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A PERCEPTUAL EVALUATION OF THE EFFECT OF A PSEUDOPALATE ON VOICELESS OBSTRUENT PRODUCTION AND MOTOR ADAPTATION

by

Megan C. Williams

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Communication Disorders

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BRIGHAM YOUNG UNIVERSITY

GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Megan C. Williams

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Megan C. Williams in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

A PERCEPTUAL EVALUATION OF THE EFFECT OF A PSEUDOPALATE ON VOICELESS OBSTRUENT PRODUCTION AND MOTOR ADAPTATION

Megan C. Williams

Department of Communication Disorders

Master of Science

Electropalatography (EPG) has proven to be a useful clinical and research tool for measuring tongue-to-palate contact. Research has shown sensorimotor adaptation to an EPG device may be possible following a short period of speech practice. This study was developed in order to better understand how a listeners' perception of speech clarity is effected by the presence of a relatively thin artificial pseudopalate in the speakers' oral cavity. Twenty listeners rated 220 speech stimuli on a visual analog scale ranging from *normal* to *very distorted* speech clarity. The stimuli included two different American English sentences. Speech clarity ratings were looked at as a function of the gender of the listener, the gender of the speaker, the type of speech sounds being heard, and the ability of the speakers to adapt their articulatory patterns over a period of 20 minutes. The results indicated that with the pseudopalate in place male speakers were generally rated by the

listeners as having more distorted speech articulation than female speakers, especially for stop-loaded sentences. Overall, fricative-loaded sentences received higher articulation ratings than stop-loaded sentences. Finally, an adaptation period of 20 minutes showed significant improvement in speech articulation in comparison to ratings immediately following pseudopalate placement, however speech remained significantly distorted.

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Introduction

Historically, our understanding of an individual's articulation of obstruent speech sounds was limited by the ability to visualize the continuous movement of the tongue and other articulators. In 1975, Fletcher, McCutcheon, and Wolf introduced a computer-based system with the capacity to track palate-lingual contact during speech, based on the principle of dynamic palatometry or electropalatography (EPG). The development of EPG has improved researchers' ability to dynamically study lingual-palatal contact during speech.

Monitoring intraoral contact patterns during articulation is particularly pertinent for the remediation of speech disorders that have not responded positively to traditional speech therapy techniques. Research has found that EPG combined with other types of therapy can be useful in remediating severe articulation disorders by providing the client and therapist with useful feedback for phonemes that are difficult to visualize (Bernhardt, Gick, Bacsfalvi, & Ashdown, 2003; Fletcher, Dagenais, & Critz-Crosby, 1991). It has been found that EPG-assisted therapy can also benefit individuals with developmental articulation errors (Dagenais, 1995), as well as individuals with articulation disorders resulting from cleft palate (Gibbon et al., 2001; Michi, Suzuki, Yamashita, & Imai, 1986), cerebral palsy (Gibbon & Wood, 2003), brain trauma (Hartelius, Theodoros, & Murdoch, 2005), or hearing impairment.

The placement of an EPG device (pseudopalate and connecting wires) in the oral cavity may result in the disruption of typical articulatory patterns, especially for phonemes produced with an approximation of articulators near the lips (i.e., p, b, m, and w), alveolar ridge (i.e., /t, d, s, z, n, and l/), and palate (i.e., /ʃ ,ʒ, tʃ, dʒ, r, and j/).

Research has indicated that with a period of practice speakers are able to adapt their articulation to compensate for structural changes in the oral cavity, such as the placement of an artificial pseudopalate, by altering their typical motor speech patterns (Baum & McFarland, 1997). The ability to produce the same sound through a variety of muscle activation patterns is based on the principle of motor equivalence (Kelso & Tuller, 1983; McFarland & Baum, 1995), whereby motor output can be adjusted through auditory and somatosensory feedback. This process, known as sensory feedback (McFarland, Baum, & Chabot, 1996), allows motor movements to be fine-tuned, particularly when discrepancies occur between the actual and intended motor output.

Previous studies examining articulatory adaption to the introduction of an artificial pseudopalate have primarily focused on the acoustic characteristics of speech and have provided less data regarding the possible effects pseudopalate placement may have on the perceptual quality of an individual's speech (Baum, McFarland, & Diab, 1996; Dean, 2008; McFarland & Baum, 1995; Searle, Evitts, & Davis, 2006). Thus, the present study investigated how the placement of a relatively thin artificial pseudopalate might impact obstruent speech production in terms of perceived articulatory quality. This study also investigated if speakers were able to adapt their speech in a perceptually relevant manner after speaking with the pseudopalate in place for a relatively short period of time (i.e., immediately following placement and after 20 minutes of conversation).

Review of Literature

This review of literature will address the manner in which obstruent sounds, both stops and fricatives, are produced and classified in American English. Also, the methods of measuring the articulatory movements of speech will be reviewed. Finally, research examining individuals' ability to adapt their articulatory patterns through sensory feedback and motor equivalence will be summarized.

Production of Obstruent Speech Sounds

Obstruent speech sounds can be classified according to the manner of their production. These types of sounds are produced with a relatively narrow approximation or a complete closure of the articulators within the oral cavity. The substantial or complete obstruction of the airstream as it flows through the vocal tract results in the production of a transient burst of noise energy, frication noise, or a combination of both sources of sound energy.

Plosives or stops are a subcategory of English obstruents formed by creating a complete closure within the vocal tract, which produces a temporary stop of airflow, resulting in an increase in air pressure behind the point of constriction (Shriberg & Kent, 2003). When the impounded air is released, a transient burst of sound, known as the stop burst, is produced. The English stop consonants /p/ and /b/ are articulated with a bilabial stop closure, /t/ and /d/ are articulated by bringing the apex of the tongue in contact with the alveolar ridge, and /k/ and /g/ are produced by bringing the posterior area of the tongue in contact with the hard palate.

Fricative production occurs when air is forced under high pressure through a narrow channel in the oral cavity (Ferrand, 2007). The incomplete closure allows air to escape, and this air stream creates a continuous noise (Shriberg & Kent, 2003). The eight fricatives of American English are represented by the symbols /θ, ð, s, z, f, v, ʃ / and / ʒ /. The interdental fricatives, /θ/ and /ð/, are produced by approximating the tip of the tongue with the bottom edge of the upper central incisors. For /s/ and /z/, alveolar fricatives, the blade of the tongue is raised near the alveolar ridge, with the sides of the tongue contacting the upper teeth and creating a small groove in the middle of the tongue through which air is allowed to flow. The labio-dental fricatives, /f/ and /v/, are produced by approximating the lower lip with the upper incisors. The palatal fricatives, /ʃ/ and /ʒ/, are produced by raising the medial and posterior sections of the tongue toward the upper back teeth and the palate (Ferrand, 2007; Secord, 2007).

Impact of Acoustic Cues on the Perception of Obstruent Speech Sounds

Speech perception research has sought to explain how the sounds that form words are accurately perceived by a listener (Ferrand, 2007). The accurate perception of a phoneme is dependent on multiple acoustic cues which signal to the listener which sound is being produced. For obstruent speech sounds, some of the important perceptual cues include the duration of the noise energy, the spectral characteristics of the stop burst or frication, and the formant transitions. In addition to these acoustic cues, voice onset time (VOT) is significant for the perception of stop consonants.

The duration of the noise burst is one of the primary cues that listeners use to differentiate between stops and fricatives (Ferrand, 2007). Fricatives have a relatively sustained period of frication (often greater than 130 ms), whereas stops are characterized by a transient burst of noise energy which lasts from 10 to 30 ms. Transient stop bursts are often preceded by a brief interval of silence, referred to as the stop gap.

The spectral characteristics of obstruent noise energy helps listeners perceptually differentiate between stops and fricatives, as well as determine the place of articulation within each obstruent division. Both stops and fricatives produce aperiodic noise diffusely spread across a range of frequencies, but the distribution and intensity of the noise differs depending on the place of articulation.

Stops are characterized by a brief energy burst across a wide range of frequencies. The vocal tract constriction for alveolar stops occurs towards the front of the oral cavity, thereby emphasizing a relatively higher range of frequencies, resulting in a spectral peak at approximately 2500 to 4000 Hz (Ferrand, 2007). Velar stops are produced farther back in the oral cavity and therefore have a lower spectral peak (at approximately 1500 to 4000 Hz). Bilabial stops typically have a spectral peak within a lower range of frequencies, between 500 and 1500 Hz (Ferrand, 2007).

Fricatives are typically characterized by a relatively wide band of acoustic energy distributed across a range of frequencies (Ferrand, 2007). For adult speakers, the spectral energy for alveolar (/s/ and /z/) and palatal (/ʃ/ and /ʒ/) fricatives has a relatively well-defined spectral shape with spectral means of approximately 4 to 6 kHz and 2.5 to 3.5 kHz, respectively. In contrast the interdental fricatives, /θ/ and /ð/, and the labiodental fricatives, /f/ and /v/, both display a relatively flat spectrum with no clear spectral peak in any particular frequency region (Jongman, Wayland, & Wong, 2000).

Formants can be defined as concentrations or bands of increased acoustic energy commonly found in sound segments that are produced with a relatively open vocal tract. The first formant (F1) is the lowest-frequency formant, with the second formant (F2) being the next highest frequency band of energy (Kent, 1997). Formant transitions or angles in the formant pattern will typically occur if a vowel-like sound is preceded or immediately followed by a consonant. For example, when transitioning from a vowel-like sound to a consonant the formant pattern of the vowel will slope up if the frequency characteristics of the consonant are relatively higher. In reverse, the formant pattern of the vowel will slope down if the energy concentration of a subsequent consonant is lower. Research has found that formant transitions assist in a listener's perception of a neighboring consonant and typically extend around 50 ms in duration (Ferrand, 2007).

F1 is associated with the amount of constriction occurring along the vocal tract. A lower spectral concentration for F1 indicates more constriction along the vocal tract while a higher frequency concentration for F1 typically indicates less constriction along the vocal tract, with the direction of the slope for F1 before and after an obstruent segment indicative of changes in vocal tract constriction. For instance, a rising slope for F1 after the obstruent segment typically indicates the vocal tract decreased in constriction when transitioning from the obstruent to following speech sound. A rising slope during the transition for F1 occurs when a stop is followed by a vowel (Kent, 1997).

For F2, the formant pattern at the beginning or the end of the vowel segment extends up or down in frequency depending on where the locus or spectral concentration of energy is for the obstruent. This is due to coarticulation, as the articulators are transitioning from the vowel position to the position required for the obstruent or transitioning from the obstruent to the vowel. Thus, if the locus or spectral mean is lower for a consonant relative to F2 of the neighboring vowel, the F2 formant will transition downward.

The perceptual impact of formant transitions on fricative identification is in part determined by the intensity of the segment's noise energy. For labiodental and interdental fricatives the noise energy is of a lower intensity and has less of an effect on the formant transitions before and after the obstruent segment. In alveolar and palatal fricatives, the noise energy is of higher intensity resulting in the formant transition before and after the obstruent segment having a greater effect on perception (Kent, 1997).

The VOT of a stop consonant, defined as the release of the stop burst relative to the initiation of voicing, is an important perceptual cue to obstruent identification. In many languages, VOT is an important perceptual cue in distinguishing between different stops in terms of place of articulation. VOT is also useful in determining whether the stop consonant is voiced or voiceless. In American English, voiced stops are characterized by a shorter or even negative VOT of approximately -20 to +20 ms, while voiceless stops have a relatively longer positive VOT of approximately 25 to 100 ms (Ferrand, 2007).

Effect of Gender on the Perception of Speech Sounds

Some research has found that the perception of speech can also be affected by the gender of both the listener and the speaker. A study by Ellis, Reynolds, Fucci, and Benjamin (1996) looked at the effect of gender on the rating of speech intelligibility. It was found that male listeners rated female speakers as more intelligible, whereas the female listeners rated male speakers as more intelligible. These results are dissimilar to findings by Markham and Hazan (2004), who found that both male and female listeners rated female speakers as more intelligible than male speakers. However, there were limitations in both studies that should be taken into account. The study by Ellis et al. (1996) included only one male and one female speaker. In addition, the study by

Markham and Hazan (2004) used speakers of British English, which may or may not generalize to American English.

Methods of Measuring the Articulatory Movements of Speech

The ability to measure the dynamic process of speech production has been complicated by the inability to observe speech movements produced in the enclosed oral cavity and vocal tract. A variety of methods have been used by researchers and clinicians to track the movement and placement of articulators during speech. These methods include using x-ray microbeam (Fujimura, Kirtani, & Ishida, 1972), magnet tracking (Dromey, Nissen, Nohr, & Fletcher, 2006; Nissen, Dromey, & Wheeler, 2007), ultrasound (Kent, 1997; Stone, 1990; Stone, Faber, Raphael, & Shawker, 1992), and EPG systems (Fletcher et al., 1975; Hardcastle, Gibbon, & Jones, 1991).

X-ray microbeam. X-ray microbeam technology is designed to examine speech production by tracking the movement of pellets attached to the articulators. The pellets are small in size, 2-3 mm in diameter, and can be detected by a series of highly sensitive x-ray detectors. The pellets are attached to desired articulation points in the oral cavity with dental adhesive. In order to track the pellets, the speaker is exposed to small doses of radiation for a limited amount of time. Each pellet's location is measured at an initial resting position and at multiple time intervals during speech production. By comparing the location of the pellets at rest relative to subsequent positions during speech, the x-ray microbeam system is able to determine the location of the pellets as a function of time (Kiritani, Itoh, & Fujimura, 1975).

Magnet tracking. The JT-3 jaw-tracking magnet system has been modified by researchers to track the anterior-posterior, vertical, and lateral movements of the tongue during speech (Dromey et al., 2006; Nissen et al., 2007). The system works by attaching a single magnet to the tongue and subsequently tracking the movements of the magnet through 24 magnetic sensors contained in a light-weight headset positioned on the head of the speaker. The JT-3 magnet tracking system can only be used to track one point in space and must use a small enough magnet to prevent significant disruption of typical patterns of articulation (Dromey et al., 2006).

Ultrasound technology. Ultrasound technology is based on the use of ultra-high frequency sound waves to produce an image of anatomical structures. Ultrasound technology uses a computer and transducer probe to emit and detect an acoustic waveform within body tissue. High frequency sound waves travel through the body until they reach boundaries between different densities of tissue, at which time the ultrasound waveforms are reflected back to the transducer probe. The distance of an object is calculated based on the amount of time required for the acoustic waves to return to the probe in conjunction with the known speed of sound in that medium. The computer component of the ultrasound calculates the motion of an object by detecting changes in the returning sound waves' relative frequencies. If the frequencies of the sound waves increase, the object is moving toward the probe; if the frequencies decrease, the object is moving away from the probe. With this information the computer is able to compute a visual representation of the motion of a structure on a computer screen.

Compared to the 2-dimensional data commonly obtained with isolated magnet and pellet tracking, ultrasound technology allows for a 3-dimensional display of the tongue during speech sound production. One possible drawback to using ultrasound technology is the relatively high cost of the measurement equipment, thereby limiting accessibility to many scientists and clinicians (Kent, 1997; Stone, 1990; Stone et al., 1992).

EPG. EPG or dynamic palatometry is a computer-based tracking system used to describe contact patterns between the palate and the tongue *(*Hardcastle et al., 1991). EPG provides visual patterns of tongue-palate contact. Historically, non-electric palatography was performed in a number of ways. One method involved dusting powder onto the hard palate to identify tongue-palate contact by determining where the dusting powder was removed from the palate (Rousselot, 1924). Another method utilized a piece of tin foil placed on the palate. The tin foil would be indented by the tongue-palate contact and thereby provide a general visual representation of tongue-palate contact patterns (Fletcher, 1992). In the latter part of the 20th century non-electric palatography gave way to EPG to describe palate and tongue contact patterns.

A palatometric system developed by LogoMetrix© uses a custom-fit pseudopalate with 116 embedded electrodes or sensors to detect and provide quantitative measures of tongue-palate contact during speech articulation (Fletcher et al., 1975). The contact sensors are contained in a relatively thin pseudopalate (0.5 to 2 mm) composed of a flexible baseplate, created from a stone model of the individual's upper teeth and palate (Searl et al., 2006). The pseudopalate resembles an orthodontic retainer, in that it is individually customized to fit the contours of the teeth and extends from the alveolar ridge to the back molars. When the tongue makes contact with the pseudopalate sensors, the contact patterns are represented by a completed electrical circuit. The contact data are then transmitted through several wires to a processing box, which collects and transfers the tongue-palate contact data to a computer (Baken & Orlikoff, 2000). These data can then be displayed as a visual representation of the articulatory contact patterns.

Clinical Application of EPG Technology

Information obtained from an EPG device may be useful to a clinician when treating an individual with a speech impairment that has not responded positively to traditional therapy techniques. EPG has therapeutic application for individuals with hearing impairment, predominantly those with a congenital etiology. Historically, training techniques for individuals with a hearing impairment have been based on auditory-oral sensation. Bernhardt et al. (2003) reported that substitutions, distortions, and decreased contrast between consonants are common articulation errors made by individuals with congenital sensorineural hearing loss; clinicians using traditional therapy approaches have difficulty treating these types of speech errors. While more research needs to be conducted, EPG has been proven effective in remediating speech disorders in individuals with a hearing impairment (Bernhardt et al., 2003; Fletcher et al., 1991).

With EPG, visual representations of tongue-palate contact patterns allow for the quick comparison between the client's and clinician's speech production. EPG gives visual feedback of speech production in real-time allowing immediate feedback for the client and the clinician. During therapy, the client is able to use visual feedback to compare and modify their intraoral contact patterns. Systematically having a client match their lingual contact patterns to those of the clinician can provide a framework for increasing the production of intelligible speech (Fletcher et al., 1991). Visual feedback is particularly pertinent for lingual patterns associated with consonants and non-low vowels (Bernhardt, Loyst, Pichora-Fuller, & Williams, 2000; Dagenais, 1995).

Structural Perturbation of the Vocal Tract

A possible drawback to EPG is the structural perturbation of the vocal tract due to the artificial pseudopalate being placed in the oral cavity and the electrical wires extending from the mouth (McFarland et al., 1996). In order to detect tongue-palate contact, the pseudopalate extends from the alveolar ridge to the back molars. Therefore, the pseudopalate changes the dimensions of the available space in the oral cavity which can be used for articulation. Since sibilant production requires a close approximation of the tongue to the palate, introduction of a pseudopalate may result in earlier tongue-alveolar ridge contact, delayed tongue-alveolar ridge separation, and a significant increase in the length of the sibilants in comparison to normal conditions (Baum et al., 1996). Research by Baum and McFarland (1997) and Baum et al. (1996) also found that the placement of a pseudopalate significantly increased the number of perceptually salient articulatory errors during speech, particularly for consonants (Baum & McFarland, 1997). Dean (2008) found that the effect of a pseudopalate on speakers' articulation differed as a function of the type of obstruent being produced. Following immediate placement of a pseudopalate in the mouth, statistical analyses revealed (a) a significant difference in the spectral mean for /p/, (b) a significant difference in spectral mean, spectral variance, spectral skewness for /t/ and /k/, and (c) a significant difference for the spectral mean of /s/ and /ʃ/.

In order for the pseudopalate and external processing box to interface, it is necessary to have wires running externally from inside the oral cavity. Electrical wires start at the pseudopalate near the alveolar ridge and run between the lips, then connect to the processing box. Bilabial consonants require complete lip closure for production and are therefore possibly affected by the presence of the electrical wires. Dean (2008) reported that EPG wires exiting the mouth may have interfered with the speaker's ability to create a complete stop occlusion, thus preventing complete articulatory compensation and causing an increase in the spectral mean and spectral variance for bilabial stops.

Adaptation to Objects in the Vocal Tract

Speech production is a flexible process, in that most individuals have the ability to adapt their articulation patterns to accommodate the introduction of foreign objects into the vocal tract. *Sensory feedback* and *motor equivalence* are principles which explain an individual's ability to adapt to structural perturbations in the oral cavity in a relatively rapid and efficient manner.

Sensory feedback describes how the brain uses sensory information to adjust motor output, and is a necessary prerequisite for the development of new articulatory motor programs (McFarland et al., 1996). Sensory feedback uses information provided through auditory and somatosensory (temperature, pain, pressure, movement, and posture) systems to inform the brain about the accuracy of the body's actual motor output compared to the intended output. The sensory feedback loop allows for motor movements to be fine-tuned according to discrepancies between actual and intended motor output.

When producing a speech sound, there are a number of different articulatory configurations of the speech mechanism that can be used to produce the same phoneme (McFarland & Baum, 1995). The motor equivalence theory, also known as the theory of speech equifinality, refers to this ability of variable muscle activation patterns to produce the same movement goal (Kelso & Tuller, 1983). Thus, articulatory mechanisms are able to produce speech sounds in a variety of ways, and by doing so, compensate for speech perturbation.

Bite blocks. Baum et al. (1996) compared the ability of 10 female, native French speakers to adapt to a bite block placed in the oral cavity. The study examined adaptation time in relation to improved articulation for vowel and consonant sounds. Recorded speech samples were collected immediately after bite block placement and post conversation. Results revealed quicker adaptation occurred for vowels while consonants required a longer adaptation period for accurate production.

Gay, Lindblom, and Lubker (1981) studied compensatory strategies used during speech with the placement of bite-blocks in the oral cavity. Results indicated that labial and lingual compensation, while a bite-block is in place, can result in vowel formant patterns close to patterns produced before placement. This study provided evidence that speakers have the capability to make articulatory adaptations to compensate for structural perturbations in the oral cavity.

Dental prostheses. Dental appliances may also cause perturbation to the oral cavity. Appliances such as orthodontic retainers and braces are commonly used in the general population and have been involved in articulatory adaption studies. While the time required for adaptation can vary, research has found that patients typically compensate for articulatory disturbances associated with dental appliances (Baum & McFarland, 1997).

Magnets attached to the tongue. A thesis by Weaver in 2005 examined the adaptation ability of speakers with a small magnet (1.2 mm thick and 7 mm in diameter) attached to the tongue during running speech. This study examined the spectral characteristics of the voiceless fricative productions of /s/ and /ʃ/ when embedded in the stimulus phrase, *Allison had to miss a sunny vacation at Shellfish Bay*. The magnets were placed in two different locations on the tongue (10 and 15 mm from the tongue tip). For each magnet location, the speakers repeated the stimulus phrase five times under four different conditions: prior to magnet placement, immediately following placement, following a 5 minute conversation, and following 10 minutes of conversation. No spectral differences were found for /s/, but changes in spectral mean and variance for /ʃ/ were statistically significant immediately after magnet placement. After 5-minutes of conversation with the magnet in place, no statistically significant differences were noted in any spectral measure for either fricative. Results indicated that over time the speakers were able to adapt to lingual magnet placement and produce the target fricative with similar spectral characteristics before and after magnet placement. These results support the theory that speakers are able to adapt to articulatory perturbations following a period of speech practice.

Artificial pseudopalates. The use of an EPG system is based on the assumption that a speaker will be able to adapt to a pseudopalate inserted into the oral cavity. Searl et al. (2006) investigated the effect of oral placement of a thin pseudopalate (0.5 mm) on speech production by measuring the acoustic features of consonants at seven points of time without the pseudopalate in place and at six points of time with the pseudopalate in place. Acoustic data indicated that individuals wearing the pseudopalate for at least 30 minutes were able to adapt their consonant productions close to the no-appliance condition. It is interesting to note that individuals participating in the study reported that placement of the pseudopalate changed their oral sensation during speech.

Baum and McFarland (1997) investigated the ability of a speaker to adapt to a pseudopalate over an extended period of time. Seven adult, female, native French speakers were fitted with a pseudopalate, and speech samples of the /sa/ syllable were elicited in 15 minute intervals over an hour span. The study focused on how the /s/ phoneme was acoustically affected by a pseudopalate. Between measurement points the subjects read /s/-loaded passages to promote increased adaptation. Results revealed significant articulatory improvement following a 15 minute target-specific practice period and again following a 45 minute target-specific practice period. At 60 minutes the individuals were able to reach near-normal speech patterns. This study indicated that a target-specific practice period reduced the amount of time needed for an individual to adapt their speech production to typical patterns of articulation with the pseudopalate in place.

Specific Purposes of the Study

A recent study (Dean, 2008) found that the placement of an artificial pseudopalate (Logometrix©) resulted in a significant disturbance of the spectral characteristics of speakers' voiceless obstruent productions. Participants demonstrated some motor adaptation to the interference caused by the pseudopalate after 20 minutes of conversation with the pseudopalate in place, yet several acoustic measures of their obstruent productions remained significantly different from typical patterns of articulation. The study by Dean evaluated participants' adaptation through acoustic measures of production; however, the perceptual relevance of such differences remains unclear. Utilizing the same speech recordings acoustically analyzed by Dean. This study examined how the placement of a relatively thin artificial pseudopalate affected the perception of American English sentences. Thus, the specific purposes of this study were to investigate the following research questions:

(1) Does the placement of a relatively thin artificial pseudopalate result in a significant disturbance in the perception of American English sentence production as rated by a group of adult listeners?

(2) Does the perceived articulatory quality of sentences produced with an artificial pseudopalate in place vary as a function of rater or speaker gender, as well as the type of obstruent being perceived (i.e., stop-loaded sentences versus fricative-loaded sentences)?

(3) Do speakers adapt their articulatory patterns in a perceptually relevant manner immediately after pseudopalate placement, or do they require a longer adaptation period of 20 minutes?

Method

Participants

Twenty adult listeners, recruited from the Brigham Young University community, participated in the study. The participants were native speakers of American English and reported no history of speech or language disorder. At the time of their participation all of the listeners exhibited pure-tone air-conduction thresholds ≤20 dB HL at octave and mid-octave frequencies from 500 to 8000 Hz, had static acoustic admittance between 0.3 and 1.4 mmhos with peak pressure between -100 and + 50 daPa, and exhibited bilateral acoustic reflexes at 1000 Hz (American Speech-Language-Hearing Association, 1990; Roup, Wiley, Safady, & Stoppenbach, 1998).

Stimuli

The acoustic recordings used in this study were collected in a previous palatometric study conducted by Sanders (2007). Speech recordings from 20 adult participants (10 male and 10 female) with a mean age of 25.2 years of age were used as stimuli. The recordings were made in an Acoustic Industries 7'x 7' single-walled sound booth using an AKG C2000B microphone and a Samson mixpad4 pre-amplifier. The microphone was placed approximately 15 - 20 cm from the mouth for each recording. Speech tokens were recorded at a sampling rate of 48 kHz and a quantization of 16-bits onto a digital analog tape (DAT) recorder (Panasonic SV3800). The average RMS value for each token was calculated and normalized to an average relative value of 29.77 dB SPL.

The stimuli used in this study included two different sentence constructions: a stop-loaded sentence (*The boot on top is packed to keep)* and a fricative-loaded sentence (*The boy gave a shout at the sight of the cake).* The term *loaded* is used to indicate a relatively higher degree of use for a particular type of obstruent when comparing the two types of sentences. For example the stop-loaded sentence had relatively more stop consonants (i.e., 10 stops) than the fricative-loaded sentence, and the fricative-loaded sentence had relatively more fricative consonants (i.e., 6 fricatives) than the stop-loaded sentence. The two sentences were produced by each speaker five times over three different speaking conditions. The three speaking conditions included (a) prior to placement of the pseudopalate (pre), (b) immediately after placement of the pseudopalate (post 1), and (c) following 20 minutes of conversation with the pseudopalate in place (post 2). The corpus of stimuli used in the present study included 200 sentences with 10 tokens from each of the 20 speakers. The fifth repetition for each sentence type was included for the pre condition and post condition 2. At post condition 1, which was immediately after placement of the pseudopalate, the first, third, and fifth repetition was included in the stimuli for both stop-loaded and fricative-loaded sentences. This means that for post condition 1 there were three repetitions for both stop-loaded and fricative-loaded sentences, and at the pre condition and post condition 2 there was only one repetition for stop-loaded and fricative-loaded sentences.

Procedure

Prior to testing, each participant read and signed an informed consent document approved by the Brigham Young University Institutional Review Board for Human Subjects Research. Custom software was used to control the randomization, presentation, and subsequent recording of perceptual judgments from the listeners. The signal was routed from a computer hard drive via Sennheisser HD 650 headphones to the subject, who was seated in a single-walled sound booth meeting American National Standards Institute S3.1 standards with ears covered (American National Standards Institute, 1999).

The intensity level of the presented stimuli was self-selected by each participant, with a starting level of approximately 60 dB HL. Before rating the stimuli each subject listened to four sample tokens: (a) two *normal* examples for each stimulus sentence and (b) two examples of *poor articulatory quality* for each stimulus sentence. The four sample tokens were selected from the corpus of stimuli and were of individuals talking before and after pseudopalate placement. Subjects were informed these tokens represented the extremes of *normal* and *very poorly articulated* speech quality for the sentences being presented to them. As used in this study, the term *articulation rating* refers to a group of listeners' judgments of the perceived articulatory quality of the elicited sentences. For example, listeners were instructed to rate a speech sample as having poor articulatory quality if they perceived it to have imprecise articulation, contain disfluencies, or be otherwise difficult to understand. The sequence of the stimulus presentation was randomized across speaker, sentence type, repetition, and speaking condition. Using a custom MATLAB routine developed by Dr. Christopher Dromey at Brigham Young University the listeners used a computer mouse to move a slider on a screen to rate the perceived articulatory quality of the presented stimuli. One end of the visual analog scale was labeled *normal* and the other end of the scale was labeled *very distorted.* The position of the slider was recorded by the software as a number ranging from 0 to 100, with higher numbers reflecting more severe speech distortion. The testing took place in a single 60-minute session.

In order to test intra-rater reliability, 10% of the samples were selected and played a second time. Intra-rater reliability was assessed by calculating a Pearson correlation between the original listener ratings and ratings for the repeated samples. Comparisons of the rating measures produced correlations of 0.58 (p = .001), with an average absolute intra-rater difference of 17.4 units on a 1 to 100 scale. The lower than expected intra-rater reliability may have due to a limited range in the data and the perceptual difficulty of the task. In addition, three of the twenty raters had a relatively higher degree of variability, with average absolute differences ranging from 29-32 points.

Data Analysis

Repeated-measures analysis of variance (ANOVA) was used to determine if the listener ratings varied as a function of the gender of the listener, gender of the speaker, sentence type, and speaking condition (i.e., prior to placement, immediately after placement, and following 20 minutes of conversation with the pseudopalate in place). A separate ANOVA was conducted to assess any differences in the 1st, 3rd, and 5th tokens in post condition 1 (immediately following pseudopalate placement). ANOVA results included a measure of effect size, partial eta squared, or η^2. The value of η^2 can range from 0.0 to 1.0, and can be considered a measure of the proportion of variance explained by a dependent variable when controlling for other factors. Greenhouse-Geisser adjustments were utilized to adjust F-tests with regard to degrees of freedom when significant deviations from sphericity were found. Furthermore, pairwise comparisons for significant within-subject factors were calculated using General Linear Model repeated-measures contrasts; comparison significance was determined using the appropriate F-tests.

Results

Listener and Speaker Gender

Results from the ANOVA indicated no significant differences for ratings of articulation as a function of the gender of the listener. The mean rating for female listeners was slightly lower (M = 31.45, SD = 3.25) than for male listeners (M = 33.69, SD = 3.25). Lower ratings indicate the sentence was perceived as having normal articulatory quality with higher ratings indicating the sentence was perceived as having poor articulatory quality. In contrast the ANOVA indicated a significant difference in ratings of articulation depending on the gender of the speaker, $F(1, 18) = 9.24$, $p = .007$, $\eta^2 = .34$. The mean ratings for the female speaker recordings (M = 30.82, SD = 2.11) were lower than the mean ratings for the male speaker recordings (M = 34.30, SD = 2.60).

Sentence Type

Results from the ANOVA indicated a significant difference in ratings of articulation between the stop-loaded and fricative-loaded sentences used in the study, $F(1, 18) = 85.18$, $p < .001$, $\eta^2 = .83$. Overall the stop-loaded sentences (M = 38.54, SD = 2.40) received higher mean ratings in comparison to the fricative-loaded sentences (M = 26.59, SD = 2.37) indicating the stop-loaded sentences had poorer perceived articulatory quality than fricative-loaded sentences. The ANOVA also indicated a significant interaction between the sentence type and the speaking condition, $F(2, 36) = 36.85$, $p < .001$, $\eta^2 = 67$. As illustrated in Figure 1, the stop-loaded sentences were rated with poorer articulatory quality at all three speaking conditions, with a mean of 10.50 (SD = 2.11) for the pre condition, 56.23 (SD = 2.84) for post condition 1, and

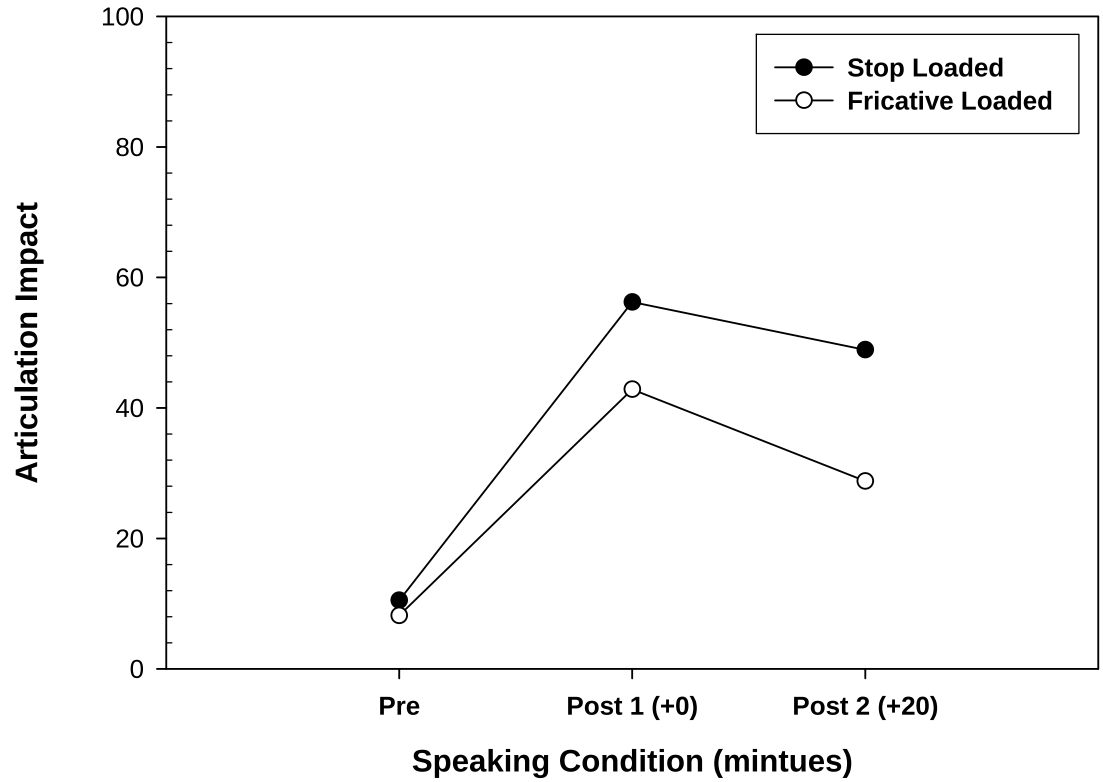

Figure 1.

Mean ratings of articulatory quality as a function of sentence type and speaking condition.

48.90 (*SD* = 3.29) for post condition 2. Fricative-loaded sentences exhibited a mean of 8.18 (*SD* = 1.73) for the pre condition, 42.83 (*SD* = 3.16) for post condition 1, and 28.77 (*SD* = 2.98) for post condition 2. Thus, the differences between ratings of articulation for the two sentence types was 2.33 at the pre condition, 13.40 for post condition 1, and 20.13 at post condition 2.

ANOVA results also indicate a significant interaction between the sentence type and speaker gender, $F(1, 18) = 32.18$, $p < .001$, $\eta^2 = .64$. As illustrated in Figure 2, for fricative-loaded sentences the ratings of articulation for male (*M* = 26.31, *SD* = 2.58) and female speakers (*M* = 26.87, *SD* = 2.28) were similar. In contrast for stop-loaded sentences there was a greater difference in ratings between male (*M* = 42.30, *SD* = 2.81) and female speakers (*M* = 34.78, *SD* = 2.24).

Speaking Condition

Results from the ANOVA indicated a significant difference for the ratings of articulation across the three different speaking conditions investigated in this study, $F(2, 36) = 195.47$, $p < .001$, $\eta^2 = 92$. Pairwise comparisons further indicated that the significant difference ($p < .001$) in ratings of articulation occurred between all three speaking conditions. The mean for the pre condition (*M* = 9.34, *SD* = 1.88) speaking level was much lower than post condition 1 (*M* = 49.53, *SD* = 2.83) and post condition 2 (*M* = 38.84, *SD* = 2.96). As demonstrated in Figure 3, post condition 2 received higher perceived articulatory quality ratings than post condition 1, but did not reach pre condition mean levels.

Results of the ANOVA also indicated a significant interaction between the speaker gender, sentence type, and speaking condition (adaptation period),

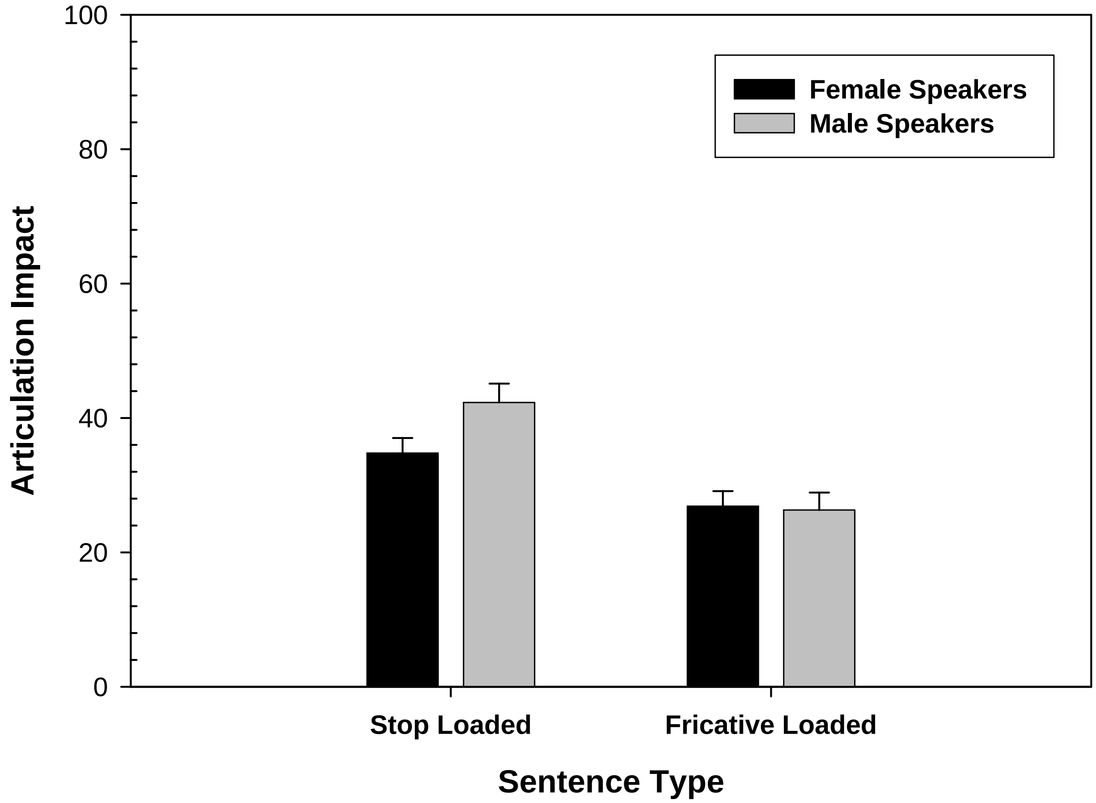

Figure 2.

Mean ratings of articulatory quality as a function of sentence type and speaker gender.

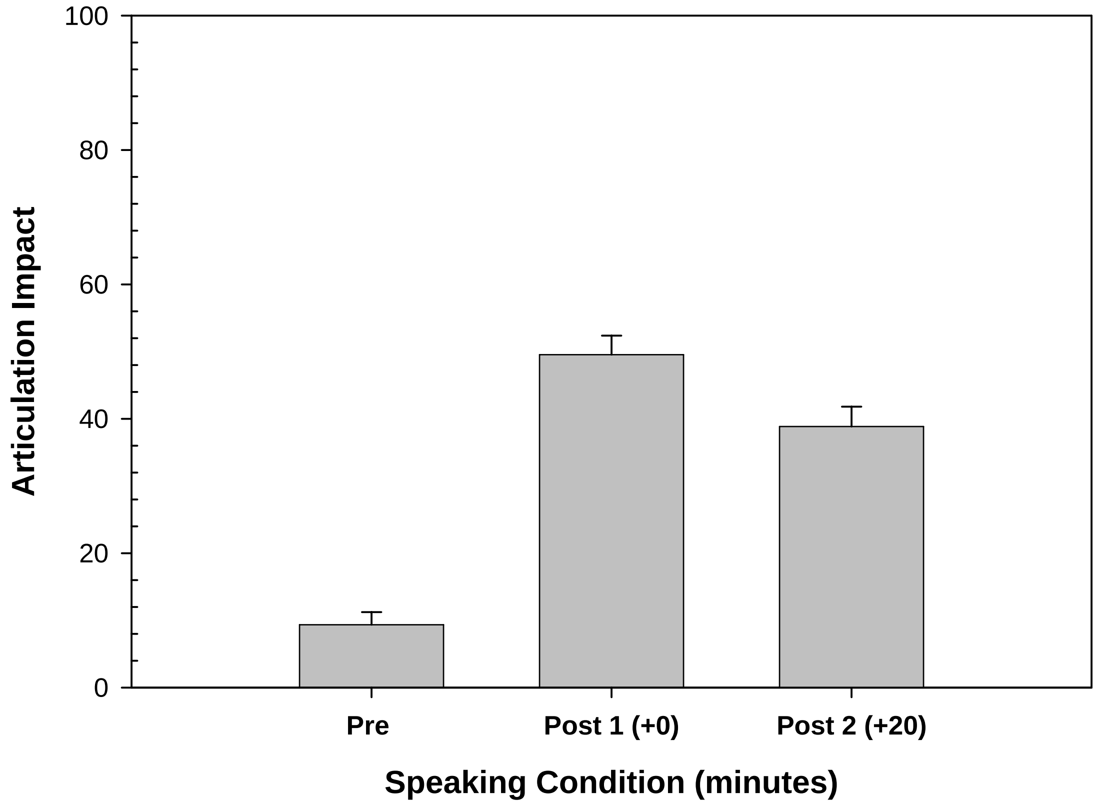

Figure 3.

Mean ratings of articulatory quality as a function of speaking condition.

$F(2, 36) = 16.85$, $p < .001$, $\eta^2 = .48$. See Tables 1-2 for mean ratings of articulation for male and female speakers according to the three conditions. Figure 4 demonstrates that for stop-loaded sentences, male speakers received poorer ratings of articulation than the female speakers at all three speaking conditions. For the fricative-loaded sentences the female speakers received better ratings of articulation for recordings produced at the pre condition (*M* = 4.94, *SD* = 1.34) and post condition 1 (*M* = 42.83, *SD* = 3.23), yet for post condition 2 (*M* = 24.70, *SD* = 3.01) the male speakers received a better perceived articulatory quality rating. Mean ratings for male and female speakers at post condition 2 did not return to the same mean ratings received for the pre condition.

Token Repetitions across Post Condition 1

Tables 3-4 are detailed statistics for ratings of articulation of the stop-loaded and fricative-loaded sentences spoken by male and female speakers as rated by male and female listeners at post condition 1. The ANOVA results revealed a significant difference in ratings of articulation between repetitions of the sentences occurring at post condition 1, $F(2, 36) = 16.24$, $p < .001$, $\eta^2 = .47$. Pairwise comparisons revealed a significant difference between the means for the first and third repetitions ($p < .001$), as well as between the means for the first and fifth repetitions ($p < .001$), but no significant difference between the third and fifth repetitions ($p = .955$). As illustrated in Figure 5, the first repetitions (*M* = 54.70, *SD* = 2.48) received a significantly higher perceived articulatory quality rating while the third (*M* = 49.49, *SD* = 3.00) and fifth repetitions (*M* = 49.53, *SD* = 2.83) received lower ratings of articulation.

Table 1

Means and Standard Deviations of Articulatory Quality Ratings for Female Listeners as a Function of Sentence Type, Speaking Condition, and Speaker Gender on a Scale of 0 - 100

		Stop-loaded		Fricative-loaded	
Condition	Speaker Gender	Rating	*SD*	Rating	*SD*
Pre	Female	5.64	2.79	3.29	1.90
	Male	14.03	3.82	11.05	3.21
Post 1	Female	49.62	4.38	42.33	4.56
	Male	59.18	4.29	40.91	4.67
Post 2	Female	45.57	4.46	33.11	4.28
	Male	49.05	5.25	23.59	4.37

Table 2

Means and Standard Deviations of Articulatory Quality Ratings for Male Listeners as a Function of Sentence Type, Speaking Condition, and Speaker Gender on a Scale of 0 - 100

		Stop-loaded		Fricative-loaded	
Condition	Speaker Gender	Rating	*SD*	Rating	*SD*
Pre	Female	8.52	2.79	6.59	1.90
	Male	13.83	3.82	11.77	3.21
Post 1	Female	52.06	4.38	43.33	4.56
	Male	64.03	4.29	44.76	4.67
Post 2	Female	47.26	4.46	32.59	4.28
	Male	53.71	5.25	25.80	4.37

Table 3

Means and Standard Deviations of Articulatory Quality Ratings for Female Listeners as a Function of Sentence Type, Speaker Gender, and Token Repetition across Post Condition 1 on a Scale of 0 - 100

		Stop-loaded		Fricative-loaded	
Repetition	Speaker Gender	Rating	*SD*	Rating	*SD*
1	Female	59.51	2.66	38.52	3.97
	Male	65.45	4.40	51.50	5.09
2	Female	52.22	5.05	38.40	4.10
	Male	63.67	5.01	35.72	5.04
3	Female	49.62	4.38	42.33	4.56
	Male	59.18	4.29	40.91	4.67

Table 4

Means and Standard Deviations of Articulatory Quality Ratings for Male Listeners as a Function of Sentence Type, Speaker Gender, and Token Repetition across Post Condition 1 on a Scale of 0 - 100

		Stop-loaded		Fricative-loaded	
Repetition	Speaker Gender	Rating	*SD*	Rating	*SD*
1	Female	58.66	2.67	41.69	3.97
	Male	66.30	4.40	56.01	5.09
2	Female	56.74	5.05	42.54	4.10
	Male	62.60	5.01	44.84	5.04
3	Female	52.06	4.37	43.33	4.56
	Male	64.03	4.29	44.76	4.67

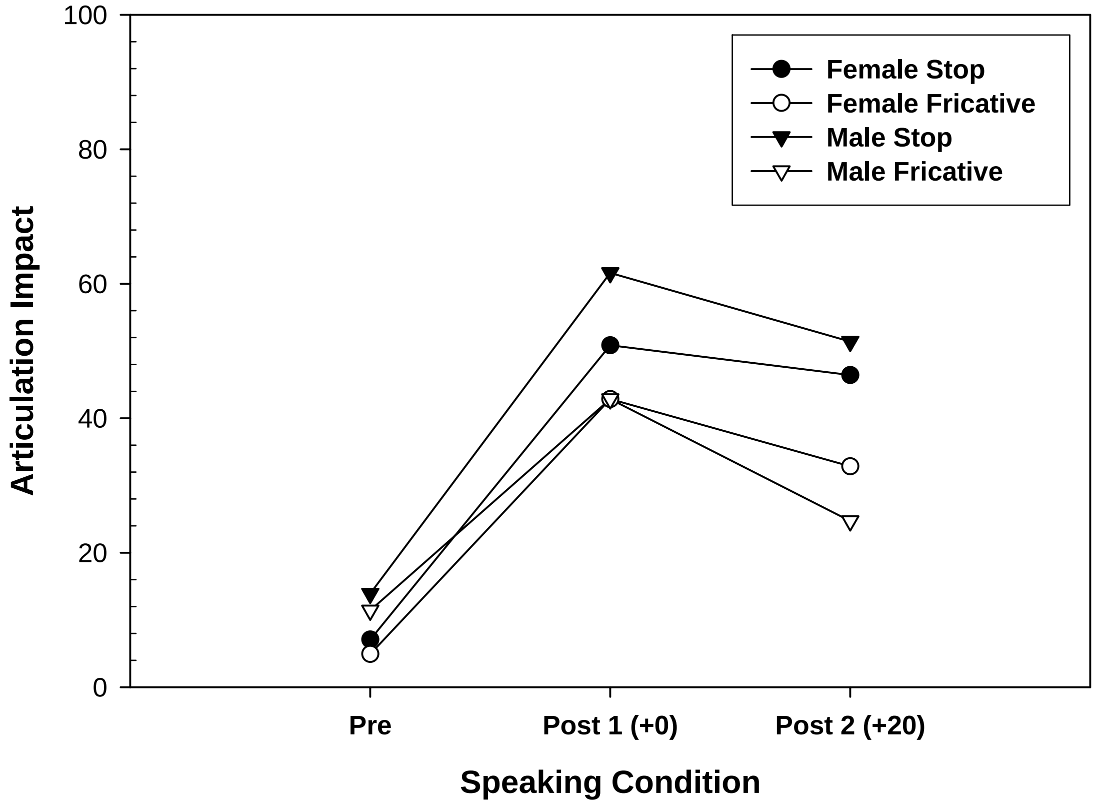

Figure 4.

Mean ratings of articulatory quality as a function of sentence type, speaker gender, and speaking condition.

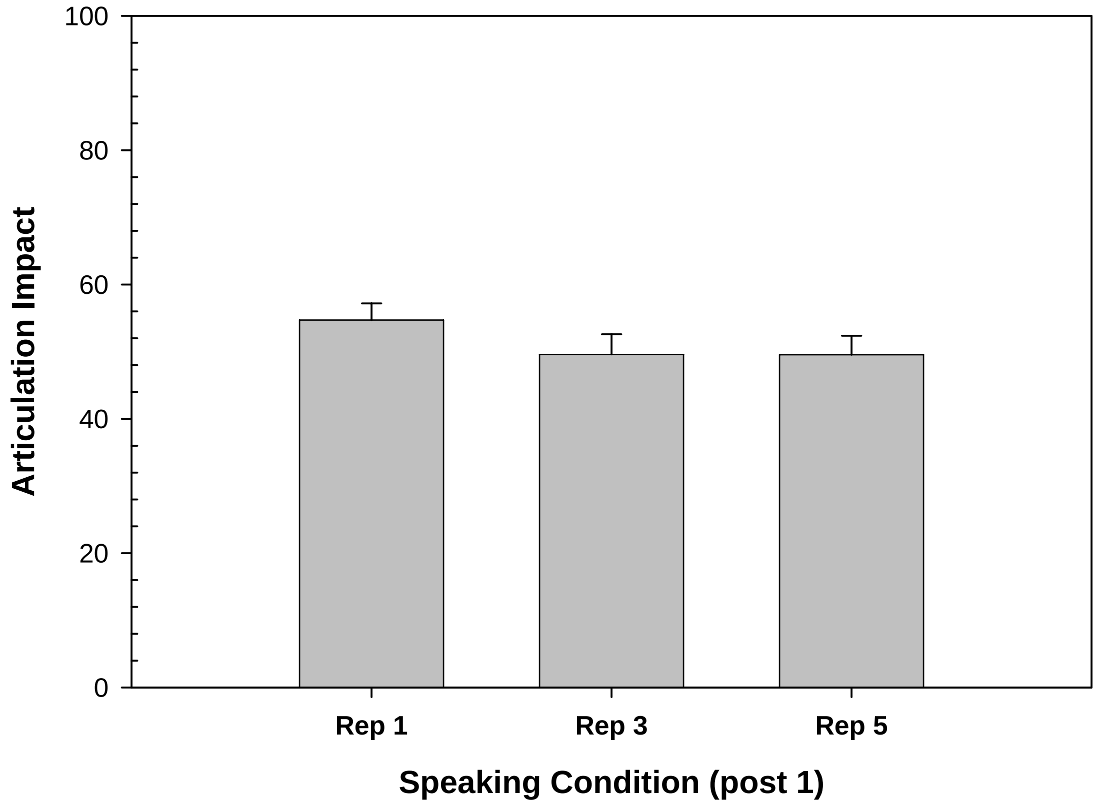

Figure 5.

Mean ratings of articulatory quality as a function of token repetition at post condition 1.

Discussion

The present study was designed to examine how a listeners' perception of articulatory quality is effected by the presence of a relatively thin artificial pseudopalate in the speakers' oral cavity. Accordingly, three research questions were raised for investigation. The following section will summarize and discuss the results of each experimental question, as well as possible areas of future research.

Effect of Study Variables on Perceived Articulatory Quality

Pseudopalate placement. Does the placement of a relatively thin artificial pseudopalate cause a significant disturbance in the perception of American English sentence production as rated by a group of adult listeners? Results indicated that the perceived articulatory quality of the speakers' sentence productions was significantly affected by the placement of the EPG device (pseudopalate and connecting wires). These results were similar to acoustic findings by McFarland et al. (1996) and Dean (2008). Thus when using EPG in therapy, it can be expected that the pseudopalate may affect the perceived articulatory quality of the wearer; however the extent to which perceived articulatory quality decreases over time will vary between individuals. Clinicians should assess the perceived articulatory quality of their client before placing a pseudopalate in the mouth in order to obtain a true representation of the client's abilities. Before using EPG as an alternative means to teach articulation patterns for individuals with hearing impairment (Bernhardt et al., 2003; Fletcher et al., 1991), clinicians need to be aware of the negative effects of a pseudopalate on perceived articulatory quality.

Gender and obstruent type. Does the perceived articulatory quality of sentences, produced with an artificial pseudopalate in place, vary as a function of rater or speaker gender, as well as the type of obstruent being perceived (i.e., stop-loaded sentences versus fricative-loaded sentences)?

Results indicated that there was no significant difference between rating scores for female and male listeners. These findings are dissimilar to those by Ellis et al. (1996) who found that male listeners indicated that female speakers had better perceived articulatory quality, and female listeners indicated that male speakers had better perceived articulatory quality. Ellis et al. reported their findings may have been due to the structure of their test which used only one male and female talker. Also, the listeners reported that the speakers' "tone" may have influenced the listeners' perceptual ratings. Several of the male listeners reported the female speakers were more understandable due to a "softer voice", a "more relaxing tone", and "less deep" voice (Ellis et al., 1996). On the other hand female listeners reported that the male speakers' were more understandable because their "deeper voice created more of a distinction between the words", their "commanding voice made me want to continue listening", and speaking "monotone made his voice stay more constant" (Ellis et al., 1996). Accordingly the findings by Ellis et al. may have accurately measured the perceived articulatory quality, but the "tone" of the speaker.

Significant differences were found in perceptual ratings between male and female speaker productions. Specifically, female speaker recordings were rated as having a more normal perceived articulatory quality than male speaker recordings. These results are similar to the Markham and Hazan (2004) study which also found that female speakers were rated by listeners as having better perceived articulatory quality than male speakers. However, data from the present study also showed that following a 20 minute adaptation period, male speakers were perceived has having better articulatory quality than female speakers for fricative-loaded sentences. This was the only time where male speakers were rated as having better perceived articulatory quality than female speakers. Currently we are unaware why the male speakers received better ratings of articulation than the female speakers for fricative-loaded sentences following a 20 minute adaptation period. It may be that male speakers take longer to adapt to the pseudopalate, and after the 20 minutes of adaptation were finally able to have improved perceived articulatory quality. Current adaptation theories (i.e., sensory feedback and motor equivalence) do not address the possibility that males and females adapt differently to objects in the oral cavity. It may be this incident of normal perceived articulatory quality by male speakers was an isolated incident, which may or may not be reproducible in future research.

Stop-loaded sentences received higher ratings, indicating that they were more distorted than fricative-loaded sentences. These findings were in accordance with previous perceptual research by Baum et al. (1996), which found that immediately following bite-block placement and a 15 minute period of conversation, isolated stop phonemes were more often misidentified than isolated fricative sounds. Differences in perceived articulatory quality across different types of obstruents may be due to the physical structure and position of the pseudopalate and connecting wires. For instance, a pseudopalate has wires exiting through the lips, which would likely have a greater impact on the complete articulatory closure necessary for the production of bilabial stops (e.g., /p/ and /b/), compared to the approximation necessary for fricative production. When EPG is used for therapy, clinicians should be cognizant that an EPG system may have a greater possibility of articulatory interference when targeting stops or with sounds produced near the alveolar ridge.

Adaptation. Do speakers adapt their articulatory patterns in a perceptually relevant manner immediately after pseudopalate placement or do they require a longer adaptation period of 20 minutes?

Results indicated that speech adaptation started shortly following pseudopalate placement. In post condition 1 (productions immediately after placement) the first repetitions were rated as having perceptually poorer articulatory quality than the third and fifth repetitions. Thus, perceived articulatory quality improved through adaptation even in a very short period of time. No significant difference was found between the third and fifth repetitions; which may signify that after an initial period of adaptation, the rate at which a speaker modified their productions likely decreased over longer periods of speech practice. A significant difference was found between post condition 1 and post condition 2, providing evidence that although the rate of adaptation decreases, perceived articulatory quality continues to benefit from relatively longer periods of speech practice. However, it is also important to note that a significant difference in listener ratings between post condition 2 and before pseudopalate placement was found, indicating that the 20 minute adaptation period was an insufficient amount of time for speakers' to completely adapt to the EPG device. Considering the limitations of this study, it is unclear if complete adaptation can be achieved, irrespective of the length of practice time.

The findings of this study are somewhat different from previous studies investigating adaptation to an EPG device. Searl et al. (2006) found that after 30 minutes with the thin pseudopalate in place, acoustic measurements for the consonants /t/ and /s/ were similar to measurements at the non-appliance condition. A similar acoustic study, which investigated adaption to the placement of a magnet on the tongue, found that with a relatively short adaptation period, speakers were able to adapt their speech to pre-placement patterns of articulation (Weaver, 2005). In contrast, the results of Dean (2008) support the findings of the present study.

This study examined the same speech recordings acoustically analyzed by Dean (2008). Dean researched the acoustic characteristics of segmented obstruent productions, while this study investigated the perceptual articulatory quality of an entire sentence containing these same productions. Dean found that, although acoustic measures of voiceless obstruent production improved after 20 minutes with the pseudopalate in place, several acoustic measures remained significantly different from typical patterns of articulation. Thus acoustic findings reported by Dean (2008) and the perceptual results of this study support the conclusion that a twenty minute adaptation period may be an insufficient amount of time for speakers' to adapt to the EPG device. Trends indicate that when using a pseudopalate in therapy or research, clinicians and researchers can expect participants to adapt their motor speech patterns to the EPG device over time, but may not completely return to a pre-placement level of perceived articulatory quality.

Future Research

This study did not investigate the effect of a pseudopalate on disordered speech but investigated how normal speakers of English are affected by a pseudopalate. It was beyond the scope of this study to determine how disordered speech maybe affected by a pseudopalate. Consequently, until research reveals the effects of a pseudopalate on disordered speech, as in normal speech, the clinical application of this study may be somewhat limited in scope.

Research has primarily used adults as subjects during EPG studies, though therapy most often uses EPG to help children improve their articulation. Future research should use children as subjects in order to determine their ability to adapt to a pseudopalate. Adults and children may adapt differently to the placement of a pseudopalate.

Stop sentences had poorer perceptual articulatory quality than fricative sentences, but it is not known which phonemes were affected the most. It is possible that only some of the stop phonemes were perceived has having poor articulatory quality, but were so severe it made the entire sentence sound distorted. Future research should investigate the extent to which each of the stops sounds /p, b, t, d, k, g/ and fricative sounds /θ, ð, s, z, f, v, ʃ, ʒ / are affected by a pseudopalate. This information would provide clinicians with a better understanding of which sounds are severely distorted by EPG, and which sounds will experience minimal distortion.

In the present study different vowels and word structures (i.e., CV versus CVC) were used in the two sentence types. It is possible that vowels and word structures had an unseen effect on the perceptual ratings of the listeners. Future research should construct sentences where all the same vowels and word structures are used. This would minimize possible confounding factors and provide further information regarding the effect of a pseudopalate on speech.

Future research should use longer adaptation periods (i.e., 20 minutes a day for one week) to discover how the perception of male and female speakers changes over time. Longer adaptation periods to a pseudopalate would enable researchers to see if male or female speakers are perceived as being able to return to pre-pseudopalate articulatory quality levels. Looking at adaptation over multiple sessions would also provide insight into whether speakers are faster at adapting each time the pseudopalate is placed in the mouth or if the rate of adaptation remains the same for each session.

Conclusion

The effect of a pseudopalate on perceived articulatory quality depended on the gender of the speaker, the speech sounds being spoken, and the length of time the pseudopalate had been in the mouth. With the pseudopalate in place male speakers were generally rated by the listeners as having poorer perceptual articulatory quality than female speakers, especially for stop-loaded sentences. Additionally, an adaptation period of 20 minutes resulted in significantly improved perceived articulatory quality; however, speech failed to return to a typical level of perceived articulatory quality. It is unclear from this study if additional practice time with the pseudopalate would eliminate these perceptual differences. Despite the narrow scope and limitations of this study, these findings provide a better understanding of the perceptual effect that an artificial pseudopalate may have on an individual's speech articulation and how speakers might adapt to the pseudopalate after a short period of practice.

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Appendix

Informed Consent Document

Consent to be a Research Subject

Introduction
This research study is being conducted by Megan Cannon, a graduate student in speech-language pathology at Brigham Young University. This work will be supervised by Dr. Shawn Nissen, who is a member of the faculty in the Department of Communication Disorders. You were selected to participate because you met the necessary language requirements (native English speaker with no known history of a speech, language or hearing problem).

Procedures
Participation in this study will involve one visit of approximately 60 minutes to a Speech Research Laboratory in the John Taylor Building on the campus of Brigham Young University. You will be seated in a chair in a sound booth and listen to English Sentences through headphones at a comfortable listening level. You will be asked to rate the sentences on a sliding scale between normal and severely abnormal.

Risks/Discomforts
There are minimal risks for participation in this study.

Benefits
Potential subjects will be given a free hearing screening. Also, it is hoped that through your participation researchers will learn more about the perceptual effects that an artificial oral device may have on typical speech production.

Confidentiality
All information provided will remain confidential and will only be reported as group data with no identifying information. All data, including digital recordings of your responses will be kept in a locked storage cabinet and only those directly involved with the research will have access to them.

Compensation
No monetary compensation is offered. However, a summary of the findings of the study will be provided to you upon request.

Participation
Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your class status, grade or standing with the university.

Questions about the Research
If you have questions regarding this study, you may contact Megan Cannon at (801) 558-1899, megsc8@gmail.com or Dr. Shawn Nissen at (801) 422-5056, Shawn_Nissen@byu.edu.

Questions about your Rights as Research Participants
If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair, 422-6461, 133 TLRB, Brigham Young University, Provo, UT 84602, Christopher_Dromey@byu.edu.

I have read, understood, and received a copy of the above consent and desire of my own free will and volition to participate in this study.

Signature:______________________________________ Date:________

MSE Approved
301 MCKB
Feb. 5, 2010