Speech Adaptation to Electropalatography in Children's Productions of /s/ and /ʃ/

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Speech Adaptation to Electropalatography in
Children’s Productions of /s/ and /ʃ/

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

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Previous research has investigated adults’ ability to adapt their speech when a electropalatographic (EPG) pseudopalate is placed in the oral cavity; however, less is known about how younger speakers who are continuing to develop their motor speech abilities might adapt their speech to the presence of the device. This study examined the effect of an EPG pseudopalate on elementary school-aged children’s ability to produce the fricatives /s/ and /ʃ/. Audio recordings of six children were collected at eight time intervals including before placement of the pseudopalate, at 30-minute increments for two hours with the pseudopalate in place, immediately following removal of the pseudopalate and 30 minutes after removal. An acoustic analysis was completed looking at consonant duration, spectral mean, spectral variance, and relative intensity. Disturbance of speech patterns from the presence of the pseudopalate was noted for most of the acoustic measures, most noticeably for the relative intensity of both /s/ and /ʃ/, as well as for the spectral mean and spectral variance of /ʃ/. Although there was a relatively high amount of variability among and within speakers, signs of adaptation were apparent after only 30 minutes for some participants. For some acoustic measures, however, full adaptation often did not occur until the pseudopalate was removed. Although future research is needed, it is hoped that this study will provide a greater understanding of children’s ability to adapt to the EPG pseudopalate.

Keywords: adaptation, electropalatography pseudopalate, fricatives, acoustic analysis, children
ACKNOWLEDGMENTS

There are many people that made the completion of this project possible. First I would like to thank Dr. Nissen for his countless hours in advising me with both the research and writing elements of this project. I would also like to thank my committee members for their time and suggestions as well as Samuel and Barbara Fletcher for their financial support. A big thank you also goes to my husband for his patience, support, flexibility, and encouragement throughout my masters program but especially with my thesis. I am also grateful for my parents as they have encouraged me throughout my life to seek a good education and supported me in my dreams.
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DESCRIPTION OF STRUCTURE AND CONTENT

This thesis is part of a larger collaborative project, portions of which may be submitted for publication, with the thesis author being one of multiple coauthors. The body of this thesis was written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. An annotated bibliography is presented in Appendix A, and the informed consent documents are in Appendix B.
Introduction

Electropalatography (EPG) is a tool used in linguistic research as well as in the treatment of articulation and phonological disorders (Gibbon & Paterson, 2006). As described by Fletcher, McCutcheon, and Wolf (1975), EPG utilizes an individually fitted pseudopalate with embedded electrodes that detect tongue to palate contact during speech and swallowing. Through wires extending out of the mouth the data stream is sent to a processing box, which collects and transfers the data to a computer for analysis and visual display. Thus the clinician and client are able to see real-time visual biofeedback on the manner in which the tongue contacts the palate during speech. However, one drawback to this technology is that it requires an appliance, similar to an orthodontic retainer, to be placed in an individual’s oral cavity with wires extending out of the mouth. This EPG device and its associated wires create a physical perturbation in the oral cavity, which may cause distortion of speech unless an individual is able to adapt their articulation to its presence. Although previous research has examined how adults adapt their speech to the presence of an EPG appliance (e.g., Aasland, Baum, & McFarland, 2006; McAuliffe, Robb, & Murdoch, 2007; Searl, Evitts, & Davis, 2006), less is known about how younger speakers who are continuing to develop their motor speech abilities might adapt their speech to the presence of the device.

In general, adults have shown the ability to adapt their speech to a number of different obstructions or physical perturbations placed in the mouth. Bite block studies have provided evidence of adult speakers’ ability to adapt to a perturbation in a relatively rapid manner. Bite blocks are a small intraoral device, typically made of rubber or Styrofoam, used to fix the jaw at a set opening in order to differentiate between tongue or lip movement and jaw movement (Netsell, 1985). A study by Gay, Lindblom, and Lubker (1981) found almost immediate
adaptation for speech sounds produced with a relatively open vocal tract configuration (i.e., vowels) to the presence of a bite block. The researchers concluded that speakers’ compensation was based on supershaping or exaggerations of the tongue and lips. Lindblom, Lubker, and Gay (1977) reported similar results describing *instantaneous* compensation in vowels to the presence of a bite block. Other bite block studies have shown that the period of adaptation differs depending on the type of speech sound being produced. Findings from a study by McFarland and Baum (1995) provided acoustic data showing that adaptation for vowels was not immediate but did take place within a 15 minute period of time, whereas adaptation for stops and fricatives was not complete after 15 minutes. A perceptual analysis of the same data showed similar results, in that adaptation for vowels took place in the first 15 minutes while adaptation for fricatives did not. The perceptual findings for stops were inconclusive (Baum, McFarland, & Diab, 1996).

Adaptation to lingual pellets and magnets placed on the tongue to track speech movements is another example of individuals’ ability to adapt their speech to a perturbation placed in the oral cavity. Previous research has shown that adaptation may occur after a relatively short period of time. Weaver (2005) reported no significant differences in spectral measures of /s/ and /ʃ/ after only five minutes of conversation in ten typical adults who had a magnet placed on the tongue. However, Weismer and Bunton (1999) reported inconclusive findings concerning the effects of four lingual pellets on speech production. The authors examined perceptual ratings of 21 speakers before and after placement of the pellets. The researchers’ perceptual findings were inconclusive in determining whether the speakers adapted to the presence of the lingual pellets; however, analysis of vowel formant frequencies revealed trends of adaptation toward pre-placement levels, but complete adaptation did not occur. For some individuals a dental prosthesis or retainer may be a perturbation that affects their speech.
Studies of adaptation to a dental prosthesis have shown mixed results. Hamlet, Cullison, and Stone (1979) reported that compensation to the dental prosthesis did not occur immediately for the fricatives /s/ and /z/, but signs of adaptation for most participants did occur within a couple of minutes. While significant sibilant lengthening for /z/ did occur, the effects of the prosthesis on speech production were not as great as expected. When similar methods were used to examine adaptation in adult speakers who had a resolved childhood articulation disorder, the adaptation results were mixed. Although all participants showed signs of adaptation after wearing the prosthesis during waking hours for a week, only seven of the thirteen participants successfully adapted their speech within that time period (Hamlet & Stone, 1982).

An orthodontic retainer is similar in structure to the pseudopalate used in EPG yet different in a number ways. The thickness of the EPG appliance is often greater than a retainer due to the embedded electrodes. The device also has wires that extend out the corners or front of the mouth. A number of studies have examined adult speakers’ ability to adapt their speech to the presence of an EPG pseudopalate placed in their mouth (e.g., Aasland et al., 2006; McAuliffe, Robb, et al., 2007; Searl et al., 2006). Researchers examining speech adaptation over a short period of time found that speakers were not able to completely adapt their stops and fricatives to the presence of the pseudopalate within 20 minutes (Dean, 2008; Williams, 2009). However, other researchers have shown that speech adaptation does continue to occur over the first few hours of wearing the pseudopalate. McAuliffe, Robb, et al. (2007) reported acoustic and perceptual data regarding eight individuals who were able to adapt to the presence of a pseudopalate after 45 minutes to three hours of wearing the palate. McLeod and Searl (2006) looked at adaptation over the span of two days (six hours per day) of wearing the pseudopalate.
and found that the impact of the EPG device on speech articulation decreased over time, with speech measurements being close to the baseline condition after only two hours.

Similar to the findings in bite block studies (McFarland & Baum, 1995), previous research has also indicated that adaptation times differ depending on the type of sound being produced by the speaker. McFarland, Baum, and Chabot (1996) found that when producing the vowels /i, a, u/, participants exhibited no significant differences in vowel production when the pseudopalate was in place, whereas the participants’ production of fricatives /s, ʃ/ was greatly affected by the presence of the pseudopalate. The authors further reported that the effects of the pseudopalate on the production of the stop consonants /p, t, k/ appeared to be minimal. However, Williams (2009) reported that stop-loaded sentences were consistently rated lower than fricative-loaded sentences in a perceptual analysis after a 20 minute adaptation time.

Many of the studies examining EPG adaptation have also reported a relatively high degree of individual variability (Baum & McFarland, 2000; McAuliffe, Lin, Robb, & Murdoch, 2007). Baum & McFarland (2000) examined the variability between speakers’ ability to adapt their productions of the /s/ phoneme to the presence of the pseudopalate after one hour of intensive practice. Differences ranged from one participant showing essentially no effects to the presence of the pseudopalate to another participant showing evidence of adaptation in the acoustic data only and another participant in only the perceptual data.

Research has thus provided valuable insights into how adults adapt their speech to the presence of an EPG pseudopalate; however, less emphasis has been placed on adaptation research in children. Considering that EPG is a device that is used in the treatment of children who have articulation errors that persist even after traditional treatment, and with a school-aged population often between 6 and 12 years of age, it is essential to understand how young speakers
adapt to the device in order to understand its effectiveness in treatment. One survey of speech therapists in Scotland showed that 52% of the 60 children being treated with EPG were between the ages of 6 and 10 years (Gibbon & Paterson, 2006). Considering the child’s maturity and cognitive development, good candidates for therapy are typically around six to seven years of age (Dagenais, 1995).

A guide to how children might adapt their speech to the presence of the EPG pseudopalate may be gained from research conducted with adult speakers; nevertheless, it remains uncertain whether children adapt in a similar manner or within the same time frame. Children’s speech production differs from adults in a number of ways, one of which is that in general, young children’s vocal tract structures are anatomically much smaller than adults. For most EPG systems the thickness of the pseudopalate is the same whether an adult or child is wearing it. Thus the EPG pseudopalate may create a greater physical obstruction in children relative to the size of their oral cavity. Cheng, Murdoch, Goozée, and Scott (2007) cautioned, “It is possible that with a smaller oral cavity, children may be more susceptible to the effects of palatal perturbation… Clinicians should be alert to the possible articulatory changes that occur when a pseudopalate is in place, particularly when interpreting EPG data from young children” (p. 386). A second fundamental difference is that children may still be learning or fine tuning the motor planning used for speech production. Although children’s speech may be perceptually intelligible, adult-like precision and articulatory consistency may be still developing, especially for later acquired affricate and fricative speech sounds (Nissen & Fox 2005; Nittrouer, 1995). A study by Cheng et al. (2007) examined developmental changes in tongue-to-palate contact variability. The authors found evidence of a protracted developmental period for speech motor control in children and adolescents, even extending as old as 17 years of age. Considering these
anatomical and developmental differences, it is unclear if younger speakers will adapt their speech to the presence of an EPG pseudopalate in a similar manner or time frame as adult speakers.

Thus the current study was designed to better understand how children adapt their speech production to the placement of an EPG pseudopalate. Specifically this study will examine the speech adaptation of children when producing the voiceless fricatives /s/ and /ʃ/. Adaptation was evaluated over a two-hour period of time and examined in terms of the acoustic measures of duration, spectral mean, spectral variance, and relative intensity.

**Method**

To allow for subsequent comparison to previous studies involving adults, this study partially replicated the methodologies of McAuliffe, Robb, et al. (2007), Dean (2008), and Williams (2009). In addition, this thesis describes one portion of a more comprehensive project on speech adaptation, thus the methodology described below is similar in nature to other studies within the project.

**Participants**

Six elementary school-aged children from the local community between the ages of 7;0 to 10;0, averaging 8;3 months, were recruited to participate in this study. All of the participants had typically developing dentition and hearing. Prior to participation, all participants had their speech screened for articulation errors and their hearing screened with pure-tone air conduction thresholds of 25 dB HL at octave frequencies from 500 to 8000 Hz. The participants were all native speakers of American English. None of the participants have worn an orthodontic retainer or have a history of a speech, language, or neuromotor disorder. Each participant and participants’ guardian read and signed an informed consent document, and prior approval was
obtained from the Brigham Young University Institutional Review Board for Human Subjects Research prior to data collection (see Appendix B).

**Procedures**

Prior to the beginning of data collection, each of the speakers had a dental impression made by a local orthodontic technician. Once the impression was made, the technician made a plaster stone model from which an artificial pseudopalate with the embedded circuit was created. The custom-made EPG pseudopalate, designed by Complete Speech©, is approximately 2 mm thick. If a participant’s pseudopalate was loose fitting due to missing teeth, a thin coating of dental adhesive was placed at the height of the maxillary arch to secure the device in place. Clinically, it is common to use dental adhesive in this manner when working with a child with a loose-fitting pseudopalate.

The participants’ adaptation to wearing the EPG pseudopalate was examined eight times during one session lasting approximately three hours. Audio recordings were collected at the following times: (a) prior to pseudopalate placement, (b) immediately following pseudopalate placement, (c) 30 minutes following placement, (d) 60 minutes following placement, (e) 90 minutes following placement, (f) 120 minutes following placement, (g) immediately following removal of palate, and (h) 30 minutes following removal of the pseudopalate. During each of these data collection times, participants repeated 12 CVC words three times in random order, while embedded in the carrier phrase *say CVC again*. As shown in Table 1, the target words were composed of an initial consonant of /t/, /k/, /s/, or /ʃ/, followed by one of the following three monophthongal vowels /i/, /u/. Participants were also asked to engage in approximately one minute of spontaneous speech. However this thesis project focuses on an acoustic analysis of only the single word utterances beginning with the fricatives /s/ and /ʃ/. 
To facilitate adaptation to the pseudopalate after placement, participants were instructed to interact in play with a group of other participants of similar age whom were also wearing the pseudopalate. Speech recordings were collected using a high-quality, low impedance dynamic microphone and preamplifier, while participants were seated in a sound-attenuating booth. All acoustic recordings were sampled at a rate of 44.1 kHz with a quantization of 16 bits. All elicitation, recording, and acoustic analysis of stimuli were aided by custom-designed computer programs (MATLAB; version R2011b).

Table 1

*Experimental Stimuli*

<table>
<thead>
<tr>
<th>teeth</th>
<th>keep</th>
<th>sheep</th>
<th>seat</th>
</tr>
</thead>
<tbody>
<tr>
<td>taught</td>
<td>cop</td>
<td>shop</td>
<td>sought</td>
</tr>
<tr>
<td>tooth</td>
<td>coop</td>
<td>shoot</td>
<td>suit</td>
</tr>
</tbody>
</table>

**Acoustic Data Analyses**

Segmentation of the onset and offset of the target sounds were conducted through a visual inspection of a waveform and spectrographic display created by Adobe Audition (version 2013). The onset of the fricative segment was characterized by a sharp increase in diffuse noise energy and the rapid increase in zero crossings, with the offset defined by a sharp decrease in diffuse noise energy. Segmentation values were then recorded into a text file (in ms) and later checked, corrected, and re-checked using custom MATLAB software designed to detect any data entry errors. All speech samples were high-pass filtered with a cutoff frequency of 70 Hz.
The speech samples were analyzed in terms of duration and relative intensity. The relative intensity was calculated by comparing the root mean square of each target fricative with the strongest component within 100 ms of the following vowel. In addition, using spectral moment analysis, the obstruent tokens will be described in terms of spectral mean (Hertz; Hz) and spectral variance (MegaHertz; MHz), following the computational algorithms outlined in previous studies (Fox & Nissen, 2005; Jongman, Wayland, & Wong, 2000; Nissen & Fox, 2005, 2009).

Measurement Reliability

To test for segmentation accuracy and reliability, 10% of all tokens were independently analyzed by a second person and subsequently correlated with the original segmentation of these same tokens. Using both sets of segmentation points, the acoustic measures were recalculated and Pearson correlations on these two sets of data were compared in terms of duration (mean absolute difference = 6.63 ms; \( r = .97, p < .0001 \)), spectral mean (mean absolute difference = 46.75 Hz; \( r = .99, p < .0001 \)), spectral variance (mean absolute difference = 0.11 MHz; \( r = .99, p < .0001 \)), and relative intensity (mean absolute difference = .13 dB; \( r = .99, p < .0001 \)).

Results

Due to a limited number of participants in the current study, the data from this study were analyzed with descriptive rather than inferential statistics, describing trends in individual participants. Means and standard deviations of the participants for duration, spectral mean, spectral variance, and relative intensity can be found in tables 2 and 3. In addition, the acoustic values for each measure are presented in figures displaying mean values, as well as each speaker’s adaptation to the pseudopalate over time.
Table 2

*Acoustic Measures (Mean and Standard Deviation) Across Speaking Conditions for /s*/

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Duration&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Spectral Mean&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Spectral Variance&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Relative Intensity&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
</tr>
<tr>
<td>Pre</td>
<td>213 37</td>
<td>5561 1077</td>
<td>4.01 2.17</td>
<td>-30.01 5.18</td>
</tr>
<tr>
<td>0</td>
<td>200 30</td>
<td>5063 812</td>
<td>4.94 1.60</td>
<td>-39.40 3.31</td>
</tr>
<tr>
<td>30</td>
<td>201 43</td>
<td>5176 663</td>
<td>4.29 0.51</td>
<td>-37.61 3.33</td>
</tr>
<tr>
<td>60</td>
<td>176 12</td>
<td>4621 1335</td>
<td>5.24 1.54</td>
<td>-36.07 2.15</td>
</tr>
<tr>
<td>90</td>
<td>202 60</td>
<td>4686 1558</td>
<td>5.09 2.22</td>
<td>-38.27 4.78</td>
</tr>
<tr>
<td>120</td>
<td>194 59</td>
<td>5383 1257</td>
<td>4.08 1.16</td>
<td>-34.68 5.85</td>
</tr>
<tr>
<td>post</td>
<td>198 46</td>
<td>6092 444</td>
<td>2.67 0.80</td>
<td>-28.54 4.42</td>
</tr>
<tr>
<td>post+30</td>
<td>195 58</td>
<td>5624 1176</td>
<td>3.35 0.72</td>
<td>-27.25 5.41</td>
</tr>
</tbody>
</table>

Note. <sup>a</sup>Values reported in milliseconds.<sup>b</sup>Values reported in hertz.<sup>c</sup>Values reported in megahertz.<sup>d</sup>Values reported in root mean square in decibels.

Table 3

*Acoustic Measures (Mean and Standard Deviation) Across Speaking Conditions for /ʃ/*

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>Duration&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Spectral Mean&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Spectral Variance&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Relative Intensity&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
<td>M  SD</td>
</tr>
<tr>
<td>Pre</td>
<td>216 43</td>
<td>5135 486</td>
<td>4.41 1.04</td>
<td>-33.19 4.37</td>
</tr>
<tr>
<td>0</td>
<td>209 36</td>
<td>4364 337</td>
<td>5.90 2.03</td>
<td>-43.26 3.12</td>
</tr>
<tr>
<td>30</td>
<td>225 57</td>
<td>4690 309</td>
<td>5.61 0.86</td>
<td>-40.24 1.72</td>
</tr>
<tr>
<td>60</td>
<td>180 59</td>
<td>4853 341</td>
<td>5.17 0.45</td>
<td>-39.02 1.68</td>
</tr>
<tr>
<td>90</td>
<td>200 41</td>
<td>4796 436</td>
<td>5.39 0.46</td>
<td>-39.27 3.12</td>
</tr>
<tr>
<td>120</td>
<td>201 57</td>
<td>4833 312</td>
<td>4.82 0.64</td>
<td>-37.19 2.43</td>
</tr>
<tr>
<td>post</td>
<td>203 46</td>
<td>5307 434</td>
<td>3.61 0.86</td>
<td>-32.85 3.81</td>
</tr>
<tr>
<td>post+30</td>
<td>191 55</td>
<td>5339 378</td>
<td>3.97 0.86</td>
<td>-30.97 3.36</td>
</tr>
</tbody>
</table>

Note. <sup>a</sup>Values reported in milliseconds.<sup>b</sup>Values reported in hertz.<sup>c</sup>Values reported in megahertz.<sup>d</sup>Values reported in root mean square in decibels.
Duration

As shown in Figure 1, overall there was not a sharp increase or decrease in duration after placement of the EPG pseudopalate for either /s/ or /ʃ/. However, as shown in Figures 2 and 3, patterns of duration varied across individual speakers. The greatest amount of intraspeaker variation was found in the productions of speaker F2, who exhibited sharp increases and decreases across time points for both /s/ and /ʃ/. In addition, for speaker F1 slight increases in duration after placement of the EPG pseudopalate were found for the /ʃ/ productions, but not for /s/. In general, the impact of the pseudopalate on duration was limited for the speakers in this study.

Figure 1. Duration means of /s/ and /ʃ/ as a function of time interval relative to EPG placement.
Figure 2. Duration of /s/ as a function of time interval relative to EPG placement for each speaker.

Figure 3. Duration of /ʃ/ as a function of time interval relative to EPG placement for each speaker.
Spectral Mean

As illustrated in Figure 4, when the data are collapsed across individual speaker, there is a noticeable decrease in the spectral mean of both /s/ and /ʃ/ immediately following the placement of the pseudopalate when compared with the baseline condition. After 120 minutes the speakers have adapted their productions of /s/, in terms of spectral mean, to near-baseline levels; however, productions of /ʃ/ only returned to baseline following the removal of the device. When the data were separated by individual speaker, the patterns of change in production immediately following the placement of the device and subsequent adaptation were relatively similar for /ʃ/ but highly variable for the production of /s/. As seen in Figure 5, productions of /s/ for two of the participants (F2 and M2) exhibited a sharp decrease in spectral mean following the placement of the device, whereas two participants showed an increase in spectral mean (F1 and M3), and the other participants (F3 and M1) showed relatively no change. Both the time and degree of adaptation for the spectral mean of the /s/ phoneme was highly variable across participants. Unlike /s/, all six speakers productions of /ʃ/ exhibited a decrease in spectral mean followed by partial or full adaptation, as shown in Figure 6. Five of the six participants demonstrated signs of adaptation after wearing the device for only 30 minutes of time.

Spectral Variance

As shown in Figure 7, overall trends of spectral variance in both /s/ and /ʃ/ demonstrated an increase after placement, with signs of adaptation occurring after only 30 minutes. However as illustrated in Figures 8 and 9 when the data are separated by individual speaker, participants were not consistent in the patterns of change in production immediately following the placement of the device and in the timing of their adaptation to the device. For five of the six participants, the spectral variance of both /s/ and /ʃ/, but decreased for one participant (F1). In general,
**Figure 4.** Means of spectral mean for /s/ and /ʃ/ as a function of time interval relative to EPG placement.

**Figure 5.** Spectral mean of /s/ as a function of time interval relative to EPG placement for each speaker.
Figure 6. Spectral mean of /ʃ/ as a function of time interval relative to EPG placement for each speaker.

Figure 7. Mean spectral variance for /s/ and /ʃ/ as a function of time interval relative to EPG placement.
Figure 8. Spectral variance of /s/ as a function of time interval relative to EPG placement for each speaker.

Figure 9. Spectral variance of /ʃ/ as a function of time interval relative to EPG placement for each speaker.
participants returned to pre-placement levels of spectral variance for productions of both fricatives after 120 minutes, but then tended to overshoot pre-placement levels once the pseudopalate was removed.

**Relative Intensity**

As illustrated in Figure 10, when the data are collapsed across individual speakers, there is a noticeable decrease in the relative intensity of both /s/ and /ʃ/ immediately following the placement of the pseudopalate when compared with the baseline condition. After 120 minutes the speakers have at least partially adapted their productions of /s/ and /ʃ/ to near baseline levels. When the data were separated by individual speaker, the patterns of change in production immediately following the placement of the device and subsequent adaptation were relatively similar for both /s/ and /ʃ/. As seen Figures 11 and 12, all six speakers sharply decreased the relative intensity of their productions for both fricatives following placement of the EPG device. However the time and degree of adaptation, in terms of relative intensity, for the speakers’ fricative productions was highly variable across participants.

**Discussion**

The initial impact from placement of the pseudopalate on participants’ productions of /s/ and /ʃ/ varied across the different acoustic measures examined in this study. In some instances the effect of the pseudopalate was similar for all six participants, such as with relative intensity and spectral mean of /ʃ/. However, for the other acoustic measures, the immediate effect that the placement of the pseudopalate had on a participant’s speech patterns and their subsequent adaptation to the device varied greatly across individual speakers. In terms of isolated acoustic measures, adaptation to the device for some participants occurred in a relatively short amount of
Figure 10. Mean relative intensity of /s/ and /ʃ/ as a function of time interval relative to EPG placement.

Figure 11. Relative intensity of /s/ as a function of time interval relative to EPG placement for each speaker.
Figure 12. Relative intensity of /ʃ/ as a function of time interval relative to EPG placement for each speaker.

Time (30 minutes), other participants required 120 minutes, whereas in some instances individuals did not adapt to the device. Nonetheless, partial adaptation occurred after only 30 minutes for at least one participant across all measures, but most consistent signs of adaptation after 30 minutes were seen with spectral mean of /ʃ/.

The least amount of initial impact from placement of the pseudopalate on participants’ productions of /s/ and /ʃ/ was seen with the acoustic measure of duration. This finding is similar to results from adaptation studies with adults, which also reported limited effect of the pseudopalate perturbation on the acoustic measure of duration. Consistent with the current study some studies reported no effect on consonant duration (McLeod & Searl, 2006; Searl et al.,
2006), while others reported the only significant increase occurring after 45 (McAuliffe, Robb, et al. 2007) or 60 minutes (Aasland et al., 2006).

The initial impact from placement of the pseudopalate on the spectral mean of /s/ was greater than that of duration was but also highly variable, as three participants demonstrated an increase in spectral mean, two decreased in spectral mean, and one participant neither increased nor decreased initially. Spectral mean of /ʃ/, however, decreased with all six participants after placement of the pseudopalate. As discussed by Nissen and Fox (2009), a decrease in spectral mean is likely indicative of the primary fricative constriction being somewhat retracted, thereby creating a longer anterior resonating cavity. A similar pattern, namely a lowering of spectral mean, was also found in /s/ productions for three of the participants. However, there was one participant that demonstrated an increase in spectral mean of /s/ after placement of the pseudopalate, which was likely the result of fronting, rather than backing, the tongue and therefore creating a shorter anterior resonating cavity.

Participants’ ability to at least partially adapt to the presence of the pseudopalate before removal of the pseudopalate was evident in the spectral mean for both /s/ and /ʃ/. Four participants exhibited partial adaptation with spectral mean of /s/ after only 30 minutes, as did five participants with spectral mean of /ʃ/. Adaptation, however, was not always consistent and great variability was noted particularly with spectral mean of /s/.

Spectral mean results from the current study were less uniform than previous studies conducted with adults. In the current study there was a general reduction in spectral mean and trends of adaptation to the pseudopalate for /ʃ/ while spectral mean of /s/ demonstrated inconsistent and irregular patterns. Results from Searl et al. (2006) demonstrated regularity with /s/, as an immediate reduction in spectral mean for /s/ was reported with a return to baseline after
only 15-30 minutes. McAuliffe, Robb, et al. (2007) reported results that were nearly opposite of the current study, with the spectral mean significantly reduced for /s/ throughout the adaptation period and no significant results with /ʃ/. McLeod and Searl (2006) also reported a significant reduction in spectral mean of /s/ for the first 120 minutes after placement of the pseudopalate. Furthermore Dean (2008) described significant results for spectral mean of both /s/ and /ʃ/.

The effect from placement of the pseudopalate on the spectral variance of /s/ and /ʃ/ was also highly variable. Half or more of the participants demonstrated an increase in spectral variance of /s/ and /ʃ/ initially, but at least one participant in both measures exhibited a decrease and another participant showed no change at all. Participants’ ability to adapt to the presence of the pseudopalate was evident in the spectral variance measures for /ʃ/. Four of the participants showed signs of adaptation after only 30 minutes. However, adaptation was not always stable, and a relatively high degree of intrasubject variability and overshoot was found for the measure of spectral variance. The variability was even greater for /s/ with only one participant showing signs of adaptation after 30 minutes and less of a general pattern was observed across participants. Dean (2008) also analyzed spectral variance of /s/ and /ʃ/, but with an adult population. Dean reported more consistent results with a significant increase in spectral variance for both /s/ and /ʃ/. It was also noted that complete adaptation did not occur after a 20 minute adaptation period.

The most consistent trends across acoustic measures were seen with relative intensity. All six participants demonstrated a decrease in relative intensity directly following placement of the EPG pseudopalate. Although five of the six participants demonstrated signs of adaptation while the pseudopalate was in place, complete adaptation was variable and did not occur until after removal of the pseudopalate for two participants with /s/ and three participants with /ʃ/. Although
relative intensity presented the most consistent patterns of adaptation, results cannot be compared to similar studies conducted with adults due to the absence of relative intensity measures reported in those studies.

Perhaps the most significant difference between adaptation studies with adults and the current work was the large degree of inter and intra-variability exhibited in the child speakers. There are a number of factors that may contribute to the variability seen in this study. One factor may be that unlike the speech patterns of many adults the motor patterns of children may not be as well established. Although the speech of children this age may sound adult-like in terms of articulation, they may still be fine-tuning their speech motor patterns; this is especially true for later acquired fricatives like /s/ and /ʃ/ (Nissen & Fox, 2005; Nittrower, 1995). Thus the intrasubject variability seen across measures in this study may be due to immature speech patterns typical of children younger than 10 years of age.

A second factor to consider is the relative size of the EPG pseudopalate to the size of the oral cavity in the child participants. Although children’s oral cavities are anatomically smaller than adults, the same size of device is used with both children and adults. The device used in the current study is the same device used with adults in the study conducted by Dean (2008). The larger relative size of the palate to the size of the oral cavity may cause children to be more susceptible than adults to changes in speech production when the EPG pseudopalate is in place (Cheng et al., 2007).

Thirdly, a child’s ability to adapt to a perturbation in the oral cavity caused by the presence of an EPG pseudopalate may be affected by the stage of their cognitive development. In general, children are not as cognitively developed as adults which may affect their ability to naturally problem solve the issue of having a perturbation placed in the oral cavity. An individual
with a more mature cognitive system will likely find more ways to adapt their articulators to the presence of the pseudopalate. Among other recommendations, Dagenais (1995) suggested considering a child’s cognitive development when deciding whether a child is a good candidate for therapy with an EPG pseudopalate.

Finally, the individual acoustic variables used in this study (duration, spectral mean and variance, and relative intensity) may not have been sensitive to the participants’ ability to adapt their speech to the pseudopalate. It may be that these acoustic parameters are not sensitive to adaptation when measured and analyzed in isolation, but are effective measures when combined together or analyzed in a holistic manner. The most effective way to evaluate a combination of acoustic parameters is by using perceptual ratings from listeners. Many of the studies completed with adults also completed a perceptual analysis in their data analysis (Aasland et al., 2006; McAuliffe, Lin, et al., 2007; McAuliffe, Robb, et al., 2007; McLeod & Searl, 2006; Searl et al., 2006; Weaver, 2009). The listener ratings combined with the acoustic measures may provide a more complete picture of how participants were affected by the placement of a pseudopalate in the oral cavity and how they were able to adapt to its presence.

There are several limitations in this study that are important to note, especially with the consideration of future research in this area. One limitation to the current study was the small number of participants. A greater number of participants would allow for inferential statistics to be conducted, which would allow for generalization of the results to the general population. A larger number of participants are also needed considering the relatively high amount of intra and inter-subject variability found in this study.

Another limitation of the current study is the possibility that the participants began to fatigue due to the extensive number of words spoken at each time interval and the overall length
of data collection (three hour session). At each of the eight time intervals participants spoke eight words, three times, for a total of 24 words that were each embedded in a short carrier phrase. The participants in this study also demonstrated greater difficulty staying on task as time progressed. It is important to be aware that children are likely more sensitive to fatigue than adults. McAuliffe, Robb, et al. (2007), a study completed with adults, described eliciting stimuli only four times over a three hour adaptation period. Adopting similar methodology may help prevent fatigue and encourage more reliable results. Decreasing the amount of stimuli to only four words, one word per consonant sound, may also be beneficial, especially considering vowel context was not found to be a significant factor in the current study. Other studies have also shown that the presence of the pseudopalate has no significant effect on vowels (McAuliffe, Robb, et al., 2007; McFarland et al., 1996).

The actual fit of the EPG pseudopalate was a further limitation of the current study. Some participants required dental adhesive to keep their pseudopalate in place, while others had pseudopalates that were tighter than ideal. One participant even complained of pressure on his teeth due to the tight fit of his pseudopalate. It is therefore advisable to allow time for refitting of the EPG pseudopalates, if needed, to ensure the best fit for all participants.

A perceptual component, as conducted with other studies done with adults (Aasland et al., 2006; McAuliffe, Lin, et al., 2007; McAuliffe, Robb, et al., 2007; McLeod & Searl, 2006; Searl et al., 2006; Weaver, 2009), is essential in more fully understanding children’s ability to adapt to the presence of an EPG pseudopalate. McAuliffe, Robb, et al. (2007) reported significant differences in acoustic and perceptual results, especially for the phoneme /s/. Other researchers (McLeod & Searl, 2006; Searl et al., 2006) also found substantial differences in the acoustic and perceptual data, where the acoustic data revealed a much greater effect on
participant’s speech than the perceptual ratings showed. A perceptual analysis would provide a broader picture of what is occurring with children’s ability to adapt to the presence of the pseudopalate.

The EPG pseudopalate is a relatively new device with the potential of impacting articulation therapy with children, especially in children where traditional articulation therapy has been unsuccessful. Disturbance of speech patterns from the presence of the pseudopalate was noted for most of the acoustic measures, namely, relative intensity of both /s/ and /ʃ/, as well as spectral mean and spectral mean of /ʃ/. Although there was a relatively high amount of variability among and within speakers, signs of adaptation were apparent after only 30 minutes for some participants. However for some acoustic measures full adaptation often did not occur until the EPG pseudopalate was removed. When conducting future research in this area, it is recommended that studies include a higher number of participants and include a perceptual component when evaluating speakers’ ability to adapt the speech to the presence of a pseudopalate. Although future research is needed, it is hoped that this study will provide a greater understanding of children’s ability to adapt to the EPG pseudopalate.
References


Appendix A

Annotated Bibliography


**Objective:** This study examined speech adaptation to productions of /s/ when wearing an electropalatographic appliance. **Method:** Nine adults (19-27 years) participated in this study all with normal dental occlusion, and no reported speech, language or hearing impairments. Participants also reported no past experience wearing a dental appliance. Each participant produced /asa/ ten times every 15 minutes over the course of an hour while wearing either a one mm or six mm artificial pseudopalate. Participants were instructed to read /s/-laden passages during the time intervals between data collection periods. The participants’ adaptation to the device was measured in terms of the /s/ duration, centroid frequency, and standard deviation of the spectrum. EPG analysis was also conducted to provide information of compensatory tongue positioning. A perceptual analysis was also conducted involving the ratings of 10 naïve listeners. **Results:** Measures for mean frication duration were found to be significantly longer 60 minutes post-placement when compared to the earlier data collection times. Measures of the centroid frequencies were higher for the thick palate condition, with the exception of the initial data collection. The EPG analyses showed that contact patterns were comparable for the first data collection, but all other contact times were less for the thin palate than the thick palate. Ratings from the perceptual analyses concerning of the quality of participants’ /s/ productions were initially greater for the thin palate condition, but switched to be greater for the thick palate after 15 minutes. **Conclusions:** Compensatory strategies were evident after an intense but relatively short target-specific period of practice, with adaptation to the EPG device beginning to take place after only one hour of practice.

**Objective:** This study examined individual variability adapting to an artificial palate. **Method:** Four female native French speakers participated in this study, of which two had worn a removable orthodontic appliance for a year or less. Participants’ speech was examined before insertion of the pseudopalate, right after placement, 60 minutes after placement, and after removal of the device. Ten nonsense syllables [si sa su ši ša šu] were elicited during each of the speaking conditions. Adaptation to the device was measured for each fricative production in terms of the centroid frequencies at the midpoint of the frication noise. In addition, a perceptual analysis was conducted using ten native French-speakers with training in articulatory assessment. The listeners rated the quality of the fricatives on a 10-cm visual analog scale. **Results:** Participant one showed evidence of adaptation in only the acoustic data, while participant two showed evidence of adaption in the perceptual data alone. The artificial palate seemed to essentially show no effect on speech articulation with participant three. Participant four showed speech adaptation both acoustically and perceptually after the hour of intensive practice. **Conclusions:** The authors found a high amount of variability across the four participants’ ability to adapt to the presence of the pseudopalate.


**Objective:** This research evaluated a group of speakers’ ability to compensate to the insertion of a bite-block of differing sizes when producing vowels, fricatives, and stop consonants. **Method:** Data collected from a previous study by McFarland and Baum (1995) was analyzed perceptually. Ten adult native French speakers with no speech, language, or hearing disorders participated in this study. Productions were elicited under four different speaking conditions including jaw-free, small bite block, large bite block,
and postconversation. Three productions of the vowels /i, / and /u/ and consonants /p, t, k, s/ and /ʃ/ for each condition were selected for analysis from the study by McFarland and Baum. Listeners identified the phoneme being spoken from a limited set of possibilities and rated the quality of each sound production. Results: When collapsed across sound type, the results were found to be significant between the no bite block and the other speaking conditions. Listener ratings of vowels were found to be significant only with /i/ in the large bite block condition. Ratings for stop consonants did not differ across the different speaking conditions, while ratings for fricatives were statistically significant between jaw-free and both the small and large bite blocks. Furthermore, ratings from the post conversation condition were also statistically significant when compared to the jaw-free condition, but only for /s/. Conclusion: The results of this study matched findings of the acoustic analysis done by McFarland and Baum (1995) for vowels and fricatives, but not for stops. Results showed the compensation to the bite block occurred quickly for vowels, but was not complete for fricatives.


Objective: The aim of this study was to examine the development of tongue-to-palate contact patterns of young children and adults. Method: Twelve individuals from each of the following four age ranges participated in the study: 6-7 years old, 8-11 years old, 12-17 years old, and adults. All participants were native English speakers and had typical speech, hearing, and oral motor skills. After being fitted with their own artificial palate each participant was required to wear the palate for a minimum of 20 minutes for desensitization. Each speaker repeated six CV and CVC words five times which were embedded in a short sentence. The consonants were chosen because of their varying place and manner. Measures were taken looking at the amount of tongue-to-palate contact, the pattern of tongue-to-palate contact, contact indexes and variability of contact. Results: Younger speakers (ages 6-11) had significantly more tongue to palate contact. Statistical
tests showed a linear reduction in tongue-to-palate contact with age for /t/ and /l/. There appears to be anterior shift that happens between 6 years of age and adulthood. They also found a significant increase in consistency of tongue-to-palate contact in the consonant /k/. Six to 11 year olds had significantly larger center of gravity values in /t/ and /s/ suggesting tongue contact that is more posterior. Conclusion: There is a significant increase in palatal contact observed in 6 to 11 year olds in comparison to adolescents and adults, as well as immature lingual control.


*Objective:* Effective treatments of children’s articulation and phonological disorders with a pseudopalate were analyzed in this study. Considerations in choosing candidates for pseudopalate treatment are also discussed. *Method:* The researchers reviewed recent articles that focused on treating articulation and phonological disorders with an EPG pseudopalate. Considerations for candidacy in children include the child’s maturity and their cognitive development. Taking these factors into consideration, typically developing children seven years and older are good candidates. *Results:* The treatment of articulation disorders needs to be reevaluated because errors made by the children seemed to actually be systematic. Treatment of phonological disorders was effective when the children were taught inventories of sounds in comparison to extinguishing phonological processes. *Conclusion:* A method to evaluate articulatory posturing needs to be determined to help improve treatment with the pseudopalate. EPG is generally used in children seven years of age and older.

Objective: Dean acoustically analyzed whether speakers adapt to wearing a pseudopalate after wearing it for 20 minutes. Method: Twenty adult participants recorded fricative and stop-loaded sentences before wearing the pseudopalate, immediately after placement, and 20 minutes after placement. Speech was analyzed acoustically looking at spectral mean, spectral variance, spectral skewness, and spectral kurtosis. Results: After wearing the pseudopalate for 20 minutes, the speakers trended back toward typical articulation, but that adaptation was not complete. Conclusions: A 20 minute adaptation period may be too short for speakers to adapt to a pseudopalate.


Objective: This study evaluated the use of a jaw tracking system in measure tongue movements during speech. Method: A magnet that was originally designed to record jaw movement was placed on the subjects’ tongues. Data were taken before and after the magnet was placed on the tongue. An acoustic analysis was conducted looking at the acoustic properties of voiceless fricatives before wearing the magnet and while wearing the magnet. Results: Spectral analysis showed no significant differences in the production of fricatives with the presence of the magnet. Conclusions: This device is similar to other devices used to track movements of the tongue; it is less expensive but has limitations that make it so you can only track one point in space, its reliability depends on keeping the head set steady, and there are effects of only being able to use smaller magnets. One benefit is that only a single magnet needs to be attached and it does not have any extra wires that other electromagnetic systems have which may impede precision of articulation.


Objective: This article is an explanation of what the palatometer is and how it works. The palatometer is a .2 mm palate with embedded electrodes. It is made by making an
impression of the individual’s palate. Lingual contact is detected and displayed either immediately or later for analysis. The information can be displayed as an average of linguapalatal contact across multiple repetitions. Multiple utterances may also be shown simultaneously accompanied with the sound spectrum. Geometrical distribution of contact may also be displayed. **Conclusions:** The palatometer is a tool to measure linguapalatal contact. It has computer-generated displays and analyses which may be used to further study articulation of speech.


**Objective:** This study addressed the question of whether there are sex-related acoustic differences in fricatives in prepubescent children. **Method:** Eighty children between the ages of six and 14 years of age and 20 adults with no history of a speech, language, or hearing disorder participated in this study. The children were divided into two year age groups, half of the participants in each group were male and half were female. Participants produced words with word initial voiceless fricatives /f, θ, s, ŋ/. Acoustic measures were taken including spectral slope, mean, skewness, and kurtosis. **Results:** The data showed significant variation for place of articulation, sex, and age. Spectral mean did no separate /s/ from /f, θ/, spectral peak did for male speakers only. Spectral slope separated all four parameters for all age groups. **Conclusion:** The authors found sex-related differences for even the six and seven year olds, although some of the acoustic differences were reduced in this young age group.


**Objective:** To determine what speakers do to compensate to having a bite block placed in their oral cavity. **Methods:** Five adult Swedish males with typical speech and hearing
participated in this study. Two different bite blocks were used, a 22.5-mm bite block for close vowels /i, o, u/, and a 2.5-mm bite block for the open vowel /u/. X-rays were obtained during the data collection, and the vowels were recorded. Vowels were produced without and then with the bite block in place. The x-rays were analyzed by tracing the vocal tract and taking cross dimensional measures. Formant frequencies were also analyzed. Results: Results of the formant frequencies showed small enough discrepancies which demonstrated that successful adaptation to the presence of the bite blocks. Tracings of the vocal tract showed that the outlines before the bite block and with the bite block matched within 5 mm. Compensatory supershaping was seen throughout the tracings. Conclusion: Individuals were able to compensate to the placement of the bite block. They were able to do this through using lip and tongue supershapes.


Objective: To obtain information on the individuals who received EPG, how their SLPS viewed their progress, and to gain insights into areas of need for further research. Method: Surveys were given to 10 speech language pathologists in Scotland who had done EPG treatment with clients. The questionnaire inquired about demographics, type of speech disorder, details of the therapy conducted, as well as judgments of the outcomes of therapy. Results: Sixty individuals had received EPG therapy. About half of the individuals had cleft palate, about one third had functional disorders, and the rest had a mix of etiologies. Almost half had received previous speech therapy for over five years, while only 20% had received it for less than a year. The individuals ranged from preschool age to over 21 years of age, but over half of the individuals were between the ages of six and ten. The sound most frequently targeted was /s/ followed by /t/. Most individuals received between six and 15 sessions. The majority of individuals had moderate success from therapy and showed difficulties with generalization. However, almost all of the individuals did show improvement in their own awareness. Conclusion: Articulation did improve in most of the individuals, but generalization was limited.

**Objective:** To determine how typical adults adapt the duration of their sibilants when a dental prosthesis is placed in the mouth. **Method:** Ten individuals participated in the first part of the study. They repeated four phrases three times during natural speech and while wearing a thin prosthesis and a thicker prosthesis. Sibilant durations were measured. The other part of the study involved six typical speaking females with no experience with a dental prosthesis. They each took home a thin prosthesis to wear for two weeks. Data were collected with the thick prosthesis before and after the two week time period. **Results:** The first part of the study reported significant lengthening with both of the prostheses with /z/ but not for /s/. Some of the participants reported the tongue seemed to touch the alveolar ridge too soon, but these observations were not reflected in the data. The second half of the study reported that the participant’s speech was considered to be normal after the adaptation period although three of the participants reported slight consonant distortions. **Conclusion:** Compensation did not occur immediately but the effects of the dental prosthesis were not as great as was expected. Adaptation did occur in a fairly short amount of time.


**Objective:** The authors had previously conducted research that showed how typical adult speakers were able to adapt to a dental prosthesis. The current study addresses the question of how individuals who successfully overcame childhood articulation disorders were able to adapt to a dental prosthesis. **Method:** Thirteen participants were found from a university population. All participants reported a childhood articulation disorder that had been resolved through speech therapy or their own efforts. None of the participants had received orthodontic treatment. Participants wore a dental prosthesis during waking
hours for two weeks. Data were collected at the beginning and end of the data collection period. Results: Seven of the thirteen participants successfully achieved adaptation, although all participants showed some signs of adaptation within the first week. The six remaining participants felt like they hadn’t successfully adapted to the prosthesis. Observations were reported that others still noticed their speech difficulties, that they still consciously noticed the prosthesis, and that they deliberately slowed down. Those who did not adapt showed tongue advancement. They also showed higher rates of further groove narrowing and an unchanged or closer jaw positioning. Conclusion: Individuals with a resolved childhood speech articulation disorder did not adapt as consistently to a dental prosthesis as typical speakers with no history of an articulation disorder.


Objective: This study sought to find acoustic measurements capable of accurately distinguishing all four places of articulation for fricative. Method: Ten adult females and ten adult males with no history of speech or hearing disorder participated in this study. The fricatives /f, v, θ, ð, s, z, ʃ, j/ were placed in the word initial position of consonant-vowel-consonant words followed by one of the following vowels /i, e, æ, o, u/. The final consonant was always a /p/, and the words were placed in the carrier phrase Say ___ again. Measurements utilized in this study include both dynamic and static properties and include spectral peak location, spectral moments, F2 onset frequency, noise amplitude, noise duration, locus equations and relative amplitude. Results: Contrary to previous research, spectral peak location accurately distinguished between all four places of articulation. Spectral moments were also able to distinguish all four places of articulation, variance and skewness proved to be most successful of the different spectral moments. Normalized and relative amplitude were also found to be useful in distinguishing place of articulation. Conclusion: All four places of articulation for fricatives can be distinguished through following acoustic measurements: spectral peak location, spectral moments, and normalized and relative amplitude.

**Objective:** Researchers looked at how individuals were able to compensate for the presence of a bite-block. **Method:** Formant frequency data were collected for Swedish vowels produced with and without a bite block. **Results:** Formant frequencies were considered to be within the normal range, despite the presence of the bite-block. **Conclusion:** Speaker’s ability to compensate for the bite-block was described as being instantaneous. Individuals were able to produce fairly typical vowels even with an obstruction in their mouth.


**Objective:** The aim of this study was to use perceptual and acoustic analysis to examine how adults adapt to an artificial palate. **Method:** Eight adult females (mean age = 24) with normal dental occlusion, no experience with orthodontic retainers, normal hearing, and no history of neuromotor or speech disturbances participated in this study. Each participant repeated a carrier phrase with twelve CVC words embedded five times under four speaking conditions: (a) normal speech, (b) immediately following insertion of the palate, (c) after wearing the palate for 45 minutes, and (d) after wearing the palate for three hours. The speech productions were analyzed perceptually by seven naïve listeners through a sliding scale rating system. The speech productions were also analyzed acoustically, looking at segment durations, first and second vowel formant frequencies, and consonant spectra. **Results:** Consonant imprecision was significantly greater immediately following the placement of the pseudopalate and 45 minutes after placement than it was before placement and three hours after placement. Perceptual analysis showed
the best consonant precision to be before placement and three hours after placement.

**Conclusions:** The results of this study suggest that individuals can adapt their speech to an artificial palate following a 45 minute to 3 hour time period. Consonant and vowel duration and formant frequencies seemed to be unaffected by the palate.


**Objective:** The aim of this study was to use perceptual and acoustic analysis to examine how adults adapt their speech to an artificial palate. **Method:** Three adult females (aged 31, 26, and 34 years) with normal dental occlusion, normal hearing and no neuromotor or speech disturbance participated in this study. Each participant repeated the carrier phrase *say CV again* with nine CV words embedded, repeated five times under three speaking conditions: (a) normal speech, (b) after wearing the palate for 45 minutes, and (c) after wearing the palate for three hours. The speech productions were analyzed perceptually by five naïve listeners for whether they thought the speaker was wearing an artificial palate or not. The speech productions were also analyzed acoustically, looking at durational measures and consonant spectra. **Results:** The naïve listeners were able to judge at a relatively high degree whether participants two and three (P2, P3) were wearing an artificial palate or not, but had difficulty making the distinction for participant 1 (P1). P1 and P3 demonstrated reduced consonant durations, while P2 showed no real change. In a spectral analysis articulation of fricatives varied across participants and /t/ was unaffected by the palate. **Conclusions:** Two of three of the participants of this study seemingly adapted to the artificial palate, while all three participants made changes to consonant articulation.

Objective: Compensation to insertion of a bite-block was assessed in regards to vowels, fricatives and stop consonants. Method: Fifteen native French speakers participated in this study. All had typical speech, language and hearing. Each participant randomly produced ten repetitions of each vowel, fricative, and stop consonant. Data were collected before placement of the bite block, right after insertion (with two different sizes of bite blocks), and after a 15 minute conversation. The samples were analyzed acoustically in terms of duration of vowels and consonants, as well as formant frequencies and centroid frequencies. Results: Duration was not significantly affected for vowels or stops, but was for fricatives. F1 values were significantly higher with the large bite block, but not the small bite block immediately following placement. Only /u/ productions were significantly different for F2 values with the large bite block. Lower centroid values were found for stop consonants with just the larger bite block and for fricative consonants with both the larger and smaller bite blocks. Centroid frequencies were still significantly lower for stops and fricatives even after the 15 minute conversation time period. Conclusion: Compensation for vowels was not immediate, but did take place after a 15 minute conversation period. Compensation for stops and fricatives was not complete after a 15 minute conversation period, suggesting that more time is required to compensate for a bite-block placed in the mouth.


Objective: Research was conducted to determine whether individuals were able to adapt their vowels, stops, and fricatives to the presence of an artificial palate and how that compares to similar studies done with bite blocks. Method: The methods closely followed the previous bite block study done by McFarland and Baum (1995). Fifteen female adults with no history of a speech, language, or hearing disorder participated in this study. All were native French speakers. Five repetitions of the following stimuli were elicited before placement, immediately following placement of the palate (with a thick and thin palate), and after 15 minutes of conversation (with the thick palate): /i, u/ in isolation,
/p, t, k/ preceding the same vowels, and /s, f/ also preceding the same vowels. Acoustic measures included vowel and consonant durations, the first two formant frequencies for vowels, and the first centroid, third skewness, and fourth kurtosis moments for the consonants. Ten adult native speakers of French also analyzed the data perceptually. Listeners were asked to listen to vowels and consonants in isolation identify the sound presented and rate its quality on a five point scale. Results: Most of the findings of duration were insignificant; significant findings were only found immediately after placement. Perceptual ratings showed high percent correct identification for vowels. Vowel quality was rated higher after the 15 minute adaptation time. Identification accuracy was lower for stops than vowels and fricatives, /k/ and /p/ were often identified as /t/. Quality ratings for fricatives were lower in the thick palate conditions in comparison to the no palate conditions. Conclusion: Effects of the palates on the participant’s vowels seemed to very minimal, and participants were able to adapt very quickly. Fricatives were greatly affected by the presence of the artificial palate. Individuals were not able to adapt to the presence of the palate in the 15 minute conversation period, but compensatory strategies appeared to be present. Due to complexity of interpreting the data for stops the authors concluded that stops were somewhere between vowels and fricatives.


Objective: This study evaluated adult speakers adaptation to wearing an EPG pseudopalate. Method: Seven adults (22-47 years) with normal hearing, no reported speech or language problems, and no previous experience with EPG participated in the study. Participants completed the following speech tasks 16 times over two days: producing the phrases /ə ti/ and /ə si/ 10 times each, counting 1-20, and reading the short version of The Rainbow Passage. On the first day the pseudopalate was worn for two hours, removed for two hours and worn again for one hour. On the second day it was worn for 30 minutes. Acoustic measures were taken looking at the first spectral measure.
(SM1), stop gap duration, syllable duration, and fricative duration. A Speech Language Pathologist listened to the recordings and judged how natural the speaker’s speech sounded and whether the palate was present or not. The participants also rated their own perception of the impact of the pseudopalate on their speech. Results: Results for stop gap duration and syllable duration were not statistically significant. SM1 was significantly reduced after putting in the pseudo EPG palate, but after one hour SM1 did not significantly differ from pre-placement values. SM1 was reduced again when the palate was once more placed in the mouth after two hours. Speech was judged to sound most distorted during the rainbow passage, but it was variable among different participants. The participants rated the impact to be the greatest right after placement of the pseudopalate, decreasing the longer they wore the device. Conclusions: Acoustic and speaker impressions showed that the participants were impacted by wearing the pseudopalate, but that the effect decreased over time, yet did not completely diminish for most participants. The spectral data showed some adaptation over time, but the values did not return to pre-placement values.


**Objective:** This study examined how bite blocks may be constructed and used for both the evaluation and treatment of speech disorders. **Method/Results:** The researchers used a material called Citricon to construct the bite blocks. The client was instructed to hold a tongue depressor in between their teeth while the material was setting up and creating a mold. The bite-block is principally used to differentiate lip or tongue involvement from jaw involvement. Tongue and jaw interactions are often evaluated by having the client produce the vowel extremes with and without the bite-block to see if their productions improve with the bite block. Another test is to have the client produce velar and alveolar consonants with vowels that require their tongue to move. To test if jaw movement is interfering with lip movement the clinician may place the bite-block in the client’s mouth and have them produce a bilabial loaded sentence. If the production improves jaw movement is likely interfering with lip movement. The authors
recommended simply counting to ten to evaluate lip-tongue-jaw interactions. Bite-blocks may be used in treatment when the desired outcome is to have the client use lip and tongue muscles with the assistance of the jaw. Bite blocks may also help clients increase range of lip and tongue movements and slow down their speech. Conclusion: Bite-blocks can be helpful resources in both the evaluation and treatment of speech disorders.


Objective: This study examined and compared the acoustic structures of voiceless fricatives in both young children and adults. Method: Participants in this study included 30 children between three and six years of age and ten adults. No participants had been diagnosed with a speech, language or hearing disorder. All children had typical articulation for their age. Stimulus included these voiceless fricatives /f, θ, s, ʃ/ followed by one of the following vowels /i, a, u/ which were placed in the carrier phrase This is a ___. The acoustic parameters included durations, normalized amplitude, spectral slope and spectral moments. Results: Statistical analysis indicated that spectral variance was the only parameter that was able to distinguish all four fricative types. Many of the other parameters were able to distinguish three of the four places of articulation. As seen in the measures of spectral mean, skewness, and kurtosis as children get older the acoustic distinction between /s/ and /ʃ/ widens. Conclusion: Articulation continues to be fine tuned through childhood and slowly becomes more adult-like.


Objective: Acoustic and spectral patterns of young children and adults were analyzed. Male and female differences were also analyzed. Method: Participants in this study included 30 children between 3 and 5 years of age and 10 adults. No participants had
been diagnosed with a speech, language, or hearing disorder. All children had typical stop production for their age. Stimuli included the voiceless stops / p, t, k/ followed by one of the following vowels /i, u/, which were placed in the carrier phrase This is a ___ again. Data were collected for stops in terms of spectral slope, mean, variance, skewness, and kurtosis. Results: Findings revealed that all of the acoustic parameters, except for spectral kurtosis, varied across place of articulation. The stop burst was also found to be significantly affected by the vowel context that followed it. For the five-year old participants and adults, significant sex-specific differences were also reported for the spectral slope, mean, and skewness measures. Conclusion: Due to the fact that the anatomy of children’s vocal tracts does not typically exhibit dimorphism in pre-pubescent children, the sex-specific differences found in the five-year old children’s speech patterns are likely due to learned or behavioral factors.


Objective: This study addressed the question of whether children’s articulation is as precise as adults’, and whether certain speech gestures become adult-like at an earlier stage of development. Method: Ten adults and 30 children between three and seven years of age participated in the study. All participants had typical speech, language and hearing. Syllables containing the consonants /s, ŋ, t/ and /k/ and the vowels /i, i/ and /u/ were produced in the carrier phrase It’s a ____ Bob. Ten samples of each syllable were elicited through a series of age appropriate pictures. The acoustic data were analyzed in terms of the first, third and fourth spectral moments. Results: The spectral mean values for fricative productions were found to differ across consonant type effects for the adults. On the contrary, first spectral moments for the stop bursts showed no differences in the consonant effect based on age. Conclusion: These data support the claim that some phonemes become adult-like sooner than others. The differences in fricative data for adults and children support the idea that adult-like precision for some consonants occurs gradually.
Objective: This study examined the effects of wearing a thin pseudopalate on speech produced by adults. Method: Eleven participants (28-48 years) with no reported speech, language, hearing, neurological, or head/neck problems participated in this research study. Five had worn orthodontic retainers, but not within the past 12 years. The data were collected before placement of the pseudopalate, and every 15 minutes for the first hour after placement, as well as 120 minutes after placement. The participants were asked to say /tik/ and /sik/ embedded in the carrier phrase a ___ again. The spectral mean, stop gap duration, frication duration, and phase duration was calculated. Ten speech-language pathologists also analyzed the data perceptually. The listeners rated the accuracy of the /t/ and /s/ in the samples on a 10-cm visual analog scale with the ends marked as distorted and not distorted. Results: The spectral mean was statistically higher for /t/ only at the 15 minute post placement measure and significantly lower for /s/ immediately after placement and after 15 and 30 minutes. Results for stop gap duration demonstrated a significant shortening immediately after placement that resolved after 30 minutes. No significant findings were found with fricative duration. The effects of the pseudopalate on phrase duration were limited in this study. In the perceptual analysis perceived distortion was relatively limited in magnitude. Listeners rated /s/ as more distorted than /t/. Conclusion: Acoustic data suggested a change in consonants /t/ and /s/ initially and adaptation after only 30 minutes. The perceptual data revealed limited effect on participants’ productions.
Objective: The aim of this study was to see how individuals were able to adapt to small magnets placed on the tongue. Method: Ten college-aged students with no history of speech, language or hearing problems participated in this study. Data was collected across two sessions, with different placements of a magnet each session. A magnet 10 mm from the tip of the tongue was placed the first session, while a magnet 15mm from the tip of the tongue was placed the second. The participants repeated the phrase, *Allison had to miss a sunny vacation at Shellfish Bay*, three times before placement of the magnet, right after placement, after a five minute conversation, and after an additional ten minute conversation. Acoustic analysis included a duration measure and calculation of the first four spectral moments. Results: It was reported that spectral differences were noted for /ʃ/ but not /s/ immediately following placement of the magnet. Higher spectral mean frequencies were found for the 10 mm position in comparison with the 15 mm position. After only five minutes of conversation no statistically significant differences were found in the spectral measures. Conclusion: In terms of the spectral measures of /s/ and /ʃ/ adaptation to lingual pellets placed in the mouth took place in a relatively short amount of time.


Objective: The effects of lingual pellets on speech production behavior were evaluated in this study. Method: Speech was analyzed for 21 individuals who had no history of hearing, speech or neuromotor disorders. The individuals repeated the phrase, *She had your dark suit in greasy wash water all year*, three times before placement of 11 lingual pellets and five times after placement of the pellets. The data were analyzed both acoustically and perceptually. The acoustical analysis included segment duration, F1-F2-F3 formant frequencies, and consonant spectra. Ten listeners rated whether the articulation in the speech samples sounded precise. Results: Speech rate appeared to not be affected by the pellets. Analysis of the formant frequencies revealed trends of adapting their speech so that the pellets wouldn’t make contact with specific places in the vocal
tract. Listeners were not consistent in determining whether the pellets were present or absent. **Conclusions:** Although varying trends were found in the data, the measures showed no consistent effects across speakers. Therefore, “point parameterization of lingual motion does not interfere with normal articulatory behaviors” (p. 2882).


**Objective:** This study was designed to perceptually analyze whether speakers adapt to wearing a pseudopalate after 20 minutes. **Method:** Speech recordings were used from a previous study, in which 20 adult participants recorded their speech before wearing the pseudopalate, immediately after placement, and 20 minutes after placement of the device. Twenty listeners evaluated the clarity of the speech recordings from normal to very distorted on a visual analog scale. **Results:** Male participants were rated as more distorted compared to female speakers, particularly when the sentences were stop-loaded. Overall stop-loaded sentences were rated as more distorted than fricative-loaded sentences. Speech increased in clarity after a 20 minute adaptation period, but the speaker’s speech still remained distorted. **Conclusions:** A 20 minute adaptation period may be too short for speakers to adapt to a pseudopalate.
Appendix B

Informed Consent Documents

Parental Permission for a Child to Be a Research Participant

Introduction
The purpose of this study will be to examine how younger speakers adapt their speech when a relatively thin palatal sensor is placed in their mouth. Your child is being invited to participate in this study because he/she is a native speaker of English with no history of speech, language, or hearing problems. This experiment is being conducted under the supervision of Shawn Nissen, Ph.D., an associate professor in the Department of Communication Disorders at Brigham Young University.

Procedures
Initially, your child will participate in a hearing screening, you will be given a summary of the results of this screening. If your child’s hearing is typical, your child will be fitted with a custom made palatal sensor (similar to an orthodontic retainer). The sensor is approximately 2 mm thick and conforms to the upper teeth and palate. You will be asked to have a dental impression created by a licensed dental professional, the cost of which will be pre-paid for you. A list of possible dental professionals will be provided, but you are welcome to produce an impression created by another dentist or technician of your choice. After the sensor is made your child will be asked to wear the sensor during one three-hour period of time. During this period of time they will be asked to interact in play and conversation with other children their age and have their speech audio recorded while reading a series of age-appropriate words and sentences, as well as several minutes of conversation. At a later date, these audio recordings will be analyzed and rated by adult listeners for intelligibility.

Risks/Discomforts
There are minimal risks associated with participation in this study. The palatal sensor is similar to an orthodontic retainer and may cause some minor discomfort to the gums or teeth during use. The participant may encounter some minor discomfort when the dental impression (which is used to create the sensor) is being created. The finished sensor is too large to be accidentally swallowed; in addition it is attached to the data collection unit. Your child’s speech may sound different with the sensor in place and it may take a period of time for them to become accustomed to speaking with the sensor in their mouth. Your child may encounter some social discomfort in talking to peers while wearing the sensor, which will be minimized by talking to group about the study beforehand and the fact that all children in the group will also be wearing a similar device.

Benefits
There are no direct or guaranteed benefits for participants of this study.

Confidentiality
The audio recordings and 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 child’s responses will be kept on a password protected computer in a locked laboratory and only those directly involved with the research will have access to them.

Compensation
Your child will be compensated $10 an hour for their participation.

Participation
Participation in this research study is voluntary. Your child has the right to refuse to participate or withdraw at any time without penalty.

Questions about the Research
If you have questions about this study, contact Shawn Nissen, Ph.D., at (801) 422-5055 or 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 the BYU IRB Administrator, A-285 ASB, Brigham Young University, Provo, UT, 84602 or at (801) 422-1451.

I have read and fully understand the consent form. Any questions have been answered to my satisfaction. I give permission for my child to participate in this research.

Signed: ___________________________ Date: __________

(signature of participant’s parent or legal guardian)

Child’s Name: ___________________________
Child Assent to be a Research Participant

We want to tell you about a research study we are doing. This study is meant to find out more about how best to help kids with their speech. You are being asked to join the study because you speak English and your speech is similar to other kids your age.

If you decide that you want to be in this study, this is what will happen.

- We will check your hearing by having you listen to some beeps in headphones.
- A person will make a mold of your teeth by having you bite into a tray filled with a material that fits around your teeth. The mold takes about 10 minutes to make. This material is a little sticky, but it can be removed by brushing your teeth after it is made. From this mold we will make a thin piece of plastic, called a sensor, that fits over your teeth like a retainer.
- You will then come to a building at BYU with your parents one time for 3 hours. During this time you will play and talk with 4 other kids your age and a speech teacher while wearing the sensor in your mouth like a retainer. All of the kids in the group will also be wearing the same sensor that you will be wearing.
- Four times while you are playing someone will record your voice with a microphone. We will not play this recording to anyone you know and we will not put your name on it. Then a small group of adults will listen to the recordings after you have left.
- You will receive $10 for each hour you participate in the study.

Do I have other choices?

You can choose not to be in this study. It’s up to you. If you say yes now, but you change your mind later, that’s okay too. All you have to do is tell us.

Will anyone know I am in the study?

We won’t tell anyone you took part in this study. When we are done with the study, we will write a report about what we found out. We won’t use your name in the report.

Before you agree to be in this study, be sure to ask the person helping with the study to tell you more about anything that you don’t understand.

If you want to be in this study, please sign or print your name.

☐ Yes, I will be in this study.    ☐ No, I don’t want to do this.

_________________________  _________________________  ________________
Child’s name               Signature of the child    Date

_________________________  _________________________  ________________
Person obtaining Assent    Signature                Date

Institutional Review Board
BYU 05/02/13 05/02/14
Approved Expires