equation cannot be computed (Robey, Schultz, Crawford, & Sinner, 1999). In Figure 5 of the current study, there was no standard deviation across the baseline sessions, and therefore, the Cohen's *d* statistic was not calculated for the /ʃ/ in the final position of untreated stimuli.

the target sound from a baseline mean of 36.67 (with a standard deviation of 8.16) to a maintenance mean of 84.29 (with a standard deviation of 17.85), resulting in a 47.62% difference between pre-and post-treatment. All session data points within the maintenance phase were greater than the plus two standard deviation confidence interval for the baseline. The Cohen's *d* calculation resulted in an ES of 5.84, which revealed a large magnitude effect size.

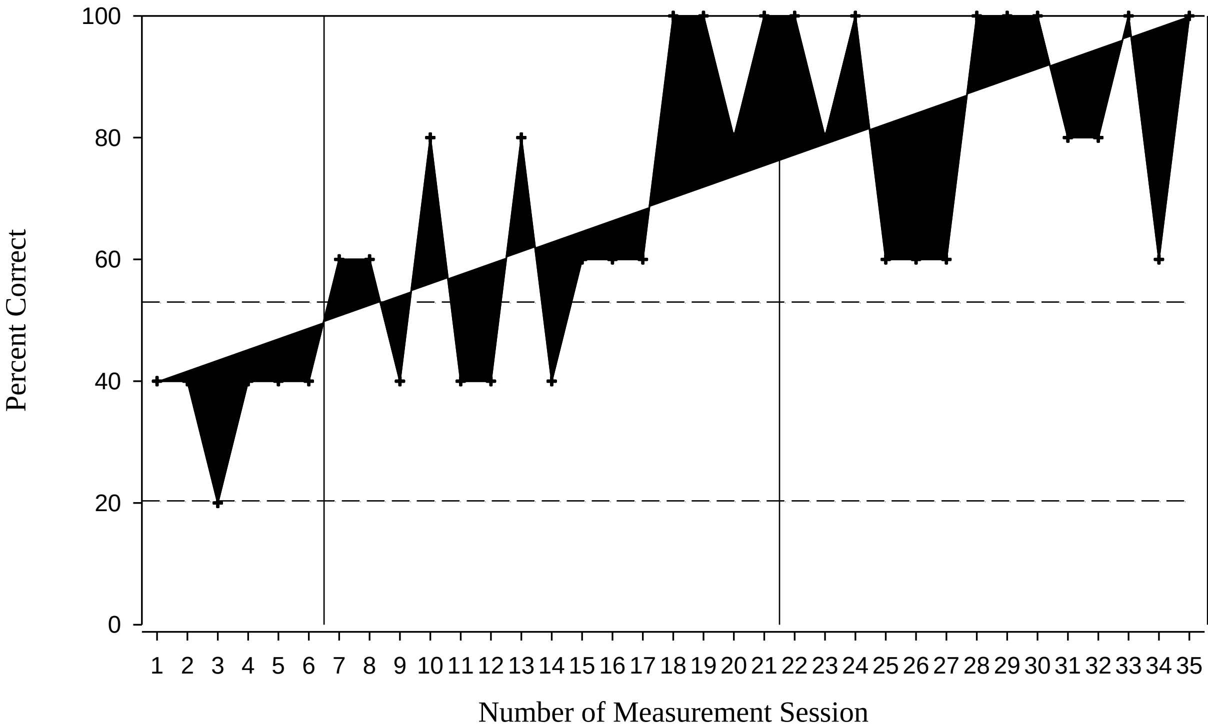

Figure 3: Percent correct values across all sessions for the "sh" in the initial position of untrained words. The solid vertical lines separate the three ABA phases. The two horizontal dashed lines represent +/- 2 standard deviation confidence interval based on the mean and standard deviation of the baseline sessions.

Figure 4 displays the participant's performance on the percent correct production of the target sound /ʃ/ in the final position of trained stimuli. The participant increased his productions of the target sound from a baseline mean of 20.00 (with a standard deviation of 17.89) to a maintenance mean of 54.29 (with a standard deviation of 18.27), resulting in a 34.29% difference between pre-and post-treatment. An equal number of session values fell above and below the two standard deviation confidence interval; however, the session values were greater than the two standard deviation interval for at least two consecutive sessions twice during the maintenance phase. The Cohen's *d* calculation was reduced (i.e., 1.92) compared to the results for the initial /ʃ/ in trained and untrained words.

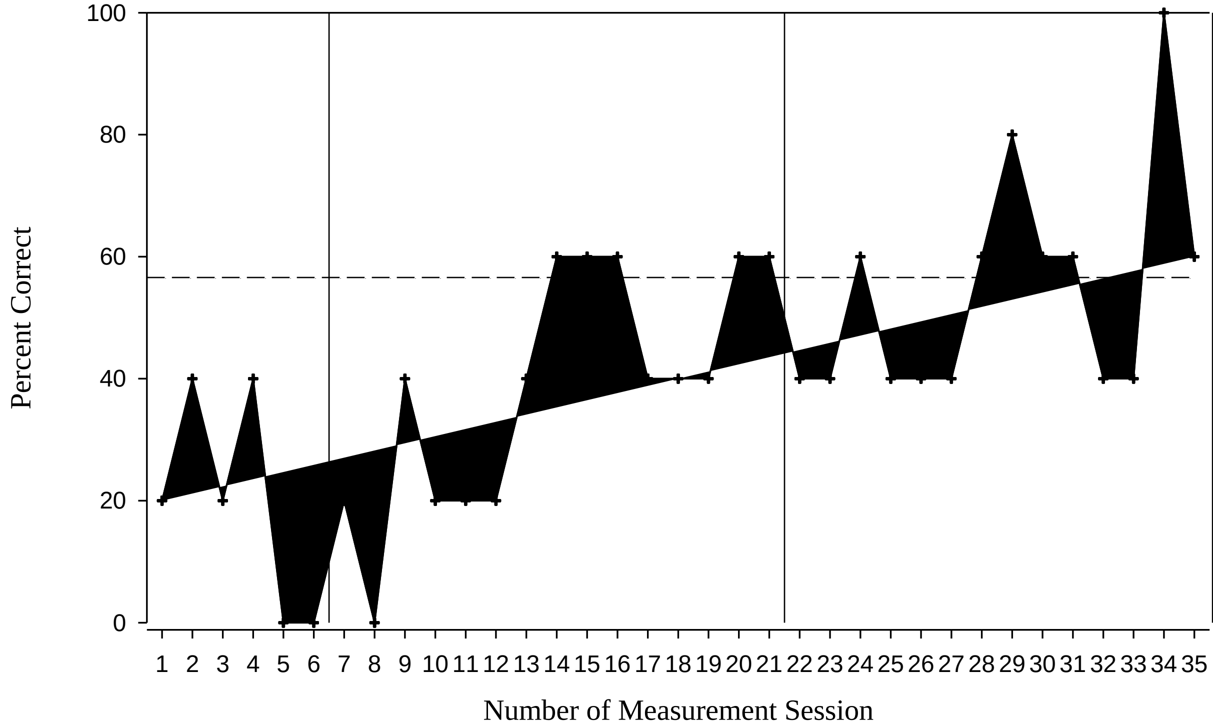

Figure 4: Percent correct values across all sessions for the "sh" in the final position of trained words. The solid vertical lines separate the three ABA phases. The horizontal dashed line represents + 2 standard deviation confidence interval basedon the mean and standard deviation of the baseline sessions.

The participant's performance on the percent correct production of the target sound /ʃ/ in the final position of untrained stimuli is displayed in Figure 5. The participant increased his productions of the target sound from a baseline mean of 0 (all session values were 0) to a maintenance mean of 32.86 (with a standard deviation of 21.64), resulting in a 32.86% difference between pre-and post-treatment. Due to the baseline phase resulting in a standard deviation of 0, the TSDM and the d_1 calculation could not be completed. It is important to note, the mean difference between pre- and post-treatment of 32.86% for these untreated words was similar to the mean difference noted for the treated words and further, the improvement came from a baseline where no correct productions were noted.

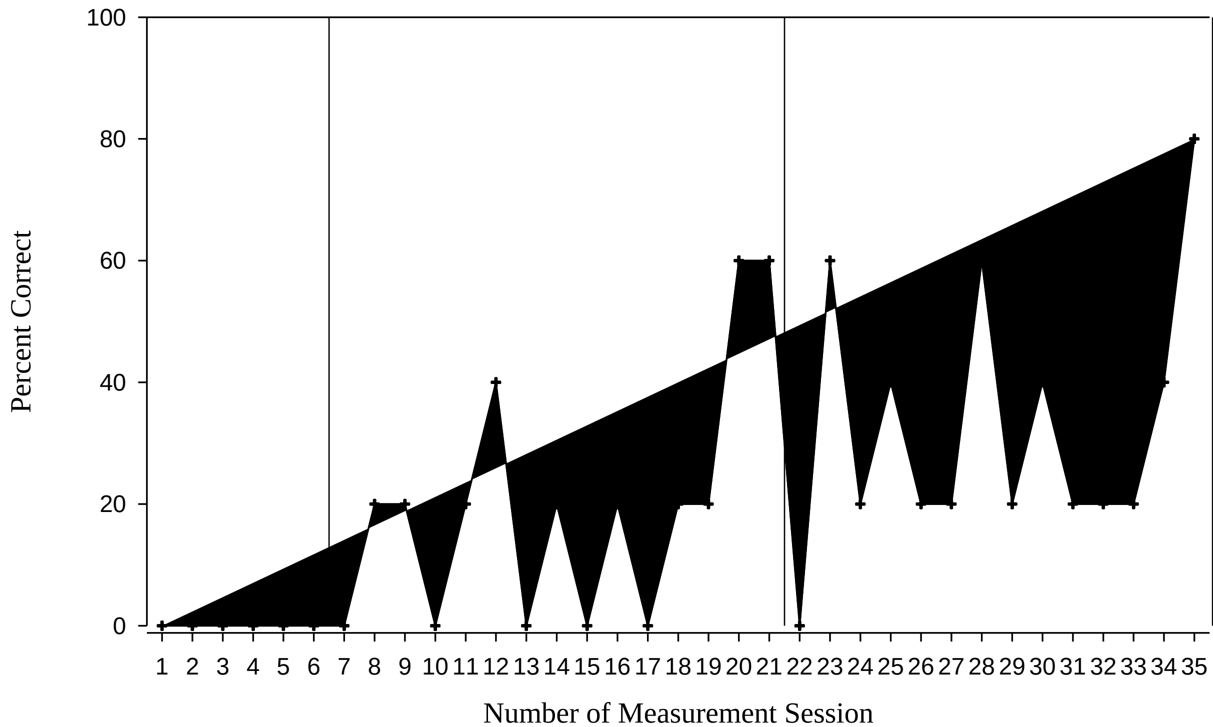

Figure 5: Percent correct values across all sessions for the "sh" in the final position of untrained words. The solid vertical lines separate the three ABA phases.

Words containing the target sound /r/ in the initial position were used as untreated controls for generalization effects and are displayed in Figure 6. These words showed variability in accuracy and little improvement throughout treatment. There were also many instances of no change in /r/ productions during the course of intervention with the CompleteSpeech system. The participant’s productions of /r/ remained relatively stable from a baseline mean of 5 (with a standard deviation of 8.36) to a maintenance mean of 7.14 (with a standard deviation of 10.69), resulting in a 2.14% difference between pre-and post-treatment and an ES of .26. Also, only two data points within the maintenance phase was greater than the plus two standard deviation confidence interval for the baseline. In summary, the little improvement in the participant’s production of /r/ (untreated control phoneme) combined with the relatively stable baselines in Figures 2-4 suggest the improvement in therapy for the trained stimuli did not result from external factors and were, in fact, results from therapy utilizing the CompleteSpeech system.

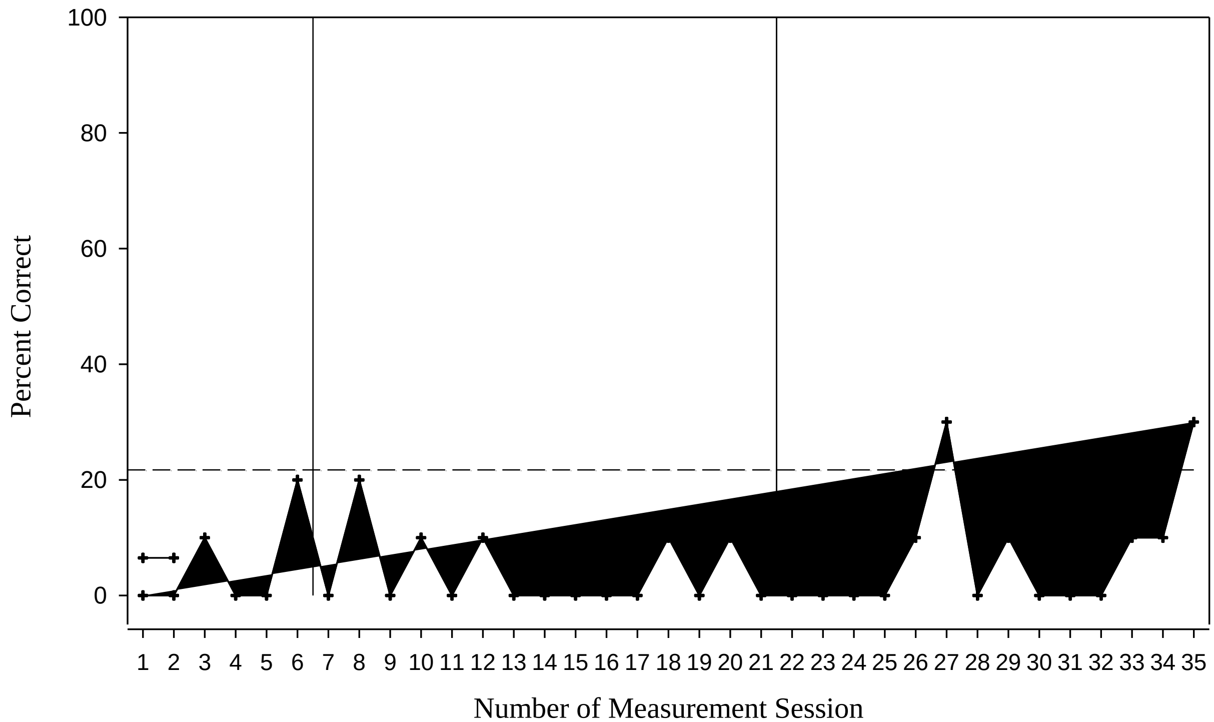

Figure 6: Percent correct values across all sessions for the /r/ in the initial position of words for an untreated control. The solid vertical lines separate the three ABA phases. The horizontal dashed line represents + 2 standard deviation confidence interval based on the mean and standard deviation of the baseline sessions.

DISCUSSION

The current study implemented a standard treatment program utilizing EPG along with an explicit motor learning framework within an ABA single subject design in the treatment of a participant with chronic acquire AOS. The impetus for the study came out of promising results from a limited number of previous studies noting improvement in the speech of individuals with AOS when incorporating EPG as a form of biofeedback (Morgan Berry, 1989; Howard & Varley, 1995; Wambaugh et al., 2006)). As indicated by a statistical analysis, the participant improved his speech sound production for /ʃ/ in the initial position of words and maintained this improvement over an extended period after therapy was terminated. Not only did the participant exhibit significant change in the treated stimuli, but these improvements were also generalized to untrained stimuli for /ʃ/ in the initial position. Although results for /ʃ/ in the final position of words were similar to the results for the initial position of words, the magnitude of effect size was larger for /ʃ/ in the initial position of words. This is most likely due to the coarticulation effects (i.e., delay in anticipatory coarticulation) that can accompany AOS (Zeigler & von Cramon, 1985; Hardcastle & Edwards, 1992; Hardcastle & Gibbon, 1997; Southwood et al., 1997;Wood & Hardcastle, 2000; Bartle-Meyer & Murdoch, 2010). With the target sound in the final position, it proved to be difficult for the participant to move his tongue and round his lips quickly enough into the correct articulatory position for /ʃ/ after the other phonemes in the stimulus words. To overcome this difficulty, the participant adopted a compensatory strategy of rounding his lips and placing his tongue in the correct position for the /ʃ/ phoneme at the beginning of words (e.g. “fish” and/or “leash”). This resulted in the distortion of some surrounding phonemes. Despite these difficulties, the participant still exhibited improvement in his speech sound production for /ʃ/ in the final position of words. These findings suggest the need for a greater amount of practice for patients who exhibit more pronounced difficulties with coarticulation.

The results indicate that an individual with AOS can improve speech production through the application of EPG as well as generalize those improvements to untrained words. Generalization occurred for /ʃ/ in both the initial and final position, as indicated in the results for untrained stimuli. Untrained stimuli for /ʃ/ in the final position could not be statistically analyzed due to the lack of variability in dependent variable during baseline phase. However, when viewing the difference between the baseline and maintenance phases, a positive increase in production can be noted. Generalization is important for new skills to carry over into functional communication . It is important with any treatment program that the participant is able to maintain and apply new production skills of target phonemes to other words and in natural contexts (McNeil et al., 2000). With this program, generalization did occur; however, the generalization did not transfer beyond the word level.

The positive results in the current study support previous findings of EPG being a potentially promising form of treatment for individuals with AOS and CAS (MorganBarry, 1989; Howard & Varley, 1995; Wambaugh et al., 2006; Lundeborg & McAllister, 2007). Results in the current study can also be compared to investigations utilizing EMA for treatment of individuals with AOS (Katz et al., 1999; Katz et al., 2010; McNeil et al., 2010). Although EPG and EMA are different instrumental techniques, they both focus on visual feedback and provide displays of lingual positioning to provide a means for remediation of speech sounds. The current study supports the use of this visual feedback, similar to positive findings in the studies utilizing EMA (Katz et al., 1999; Katz et al., 2010; McNeil et al., 2010).

A secondary finding was that the use of motor learning principles, including feedback, modeling, task-specificity and stimuli presentation (i.e. blocked vs. random order), appeared to be beneficial to the treatment program. All of these motor learning principles are suggested to increase acquisition and retention of skills in individuals with AOS; however, which one(s) contributed the most toward positive outcomes is undetermined. Also, determining the optimal time to alter the scheduling of each principle (e.g. moving from continuous feedback to variable feedback or knowledge of performance to knowledge of results) is relatively unknown. Scheduling within the present study was altered in an attempt to move from aspects of motor learning which target sound acquisition to scheduling which focus on retention. Quite often this change was gradual and was dictated by session performance. For instance, initially 8 productions each would be completed until moving to the next word. The intent was to provide the participant with a great deal of practice within the session. As the participant produced the training words more accurately, the number of practice tokens was reduced for a given word, moving toward more random form of practice (i.e., moving from one word to the next). Separating the influence of motor learning principles contributes and visual feedback using EPG should be considered in future research.

The effect sizes for Cohen’s *d* ranged from 1.92 to 5.84, which represent medium to large effect sizes based on Robey et al., (1999). Therefore, the strength of association between the participant’s speech sound productions from the baseline phase to the maintenance phase appeared to be significant. Also, the TSDM was utilized in Figures 2-4 and at least two consecutive percent correct session values within the maintenance phases fell above the 2 standard deviation baseline interval; therefore, a significant change in treatment occurred in all.

The TSDM was also utilized in Figure 6 and it displayed the untreated control /r/ did not significantly change, supporting that the change in treated stimuli resulted from the EPG treatment program, and not from external factors (Kearns, 1986).

Limitations

The present study involved only one participant. The participant was unique in that he was highly motivated, exhibited good language comprehension and cognitive skills (e.g., attention), was neurological stable and consistently attended sessions. He exhibited the majority of the characteristics important to the success of treatment of individuals with motor speech disorders (Yorkston et al., 2010). The study must be replicated with individuals exhibiting the same and different qualities to evaluate the presence of change (Kearns, 1986)

The uneven number of baseline and maintenance sessions led to the experimenter's inability to perform more rigorous statistical analysis (e.g. t-test), which is often used in research to further determine statistical significance (Brossart et al., 2006; Hough, 2010). Further, the difference in the number of sessions between phases failed to allow for an evaluation of the presence of autocorrelation. The presence of autocorrelation for data points between phases can invalidate measures of variability (Brossart et al., 2006). Without completing this evaluation, the present results should be viewed with some caution.

Another limitation was the adoption of lip rounding as an additional strategy which began around the seventh treatment session. At that time, it was noted by the experimenter that the participant was achieving adequate tongue-to-palate contact, but was not rounding his lips. This resulted in error in the /ʃ/ production; therefore, a mirror was used to provide visual feedback of lip rounding for the participant. Although the experimenter felt this was a necessary addition, it makes it difficult to determine the influence on the positive changes (i.e. visual feedback for tongue-to-palate contact, lip rounding, or a combination of the two).

The next limitation noted was limited practice without visual feedback. The removal of visual feedback has been suggested to be an important step in therapy with EPG (Gibbon et al., 1990; Hardcastle et al., 1991). Due to a limited number of sessions in the current study, removal of visual feedback was only implemented for a small portion (i.e. 15 minutes) of the final 3-4 sessions. According to Hardcastle et al., (1991), as soon as a participant demonstrates mastery at a target phoneme and/or behavior, the artificial palate should be removed, and practice should continue. Following this framework, the experimenter only discontinued visual feedback for a given word when he correctly produced the target phoneme the majority of the productions (i.e. 2/3 correct). Therefore, not all words were practiced with the removal of visual feedback and this may have affected generalization, especially the words containing /ʃ/ in the final position. As indicated earlier, the participant's accuracy level was lower for the /ʃ/ in the final than in the initial position. Increase in the number of treatment session may allow for full mastery of target sounds and adequate time for the removal of visual feedback. Also affected by the limited number of treatment sessions was the participant's limited improvement beyond the word level. With increasing the number of treatment sessions, participants may improve beyond the word level, further enhancing generalization in natural conversation.

With previous studies using EPG, production of target sounds with no airstream appeared to be a vital step in the treatment process (Hardcastle et al., 1991). However, these studies were based on communication disorders other than AOS. When attempting this step, the participant had difficulty maintaining the correct posture for the target sound without airstream (i.e. no voicing). Due to these difficulties, this step was discontinued in the current treatment program. In individuals with AOS, it has been suggested that the use of part practice (i.e. breaking down a complex motor skill into a more simplified form) may be less effective for the learning of a complex motor skill (Rosenbek & Jones, 2009). Edwards & Miller (1989) experienced similar difficulties with their participant diagnosed with dyspraxia during oral non-verbal tasks.

Future Research

There is need for further research using EPG with the AOS population. It has been shown that individuals with AOS exhibit errors in timing and sequencing of movements (Wood & Hardcastle, 2000). For the present study, visual feedback only focused on static postures. Future studies should also focus on dynamic movements of the lingual contact and the timing aspects of speech similar to Howard & Varley (1995), where they focused on the approach and release phases as well. Treatment involving feedback of dynamic movements using the EMA system have also been found to be successful for treating individuals with AOS (Katz et al., 1999; Katz et al., 2010). Future investigations may also want to perform a vigorous analysis of specific tongue-to-palate contacts for target sounds of the participant in order to guide treatment. For instance, if based on the EPG evaluation, distorted spatial patterns were noted for one participant and misdirected articulatory gestures were noted for another, different forms of therapy may need to be implemented. The current study did not evaluate the participant's specific EPG patterns prior to therapy as a means to obtain a better understanding of the underlying motor behavior associated with the speech sound errors. Finally, principles of motor learning should continue to be implemented with the AOS population; however, the effects of which principles to implement, and to what degree, still require further research.

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Appendix 1: List of words for assessment

Dear	Dip	Die	Dot	Dame
Tear	Tip	Tie	Tot	Tame
Gore	Gap	Gay	Got	Game
Core	Cap	Kay	Cot	Came
Pad	God	Sad	Tad	Ride
Pat	Got	Sat	Tat	Right
Pug	Gag	Sag	Tag	Rig
Puck	Gawk	Sack	Tack	Rick
Sin	Same	Sore	Sit	Sauce
Zen	Zoom	Czar	Zit	Zeus
Shine	Shame	Shore	Sheet	Shoes
Bus	Sauce	Face	Race	Kiss
Buzz	Saws	Faze	Raise	Keys
Bush	Sash	Fish	Rash	Cash
Choke	Chain	Chill	Choice	Cheat
Joke	Jane	Jill	Juice	Jet
Nine	Net	Nail	Nice	Knock
Wren	Right	Rail	Rash	Rock
Line	Light	Liar	Lash	Lack
Fetch	Batch	Latch	Witch	Notch
Fudge	Budge	Ledge	Wedge	Nudge
Fan	Bun	Line	Sun	Nun
Fire	Bear	Wire	Sore	Near
File	Bale	While	Soil	Kneel
Ski	Star	Sled	Swing	Small
Clown	Black	Flag	Sled	Glass

Crown Break Freeze Trip Grass

Appendix 2: Word lists for treated and untreated stimuli

Treated stimuli for target sound /ʃ/:

Shine	Bush
Shame	Push
Shore	Fish
Sheet	Leash
Shoes	Cash

Untreated stimuli for target sound /ʃ/:

Shin	Rash
Ship	Sash
Shark	Wash
Shift	Wish
Shoot	Dish

Untreated control stimuli for the phoneme /r/:

Wren

Right

Rail

Rash

Rack

Rich

Rhyme

Ran

Rome

Ring

Appendix 3: Treatment steps

Level one: Introduction to the EPG system

Step I: While wearing the SmartPalate that is attached to the CompleteSpeech system, the experimenter initially described the palatal display screen. She discussed the anatomy indicating the posterior, anterior, and lateral aspects of the palate. The experimenter explained what the dots/circles on the screen represent (i.e. each dot is associated with a sensor embedded in the SmartPalate). The experimenter indicated when the tongue makes contact with the sensor, the dot becomes filled in. This was used to give the participant feedback regarding the contact of his tongue to the palate. The experimenter demonstrated this concept of making tongue-to-palate contact by making contact with the posterior, anterior, and lateral sections of the palate one at a time, as well as making bilabial contacts, explaining before and after each where she was touching her tongue in her mouth and pointing to the screen where the dots should turn blue.
Step II: The experimenter produced a number of different lingual sounds in isolation (/ʃ/, /k/, /t/, /g/, /d/, /s/), pausing between each to explain to the participant the relationship between the different tongue to palate contacts associated with the phonemes and the resulting sound heard. Also pointing out where the dots are filling in and where that related to the inside of her mouth.

Level two: Non-speech tasks

Step I: The experimenter first instructed the participant to make bilabial contact, then velar tongue-to-palate contact. She instructed him to repeat this process five times. Following this, the experimenter instructed the participant to make alveolar tongue-to-palate contact, then velar again and repeat this five times. Finally, the experimenter instructed the participant to make lateral tongue-to-palate contact one side at a time, then repeat this five times. She paused between each one pointing to the screen where the dots were turning blue and where that related to the inside of his mouth or contact locations.

Step II: The experimenter pointed to certain sections of the participant's palate on the screen and instructed the participant to move his tongue to make contacts with the dots to turn the dots blue. This task was to give the participant more practice at feeling where his tongue is in his mouth and how to use visual feedback to guide his tongue to different locations on his palate.
Step III: The experimenter instructed the participant to produce a number of different lingual sounds in isolation (/k/, /t/, /g/, /d/, /s/, /b/, /p/), pausing between each to explain to the participant the relationship between the different tongue to palate contacts associated with phonemes and the resulting sound heard. Also pointed out where the dots were turning blue and where that related to the inside of his mouth or contact locations.

Level three: Isolated target sound

Step I: The experimenter set both her screen and the participant's screen to the pre-recorded target sound for /ʃ/. She modeled for him several times the production of the target sound, with

no airstream, (recording and freezing the palate-contact data) explaining that he wants to "turn the green circles blue" and "if there are orange circles, you are touching outside the target zone". The experimenter explained to the participant that airstream isn't being used so he can concentrate on where his tongue is at in his mouth as well as feel his tongue-to-palate contact without worrying about the sound for now.
Step II: The experimenter instructed the participant to produce the target phoneme 10 times in isolation, with no airstream, while recording each production and pausing to look at the contact data and explain in detail what he was doing with his tongue. During this time, feedback was 100% and consisted of knowledge of performance (i.e. "you touched your tongue a little too far forward, if you look at the screen, you want it moved back here more").

Step III: The previous 2 steps were repeated, adding in airstream.

Level four: words with target sound

Step I: The experimenter sat beside the participant and instructed him to repeat a word after her (the participant also has it written in front of him). The experimenter presented the word to the participant and instructed him to repeat it a number of times (8 repetitions initially, moving to as little as 1 repetition to increase practice). Initially, she provided him with feedback after each trial consisting of knowledge of performance (i.e. specific feedback "your tongue is too far back").

Step II: The experimenter performed this with the 5 other words (initially utilized 6 target words and moved to 10 partway through treatment) and randomly selects the order. This is known as a modified block practice approach.