2015-06-01

Establishing Normative Data for Contact Patterns of Fricative Production by Native German Speakers: An Electropalatography Study

Lisa Diane Isaacson
Brigham Young University - Provo

Establishing Normative Data for Contact Patterns of Fricative Production

by Native German Speakers: An Electropalatography Study

Lisa Diane Isaacson

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 W. Channell
Kristine Tanner

Department of Communication Disorders

Brigham Young University

June 2015

ABSTRACT

Establishing Normative Data for Contact Patterns of Fricative Production
by Native German Speakers: An Electropalatography Study

Lisa Diane Isaacson
Department of Communication Disorders, BYU
Master of Science

Electropalatography (EPG) provides real-time visual biofeedback for linguapalatal contact during speech and swallowing. Historically, EPG has proved to be an effective tool for assessment and treatment of a variety of speech disorders across a wide age range. The present thesis is part of a larger study examining the effectiveness of using EPG in assisting second language (L2) learners to acquire the German fricatives [ç], [x], and /ʃ/. Real and nonsense word productions were collected from six native German speakers. Electrode activation levels were generally highest for [ç] and lowest for [x]. Even when considering the impact of vowel context, [x] consistently showed only trace linguapalatal contact. Further research regarding the use of EPG as a tool for second language acquisition may include the development of linguapalatal contact maps from which L2 learners can compare their production of [ç], [x], and /ʃ/ to native production. It is hoped that the information contained in this thesis will expand the current uses of EPG as a tool to assist L2 learners in acquiring non-native speech sounds.

Keywords: electropalatography, second-language acquisition, German

ACKNOWLEDGMENTS

I would like to thank everyone who has helped bring each piece of this thesis together into one complete project. To name a just few of these people, I would first like to thank Dr. Nissen for heading up the chair of my committee. His insight, patience, and attention to detail have been invaluable in developing, carrying out, and writing this thesis from start to finish. I would also like to express thanks to my committee members Dr. Channell and Dr. Tanner for contributing their unique backgrounds and expertise. This project was only possible because of a fabulous committee, who were fun to work with and who taught me a great deal about conducting quality research. Additionally, I would like to thank Dr. Bell and Dr. Smith for sharing their expertise on the beautiful German language. I would also like to thank each of my roommates for showing me how to maintain balance in life and the power of chocolate. To my amazing parents and siblings, I express my deep gratitude for their prayers, listening ears, good advice, and encouragement all along the way.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

DESCRIPTION OF STRUCTURE AND CONTENT

This thesis is part of a larger collaborative project regarding the application of electropalatography to second language acquisition. The analyses conducted in this study were based on a set of recordings originally collected by Nissen (2014). The body of this thesis has been written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology such as the American Journal of Speech-Language Pathology, and as such follows length and style guidelines consistent with manuscripts submitted to that journal. In addition, some of these data may be submitted for publication elsewhere, with the thesis author being listed as one of multiple contributing coauthors. An annotated bibliography is presented following the reference section in Appendix A. The consent form used in this study is found in Appendix B.

Introduction

Advances in technology have led to the development of electropalatography (EPG), a computer-based system designed to track linguapalatal contact during speech and swallowing. In the past, EPG has been shown to be an effective tool in assessing and treating a variety of speech and language disorders. Because EPG technology provides real-time visual biofeedback, EPG technology may also be a useful tool for second language (L2) learners when acquiring difficult sounds. When using EPG, learners of an L2 can access visual models of correct articulation produced by native speakers. L2 learners can then use the real-time visual biofeedback provided by EPG to model their own linguapalatal contact patterns after native speakers' contact patterns. By doing so, the L2 learner may be able to acquire difficult sounds in their L2 (Bright, 1999; Gibbon, Hardcastle & Suzuki, 1991; Gibbon & Katerina, 1999; Schmidt, 1998).

EPG or dynamic palatometry consists of several different parts, including an orthodontic device containing a number of sensors, a data processing link, and software that displays the linguapalatal contact patterns. The orthodontic device is known as a pseudopalate. Similar to an orthodontic retainer, this pseudopalate is a relatively thin (0.5-2mm) mouthpiece made from the mold of an individual's upper dentition and maxillary structures. The pseudopalate encapsulates the teeth and is fitted closely to the hard palate. Complete Speech International© has developed a relatively new EPG system. Embedded within the pseudopalate for this EPG system are 126 gold-plated electrode sensors in a grid-like pattern across common palatal contact points. These electrodes are activated by contact with the tongue. The electrode signal is sent from the point of contact through wires out to a processing box, where the data are gathered and sent through a USB connection to a computer. A visual representation of all electrodes is displayed on a computer screen, with any activated electrodes highlighted in blue (Fletcher, McCutcheon, & Wolf, 1975; SmartPalate Software, 2014).

Historically, EPG has been a helpful tool in assessing and remediating a variety of speech disorders across a wide range of ages. For example, EPG has been used to assess perceptual articulatory undershoot in patients with Parkinson's disease (McAuliffe, Ward, & Murdoch, 2006). EPG has also been a helpful tool in analyzing both general and specific elements of apraxic speech (Hardcastle & Edwards, 1992; Southwood, Dagenais, Sutphin, & Garcia, 1997). Kuruvilla, Murdoch, and Goozee (2008) used EPG data to objectively compare post-Traumatic Brain Injury (TBI) dysarthric speakers to typical speakers. Suzuki (1989) notes that EPG has also been used to assess and treat several different disorders including cleft lip and palate, mandibular prognathism and open-bite, ankyloglossia, congenital velopharyngeal incompetence, and motor speech disorders. Additionally, EPG has been found to be a successful therapy tool for articulation difficulties associated with hearing loss and orthodontic abnormalities (Dent, Gibbon, & Hardcastle, 1995). Because hearing impaired individuals cannot capitalize upon incoming auditory information, the visual feedback from EPG has been a very useful compensatory tool for treating articulation difficulties for individuals with hearing loss (Crawford, 1995).

In fact, although EPG is a versatile tool used to treat a number of communication disorders, one of the most common and successful uses of EPG is the treatment of articulation disorders for both those with and without hearing impairments (Carter & Edwards, 2004; Crawford, 1995). Dagenais (1995) summarized previous efficacy studies in this area and concluded that EPG can be successful in treating articulation disorders where there are no underlying cognitive or language problems. Carter and Edwards (2004) found that EPG was beneficial for treatment of long-standing speech disorders of no known etiology for children between ages 7 and 14. EPG biofeedback has also been particularly successful in treating persistent articulation difficulties of clients who had either been previously unresponsive to traditional articulation therapy or have reached a plateau using only traditional articulation therapy (Dent et al., 1995).

Both children and adults with articulation disorders face similar challenges to many learners of an L2, in that these individuals often experience difficulty moving the tongue and other articulators to the correct placement required for a particular sound to be produced in an intelligible manner (Bright, 1999; Dent et al., 1995; Gibbon et al., 1991; Munro, 1992).

L2 learners may acquire some speech sounds of a second language after only a relatively brief period of practice by using more traditional language learning approaches based on auditory feedback. In these more traditional approaches, L2 learners are expected to acquire L2 sounds using behavioral methods with acoustic feedback. Instructors will often model L2 sounds and expect students to repeat the L2 sounds heard (McLaughlin, 2012). This process helps L2 learners use existing sounds in their first language (L1) in order to learn similar sounds in L2 (Munro, 1992; Schmidt, 1998; Strange & Shafer, 1992). However, there are two primary reasons why some L2 sounds may be difficult to acquire using these more traditional language learning approaches.

The first problem arises when an L2 sound does not have a close equivalent in L1. Because traditional approaches rely so heavily on L1 sounds in order to learn similar L2 sounds, L2 sounds may be difficult to acquire when there is no existing similar sound in L1. In order to acquire these sounds for intelligible speech, the articulators are required to learn a novel motor pattern unlike any existing motor pattern in their L1 (Bright, 1999; Munro, 1992; Schmidt, 1998; Strange & Shafer, 1992; Weiss & Wängler, 1985).

Furthermore, the visual inaccessibility of the tongue for many sounds creates an additional difficulty for acquiring L2 sounds through more traditional approaches. For sounds that are not easily visualized, such as those made with a more posterior constriction, the learner is often trying to produce correct motor patterns through a type of trial and error, using auditory feedback that may only be indirectly related to movement of the articulators. In other words, visual inaccessibility of a sound can make it difficult for the learner to know whether to move the tongue in a posterior, anterior, or lateral direction in order to achieve the desired sound. Additionally, a lack of visual access creates difficulty knowing if the tongue is the only articulator that needs to be adjusted to produce a particular sound. Many speech sounds are a result of multiple articulators moving simultaneously. The L2 learner cannot produce the sound simply because it is not clear to them which articulators are involved and how those articulators need to be placed to produce the sound (Gibbon et al., 1991). Although EPG doesn't necessarily solve the challenge associated with sounds produced with multiple constrictions (e.g., lips and tongue), it can provide more *direct* feedback on how to modify the linguapalatal contact patterns for intelligible speech (Dent et al., 1995; Gibbon & Katerina, 1999).

A second possible limitation of more traditional language learning approaches is brought about because of an assumption upon which the approach is based. The traditional language learning approach is based on the assumption that perception precedes production (Cheng & Zhang, 1999; Crawford, 1995; Strange & Shafer, 1992). Cheng and Zhang (1999) found that there generally exists for consonants a strong positive correlation between the perception and production of sounds. If a person cannot perceptually distinguish between accurate and inaccurate production of sounds using auditory information, they will likely be unable to accurately produce the sounds themselves (Bright, 1999). This often occurs when L2 learners encounter one or more L2 sounds that are assimilated in L1. According to Best's *Perceptual Assimilation Model* (1994), native sounds are assigned distinct categories within a metaphoric phonological space. When non-native sounds are heard, L2 learners perceptually assimilate sounds into existing L1 sound categories based on their similarity to L1 sounds. Due to assimilation, L2 learners may be unable to perceive and therefore produce the target using only auditory feedback as is commonly used for more traditional language learning approaches (Bright, 1999; Strange & Shafer, 1992; Weiss & Wängler, 1985).

A well-documented example of this is shown through the difficulties that native Japanese speakers experience when learning the contrast between /r/ and /l/ in the English language. According to Best's model discussed previously (1994), this difficulty occurs because in L1 (Japanese), the /l/ and /r/ phoneme categories are assimilated into one single category. The Japanese speaker may fail to perceive a contrast in linguistic meaning between the two assimilated phonemes even after instructor modeling. As a result, these L2 learners may exhibit difficulty acquiring the phonemes /l/ and /r/ within their own speech. The acoustic feedback provided through a traditional language learning approach may be insufficient for learning to acquire sounds assimilated in their L1 (Gibbon et al., 1991; Strange & Shafer, 1992).

Because EPG provides visual biofeedback and has been successful in treating similar problems in subjects with articulation disorders, EPG may also be an effective tool in helping L2 learners acquire difficult to learn non-native speech sounds. In particular, EPG may be a viable supplement for L2 learners who have previously shown little or no progress after years of practice using traditional L2 learning approaches (Strange & Shafer, 1992).

A very limited number of studies have been conducted in order to assess the efficacy of using EPG to assist L2 learners acquiring difficult sounds. Gibbon et al. (1991) conducted a study in which two Japanese learners of English who could not accurately perceive or produce an acoustic contrast for /r/ and /l/ were able to produce both sounds accurately after four sessions working with the visual feedback provided through EPG. The /r/ and /l/ sound contrast was an ideal distinction to study because perceptually, they are very similar, but EPG shows distinct visual contact patterns. The authors also noted that participants reported that they were better able to auditorily discriminate between /r/ and /l/ after treatment (Gibbon et al., 1991). In addition to Japanese, EPG has also been effectively used for accent reduction in native Spanish speakers learning English (Bright, 1999). Results of a third study showed that EPG was also a useful therapy tool for learning difficult-to-acquire English sounds for native speakers of Thai (Schmidt, 1998).

Despite these positive outcomes, the authors note that due to the limited scope of these studies, more research needs to be conducted in order to make broad claims regarding the efficacy of using EPG as a tool for L2 acquisition of difficult sounds (Bright, 1999; Gibbon et al., 1991; Schmidt, 1998). This thesis is part of a larger study aiming to further assess the efficacy of supplementing L2 acquisition with EPG biofeedback for native English speakers learning German. Before we can measure the efficacy of using EPG as a training tool, normative data of native German speech patterns must be established (Gibbon & Katerina, 1999). These normative speech patterns can then be used as native speech sound models with which new learners of the language will be able to train. Specifically, this study will gather normative data to describe the difficult-to-acquire German sound contrasts [ç], [x], and /ʃ/, with data gathered from six native German speakers.

The sounds [ç] and [x] are allophones of the phoneme /x/ and were selected because they have a history of being difficult for American English speakers to acquire, yet they have good linguapalatal contact. These sounds are two German consonants that have no L1 equivalent for American English speakers, requiring L2 learners to produce novel motor patterns. The sound /ʃ/ was also included as this sound often interferes with accurate production of [ç] (Hall, 1992; MacCarthy, 1975; Weiss & Wängler, 1985).

Method

Participants

Six young adult speakers (ages 20-25) participated in this study. Participants identified themselves as native speakers of High German (Hochdeutsch) who were currently living in the United States of America. In addition, each participant reported that they continue to converse in German on a consistent basis. All participants denied history of a speech or language disorder. Additionally, each participant denied significant dental problems.

Stimuli

The following thesis is part of a larger study where the following German sounds were collected: [ç and x] as well as /ʃ, l, ts, s, t, d, p, b, k, g, f, pf, ʧ/. Target sounds were assessed in both real and nonsense words. Patients were randomly assigned to be initially presented with either a real or nonsense wordlist, with the remaining wordlist presented afterwards. Words within each list were randomized and then presented via timed PowerPoint presentation, with one target word per 2.0-second slide for nonsense words in isolation and one target word per 3.5-second slide for real words in a carrier phrase. Prior to data collection, participants were educated on all target words and were given a practice set of target words via timed PowerPoint presentation. Nonsense words assessed [ç], [x], and /ʃ/ in the final position of words in a vowel consonant (VC) context, with a preceding high-front (HF) vowel (namely /i/ and /I/), a high-back (HB) vowel (namely /u/ and /ʊ/), and a low-back (LB) vowel (namely /ɑ/). The wordlist contained six unique words with 10 tokens of each word presented in random order, with a total of 60 nonsense words collected from each participant. See Table 1 below for a complete wordlist.

The same target sounds were also assessed in the final position of real German words. Participants were instructed to use the carrier phrase *Ich sage...* (I say) prior to saying each target word. The carrier phrase and one target word were shown on each PowerPoint slide. This wordlist contained 12 unique German words with five tokens of each word presented in random order, with a total of 60 real words collected from each participant. Linguistic context was controlled for by selecting only monosyllabic words, with a high-front vowel preceding [ç] and /ʃ/ as well as both a low-back and a high-back vowel preceding target sounds [x] and /ʃ/. Of note, not all three target sounds were assessed in all three phonetic contexts for both real and nonsense words because [ç] and [x] are context-dependent sounds. For example, [ç] occurs more anteriorly in the oral cavity; consequently, it does not occur in German following back vowels. In contrast, [x] occurs more posteriorly and does not occur in German following front vowels (Hall, 1992; MacCarthy, 1975; Mangold, 2000; Prowe et al., 2007; Weiss & Wängler, 1985). See Table 2 below for selected words representing target sounds.

Table 1

List of Nonsense Words for [ç], [x], and /ʃ/

Sound	Preceding Vowel		
	HF	HB	LB
[ç]	ich	---	---
[x]	---	uch	ach
/ʃ/	isch	usch	asch

Table 2

List of Real German Words for [ç], [x], and /ʃ/

Sound	Preceding Vowel		
	HF	HB	LB
[ç]	mich sich dich	---	---
[x]	---	Fluch such' Buch	Fach Dach mach'
/ʃ/	Fisch	Tusch	wasch'

Procedure

Each participant had a dental impression made by a dental assistant. From this dental impression, a stone cast of the upper teeth and palate was made in order to create an individualized pseudopalate. Speech data from each participant were collected in an hour-long session. The initial 20 minutes of the session was spent in conversation with the participant in order to desensitize the participant to the physical presence of the pseudopalate in their mouth.

Participants were then instructed to read each wordlist presented via timed PowerPoint presentation with a brief rest period between wordlists.

The EPG data were collected by a small processing box and then subsequently transferred to a computer via a USB cable. A simultaneous sound recording was also obtained as a backup reference to the EPG data collected through the palatometer. These audio recordings were sampled at a rate of 44.1 kHz with a quantization of 24 bits.

Data Analysis

Spectrographic inspection of a waveform display in Adobe Audition assisted in segmenting the onset and offset of target consonant productions. The onset was identified by a sharp increase in diffuse noise energy, and the offset was identified by a sharp decrease in diffuse energy. Time values of each segment (in ms) were saved as text files and then checked, corrected, and re-checked using a customized MATLAB computer program which showed the segment boundaries superimposed over the waveform for each token in order to identify any outliers in the data.

Using the segmentation data as reference point as to beginning and end of individual target sounds, EPG contact patterns were then analyzed dynamically as a series of consecutive 20 ms analysis frames calculated across the duration of each sound, with the first and last two frames excluded in order to isolate the medial portion of each sound segment for analysis. The data from each of these analysis windows were used to compute electrode activation in a number of EPG regions. As show in Figure 1, the pseudopalate electrodes were divided into eight regions: front, central, right/left anterior, right/left medial, and right/left posterior. Electrode activation within each region was computed using a custom designed MATLAB software program.

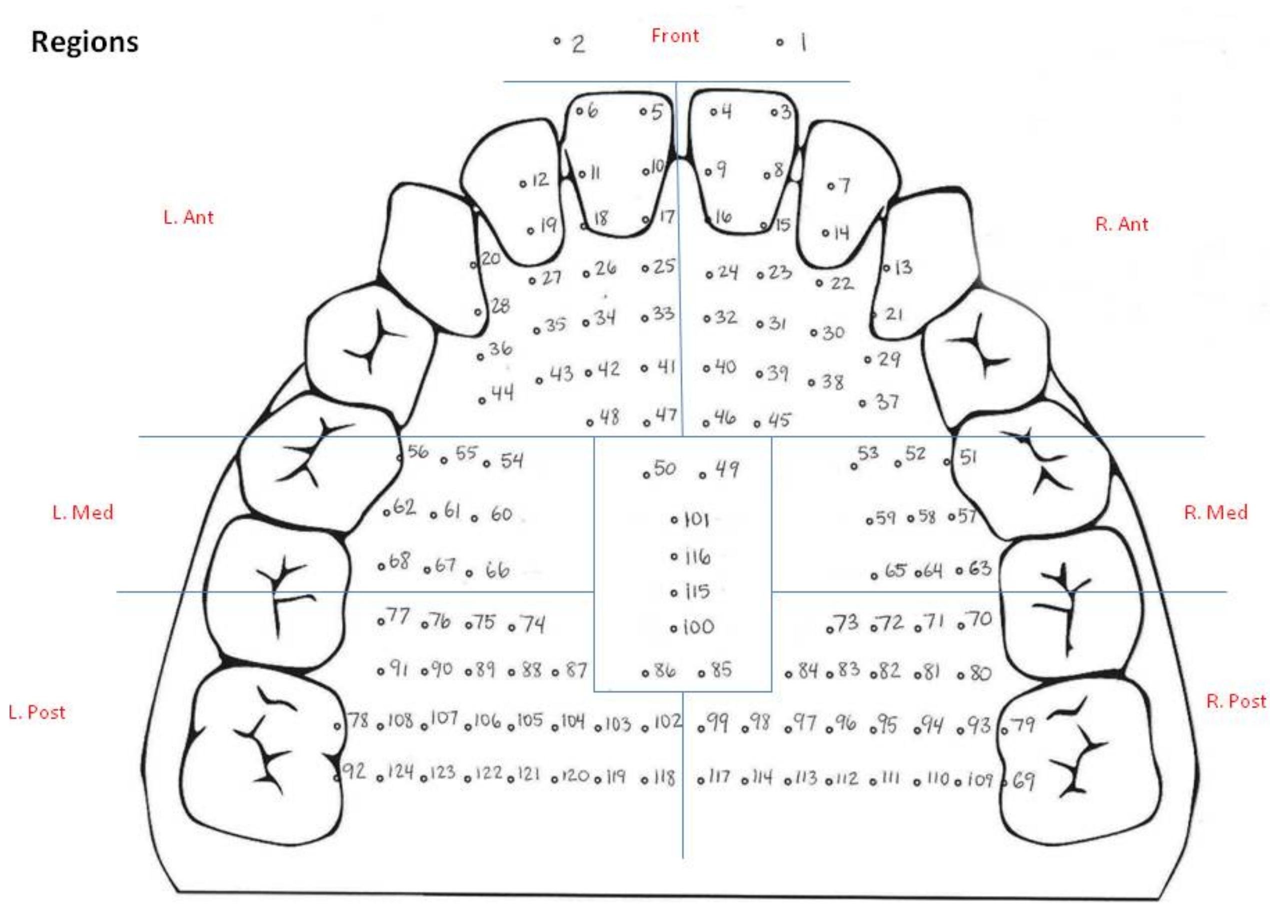

Figure 1. Regions of the pseudopalate

Results

Speech production data from two out of the six participants experienced probable software errors during collection; consequently, the following results are reported only for the remaining four participants (P3-P6) in order to increase validity for this study. Out of the original six participants, P1, P2, and P6 were females and P3, P4, and P5 were males. Although this study was originally designed to include an equal number of male and female participants, excluding results for P1 and P2 creates an imbalance, with results reporting on only one female (P6) and three males (P3, P4, and P5). For these four participants, descriptive statistics were used to report the electrode activation level across six different regions.

Fricative Duration

The duration means and standard deviations for each sound type as a function of word type and participant are shown in Table 3 and Table 4. As illustrated in Figure 3, overall the mean duration for nonsense words was greater than the duration for real words. For example, participant 3 demonstrated a mean duration for [ç] in a HF vowel context of 283 ms for real words, increasing to 413 ms in nonsense words. Tables 3 and 4 show this trend to be consistent across participants. In addition to word type, there was also considerable variation in mean duration between participants, as shown in Figure 2. While participant 5 had a mean duration for [ç] in a real word, HF vowel context of 230 ms, participant 4 more than doubled participant 5, with a mean value of 545 ms for the same sound. In terms of sound type, the durations of [ç], [x], and /ʃ/ for a given participant were relatively similar.

Electrode Activation Across Region

Overall mean and standard deviation were calculated for each region by collapsing data across individual participants and repetitions of each sound and word type. A detailed listing of these values for the real and nonsense words are included in Tables 5 and 6, respectively. These data indicate that the electrode activation contact patterns were fairly symmetrical for the left and right-paired regions across an anterior-posterior range. For example, the mean activation level for both the right and the left posterior regions of [ç] in a HF vowel context was 0.63. When collapsed laterally across left and right sides as well as across regions, [x] generally had little or no contact, with an activation mean for real words of 0.00 for anterior and medial regions and 0.06 and 0.04 for HB vowel in the left and right posterior regions, respectively. Of note, [x] did have lower activation levels for real words than for nonsense words (unlike [ç] and /ʃ/, which remained fairly stable); however, even in nonsense words, [x] had minimal contact, ranging from

Table 3

Target Sound Duration in ms for Nonsense Words

		Sound					
		[ç]		[x]		/ʃ/	
Region	Vowel	Mean	SD	Mean	SD	Mean	SD
Participant 3	HF	413	58	---	---	437	71
	HB	---	---	381	35	358	63
	LB	---	---	400	67	391	58
Participant 4	HF	518	127	---	---	599	116
	HB	---	---	523	91	544	93
	LB	---	---	514	147	476	93
Participant 5	HF	273	40	---	---	333	52
	HB	---	---	338	50	354	63
	LB	---	---	345	54	333	42
Participant 6	HF	370	68	---	---	399	55
	HB	---	---	348	66	392	64
	LB	---	---	355	64	350	69

Table 4

Target Sound Duration in ms for Real Words

		Sound					
		[ç]		[x]		/ʃ/	
Region	Vowel	Mean	SD	Mean	SD	Mean	SD
Participant 3	HF	283	68	---	---	292	20
	HB	---	---	274	20	310	23
	LB	---	---	246	22	242	15
Participant 4	HF	545	112	---	---	474	109
	HB	---	---	537	94	630	144
	LB	---	---	461	95	440	71
Participant 5	HF	230	33	---	---	224	18
	HB	---	---	255	46	248	18
	LB	---	---	230	54	232	28
Participant 6	HF	333	53	---	---	316	42
	HB	---	---	279	44	338	82
	LB	---	---	289	49	316	46

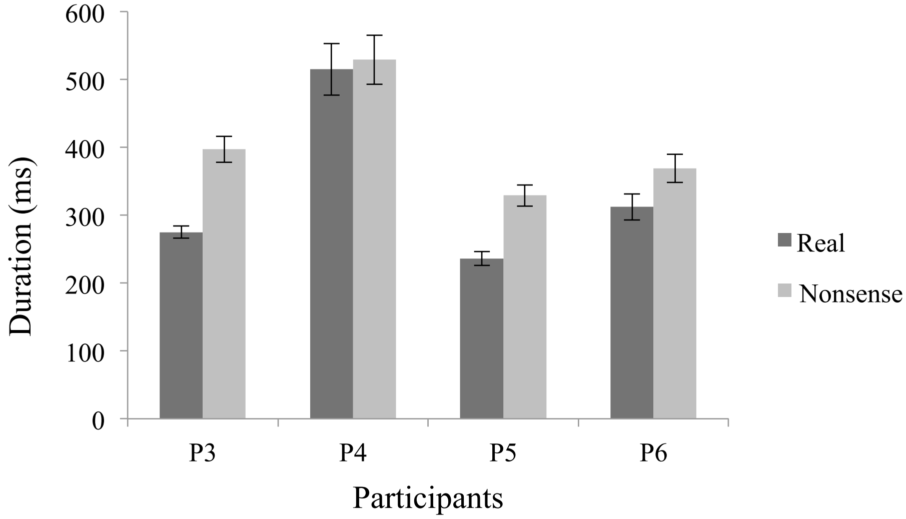

Figure 2. Mean fricative duration and standard error of the mean for real and nonsense words in milliseconds (ms) collapsed across all sounds and vowel contexts for each participant (P).

0.00 to 0.14. The sound /ʃ/ generally showed greater contact than [x] even when both sounds were produced with the same vowel context. When both sounds were produced in a HB vowel context for real words, the left posterior region showed only 0.06 activation for [x], but showed 0.34 activation for /ʃ/. Although /ʃ/ generally had higher activation levels than [x], Figure 3 reveals that the sound [ç] proved to have the highest activation of the three sounds analyzed. The mean activation level for the right medial region for the [ç] sound in a HF vowel context was 0.76 as compared to 0.47 for /ʃ/ under the same conditions.

As shown in Figure 3, electrode activation level also varied under different linguistic contexts. The sound /ʃ/ was assessed in all three linguistic context (HF, HB, and LB) and showed the highest and lowest activation levels in a HF and HB vowel context, respectively. The sound [x] was assessed in a HB and LB vowel context, with higher activation levels occurring given a LB context.

Table 5

Electrode Activation Percentages for Nonsense Words

		Sound					
		[ç]		[x]		/ʃ/	
Region	Vowel	Mean	SD	Mean	SD	Mean	SD
Left Anterior	HF	0.07	0.05	---	---	0.10	0.05
	HB	---	---	0.00	0.00	0.06	0.04
	LB	---	---	0.01	0.03	0.05	0.04
Left Medial	HF	0.86	0.09	---	---	0.59	0.11
	HB	---	---	0.03	0.08	0.51	0.11
	LB	---	---	0.08	0.20	0.57	0.12
Left Posterior	HF	0.63	0.06	---	---	0.46	0.08
	HB	---	---	0.11	0.06	0.35	0.05
	LB	---	---	0.14	0.12	0.38	0.07
Right Anterior	HF	0.15	0.07	---	---	0.12	0.07
	HB	---	---	0.01	0.02	0.06	0.03
	LB	---	---	0.01	0.02	0.07	0.04
Right Medial	HF	0.76	0.11	---	---	0.47	0.14
	HB	---	---	0.02	0.07	0.43	0.15
	LB	---	---	0.06	0.16	0.52	0.13
Right Posterior	HF	0.63	0.08	---	---	0.40	0.08
	HB	---	---	0.06	0.05	0.30	0.05
	LB	---	---	0.08	0.09	0.32	0.04

Table 6

Electrode Activation Percentages for Real Words

		Sound					
		[ç]		[x]		/ʃ/	
Region	Vowel	Mean	SD	Mean	SD	Mean	SD
Left Anterior	HF	0.10	0.05	---	---	0.08	0.02
	HB	---	---	0.00	0.00	0.06	0.02
	LB	---	---	0.00	0.00	0.06	0.03
Left Medial	HF	0.82	0.10			0.55	0.10
	HB	---	---	0.00	0.00	0.60	0.06
	LB	---	---	0.00	0.00	0.72	0.08
Left Posterior	HF	0.64	0.06	---	---	0.43	0.06
	HB	---	---	0.06	0.03	0.34	0.03
	LB	---	---	0.05	0.03	0.39	0.05
Right Anterior	HF	0.18	0.06			0.09	0.03
	HB	---	---	0.00	0.00	0.07	0.02
	LB	---	---	0.00	0.00	0.07	0.02
Right Medial	HF	0.76	0.10			0.41	0.10
	HB	---	---	0.00	0.00	0.51	0.09
	LB	---	---	0.00	0.00	0.63	0.12
Right Posterior	HF	0.66	0.07			0.37	0.06
	HB	---	---	0.04	0.02	0.32	0.02
	LB	---	---	0.03	0.02	0.33	0.04

Further analysis on the portion of electrodes activated between distinct regions for one sound reveals two primary trends that can be seen in Figure 4. First, the sound [x] generally resulted in more activation in the medial regions than in the anterior regions, with the most electrodes activated in the posterior region. The second trend was observed through the remaining two sounds [ç] and /ʃ/. Similar to the first trend, these two sounds showed the least amount of contact in the anterior regions, but unlike the first trend, maximal contact was consistently found not in the posterior regions, but in the *medial* regions.

Discussion

The purpose of this study was to describe native linguapalatal contact patterns for three German fricatives: [ç], [x], and /ʃ/. Electrode activation levels were generally highest for [ç] and lowest for /ʃ/. Although there is no known research regarding EPG data on these sounds with which these results can be compared, the lower activation levels may have been caused by a lowered tongue position, a retracted tongue position, or a combination of both. Vowel context was also noted to affect activation level, with higher activation levels for target sounds produced after a LB than a HB vowel. There was also considerable variation between target sound duration that may have been caused by variable levels of adaptation to the pseudopalate, age, gender, or other factors.

When considering results of this study, it is particularly interesting to note the variability between the speakers themselves. Speaker production varied widely, with the mean duration for P5 approximately twice the mean duration for P3 or P4. This difference in duration may cause reason to question the naturalness of the speaker data collected. Speakers such as P5 may have been using a slower speech than is actually used during connected speech. Because of this, the

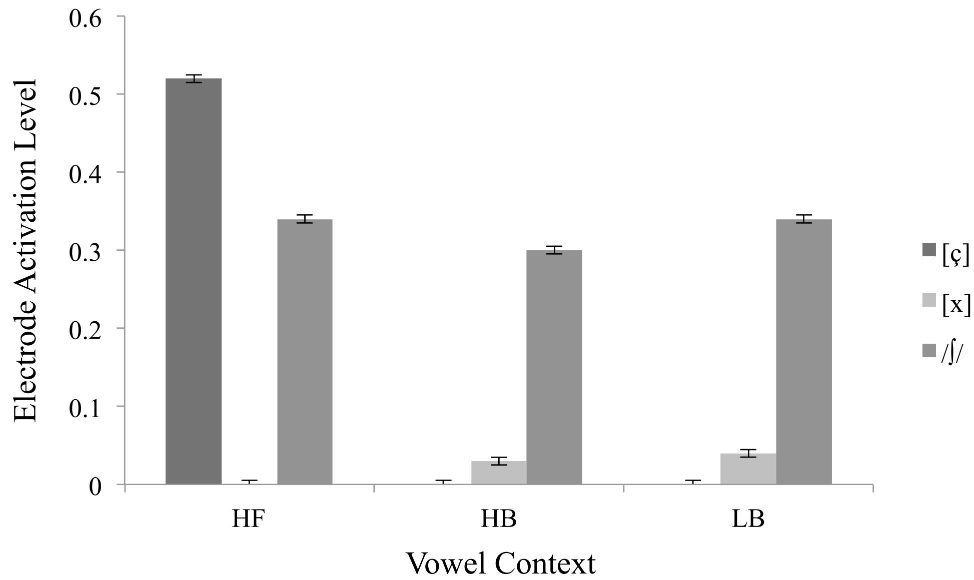

Figure 3. Level of activation and standard error of the mean for [ç], [x], and /ʃ/ given a high-front (HF), a high-back (HB), or a low-back (LB) vowel context and collapsed across word type (real/nonsense), participant, region, and right/left side.

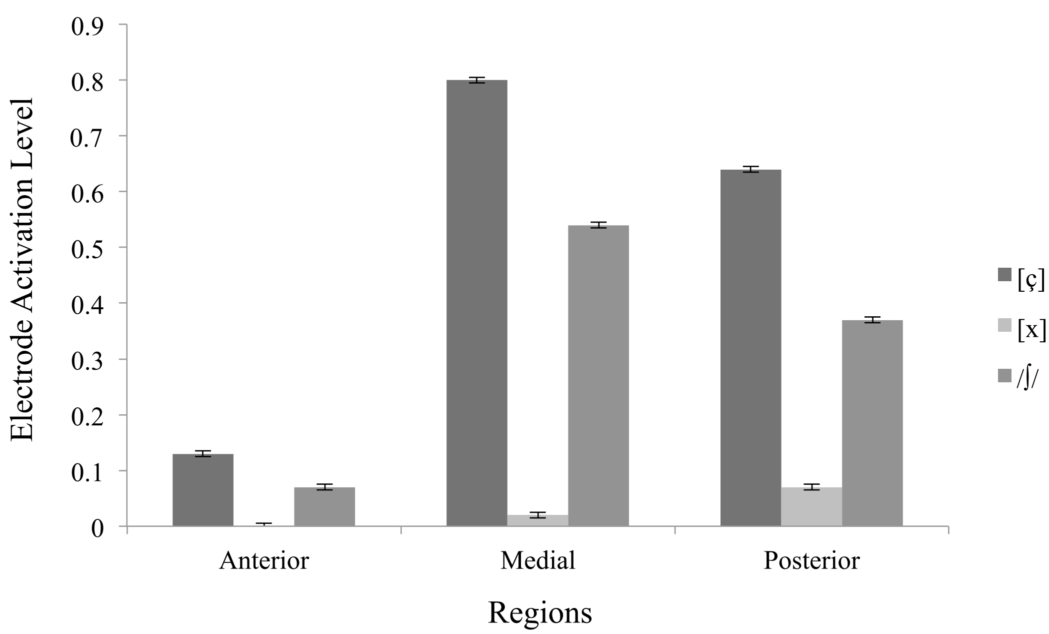

Figure 4. Electrode activation level within each region, collapsed across right/left side, word type (real/nonsense), participant, and vowel context.

descriptions of German fricatives in this study may not accurately describe those produced in connected speech.

The fact that inter-speaker duration variability exists may also be an indication of variable levels of pseudopalate adaptation. The current study allowed for a 20-minute adaptation period to minimize any atypical articulatory patterns that may have been initially introduced with the pseudopalate in the oral cavity. Findings in previous research are varied regarding adaptation, with some researchers reporting no perceptible speech difference after only five minutes of adaptation, whereas many other researchers claim that even after extensive time, some speakers may never fully adapt to articulating with the pseudopalate present. Additionally, past studies have noted a variety between participants in the time required to adapt. For this study, it may be noted that not all participants may have completely adapted to the pseudopalate prior to data collection (Barrett, 2012; Gibbon et al., 1991).

There may be a number of possible explanations involving lingual movement as a factor causing significant variation in electrode activation level between the three German fricatives. Because pseudopalate electrodes are activated by linguapalatal contact, we can infer approximate tongue placement based on the electrode activation data. A higher level of electrode activation likely indicates a larger surface area of linguapalatal contact in a given region. One possible explanation for the high level of contact attained by [ç] may be that tongue placement was simply more anterior, therefore activating a greater portion of electrodes overall. In contrast, the lingual placement for /ʃ/ may have been slightly more posterior, causing lower activation levels across all regions. The little or no contact observed for [x] may have simply been because [x] was formed posteriorly beyond the edge of the pseudopalate itself, limiting visualization for the place of articulation. However, the likelihood of this explanation as a cause for the minimal contact observed is challenged when considering that the pseudopalate encompasses much of the posterior region of the oral cavity, with its edge extending slightly beyond the back molars.

There is another possible explanation for the reduced amount of contact for [x]. Rather than not capturing articulation placement due to far posterior production of [x], this sound may not have shown significant contact because it was produced with the tongue in a slightly inferior position relative to [ç] and /ʃ/. In essence, lowering the tongue away from the palate may naturally result in reduced electrode activation. Because EPG measures only linguapalatal contact, however, the above explanation cannot be confirmed using EPG data alone.

In addition to the differences observed between sounds, differences within a given sound were also observed under different linguistic contexts. A fairly high level of contact was made in the context of HF vowel. This is expected given that this context places the tongue in an anterior and superior position close to the pseudopalate. In contrast, the linguistic context that might be expected to produce the least contact would be a LB context farthest away from the pseudopalate; however, the least contact was actually made in a HB context for both /ʃ/ and [x]. One explanation for this may be because LB vowels may have been produced with more tension and HB vowels may have been more lax. These possibly lax, HB vowels, may have resulted in lighter contact with the pseudopalate material with inadequate pressure to activate electrodes. Of note, even though [x] and /ʃ/ showed more contact in a LB than a HB context, [x] consistently demonstrated little contact for both vowel contexts, likely for reasons discussed previously.

Although [x] showed only minimal contact, EPG may still be an effective tool in aiding L2 learners of German in acquiring all three German fricatives. English L2 learners of German tend to confuse the production of [ç] and /ʃ/. Because EPG shows distinct, visual patterns with good contact for both [ç] and /ʃ/, L2 learners may benefit from using EPG visual biofeedback to first learn the contrast between these two sounds. Because of poor contact, EPG may initially appear to be a less effective tool for acquiring [x], where it would remain unclear to the L2 learner whether to move the tongue in a more posterior or inferior direction in order to achieve the desired sound. However, this is not necessarily the case. MacCarthy (1975) claims that through traditional language learning methods involving auditory feedback, L2 learners can learn to approximate accurate productions for these three fricatives; however, their productions "nearly always [leave] something to be desired: their mistake normally consists of failing to make sufficient difference between the two main types of CH-sounds, i.e. they fail to make the front articulation *front enough* and to make the back articulation *back enough*" (p. 87). Of particular interest, the poor contact itself is a distinctive pattern from [ç] and /ʃ/. In this regard, even though [x] has little contact, an L2 learner may still benefit from using EPG biofeedback to bridge the gap between a sound approximation "with something to be desired" (p. 87) and true native production by visually ensuring that the learner's production of [x] is produced far enough posteriorly in order to create distinction from [ç] and /ʃ/ (MacCarthy, 1975; Weiss & Wängler, 1985).

In order to more effectively use this EPG data as a tool for second-language acquisition, further research needs to be completed. For example, the data from this study that is currently in a raw number format can be transposed into a more visual format such as a linguapalatal contact map. This map showing activated electrodes for a given sound may be created by calculating indices values to mark the anterior-posterior and lateral margins for each region. This will provide the L2 learner a model from which they may be able to approximate native production for one of the three fricatives assessed. The efficacy of using these visual models as a second-language tool may then be assessed.

Prior to generalizing findings from current study, further research should also be conducted to broaden the scope and depth of these findings. For example, the current project described only three German sounds, with only two sounds showing good contact. Research on a variety of sounds within the German language as well as sounds in other languages may be useful, particularly for sounds produced more anteriorly with good contact in order to capture accurate visual models of articulation.

Even for the three sounds that were described in this analysis, further research is required prior to generalizing findings across the general German-speaking population as a whole. The current study only included participants ages 20-25. While this reduced confounding variables such as the effect of large age differences on articulation, current results can only be applied to individuals within this age range. Further research will need to be conducted in order to describe any change in production of these three fricatives for German speakers across different ages.

While all speakers for the current study self-reported that they speak High German (Hochdeutsch), even this single dialect is not entirely uniform amongst its speakers and may contain some variation. Sanders (2007) found that there is significant inter- and intraspeaker variability within a dialect. In an attempt to reduce intraspeaker variability for this study, contact patterns were averaged across multiple tokens; however, due to the limited number of participants for this study, this study was likely unable to represent the true extent of interspeaker variability that may exist within High German. In order to gain more insight on the true variation for the production of sounds in typical High German speakers, further research may include a larger number of participants. Additionally, an even greater level of variation might be expected for entirely different dialects of German. The particular dialect of the German speaker is highly likely to result in different contact patterns for each sound. Further researchers may consider not only increasing participant number, but also increasing dialect variety (Fletcher et al., 1975; Hall, 1992; MacCarthy, 1975; Weiss & Wängler, 1985).

While further research may be highly valuable in better understanding the efficacy of using EPG as a tool for second language acquisition, the current study provides a good foundation upon which further research may be built. This study was successfully able to describe native contact patterns for three German fricatives. Even though one of these sounds, [x], was only described in this study by minimal contact patterns, all three sounds were shown to be visually distinctive and therefore may be good candidates for further research in assessing EPG as a tool for acquiring difficult sounds in the German language.

References

Barrett, J. (2012). *The correlation between spectral moment measures and electropalatometric contact patterns for /t/ and /k/.* (Master's thesis, Brigham Young University). Retrieved from http://scholarsarchive.byu.edu/etd/3304/

Best, C. T. (1994). The emergence of native-language phonological influences in infants: A perceptual assimilation model. In J. Goodman & H. C. Nusbaum (Eds.), *The development of speech perception: The transition from speech sounds to spoken words* (pp. 167-224). Cambridge, MA: MIT Press.

Bright, A. L. (1999). *The palatometer as an instrument for accent reduction therapy with three native ESL Spanish speakers.* (Master's thesis, Brigham Young University). Retrieved from http://etd.byu.edu/

Carter, P., & Edwards, S. (2004). EPG therapy for children with long-standing speech disorders - predictions and outcomes. *Clinical Linguistics and Phonetics, 18*, 359-372. doi:10.1080/02699200410001703637

Cheng, B., & Zhang, Y. (2009). The relationship between speech perception and production in second language learners. *The Journal of the Acoustical Society of America*, *125,* 2754. Retrieved from http://dx.doi.org/10.1121/1.4784618

Crawford, R. (1995). Teaching voiced velar stops to profoundly deaf children using EPG-two case studies. *Clinical Linguistics and Phonetics*, *9,* 255-269. doi: 10.3109/02699209508985336

Dagenais, P. A. (1995). Electropalatography in the treatment of articulation/phonological disorders. *Journal of Communication Disorders, 28*, 303-329. Retrieved from http://www.sciencedirect.com/science/journal/00219924

Dent, H., Gibbon, F., & Hardcastle, B. (1995). The application of electropalatography (EPG) to the remediation of speech disorders in school-aged children and young adults. *European Journal of Disorders of Communication*, *30*, 264-277. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7492857

Fletcher, S. G., McCutcheon, M. J., & Wolf, M. B. (1975). Dynamic palatometry. *Journal of Speech and Hearing Research*, *18*, 812-819. Retrieved from http://jslhr.pubs.asha.org/

Gibbon, F., Hardcastle, W. J., & Suzuki, H. (1991). An electropalatographic study of the /r/, /l/ distinction for Japanese learners of English. *Computer Assisted Language Learning*, *4*, 153-171. Retrieved from http://www.tandfonline.com/

Gibbon, F., & Katerina, N. (1999). Palatography. In W. Hardcastle & N. Hewlett (Eds.), *Coarticulation: Theory, data and techniques* (pp. 229-245). Cambridge, NY: Cambridge University Press.

Hall, C. (1992). *Modern German Pronunciation*. New York, NY: Manchester University Press.

Hardcastle, W., & Edwards, S. (1992). EPG-based description of apraxic speech errors. In R. D. Kent (Ed.), *Intelligibility in speech disorders: Theory, measurement, and management* (pp. 287-328). Philadelphia, PA: John Benjamins Publishing.

Kuruvilla, M. S., Murdoch, B. E., & Goozee, J. V. (2008). Electropalatographic (EPG) assessment of tongue-to-palate contacts in dysarthric speakers following TBI. *Clinical Linguistics and Phonetics, 22*, 703-725. doi: 10.1080/02699200802176378

MacCarthy, P. (1975). *The pronunciation of German*. London, England: Oxford University Press.

Mangold, M. (Ed.). (2000). *Duden, Aussprachewoerterbuch* [The Pronunciation Dictionary]. Mannheim, Germany: Bibliographisches Institut & F. A. Brockhaus AG.

McAuliffe, M., Ward, E., & Murdoch, B. (2006). Speech production in Parkinson's disease - I. An electropalatographic investigation of tongue-palate contact patterns. *Clinical Linguistics and Phonetics, 20*, 1-18. doi: 10.1080/02699200400001044

McLaughlin, B. (2012). *Second-language acquisition in childhood.* New York, NY: Psychology Press.

Munro, M. J. (1992). Foreign accent and speech intelligibility. In M. J. Munro (Ed.), *Phonology and Second Language Acquisition* (pp. 194-218). Philadelphia, PA: John Benjamins Publishing.

Nissen, S. L. (2014). [Native German EPG speech productions]. Unpublished raw data.

Prowe, G., Schneider, J., Morris, R., Sawers, R., Rollin, N., & Vennebusch, E. (2007). *The Oxford new German dictionary*. New York, NY: The Berkley Publishing Group.

Sanders, M. C. (2007). *Inter- and intra-speaker variability: A palatometric study.* (Master's thesis, Brigham Young University). Retrieved from http://etd.byu.edu/1201/

Schmidt, A. M. (1998). Electropalatography treatment for training Thai speakers of English. *Clinical Linguistics& Phonetics*, *12*, 389-403. Retrieved from http://www.icpla.org/

SmartPalate Software. (2014). Retrieved April 15, 2014 from http://www.completespeech.com/

Southwood, M. H., Dagenais, P. A., Sutphin, S. M., & Garcia, J. M. (1997). Coarticulation in apraxia of speech: A perceptual, acoustic, and electropalatographic study. *Clinical Linguistics & Phonetics, 11*, 179-203. Retrieved from http://www.icpla.org/

Strange, W., & Shafer, V. L. (1992). Speech perception in second language learners: The re-education of selective perception. In J. G. Hansen Edwards & M. L. Zampini (Eds.), *Phonology and Second Language Acquisition* (pp. 153-191). Philadelphia, PA: John Benjamins Publishing.

Suzuki, N. (1989). Clinical applications of EPG to Japanese cleft palate and glossectomy patients. *Clinical Linguistics and Phonetics, 3*, 127-136. Retrieved from http://www.icpla.org/

Weiss, R., & Wängler, H. (1985). *German pronunciation: A phonetics manual*. Bellingham, WA: Western Washington University Press.

Appendix A - Annotated Bibliography

Barrett, J. (2012). *The correlation between spectral moment measures and electropalatometric contact patterns for /t/ and /k/.* (Master's thesis, Brigham Young University). Retrieved from http://scholarsarchive.byu.edu/etd/3304/

Objective: The author seeks to measure correlation between spectral moment measures and EPG patterns for /t/ and /k/. *Method:* Eight speakers were recorded and assessed with spectral moment analysis and electropalatography. *Results:* Similar to prior studies, most of the correlations examined were statistically significant. *Conclusion:* One factor that may have affected this study includes the adaptation to the pseudopalate. A review of previous literature reveals that findings on this are variable. While some researchers found no perceptible articulation difference after only five minutes, other researchers remark on the possibility that some speakers may never fully adapt even after extensive practice articulating with the presence of an EPG device in their oral cavity. Lingual movement and linguapalatal contact are contributing factors to the spectral characteristics for /t/ and /k/; however, the articulatory movements for these sounds are more complex with other contributing factors that may involve overall shape of the vocal tract.

Bright, A. L. (1999). *The palatometer as an instrument for accent reduction therapy with three native ESL Spanish speakers.* (Master's thesis, Brigham Young University). Retrieved from http://etd.byu.edu/

Objective: The purpose of the following study was to use EPG feedback for accent reduction therapy of native Spanish speakers. Adult learners of a second language have difficulty producing unfamiliar sounds when their phonetic features are significantly different from their native language. The author quotes Coates and Regdon (1974), noting that when this occurs, sounds from a second language become "a mixture of whatever parts of the sound and structure of English they have learned correctly and whatever substitute sounds and structures they borrow from other languages to complete the expression of their ideas" (p. 365). When learning a second language, accent reduction is important for effective and intelligible communication. Previously, an audio-lingual approach was taken to learn sounds in a second language. In this approach where each sound is taught and drilled, there is an underlying philosophy that second languages that are more similar to English are easier to learn. Self-discrimination of speech sounds plays a key role in teaching the pronunciation of second-language sounds. *Method*: Three adult females who were native Spanish speakers and knew English as a second language participated in this study. Data were collected on target phonemes before and after therapy and then given a score based on judges who were native English speakers. A formal accent articulation test was also given. *Results*: The results showed a significant reduction in accent from 16% to 59%. *Conclusion*: The audio/visual feedback by EPG is a viable option for teaching discrimination during accent reduction therapy.

Carter, P., & Edwards, S. (2004). EPG therapy for children with long-standing speech disorders - predictions and outcomes. *Clinical Linguistics and Phonetics, 18*, 359-372. doi:10.1080/02699200410001703637

Objective: There were two primary aims of this study: (a) to assess EPG benefit in treating long-standing speech disorders of no known etiology and (b) to investigate whether or not it was possible to predict which children would show maximum improvement. *Method*: Ten children (eight male and two female) between ages 7 and 14 with long-standing speech disorders of no known etiology participated in this study. Target sounds were most commonly alveolar sounds /t/, /d/, /s/, and /z/, but also included /k/ and /g/. Several factors were identified as possible predictors of success, including age, existence of cognitive abnormalities, and sensitivity to the palate, dentition, and motor control. Baseline data for each speaker were gathered using word lists. Scores were calculated based on the number of correct pronunciations of consonants. Subject treatment consisted of 10 half-hour therapy sessions followed by re-assessment using the same word lists used at baseline. *Results*: Carter and Edwards compared pre- and post-treatment data and found that there was a significant improvement in post-treatment data, although some measured factors did not predict improvement as expected. For example, age was not found to be a predictor of success whereas motivation (based on subjective clinician measures) was a fairly consistent predictor for level of success. *Conclusion*: Although Carter and Edwards did not establish quantitative evidence on the extent of EPG effectiveness, they were able to conclude that EPG was beneficial for treating long-standing speech disorders in children.

Cheng, B., & Zhang, Y. (2009). The relationship between speech perception and production in second language learners. *The Journal of the Acoustical Society of America*, *125,* 2754. Retrieved from http://dx.doi.org/10.1121/1.4784618

Objective: Cheng and Zhang studied the relationship between perception and production skills in learners of a second language. *Method*: Participants included 39 Chinese college students who had received at least eight years of English instruction in school. Data were collected using two different programs. Participant production of words was rated on a scale of 1 to 5 by two native English speakers. *Results*: This study found that there is a complex relationship between the perception and production of sounds for second language learners. Overall, there was a significant, positive correlation between perception and production for consonants. In contrast, vowels did not show significant correlations between perception and production. *Conclusion*: Both the perception and production of second-language sounds play significant roles in second language acquisition.

Crawford, R. (1995). Teaching voiced velar stops to profoundly deaf children using EPG-two case studies. *Clinical Linguistics and Phonetics*, *9,* 255-269. doi: 10.3109/02699209508985336

Objective: Most auditory training programs for hearing impaired individuals and phonological therapy programs are based on the assumption that perception precedes production. Deaf children are required to perceive the target sound (which is inherently difficult because of hearing deficits) before they can acquire sound in their own speech. This article examines two case studies showing the effectiveness of using EPG to teach children who are profoundly deaf. *Method*: Two females (ages 10 and 11) who were of normal intelligence who had previously received therapy for the accurate production of voiced velar stops and who were severely unintelligible participated in this study. *Results*: After five treatment sessions, the participants were able to accurately produce voiced velar sounds with 60-100% accuracy within words and phrases. These levels were maintained without continued visual feedback. *Conclusion*: EPG was an effective therapy tool, although further research needs to be conducted in order to assess its effect in spontaneous speech.

Dagenais, P. A. (1995). Electropalatography in the treatment of articulation/phonological disorders. *Journal of Communication Disorders, 28*, 303-329. Retrieved from http://www.sciencedirect.com/science/journal/00219924

Objective: Dagenais studies the treatment of *functional* articulation and phonological disorders using EPG by summarizing previous research. In this context, a *functional* articulation problem is defined as an isolated speech sound disorder that is not secondary to any cognitive or language problems. The author also notes that the following are possible sounds that can be addressed using EPG: /t, d, k, g, n, ŋ, s, z, ʃ, tʃ, ʒ, dʒ, l, r/ as well as high vowels /i, I, Ɛ, u, ʊ/. Considering the relatively high expense of the pseudopalate as well as the skills needed for EPG, the child should exhibit a level of maturity and cognitive development in order to be a viable candidate for therapy. Generally children who are good candidates for therapy are at least seven years old. *Results*: Children participating in these studies generally made good articulatory gains and demonstrated fewer phonological processes following treatment using EPG. The author also found that children with phonological disorders actually articulate sounds with systematic differences, despite their perception as being *neutralized* phonemes. *Conclusion*: EPG is useful for precise assessment as well as treatment of functional articulation and phonological disorders.

Dent, H., Gibbon, F., & Hardcastle, B. (1995). The application of electropalatography (EPG) to the remediation of speech disorders in school-aged children and young adults. *European Journal of Disorders of Communication*, *30*, 264-277. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7492857

Objective: The following paper studies the success of using the computer-based biofeedback technique EPG as a therapeutic tool for a variety of speech disorders in a large group of children and young adults and quantifies resulting changes in articulatory patterns. This article postulates that the additional, visual biofeedback from EPG enhances the difficult task of learning (or re-learning) speech motor patterns required for speech. *Method*: A total of 23 clients (ages 8 to 20 years old) were referred to this study by local speech therapists. While some articulation difficulties were the result of cleft palate and velopharyngeal port insufficiency, over half (13) of the participants were treated for functional articulation disorder (individuals with articulation disorders and associated problems including delayed language, hearing loss, orthodontic abnormalities, and learning disabilities). All clients were either unresponsive to traditional articulation therapy or the client's progress had reached a plateau using only traditional articulation therapy. Although target sounds differed between the clients, each client was treated using visual EPG biofeedback. The number of treatment sessions varied from 4 to 40 sessions depending on the client. *Results*: Out of the 23 participants involved, 18 completed their EPG treatment and exhibited perceptually normal articulation for target sounds. Three participants failed to show measurable progress. These three participants were 7 to 9 years old and showed less awareness of their speech-sound production compared to the participants who made progress using EPG. It was noted that one of these three unsuccessful participants had a mild learning disability. *Conclusion*: EPG was found to be a useful technique tool in treating articulation disorders in children, adolescents, and young adults; however, the number of treatment sessions in order for EPG to be effective varied widely. In addition, this study found that EPG is most successful for clients with sufficient awareness of speech-sound production. The conclusions of this study substantiate the argument that EPG biofeedback enhances the learning process when acquiring new motor patterns or modifying current motor patterns.

Fletcher, S. G., McCutcheon, M. J., & Wolf, M. B. (1975). Dynamic palatometry. *Journal of Speech and Hearing Research*, *18*, 812-819. Retrieved from http://jslhr.pubs.asha.org/

Objective: Dynamic Palatometry was developed in order to analyze linguapalatal contact within the mouth. *Method*: This pseudopalate was 0.2 mm thick and contained 48 electrode contacts. A 100 mV sinusoidal signal was attached to the wrist of the participant. Linguapalatal contact completed the signal path. A visual representation of the pseudopalate was shown using a light emitting diode (LED) display. The LEDs reflect the position of each electrode on the pseudopalate and indicate when and where there is linguapalatal contact. Even when simple utterances are repeatedly produced by a speaker, however, there exists some variation. An average of the repeated utterances may be taken in order to find common production patterns. Each repeated utterance was recorded at 50 sample frames. The frames were then analyzed for the amount of linguapalatal contact. An average of this data was obtained from several repeated utterances. *Conclusions*: The palatometry system can measure dynamic speech using linguapalatal contact during speech. The palatometry system can measure the amount and position of linguapalatal contact both over a period of time as well as at distinct points in time.

This offers information concerning how specific sounds are articulated, which can then be compared and contrasted between different speakers.

Gibbon, F., Hardcastle, W. J., & Suzuki, H. (1991). An electropalatographic study of the /r/, /l/ distinction for Japanese learners of English. *Computer Assisted Language Learning*, *4*, 153-171. Retrieved from http://www.tandfonline.com/

Objective: The purpose of this study is to determine the effect of EPG in helping Japanese learners of English learn the distinction between the /r/ and /l/ phonemes. The distinction between these phonemes is an ideal one to study because both of these sounds are acoustically similar but show distinct differences in their EPG contact patterns. It is essential that the pseudopalate fit exactly and is not loose. Increased saliva is a normal reaction for the first time the pseudopalate is worn. There are varying degrees of linguapalatal contact for English obstruents, approximants, nasals, and lateral /l/. While there is also some contact with close vowels such as /i/ and /I/, there is usually little contact for back and open vowels. If the speaker has had an adaption period, speech was not noticeably altered by wearing the pseudopalate. *Method*: Two Japanese speakers who had been learning English for eight years were issued pseudopalates. Participants were given a perception test with /l/ and /r/ minimal pairs in order to confirm their difficulty perceiving the distinction between the two phonemes. Participants were given four practice sessions over two weeks. *Results*: Neither speaker produced consistent contrasts for /r/ and /l/ before the sessions, but were able to produce typical contact patterns for both sounds after treatment. The speakers also reported that they were better at discriminating between /r/ and /l/ auditorily following treatment. *Conclusion*: EPG was successful in producing a previously difficult-to-perceive contrast in a second language, although further research should be conducted on a larger scale in order to draw broad conclusions.

Gibbon, F., & Katerina, N. (1999). Palatography. In W. Hardcastle & N. Hewlett (Eds.), *Coarticulation: Theory, data and techniques* (pp. 229-245). Cambridge, NY: Cambridge University Press.

Objective: Gibbon and Nicolaidis explain the workings of palatography and data reduction Method. While different EPG systems differ, all palatography includes similar components. Palatography typically includes a pseudopalate which fits over the upper teeth and is molded to the speaker's hard palate. The artificial palates are made of acrylic, polyester, or similar materials. Although the number varies from approximately 48 to 96 electrodes, all pseudopalates contain electrodes (also known as sensors) embedded within the artificial palate. A signal is conducted when the tongue contacts the electrodes. This signal travels via wires out of the mouth out to a processing box. A computer compiles both tongue-palate contact data as well as acoustic data from a microphone. This information is sent to a computer where acoustic and tongue-palate contact data are displayed. The palatometer is often divided into phonetically-relevant regions such as the alveolar and postalveolar regions where tongue-palate contact is likely to occur more frequently. EPG records data for many lingual obstruents, approximants, laterals, and nasals as well as some measurable vowels. There is insufficient contact with the pseudopalate, however, for backed or open vowels. *Conclusion*: Gibbon and Nicolaidis claim that although raw data obtained from EPG can be useful in visualizing articulation, contact patterns need to be quantified in order to maximize EPG usefulness.

Hall, C. (1992). *Modern German Pronunciation*. New York, NY: Manchester University Press. *Objective:* Consequences of poor pronunciation of German may include unintelligibility, misunderstandings, and detrimental social ramifications. Hall posits that good pronunciation cannot be acquired simply via listening (as occurs developing L1) because pronunciation habits of L1 will automatically attempt to transfer to L2 unless consciously avoided. German includes several regional accents that vary widely, to the extent that local southern German accents may not be easily understood by North Germans. Considerable variation occurs not only between the northern and southern portions within Germany, but variation is also encouraged because German is spoken in different countries, including Austria and Switzerland. Because German has more than one distinct center and standard, it is referred to by scholars as a *plucentric* language. The variation within the German language is also affected by a history of political fragmentation. In order to facilitate communication, the standardization of German began at the end of the Middle Ages and continued for many years. In 1898, Profesor Theodor Siebs organized a set of guidelines to standardize German pronunciation for the theater. These guidelines did not come from one single regional dialect. Rather, they were a compromise between several dialects, although these guidelines aligned more closely with Northern German due to its stature of being known as the *purest* form of German amongst some social circles. This new *standard* German was also the closest to written German, which had already been fairly standardized previously. Essentially, this set of guidelines provided pronunciation standards for written High German. This standard German, often referred to as *Hochlautung, Standardlautung,* or *Hochdeutsch*. Due to criticism, Southern Germany as well as Austria and Switzerland never accepted this standard form of German; however current pronunciation dictionaries since that time retain one element of Sieb's guidelines: pronunciation is a compromise between regional dialects, with heavy influence of North German speech. It is this Hochdeutsch that is taught to L2 learners of German and is regarded by Germans (even those who do not speak it) as the *best* pronunciation. Additionally, Hall notes that *Hochdeutsch* is close to the pronunciation of the educated German population. Hall notes that English learners often demonstrate difficulty acquiring the [ç] and [x] sounds. Of note, speakers in Switzerland and the far south-west portions of German do not use the [ç] sound, instead producing only [x] for all linguistic environments. The sound /ʃ/ does not usually present significant problems of English speakers; however, some English speakers do not demonstrate sufficient lip rounding for these sounds.

Hardcastle, W., & Edwards, S. (1992). EPG-based description of apraxic speech errors. In R. D. Kent (Ed.), *Intelligibility in speech disorders: Theory, measurement, and management* (pp. 287-328). Philadelphia, PA: John Benjamins Publishing.

Objective: Hardcastle and Edwards describe apraxic speech errors using EPG data. Apraxia may be difficult to diagnose because apraxia shares symptoms similar to other speech disorders. Differences such as the regularity of the substitution and the distance from the target phoneme can indicate whether the substitution may have a motor origin (as in apraxia) or a linguistic origin (as in aphasia); however, these differences can be difficult to detect auditory-perceptually or acoustically. Using EPG to assess specific substitutions may assist in diagnosing apraxia (as opposed to aphasia or similar disorders). *Method*: The study includes four male participants in their 60s who had all been diagnosed with aphasia and apraxia due to left-hemisphere CVAs. According to a speech therapist, the aphasia had resolved, but the participants still exhibited apraxia. EPG data were compared to a control group of four typical adult speakers. Speakers read a word list with a variety of speech sounds and vowels in different articulatory contexts. Each word was produced immediately following a definite or indefinite article. The rationale for saying the article was to "prevent coarticulatory effects spreading from one word to the next and to provide a consistent baseline for EPG records for the word initial consonants" (p. 300). Participants also completed a connected speech task in order to elicit errors to analyze with EPG. *Results*: Despite variability regarding the type of speech errors made, in general, the apraxic subjects exhibited greater temporal and spatial variability than the typical speakers. This was particularly true in complex consonant clusters such as /tk/, /kt/, and /kl/. Apraxic subjects also showed a larger number of misdirected gestures (giving the subjective impression of *sound searching* or *groping*) that is characteristic of apraxia. *Conclusion*: Authors were able to quantify characteristic errors of apraxic speech using EPG. Some errors were also determined auditory-perceptually, whereas other errors (such as substituted sounds in the final position of words) were only noticed on the EPG data and not auditory-perceptually. EPG data offer information about one aspect of intelligibility—tongue to palate contact, which contributes greatly to the speech disorder apraxia. Although some speech elements can be detected auditory-perceptually, EPG may provide additional feedback that would otherwise remain undetected by the ear.

Kuruvilla, M. S., Murdoch, B. E., & Goozee, J. V. (2008). Electropalatographic (EPG) assessment of tongue-to-palate contacts in dysarthric speakers following TBI. *Clinical Linguistics and Phonetics, 22*, 703-725. doi: 10.1080/02699200802176378

Objective: Kuruvilla, Murdoch, and Goozee compared post-TBI dysarthric speakers to typical speakers of matched age and gender using both spatial and timing measures from EPG data. *Method*: There were 11 dysarthric participants who were compared to 10 participants with typical speaking abilities. All participants produced repeated sentences and syllables at normal speaking rates and loudness levels with an artificial palate in place to record lingua-palatal contact. The repeated syllables *ta*, *sa*, *sha*, *la*, and *na* were analyzed. Initially, researchers intended to also include *ka* in their study but most participants failed to exhibit sufficient tongue-palate contact in order to analyze this syllable. Each assessment took approximately 40 minutes to complete. *Results*: Analysis of the EPG data showed that compared to typical speakers, the post-TBI dysarthric speakers exhibited prolonged consonant production (attributed to slower articulatory movements, less motor speech control, and decreased motor coordination). The EPG data also indicated that there were also significant spatial differences between the typical and dysarthric groups. *Conclusion*: Both spatial and timing differences cause a perceptual difference between typical and dysarthric speakers.

MacCarthy, P. (1975). *The pronunciation of German*. London, England: Oxford University Press.

Objective: Native English speakers demonstrate difficulty learning /ç/ and /x/ because there are no similar sounds in English. Initial attempts at production often include /ʃ/ for /ç/ and /k/ for /x/. With practice, approximate production can be achieved by L2 learners; however, their productions "nearly always [leave] something to be desired: their mistake normally consists of failing to make sufficient difference between the two main types of CH-sound, i.e. they fail to make the front articulation *front enough* and to make the back articulation *back enough*" (p. 87).

Mangold, M. (Ed.). (2000). *Duden, Aussprachewoerterbuch* [The Pronunciation Dictionary]. Mannheim, Germany: Bibliographisches Institut & F. A. Brockhaus AG.

Objective: German pronunciation guide.

McAuliffe, M., Ward, E., & Murdoch, B. (2006). Speech production in Parkinson's disease - I. An electropalatographic investigation of tongue-palate contact patterns. *Clinical Linguistics and Phonetics, 20*, 1-18. doi: 10.1080/02699200400001044

Objective: It has been suggested that people suffering from Parkinson's disease (PD) often use less precise consonant precision than typical speakers due to reduced lingual movement known as articulatory undershoot. The researchers sought to determine whether or not this claim is supported by EPG data. *Method*: Two listeners (speech-language pathologists) rated speaker recordings as including or not including articulatory undershoot. These perceptual data were then compared to quantifiable EPG data. Researchers measured articulatory undershoot of different speakers by comparing tongue-palate contact using EPG data. Nine participants with PD were compared against both an aged (57-83 years) and a young (23-31 years) control group of seven and eight speakers, respectively, in order to account for any natural effects of aging on lingual movement. With the palatometer in place, participants read aloud the phrase *I saw a* _____ *today*. Researchers analyzed consonants /l/, /s/, and/t/ in the initial position of words in two different vowel contexts. *Results*: While listeners (two speech pathologists) were able to distinguish the group with PD due to perceived articulatory undershoot, the EPG data did not indicate that articulatory undershoot of consonants analyzed occurred in speakers with PD.

Conclusion: The authors suggest that perceived articulatory undershoot may be caused not by decreased tongue movement, but by decreased pressure of tongue-palate contact.

McLaughlin, B. (2012). *Second-language acquisition in childhood.* New York, NY: Psychology Press.

Objective: This text describes four general language learning approaches that were used during the 20th century. Two approaches, the audio-lingual approach and the direct method, are still widely used today. The direct method focuses on listening, practice, and repetition as well as emphasizing phonetics in order to approximate native pronunciation. Similarly, the audio-lingual approach is a behavioral approach targeting phonological accuracy through repetitive drills and audio-feedback. An example of the audio-lingual approach shows a teacher saying a sentence that the students repeat. The teacher then modifies one word in the sentence and the students repeat the sentence again. Overall, this approach was intended to approximate the manner in which first languages are acquired—through hearing and speaking instead of translating and memorizing grammar rules. *Conclusion*: Both the audio-lingual approach and the direct method for learning language include elements of approximating native speaking patterns through drills and are widely used today.

Munro, M. J. (1992). Foreign accent and speech intelligibility. In M. J. Munro (Ed.), *Phonology and Second Language Acquisition* (pp. 194-218). Philadelphia, PA: John Benjamins Publishing.

Objective: Foreign accents are evidence that knowledge of sounds within a first language affect sounds with a second language. Accents may have an effect on how a speaker is perceived by others, including diminished acceptability, negative evaluation, and diminished intelligibility. An accent will not necessarily affect intelligibility in all cases, however. *Conclusion*: Understanding that foreign accent can affect speech intelligibility provides motivation to treat misarticulated sounds within a second language.

Prowe, G., Schneider, J., Morris, R., Sawers, R., Rollin, N., & Vennebusch, E. (2007). *The Oxford new German dictionary*. New York, NY: The Berkley Publishing Group.

Objective: A German-English Dictionary used to identify German words.

Sanders, M. C. (2007). *Inter- and intra-speaker variability: A palatometric study.* (Master's thesis, Brigham Young University). Retrieved from http://etd.byu.edu/1201/

Objective: Sanders attempted to assess the feasibility of developing a database of standardized palatometric articulation files by assessing inter- and intraspeaker variability. *Method*: Twenty speakers of the Standard English dialect were fitted with pseudopalates. Participants verbalized vowel consonant vowel (VCV) nonsense words with a schwa in the initial position, 15 palatal consonants, and three corner vowels /ɑ/, /i/, and /u/. Data were gathered at the maximal contact frame, which is the point where the highest number of electrodes was activated. From the data a variability index was created in order to examine inter- and intraspeaker variability. *Results*: Consonants coarticulated with /ɑ/ showed significantly less variability than consonants coarticulated with /u/. Speakers who showed more variability in one vowel context generally also tended to exhibit a higher level of variability in other vowel contexts. *Conclusion*: There is significant variability within and between speakers with normal articulation. When treating disordered articulation using EPG, some variability is to be expected and is still considered within normal range.

Schmidt, A. M. (1998). Electropalatography treatment for training Thai speakers of English. *Clinical Linguistics& Phonetics*, *12*, 389-403. Retrieved from http://www.icpla.org/

Objective: The aim of this study was to teach native speakers of Thai three English contrasts using EPG. Adult L2 learners often use sounds from their first language to learn to speak a new language. *Method*: Three adult native speakers of Thai participated in this study. All participants passed bilateral hearing screenings. Participants were instructed to wear a practice pseudopalate to desensitize themselves to the pseudopalates two weeks prior to data collection. Participants were recorded saying consonant vowel (CV), VCV, and VC nonsense syllables in English, including the following English sounds: /t, d, k, g, ʧ, l, n, s, z, and ʃ/. The three contrasts chosen for EPG treatment were chosen because at least one of the two sounds in each of the three pairs of contrasts had adequate linguapalatal contact visible through EPG. Participants were seen for

45-minute sessions biweekly for 24 weeks. *Results*: All participants were able to successfully alter articulators in order to correctly produce the target contrasts. Subjects reported that the EPG visual feedback was helpful, particularly in the early stages of therapy. *Conclusion*: While all participants were able to learn accurate, novel motor patterns using EPG, additional articulatory practice was necessary in order to generalize these new motor patterns, implying that simply teaching one static sound is insufficient practice. Opportunities to practice the new sound and establish coarticulatory motor patterns were necessary for generalization. Interestingly, participants were able to acquire novel motor patterns more quickly than they were able to modify old, inaccurate productions of sounds.

Southwood, M. H., Dagenais, P. A., Sutphin, S. M., & Garcia, J. M. (1997). Coarticulation in apraxia of speech: A perceptual, acoustic, and electropalatographic study. *Clinical Linguistics & Phonetics, 11*, 179-203. Retrieved from http://www.icpla.org/

Objective: Researchers used EPG in order to determine whether or not apraxic speakers' coarticulation was typical or not. *Method*: One apraxic speaker was compared to one typical speaker using acoustic, perceptual, and EPG analyses. Vowels /i/, /ɑ/, and /u/ were analyzed in the repeated phrase *Say* ___ *again*. The vowels were *gated* leaving only 0, 1/4, or 1/2 of the vowel to be heard. Listeners then chose the vowel they heard from a list of several different vowels. *Results*: Listeners identified fewer vowels correctly in apraxic speech. For both the apraxic and typical speaker, /i/ was more often correctly identified than /u/. In addition, accurate vowel identification was higher in slow speech than in rapid speech. The initial consonant influenced listener perception of the vowel following the consonant. EPG patterns of apraxic speakers varied and were often inappropriate for the target vowel. *Conclusion*: Despite previous contradictory perceptual and acoustic data on coarticulation in apraxia, EPG analyses assisted in supporting the research finding that apraxic speakers do not coarticulate typically. The combined data suggest that the apraxic speaker's coarticulation was delayed and distorted regardless of speech rate.

Strange, W., & Shafer, V. L. (1992). Speech perception in second language learners: The re-education of selective perception. In J. G. Hansen Edwards & M. L. Zampini (Eds.), *Phonology and Second Language Acquisition* (pp. 153-191). Philadelphia, PA: John Benjamins Publishing.

Objective: Most L2 learners produce some sounds within L2 in a markedly different manner from native speakers, the result of which is an accent. These L2 age learners not only struggle with production, but also perception of second-language sounds. Sounds that are "phonologically distinctive in the L2, but not in the learners' native language are often not correctly recognized and categorized, leading to difficulties in comprehension of spoken L2 utterances" (p. 153). The author posits that the underlying sound production problem is caused by perception difficulties that L2 learners experience. While infants and young children can perceive contrasts between sounds, similar studies of adult perception have shown that non-native contrasts are very difficult to perceive for adults. Even after years of exposure to L2, many L2 learners remain resistant to changes in their perceptive abilities. A well-documented example of this is shown by the difficulties that native Japanese speakers experience when learning the contrast between /r/ and /l/ in English. Best's *Perceptual Assimilation Model* provides one possible explanation for the difficulty L2 learners have distinguishing between non-native sounds. According to this model, native sounds are assigned distinct categories within a metaphoric phonological space. When non-native sounds are heard, L2 learners perceptually assimilate sounds into existing L1 sound categories based on their similarity to L1 sounds. Sounds that are completely different from any existing L1 category are heard as *uncategorizable* speech sounds and sounds that are not recognized as speech sounds at all (e.g., Zulu click consonants) are known as *unassimilable* speech sounds.

Suzuki, N. (1989). Clinical applications of EPG to Japanese cleft palate and glossectomy patients. *Clinical Linguistics and Phonetics, 3*, 127-136. Retrieved from http://www.icpla.org/

Objective: EPG was used to study articulatory movements in cleft palate and glossectomy cases. *Method*: Suzuki studied 25 cleft palate and 3 glossectomy cases producing Japanese VCV syllables. *Results*: For those with cleft palates, three types of misarticulation were confirmed: Japanese palatalized articulation, Japanese lateral misarticulation, and Japanese nasopharyngeal

articulation. This study also found that those with glossectomies experienced palato-lingual contact limited to a definite region of the palate for a variety of different consonants, although intelligibility varied depending on the manner of articulation. *Conclusion*: Historically, EPG had been a useful tool for diagnosing and treating cleft lip and palate, speech disorders after operation on tumours/cysts, mandibular prognathism and open-bite, ankyloglossia, congenital velopharyngeal incompetence, motor speech disorders, and functional articulation disorders. This study confirms that EPG is a useful diagnostic tool for assessing articulation disorders in cleft palate and glossectomy patients.

Weiss, R., & Wängler, H. (1985). *German pronunciation: A phonetics manual*. Bellingham, WA.: Western Washington University Press.

Objective: Second languages are almost completely learned through the lense of L1. Second language learners automatically grasp for similarities between L1 and L2 sounds, assuming equivalents between the two languages. In this regard, L1 interferes, but is also a necessary pathway to acquiring L2. No two languages have identical sound systems. Some sounds may be similar, but because they come from different systems, they are consequently not truly the *same* sounds. L2 learners must learn new patterns of muscular activity in order to produce a new set of speech sounds. Adult hearing as well as speech becomes highly selective and one-sided. Adults can no longer hear foreign sounds and have no "auditory framework for them. The foreign language student is thus in the unenviable position of not only being physiologically handicapped to produce the foreign sounds, but whose hearing is impaired as well. He cannot trust his ears to serve as an effective self-monitor when it comes to foreign sounds" (p. 8). The authors note the "clear association between production and perception" (p. 95) as well as the importance of building both skills simultaneously in L2 learners. The authors also note difficulty for native English speakers learning some sounds because the English language has similar sounds that will interfere with L2 sounds. Additionally, native English speakers learning German will likely experience difficulty learning new sounds dissimilar to L1 sounds, requiring L2 learners more than slight adjustments for current articulatory patterns. There are two consonant sounds in German that are completely new sound for American English speakers—[ç] and [x]. These sounds, along with the German r, contribute to the distinctly *gutteral* sound of the German language. In standard German (*Hochsprache*), these two sounds are allophonic variants of each other and are entirely dependent upon the linguistic context in which they are found. The sound [ç] occurs after front vowels and in the initial position of words, whereas [x] is used in all other contexts. Additionally, native English speakers often confuse the articulation of [ç] and /ʃ/.

Appendix B - 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 have experience speaking a second language and no known history of a speech, language or hearing problems.

Procedures
Participation in this study will involve approximately 3 hours. You will be asked to visit a local licensed dental/orthodontic professional to have a dental impression taken of your upper teeth, which will be created at no cost to yourself. 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 engage in everyday conversation and read a series of words and sentences, while having your speech recorded. The recording will take place in the John Taylor building located on the Brigham Young University campus. 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. In the event that the EPG pseudopalate is loose-fitting, a small amount of over-the-counter denture adhesive may be placed on the roof of your mouth to secure the sensor. You will be provided a toothbrush to remove the adhesive after removing the sensor. Your speech may sound different with the sensor in place and it may take a period of time for you to become accustom 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.

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 $15 per hour for your participation in this study, involving approximately 3 hours of your time.

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: ___________________________________

BYU	Institutional Review Board	
	6-24-14 Approved	8-14-15 Expires