The Correlation between Spectral Moment Measures and Electropalatographic Contact Patterns for /\textit{s}/ and /\textit{ʃ} /

Benjamin James Marshall

Brigham Young University - Provo

Follow this and additional works at: https://scholarsarchive.byu.edu/etd

Part of the Communication Sciences and Disorders Commons

BYU ScholarsArchive Citation

Marshall, Benjamin James, "The Correlation between Spectral Moment Measures and Electropalatographic Contact Patterns for /\textit{s}/ and /\textit{ʃ}/" (2012). All Theses and Dissertations. 3231.
https://scholarsarchive.byu.edu/etd/3231

This Thesis is brought to you for free and open access by BYU ScholarsArchive. It has been accepted for inclusion in All Theses and Dissertations by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu.
The Correlation Between Spectral Moment Measures and Electropalatographic Contact

Patterns for /s/ and /ʃ/

Benjamin J. Marshall

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

Master of Science

Shawn L. Nissen, Chair
Ron Channell
Christopher Dromey

Department of Communication Disorders
Brigham Young University
June 2012

Copyright © 2012 Benjamin J. Marshall
All Rights Reserved
ABSTRACT

The Correlation Between Spectral Moment Measures and Electropalatographic Contact Patterns for /s/ and /ʃ/

Benjamin J. Marshall
Department of Communication Disorders, BYU
Master of Science

Spectral Moment Analysis has helped further our understanding of the spectral properties of obstruent speech production; however, the physiologic correlates of these spectral measures are not well understood. The aim of the present study was to examine the possible correlations between the linguapalatal contact patterns used to produce the fricatives /s/ and /ʃ/ and the resulting spectral characteristics. Using spectral moment analysis and electropalatography (EPG), the real-word productions of eight speakers of American English were investigated. The spectral measures for the fricative tokens in the present study were found to be similar to data reported in previous research with adult speakers. Although the majority of the correlations examined in this study were found to be statistically significant, none of the correlations accounted for a large proportion of the variance in the data. Generally the strongest correlations were found between the spectral mean and the symmetry of the contact pattern in the anterior region of the hard palate and the width of the contact pattern in the medial region of the palate. These findings may indicate that although the width and symmetry of linguapalatal contact contributes to the spectral signature /s/ and /ʃ/ fricatives, they are likely only part of a much more complex process that may involve other mechanisms such as lip rounding, tongue groove depth and shape, aerodynamic factors, and the shape of the vocal tract in other regions.

Keywords: spectral moments, electropalatography, fricatives
ACKNOWLEDGMENTS

I would like to thank Dr. Nissen for his outstanding guidance and patience during this project. Without his leadership and insight, this project never would have been possible. I would also like to thank Dr. Channell and Dr. Dromeys for their help in editing and with inspiration during the initial process of this thesis. This project would not have gotten off the ground and would not have been nearly as fun without the help of Sadie. Thank you for always being there, for storing so much knowledge and for helping me appreciate the idea of expecting the unexpected. Janelle Barrett was incredibly instrumental from the beginning to the end of this project and I will always be in her debt. To Hillary Benton for always being so reliable, thank you. Thank you Patrick and Luke for always believing in me and for being a happy distraction from the hard work of graduate school. Finally, I could not have finished this project without the never-ending support of my dearest friend and wife Megan. Without her support and encouragement, I would not have come this far. My successes are just as much hers as they are mine.
Table of Contents

List of Tables ........................................................................................................................................ vi

List of Figures ....................................................................................................................................... vii

Description of Structure and Content ................................................................................................. viii

Introduction ........................................................................................................................................ 1

Theoretical Basis of Spectral Moment Analysis ....................................................................................... 1

Applications of Spectral Moment Analysis ............................................................................................. 2

Electropalatography ............................................................................................................................... 4

Study Purpose ........................................................................................................................................ 6

Method ................................................................................................................................................... 7

Participants ........................................................................................................................................... 7

Stimuli ................................................................................................................................................... 7

Procedures ............................................................................................................................................ 8

Data Analysis ......................................................................................................................................... 9

Regions and Indices ................................................................................................................................. 10

Reliability of the Measures .................................................................................................................... 10

Results ................................................................................................................................................... 13

Spectral Mean ........................................................................................................................................ 14

Spectral Variance ................................................................................................................................... 17

Spectral Skewness .................................................................................................................................. 17
Spectral Kurtosis .................................................................................................................. 18
Discussion ........................................................................................................................... 18
References .......................................................................................................................... 22
Annotated Bibliography ........................................................................................................ 24
Appendix - Informed Consent Document ............................................................................. 30
List of Tables

1. Descriptive Statistics of Means and Standard Deviations of Spectral Moments for /s/ and /ʃ/ Productions .................................................................13

2. Descriptive Statistics of Means and Standard Deviations for /s/ and /ʃ/ Tongue Groove Widths and Symmetries .................................................................14

3. Correlations between Spectral Moments and EPG Indices for /s/ Productions .........................15

4. Correlation Between Spectral Moments and EPG Indices for /ʃ/ Productions ..........................16
List of Figures

1. Sample Tongue Contact Pattern.................................................................6
2. Regions of the Pseudopalate ......................................................................11
3. Lateral Indices of the Pseudopalate ............................................................12
Description of Structure and Content

The body of this thesis is written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. An annotated bibliography is presented following the reference section.
Introduction

Spectral Moment Analysis (SMA) is a method that allows researchers to quantitatively describe a number of acoustic characteristics of specific speech sounds. These spectral moment values can be used to identify unique and discrete patterns of acoustic energy within the speech signal that are perceptually relevant (Nissen, 2005). A current drawback to SMA is that there is not a good understanding of the physiologic mechanisms that underlie observed changes in the spectral moment measures. Thus there is a need for research which correlates the movements of the articulators and the resulting spectral signature.

Theoretical Basis of Spectral Moment Analysis

Currently SMA is used by researchers to examine the spectral patterns of noise energy in obstruent speech sounds, which include stop and fricative consonants in American English. These types of sounds are labeled as obstruents because their production involves a partial or total blockage of the flow of air through the vocal tract by the articulators. For stop consonants, a relatively high amount of intraoral air pressure builds up behind the articulatory constriction within the oral cavity. The rapid release of this type of articulatory obstruction results in a transient burst of noise energy, known as a stop plosive, whereas for fricative sounds, noise energy is created by continuous airflow moving through a partial obstruction within the oral cavity, creating a period of turbulent noise. For both stops and fricatives, listeners rely on the spectral characteristics of these segments to assist in their perceptual identification.

SMA uses statistical moments to quantify how the noise energy within obstruent sounds is distributed across a range of frequencies. Static SMA uses a Fast Fourier Transform (FFT) spectrum derived from a single window of analysis. Each FFT spectrum is then considered a randomly distributed probability from which four statistical moments are calculated, namely
mean, variance, skewness, and kurtosis. Each set of spectral moments represents a spectral snapshot of the acoustic energy within a particular window of analysis (Nissen, 2005). The first spectral moment, or spectral mean, is used to define the frequency of average energy distribution. The second moment, the variance, is used to describe the frequency variability over which the power spectrum is spread. The third moment describes the general skewness of the spectral distribution, sometimes known as spectral tilt. A positive spectral skewness indicates that the median component of the spectrum has a higher frequency than the mean (Nissen & Fox, 2005). The fourth spectral moment describes the kurtosis (peakedness) of the energy distribution. If the kurtosis is high, the spectral peaks are usually well defined. If the kurtosis is low, then the distribution of the spectrum is relatively flat.

**Applications of Spectral Moment Analysis**

Historically, SMA has been used for three different purposes: (a) the discriminant classification of speech into phoneme types, (b) a means to further examine the acquisition and development of obstruent sounds in children, and (c) a method to detect disordered speech production at early stages of development.

One of the earliest studies to use SMA for discriminate classification of speech was conducted by Forrest et al. (1988). This study sought to statistically discriminate between different stop and fricative phonemes based on patterns of spectral energy within their associated noise segments. Using a discriminant analysis of the spectral moment data from the initial 40 ms of the stop burst, the authors found that the phonemes of /p/, /t/, and /k/ could be classified statistically at a rate of 92%. Their findings indicated that velar stops are statistically distinguished more by the measure of spectral kurtosis than the other spectral moments, while labial and alveolar stops were differentiated more by the spectral mean and skewness values.
Correlation between SMA and EPG (Forrest, 1988). Using a similar technique, the study further found that voiceless fricative sounds (/f, θ, s, š/) were classified at a somewhat lower rate of approximately 75%. The authors concluded that the spectral mean, skewness, and kurtosis could be used to discriminate between these types of voiceless obstruents. A later study by Jongman et al. (2000) largely supported the results of Forrest et al. (1988), finding that the spectral mean, skewness, and kurtosis could be used to statistically distinguish between both voiced and voiceless fricatives. However, unlike the conclusions of Forrest et al., Jongman (2000) and colleagues found that the second spectral moment of variance was also an important factor in distinguishing between sibilant and non-sibilant fricatives. Likewise, Nissen and Fox (2005) found that the only spectral moment measure which was able to correctly classify all four places of fricative articulation was spectral variance.

SMA has also been used to gain a greater understanding of stop and fricative acquisition in typically developing children. Researchers have found that obstruent sound productions are developed at different rates depending on the gender of the speaker and the place of articulation (Fox & Nissen, 2005; Nissen & Fox, 2005, 2009; Nittrouer, 1992, 1995). Nissen and Fox (2009) found that sex-related differences in spectral mean for bilabial stop productions begin to emerge at around 5 years of age and may be associated with behavioral and/or learned factors. They also found that such differences for alveolar and velar stops emerged at 4 years of age (Nissen & Fox, 2009). These findings support the work of Nittrouer (1995), who found that children continue to fine-tune or adapt their production of /s/ and /ʃ/ even into early adolescence.

The use of SMA is used to detect disordered speech production at early stages of development. By undertaking a close examination of the spectral properties of sound production at an early stage of development, researchers have been able to identify specific errors in tongue
placement, errors that are sometimes difficult to perceptually identify with auditory or visual approaches. Results of the study done by Nissen & Fox (2009) indicated that even though a child’s velar and alveolar stops were not perceptually different, data from SMA could classify the different phonemes with 87% accuracy. Using SMA, clinicians have also been able to identify a developing phonological contrast during an early stage of development, often before clinicians are able to perceptually detect a difference (Forrest et al., 1990).

While researchers have gained valuable information from SMA, the physiologic mechanisms that underlie differences in spectral patterns are not well understood. Some researchers have suggested that differences in the spectral mean are likely related to an advancement or retraction of the stop consonant or fricative constriction, thereby creating a smaller or larger anterior resonating cavity (Nissen & Fox, 2009; Nittrouer, 1995). However since a direct correlation has yet to be established between constriction patterns and the resulting spectral moments (e.g., skewness and kurtosis), such assumptions are mostly theoretical. Thus more research is needed that directly examines the associations between SMA and the points of constriction or patterns of linguapalatal contact characteristic of these types of obstruent speech sounds (Nissen & Fox, 2005).

**Electropalatography**

The development of electropalatography (EPG) has allowed researchers to dynamically study lingual-palatal contact during speech. Historically researchers were able to see where the contact of the articulators had been after a sound had been produced by using a technique known as static palatometry. One of the first methods of static palatometry used a mixture of flour and gum which coated a person’s hard palate. Their tongue would touch a certain spot on the mixture which would wipe it clean. This method was used to map a model palate. A second method
used a piece of tin foil placed on the palate. The tin foil would be indented by the tongue-to-palate contact and thereby provide a general visual representation of contact patterns of the articulators (Fletcher, 1991; Fletcher, 1989). In the latter part of the 20th century, non-electric palatography gave way to methods that used the completion of an electronic circuit to track contact patterns within the oral cavity.

Some of the limitations of previous methods of palatometry have been resolved by more recent technology. In 1975, Fletcher, McCutcheon, and Wolf introduced a measurement system with the capacity to dynamically track linguopalatal contact during speech called electropalatography (EPG). Advancements in EPG have led to a computer-based, dynamic tracking system which can provide visual feedback on a continuous, real-time basis. EPG has been found to be an effective tool in the treatment of a number of speech disorders (Carter & Edwards, 2004; Dagenais, 1995).

A recent EPG design by Smartpalate International© uses a relatively thin (0.5 – 2 mm) custom-fit pseudopalate, similar to an orthodontic retainer, which is molded to fit snugly over a person’s upper teeth and hard palate, extending back to the anterior portions of the soft palate and posterior molars. In order to detect the contact of the tongue to the palate during speech, the pseudopalate contains 126 gold-plated sensors that are arranged in a grid pattern across its surface. When the tongue makes contact with the pseudopalate sensors, the contact patterns are represented by a completed electrical circuit (see Figure 1). The contact data are then transmitted through several wires that extend from the front of the pseudopalate to a relatively small processing box suspended below the speaker’s mouth. This processing unit then collects and transfers the tongue-palate contact data to a computer through a USB connection. This system can provide a record of linguopalatal contact as frequently as 200 times per second.
These data can then be displayed as a visual representation of articulatory contact patterns of the palate (see Figure 1). The proportion of the electrodes being touched by the tongue in any given region produces a time-varying record of the relative degree of tongue contact in these separate regions during speech.

Figure 1. Sample tongue contact pattern (www.completespeech.com)

Study Purpose

SMA has helped further our understanding of the spectral properties of obstruent speech production; however, the physiologic correlates of these spectral measures are not well understood. EPG may be a valuable method to accurately track and subsequently correlate points of constriction during obstruent production with the resulting patterns of spectral energy. This idea motivated Bennet (2009) to investigate the associations between SMA and the
linguopalatal contact patterns measured by EPG. Twenty adults were fitted with pseudopalates and asked to repeat VCV nonsense syllables with an initial schwa, followed by /s/, and ending with a corner vowel. A subsequent analysis of the overall set of data failed to find any strong correlations between the acoustic and EPG data. Bennett did find that, on an individual speaker basis, some of the adults showed significant correlations between tongue contact patterns and spectral mean and variance. Bennett stated that the lack of correlation between the two sets of data might be due to a lack of specificity in the indices used to quantify the electropalatographic measures or because of a temporal misalignment between specific contact patterns and the segment of noise energy being evaluated in SMA.

The aim of the present study was to further examine the possible correlations between the spectral characteristics of obstruent productions and the physiologic movements of the articulators, using a new technology that has more reliable temporal linkage of the audio and contact pattern records. This study specifically aimed to correlate the four spectral moment measures (mean, variance, skewness, and kurtosis) with the associated electropalatographic contact patterns for the typical production of /s/ and /ʃ/.

Method

Participants

Eight speakers of American English, with no history of a speech or language disorder, participated in the study. Prior to data collection, all subjects passed a hearing screening, bilaterally, at 25 dB HL at 500, 1000, 2000, 4000, and 6000 Hz.

Stimuli

The following four types of speech samples were gathered from each speaker using a counter-balanced protocol: (a) individual phoneme productions, (b) real and nonsense words,
(c) sentences constructed to target specific consonant sounds (e.g., The cat ate the top of the cake.), and (d) reading passages which were several paragraphs in length (e.g., the Rainbow Passage). Targeted sounds included /s, ʃ, t, k, z, l, r, d, g, ʧ, ʤ, ʒ/ in initial and final word position, across four different vowel contexts, namely the corner vowels /i, ɑ, æ, u/. The focus of the present study was on the 16 real-word productions which were selected to target the production of /s/ and /ʃ/, with each word having been produced 10 times by each participant.

**Procedures**

A dental impression was made for the participants by a licensed orthodontic technician. This impression of the upper teeth and palate was used to make a pseudopalate, to which a flexible printed circuit was applied for each individual speaker. Participants were instructed to brush their teeth and use mouth wash prior to placement of the pseudopalate to avoid possible interference of food particles with the fit of the appliance or the tongue-to-palate contact sensors (Sanders, 2007). Data were collected during seven separate sessions of about one hour each. During the first two sessions, audio recordings targeting consonant production without the pseudopalate were made in order to obtain an acoustic baseline. For the rest of the sessions, the speakers were engaged in conversation for fifteen minutes to allow them time to adapt to the presence of the pseudopalate before data collection began. During data collection sessions, speakers were given intermittent five minute breaks. Speech productions were elicited through a series of PowerPoint slides. All EPG data were transferred to a local computer via a USB connection. Audio recordings were also collected as a backup reference to the sound files connected to the EPG data, sampled at a rate of 44.1 kHz with a quantization of 24 bits. Recording, elicitation, and acoustic analysis of stimuli were facilitated by custom designed Matlab computer programs.
Data Analysis

By using a waveform display, the onset and offset of target consonant productions were segmented, assisted by spectrographic inspection using Adobe Audition. A sharp increase in diffuse noise energy and a sudden increase in zero crossings helped to identify the onset of the stop burst; a sharp decrease in diffuse noise energy helped to identify its offset. Time values of segmentation (in ms) were recorded into a text file and subsequently checked, corrected, and re-checked using a Matlab computer program which displayed the segmentation marks superimposed over a display of the token’s waveform. After this was done, in order to verify accuracy and reliability of waveform segmentation data, 10% of all tokens were independently analyzed by a second person and again correlated with the original segmentation of each respective token.

All speech samples had a high-pass filter applied with a frequency limit of 70Hz. Each of the four spectral moments—mean, variance, skewness, and kurtosis—was computed for each portion of the waveform that corresponded to a time-locked EPG contact frame using custom software developed in Matlab. According to the computational algorithms described in previous studies (Fox & Nissen, 2005; Jongman et al., 2000; Nissen & Fox, 2005, 2009), spectra were derived from a series of 20 ms cascading Hamming windows centered over pertinent time-points of the waveform. The number of analysis windows differed based on the overall duration of each speech sound that was analyzed. Spectral measures were taken with a cap on the higher frequencies, which was limited to 11 kHz. This cap served the purpose of limiting the influence of high frequency noise located above human perception.

A 20 ms analysis window, time-synchronized to the previously described spectral analysis, was used to extract a number of quantitative measures of the tongue groove width and
Correlation between SMA and EPG

symmetry during the production of the fricative productions from the EPG recording. The calculation of these groove width and symmetry indices was facilitated by a Matlab script. Pearson’s $r$ correlations were used to evaluate associations between the spectral moment and EPG data.

**Regions and indices.** As shown in Figure 2, the pseudopalate was divided into eight different regions: front, central, right and left anterior, right and left medial, as well as right and left posterior. For the six anterior, medial, and posterior regions, lateral indices were calculated based on the level of activation in a column of sensors. If a column of sensors within a region was found to have 50% or greater activation, that column was considered that region’s lateral margin of the linguopalatal contact and assigned a numerical value as shown in Figure 3. The palate midline was assigned a zero value and then each column to the left and right of midline was assigned a consecutive negative or positive integer, respectively. From these lateral indices, the width and symmetry of the tongue groove was calculated for each 20 ms EPG window of analysis.

**Reliability of the measures.** To examine the reliability of the segmentation points of the targeted speech samples, 10% of the speaker productions were selected and reanalyzed again by another individual. This set of addition segmentation points was extracted and recorded in the same manner as the original measures. Comparisons of the two sets of data resulted in a Pearson correlation of 0.99, with a mean absolute difference in segmentation of 34.5 ms. Due to the inter-rater differences between the two sets of segmentation points and to avoid possible spectral interference from neighboring sounds, data from the initial and final two analysis windows were not included in the statistical analysis.
Figure 2. Regions of the Pseudopalate
Figure 3. Lateral Indices of the Pseudopalate
Results

Descriptive statistics of means and standard deviations of the four spectral moments were obtained for the /s/ and /ʃ/ sound tokens. A specific listing of the spectral moment results can be found in Table 1. In terms of the EPG contact patterns, differences between the /s/ and /ʃ/ productions of tongue groove width were less than one sensor column for each set of regions (e.g., anterior, medial, posterior). As expected the /s/ productions exhibited a narrower anterior tongue groove (6.3 sensor columns) when compared to the /ʃ/ productions (7.26 sensor columns). To a lesser degree, the groove widths at the medial and posterior regions were greater for the /s/ fricatives. In general, the linguapalatal contact patterns of both types of fricative were found to be fairly symmetrical. A detailed listing of the EPG contact pattern widths and symmetry can be found in Table 2.

Table 1

*Descriptive Statistics of Means and Standard Deviations of Spectral Moment Measures for /s/ and /ʃ/ Productions*

<table>
<thead>
<tr>
<th></th>
<th>/s/</th>
<th></th>
<th>/ʃ/</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Spectral Mean&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5672.4</td>
<td>1349.6</td>
<td>4402.9</td>
<td>804.8</td>
</tr>
<tr>
<td>Spectral Variance&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.6</td>
<td>2.6</td>
<td>3.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Spectral Skewness</td>
<td>-.82</td>
<td>1.03</td>
<td>.51</td>
<td>.93</td>
</tr>
<tr>
<td>Spectral Kurtosis</td>
<td>.85</td>
<td>3.65</td>
<td>.85</td>
<td>2.91</td>
</tr>
</tbody>
</table>

*Note.* <sup>a</sup>Measured in hertz; <sup>b</sup>measured in megahertz.
Correlation between SMA and EPG

Table 2

*Descriptive Statistics of Means and Standard Deviations for /s/ and /ʃ/ Tongue Groove Widths and Symmetries*

<table>
<thead>
<tr>
<th></th>
<th>/s/</th>
<th></th>
<th>/ʃ/</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Anterior Width</td>
<td>6.3</td>
<td>1.1</td>
<td>7.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Medial Width</td>
<td>12.01</td>
<td>1.4</td>
<td>11.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Posterior Width</td>
<td>11.5</td>
<td>1.71</td>
<td>10.64</td>
<td>1.64</td>
</tr>
<tr>
<td>Anterior Symmetry</td>
<td>-.27</td>
<td>.929</td>
<td>.02</td>
<td>.589</td>
</tr>
<tr>
<td>Medial Symmetry</td>
<td>-.3</td>
<td>.546</td>
<td>-.32</td>
<td>.532</td>
</tr>
<tr>
<td>Posterior Symmetry</td>
<td>-.48</td>
<td>.684</td>
<td>-.51</td>
<td>.676</td>
</tr>
</tbody>
</table>

*Note.* Measured in number of sensor columns.

A series of Pearson bivariate correlations were conducted for each of the four spectral moments with the gap width and symmetry indices for the anterior, medial, and posterior regions of the palate, as displayed by the EPG contact patterns. The correlations, $p$-values, and sample sizes for the /s/ and /ʃ/ tokens are listed in Tables 3 and 4, respectively. Considering the number of different correlations calculated in this analysis, a Bonferroni approach was used to control for Type I errors, with a $p$-value of less than .001 required for significance. Although the majority of the correlations were found to be statistically significant, only the correlations that accounted for a relatively greater amount of the variation in the data are discussed below.

**Spectral Mean**

The results of the correlation analyses between the EPG indices and the spectral mean for /s/ tokens presented in Table 1 indicate that 5 out of the 6 correlations were statistically significant. The symmetry of the contact pattern in the anterior region accounted for the greatest
Table 3

Correlations between Spectral Moments and EPG Indices for /l/ Productions

<table>
<thead>
<tr>
<th>Spectral Moment Measures</th>
<th>EPG Indices</th>
<th>Mean</th>
<th>Variance</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anterior width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r-correlation</td>
<td>-.043</td>
<td>.119*</td>
<td>-.060</td>
<td>.024</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>.026</td>
<td>.001</td>
<td>.002</td>
<td>.218</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>2610</td>
<td>2610</td>
<td>2610</td>
<td>2610</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medial width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r-correlation</td>
<td>.216*</td>
<td>-.147*</td>
<td>-.116*</td>
<td>.093*</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior width</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r-correlation</td>
<td>.087*</td>
<td>-.034</td>
<td>-.127*</td>
<td>-.009</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>.001</td>
<td>.051</td>
<td>.001</td>
<td>.626</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anterior symmetry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r-correlation</td>
<td>.221*</td>
<td>-.082*</td>
<td>-.241*</td>
<td>.095*</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>2610</td>
<td>2610</td>
<td>2610</td>
<td>2610</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medial symmetry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r-correlation</td>
<td>-.106*</td>
<td>.046</td>
<td>-.033</td>
<td>.041</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>.001</td>
<td>.009</td>
<td>.056</td>
<td>.019</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Posterior symmetry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r-correlation</td>
<td>-.114*</td>
<td>.082*</td>
<td>-.100*</td>
<td>-.053</td>
<td></td>
</tr>
<tr>
<td>p-value</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.002</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
<td></td>
</tr>
</tbody>
</table>

Note: * p < 0.001, 2-tailed.
Table 4

*Correlations between Spectral Moments and EPG Indices for /ʃ/ Productions*

<table>
<thead>
<tr>
<th>EPG Indices</th>
<th>Mean</th>
<th>Variance</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior width</td>
<td>-.175*</td>
<td>.083*</td>
<td>-.059*</td>
<td>.058</td>
</tr>
<tr>
<td>r-correlation</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.003</td>
</tr>
<tr>
<td>p-value</td>
<td>2574</td>
<td>2574</td>
<td>2574</td>
<td>2574</td>
</tr>
<tr>
<td>Medial width</td>
<td>.216*</td>
<td>-.147*</td>
<td>-.116*</td>
<td>.093*</td>
</tr>
<tr>
<td>r-correlation</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
</tr>
<tr>
<td>p-value</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
</tr>
<tr>
<td>Posterior width</td>
<td>.087*</td>
<td>-.034</td>
<td>-.127*</td>
<td>-.009</td>
</tr>
<tr>
<td>r-correlation</td>
<td>.001</td>
<td>.051</td>
<td>.001</td>
<td>.626</td>
</tr>
<tr>
<td>p-value</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
</tr>
<tr>
<td>Anterior symmetry</td>
<td>.221*</td>
<td>-.082*</td>
<td>-.241*</td>
<td>.095*</td>
</tr>
<tr>
<td>r-correlation</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
</tr>
<tr>
<td>p-value</td>
<td>2610</td>
<td>2610</td>
<td>2610</td>
<td>2610</td>
</tr>
<tr>
<td>Medial symmetry</td>
<td>-.106*</td>
<td>.046</td>
<td>-.033</td>
<td>.041</td>
</tr>
<tr>
<td>r-correlation</td>
<td>.001</td>
<td>.009</td>
<td>.056</td>
<td>.019</td>
</tr>
<tr>
<td>p-value</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
<td>3294</td>
</tr>
<tr>
<td>Posterior symmetry</td>
<td>-.114*</td>
<td>.082*</td>
<td>-.100*</td>
<td>-.053</td>
</tr>
<tr>
<td>r-correlation</td>
<td>.001</td>
<td>.001</td>
<td>.001</td>
<td>.002</td>
</tr>
<tr>
<td>p-value</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
<td>3291</td>
</tr>
</tbody>
</table>

*Note.* *p* < 0.001, 2-tailed.
Correlation between SMA and EPG

proportion of the variation, \( r (2610) = .221, p < .001 \). The width between the left and right tongue contact in the medial region was found to be slightly less correlated with the spectral mean, \( r (2608) = .216, p < .001 \). For the /ʃ/ tokens the spectral mean was also significantly correlated with 5 of the 6 indices. The measure of contact width in the medial region was found to have the highest correlation with spectral mean, \( r (3567) = .25, p < .001 \). No other correlation had an \( r \)-value above .20.

**Spectral Variance**

The correlation analyses between the EPG indices and the spectral variance for /s/ tokens indicated that 5 out of the 6 were statistically significant. The symmetry of the contact pattern in the medial region accounted for the greatest amount of variation, \( r (2610) = .119, p < .001 \). For the /ʃ/ tokens the spectral variance was also significantly correlated with 2 of the 6 indices. The measure of contact width in the medial region was found to have the highest correlation with spectral variance, \( r (3569) = -.097, p < .001 \). The width between the left and right tongue contact in the anterior region was found to be slightly less correlated with the spectral variance, \( r (2574) = .083, p < .001 \).

**Spectral Skewness**

A Pearson’s correlation between the EPG indices and the spectral skewness for /s/ tokens indicate that 4 out of the 6 were statistically significant. The symmetry of the contact pattern in the anterior region accounted for the greatest proportion of the variation, \( r (2610) = -.241, p < .001 \). For the /ʃ/ tokens the spectral skewness was also significantly correlated with 6 of the 6 indices. The measure of contact width in the anterior region was found to have the highest correlation with spectral skewness, \( r (2574) = .127, p < .001 \).
Spectral Kurtosis

The results of the correlation analyses between the EPG indices and the spectral kurtosis for /s/ tokens indicate that 2 out of the 6 were statistically significant. The symmetry of the contact pattern in the anterior region accounted for the greatest proportion of the variation, \( r(2610) = 0.095, p < .001 \). For the /ʃ/ tokens the spectral kurtosis was also significantly correlated with 4 of the 6 indices. The measure of contact width in the medial region was found to have the highest correlation with spectral kurtosis, \( r(3569) = -0.180, p < .001 \). The width between the left and right tongue contact in the posterior region was found to be slightly less correlated with the spectral kurtosis, \( r(3564) = 0.118, p < .001 \).

Discussion

The aim of the present study was to examine the possible correlations between the linguapalatal contact patterns used to produce the fricatives /s/ and /ʃ/ and the resulting spectral characteristics. The spectral moment measures were similar to data reported in previous research examining the fricative productions of adult speakers (Fox & Nissen, 2005; Jongman, 2000; Nissen & Fox, 2005). In terms of the EPG contact patterns, differences between the /s/ and /ʃ/ productions of tongue groove width were less than one sensor column for each set of regions (e.g., anterior, medial, posterior). In general, the linguapalatal contact patterns of both types of fricative were fairly symmetrical.

Although the majority of the correlations between the spectral and EPG measures examined in this study were statistically significant, none of the correlations accounted for a large proportion of the variation in the data (\( r \)-values < .25). Similar to the findings of Bennett (2009), generally the strongest correlations were found between the spectral mean and the width and symmetry of the contact pattern in the anterior and medial regions of the hard palate. These findings may indicate that although the width and symmetry of linguapalatal contact contributes
Correlation between SMA and EPG

to the spectral signature of /s/ and /ʃ/ fricatives, they are likely only part of a much more complex process that involves a number of other speech mechanisms. As has been well documented in previous research, lip-rounding likely had a significant effect on the length of the anterior resonating cavity during the fricative productions, which would have resulted in a change in the frequency distribution of the noise energy. Although the EPG device used in this study has two sensors located in the region of the lips, they were unable to measure a speaker’s lip rounding in an accurate manner. This would have enabled us to know if the speakers were adjusting their lips in order to articulate more accurately. Other physiologic factors such as tongue groove depth and shape, aerodynamic factors, and the shape of the vocal tract in other regions may also have accounted for the variation in spectral moment measures.

The findings of this study might have also been affected by the nature of the statistical analysis. Bivariate Pearson correlations were used to examine the association between changes in the spectral moment measures and the indices of palatal contact (i.e., tongue groove widths and symmetry). This type of analysis correlates variables in a linear manner; thus if the relationship between the variables was curvilinear, the statistical analysis may not have adequately captured the association between the spectral and EPG variables.

It might also have been the case that the presence of the EPG device caused the speakers to produce the fricative productions in an atypical manner. Although each participant was asked to talk with the pseudopalate in place for a 20 minute adaptation period prior to any data collection, the device may have continued to cause a significant disruption in their typical motor patterns. The adaptation period prior to data collection was provided in an attempt to minimize these effects, yet it remains possible that some speakers never entirely adjusted to the pseudopalate (Aasland et al. 2006; Baum & McFarland, 1997). Research studies examining the
adaptation rate for EPG technology have reported varied findings. Flege (1986) found that after five minutes of adaptation an EPG pseudopalate did not perceptibly interfere with speech production. Conversely, researchers have found that some speakers may not completely adapt to the pseudopalate even after extensive practice (Stone, 1974; Weaver, 2005). It could be that due to the physical presence of the device, speakers used alternative mechanisms of production (e.g., lip-rounding) to produce a perceptually acceptable fricative. McFarland et al. (1996) concluded that due to the quantal nature of fricative production, speakers were not able to adapt their productions of the sibilant fricatives /s/ and /ʃ/ to the same degree as other types of speech sounds. This may have been the reason why the overall differences in tongue width between the different fricative types were relatively small (< 1 sensor column). Although the fricative productions were embedded in a variety of vowel contexts to elicit coarticulation, if the EPG device was not sensitive enough to detect these small articulation changes, then there may not have been enough variation in the data to obtain strong correlations between the variables.

It also may be the case that the approximating nature of fricatives may have lacked the tongue pressure necessary to activate certain electrodes along the periphery of tongue contact. Although this study did not involve a large number of participants, a strength of the current study is that it did involve a large number of comparison samples (i.e., approximately 7,500). In addition, the spectral moment analysis and the EPG contact patterns were reliably time-synchronized, thereby addressing some of the limitations of previous research (Bennett, 2009).

Future research may improve upon this study’s current findings by using an EPG device that presents less interference to typical fricative production. It would be helpful if the EPG device was able to bring the lead wires out of the corners of the mouth rather than through the middle of the mouth. The use of wireless means of data transmission would also be a significant
improvement to the device. Future research may also involve a technology such as ultra-sound, which could capture the nature of the tongue groove shape in three dimensions. In addition, this area of research would benefit from future studies that use a single technology or combination of devices that could simultaneously capture multiple aspects of the articulatory process, namely lip-rounding and tongue articulation. Despite the limitations in the current study previously mentioned, it is hoped that the findings found in this study will promote greater understanding of the physiologic mechanisms of obstruent production and the correlation between spectral moment measures and electropalatographic contact patterns for /s/ and /ʃ/. In addition, it is anticipated that the methodological insights discussed in this study will facilitate more accurate future studies in this area.
Correlation between SMA and EPG

References


Annotated Bibliography


This study investigated a speaker’s ability to adapt their motor speech patterns to a palatal perturbation. Nine individuals were instructed to wear two types of pseudo palates while producing a series of nonsense words; a *normal* palate approximately 1mm thick, and a *perturbed* palate with an acrylic buildup of material at the alveolar ridge of approximately 6mm. The participants were asked to say the target /øsɑ/ 10 times without a palate for a baseline, 10 times with both the thin and the thick palates, and 10 times after removing the palates to check for residual effects on their speech. The results showed that after 15 minutes with the thick palate there was a significant difference between the participant’s speech when wearing the thick palates and also when wearing the thin palates. After 60 minutes, however, there was no statistically significant difference between the two speaking conditions.


Baum and McFarland examined participants’ ability to modify their speech production after adapting to the presence of an artificial palate. This study involved 7 adult female speakers with a mean age of 23 years. All but one of the participants had been involved in a previous study investigating compensation to a palatal modification. The participants were asked to produce multiple repetitions of the syllable /sɑ/ with an artificial palate in place, over five different time intervals (i.e., 0, 15, 30, 45, and 60 minutes). In between measurements, the participants were asked to read an /s/ laden passage in order to adapt to the presence of the pseudopalate. The authors found that while the /s/ productions were initially susceptible to distortion with the device in place, intense and specific practice enabled individuals to adapt to the presence of the artificial palate.


Twenty adults, fitted with pseudopalates, were asked to repeat VCV nonsense syllables consisting of an initial schwa followed by the target consonant /s/. The speakers were given 30 minutes to adjust to the pseudopalates before data collection began. Bennett found that when the EPG index values increased, the spectral mean and variance decreased. However, Bennett did not find a strong correlation between individual speakers’ linguapalatal contact patterns and spectral moment measures of /s/ productions. The author stated that this might be due to a lack of specificity in the indices used to
Correlation between SMA and EPG

quantify the electropalatographic data or because of a temporal misalignment between the two sets of data. Bennett concluded that analysis using the newer version of the palatometer (which is currently available) will help reduce misalignment of the EPG and the acoustic data which was mentioned as a limitation of the study.


In this study, ten children ages 7-14 years old with persistent speech difficulties participated in ten sessions of speech therapy using electropalatographic feedback. Prior to therapy, baseline measures were collected from a series of 43 real words containing velar plosives and fricative consonants. Results of the study indicated that in general the children had significantly fewer speech sound errors after therapy. Carter and Edwards cautioned, however, that their findings were limited to a time period immediately following the conclusion of the ten therapy sessions and do not provide information about long term generalization.


Dagenais reviewed efficacy data from a series of case studies in which clinicians used EPG feedback in the treatment of children with articulation disorders. Findings indicated that a 12 year-old boy with a lateral lisp was able to produce a salient /s/ sound after four, one hour a week treatment sessions. A ten year-old girl who prior to treatment dentalized /s/ and /z/ phonemes, as well as lateralizing /ʃ/, /ʒ/, /ʒ/ and /ʤ/, showed marked improvement in her speech production after only a week of therapy. A 9 year-old girl with alveolar backing for stop consonants had not benefitted from traditional therapy. After 12 weeks the participant was able to produce perceptually distinct alveolar stops. Dagenais concluded that many children are able to overcome their articulation and phonology problems by using electropalatography.


The study by Dromey and Sanders aimed to determine the variability which exists within and between speakers using standardized palatometric articulation files. Twenty adult participants between 18 to 25 years of age participated in the study. Test stimuli consisted of VCV nonsense words using a schwa in the initial position, followed by an oral consonant, and the three corner vowels /a/, /i/, and /u/. By having the speakers produce a schwa in the initial position of the words the researchers intended to place the tongue in a neutral position prior to the production of the target consonants. A variability index was created to examine the amount of intra and interspeaker variability in
consonant articulation. The authors found a significant difference in variability between the different vowel contexts, as well as the consonant sounds /l/, /r/, and /s/.


Fletcher and McCutcheon discussed the history, uses, and reasoning for the use of palatometry. The authors also described a type of dynamic palatometer, which utilized a pseudopalate containing 48 electrode contacts. This electropalatographic device was approximately .2 mm thick.


This study involved 9 typically developing children from 6 to 14 years of age. The participants were divided into three different age groups of 6 to 8, 9 to 10, and 11-14 years. Fletcher used electropalatometry to acoustically and kinematically describe the participants’ stop, affricate, and fricative productions. Findings indicated the speakers in the oldest age group reached initial articulatory positions faster, produced consonant sounds more quickly, and produced vowels with shorter durations. In addition, the oldest group of children articulated their consonants in more posterior position in the oral cavity than the younger children.


This study examined the efficacy of using palatometry to remediate sound articulation errors in five profoundly hearing-impaired participants. The participants ranged in age from 10 to 16 years. Therapy focused on the correct production of the consonants /t/, /d/, /k/, /g/, /l/, /s/, /z/, and /f/. Participants received two training sessions daily during a 3-4 week time period. Results of the study showed that all of the participants acquired more accurate linguapalatal contact patterns for the sounds taught and listeners reported improved intelligibility.


This study described the spectral characteristics of obstruent production of typical speaking adults using spectral moment analysis. Five male and five female adults between 18 and 31 years of age participated in the study. Stimuli used in the study focused on word initial voiceless obstruents. The subjects were asked to listen to a recording of the target words and then repeat the words embedded in the carrier phrase, *I can say ___ again*. Results of the spectral moment analysis indicated that labial and
alveolar stops could be statistically classified in terms of the spectral mean and skewness. The speakers’ productions of velar stops could be statistically distinguished from the other obstruents by the measure of spectral kurtosis.


Using spectral moment analysis, this study provides a spectral description of the alveolar and velar stop consonants /t/ and /k/ in both a group of typical developing children and a group of children with phonological disorders. A statistical analysis of the sounds produced by the typically developing children was able to predict the place of articulation with 82% accuracy. However, the sound productions from only one of the children with a phonological disorder could be statistically discriminated using spectral moment analysis, even though they sounded the same perceptually.


This study investigated the sex-related acoustic changes of voiceless English fricatives. A wide range of participants participated in the study, ranging in age from 6 to 52 years. The participants were divided into five different age groups (6-7, 8-9, 10-12, 13-14, and adult) with an equal number of male and female speakers. The sounds of interest in this study included the voiceless fricatives (/θ/, /s/, /ʃ/, and /ʒ/) in a syllable initial context. The authors found significant sex-related differences in the fricative productions of the prepubescent children, with differences likely starting to emerge at around 5 years of age. The researchers concluded that the sex-related acoustic differences found in this study may be associated with behavioral and/or learned factors.


The study by Jongman, Wayland, and Wong provides a descriptive analysis of the acoustic and spectral characteristics of American English fricatives produced by a group of adult speakers. The researchers document the fricative productions in terms of both static and dynamic characteristics: spectral peak location, spectral moments, noise duration, normalized amplitude, and locus equation. It was found that all of the extracted acoustic and spectral measures, with the exception of locus equations, were able to statistically distinguish all four places of fricative articulation (i.e., labiodental, interdental, alveolar, and palate-alveolar). The authors concluded that spectral moment measures can provide unique information about each type of fricative despite differences in speaker profile, vowel context, and voicing.
This study by Nissen and Fox examined the acoustic and spectral characteristics of young children’s fricative productions. Three groups of children between 3 and 6 years of age and 10 adults (as a comparison group) were recruited for this study. The speaker’s productions consisted of CV(C)(C) syllables, created by combining four different voiceless obstruents in the initial position with four monophthongal vowels. The stimuli were real words repeated 5 times and embedded in the carrier phrase, *This is a ______ again*. The authors analyzed the fricative productions in terms of the spectral measures of slope, mean, variance, skewness, and kurtosis, as well as for duration and amplitude. It was found that the male speakers exhibited higher spectral mean values for /f/, /ɵ/, and /s/. It was further reported that the contrast between /s/ and /ʃ/ for several spectral parameters was less distinguished in children than adults, starting at about 5 years of age.


This study was designed to describe the acoustic and spectral patterns characteristic of the voiceless stop consonants /p, t, and k/, as produced by typically developing children. The authors also examined the degree to which the acoustic and spectral characteristics of the fricative productions differed with regards to the age and sex of the speaker, as well as the vowel context and place of fricative articulation. The study involved 30 children between the ages of 3 and 5, as well as a comparison group of 10 adults. Similar to the methodology used in Nissen and Fox (2005), the stimuli of this study were real words repeated 5 times and embedded in the carrier phrase, *This is a ______ again*. The authors analyzed the stop productions in terms of the spectral measures of slope, mean, variance, skewness, and kurtosis, as well as for duration and amplitude. Sex-specific differences were found for the measures of spectral slope, mean, and skewness. These differences were found for the 5 year-old and adult speakers. The authors concluded that the adult differences were likely the result of physiological differences in vocal tract anatomy. However since vocal tract dimorphism is typically not present in young children, significant differences in these ages is possibly due to behavioral and/or learned factors.


Nittrouer looked at age-related differences in the perceptual effects of formant transitions within syllables and across syllable boundaries. Sixteen adults between 20 and 40 years of age, 10 children between 5 and 7 years of age, and 9 children 3 years of age participated in this study. Findings from this study indicate that children are more sensitive than adults to intrasyllabic formant transitions. In addition, children seem to
Correlation between SMA and EPG

demonstrate higher phoneme boundaries on the silent-gap continuum for syllables with an ambiguous F₁ transition.


This study by Nittrouer aimed to examine children’s obstruent productions from a developmental perspective. Ten adults and 30 children between the ages of 3 and 7 years of age produced 12 consonant-vowel syllables consisting of the consonants /s/, /ʃ/, /t/, and /k/ consonants combined with the vowel /a/, /i/, or /u/. The CV syllables were produced in the carrier phrase, It’s a ____ Bob. Results indicated that young children do not spectrally differentiate their productions of these obstruents in an adult-like manner. Nittrouer concluded that children continue to fine-tune their productions as they continue into adolescence.


This study examined the effect of a lingual magnet on fricative production in ten typical adult speakers. This study was also designed to investigate if the participants would adapt their speech patterns (i.e., /s/ and /ʃ/) to the presence of the attached magnet after speaking with it for a short period of time. Data were taken before magnet placement, immediately after placement, after 5 minutes of conversation, and after an additional ten minutes of conversation. Using spectral moment analysis, the researcher found that the placement of the lingual magnet does result in a significant disturbance of some of the spectral characteristics of /ʃ/. Even after 10 minutes of conversation, the speakers did not completely adapt to the presence of the magnet.
Appendix A - Informed Consent

Consent to be a Research Subject

Introduction
The purpose of this research is to provide new insight into the manner in which individuals move their tongue to produce speech sounds. 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. You are invited to participate because you are a native English speaker with no known history of a speech, language or hearing problem.

Procedures
Participation in this study will involve ten sessions of approximately 1 hour; the first session will involve a hearing screening administered in a research laboratory in the John Taylor Building at BYU. If you pass the hearing screening you will be asked to visit a local licensed dental/orthodontic professional to have a dental impression taken of your upper teeth. This impression will be used to create a sensor similar to an orthodontic retainer that fits over the palate of your mouth. You will then be asked to participate in eight 1-hour data collection sessions, in which you will be asked to engage in everyday conversation, read a few paragraphs, as well as a series of English sounds, words, and sentences. You will be asked to participate in these speech tasks with and without the sensor in place.

Risks/Discomforts
There are no known risks associated with participation in this study. Pseudopalate sensors like the one used in this study have been used for a number of years in the speech pathology community without any reports of adverse events. The sensor used in this research is similar to an orthodontic retainer and therefore may cause some minor discomfort to the gums or teeth during use. In addition, the participant may encounter some minor discomfort when the dental impression (which is used to create the sensor) is being created. Your speech may sound different with the sensor in place and it may take a period of time for you to become accustomed to speaking with the sensor in your mouth.

Benefits
Each participant will be given a free hearing screening during the study. The results of the screening will be made available upon request with no charge. It is hoped this study will benefit society by resulting in a more comprehensive understanding of the physical mechanisms that underlie speech production which will ultimately assist clinicians and researchers in developing more effective models with which to assess and treat communication disorders.

Confidentiality
All data collected will remain confidential and only be reported as group data with no personally identifying information. Records and files will be kept on password protected computers in a locked laboratory and only those directly involved with the research will have access to them.

Compensation
You will be paid $100 for your participation in this study, involving approximately 10 hours of your time. If you complete, but fail to pass the hearing screening, you will receive a pro-rated amount of $10.

Participation
Participation in this research study is voluntary. You have the right to withdraw at any time without jeopardy.

Questions about the Research
If you have questions regarding this study, you may contact Shawn Nissen, Ph.D., at (801) 422-5056 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) 422-1461.

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

Signature: ___________________________ Date: ________________

Printed Name: ___________________________