The Distinction Between Lingua-Palatal Contact Patterns of English Light and Dark [ɫ]: A Precursor to Using Electropalatography in Second Language Instruction

Kallie Lynne Chaves
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The Distinction Between Lingua-Palatal Contact Patterns of English Light and Dark [l]:
A Precursor to Using Electropalatography in Second Language Instruction

Kallie Lynne Chaves

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

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ABSTRACT

The Distinction Between Lingua-Palatal Contact Patterns of English Light and Dark [ɫ]:
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Master of Science

Electropalatography (EPG) is a system designed to provide visual feedback of lingua-
apalatal contact via electrodes and computer software in real-time. Traditionally, EPG technology has been effective in the treatment of both developmental and acquired speech disorders. Little research, however, has been done to show the effectiveness of EPG feedback in second language instruction and foreign accent reduction. The present thesis is part of a larger project examining the utility of EPG technology as a potential tool for teaching English speakers learning German as a second language (L2). A common error that English speakers make in German pronunciation is the incorrect use of dark [ɫ], when only light [l] should be present. This study seeks to identify the individual contact patterns of light and dark [ɫ] in English to determine if the differences in lingua-palatal contact patterns warrant further testing of EPG feedback in L2 instruction of German. Productions of light and dark [l] were collected from twelve native English speakers in phrases, words, and nonsense words. Regional activation percentages, center of gravity measures, and visual lingua-palatal contact maps indicated distinct differences between the participants light and dark [l] productions. These differences typically did not vary significantly across vowel type, but did change as a function of the linguistic task. The findings of this study indicate that additional research into the efficacy of EPG visual feedback with L2 German learners is warranted. Thus, EPG may be an effective tool in teaching the allophonic sound contrast between light and dark [l] for L2 learners.

Keywords: electropalatography, EPG, second language instruction, German, German teaching
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# TABLE OF CONTENTS

ABSTRACT .................................................................................................................................... ii

ACKNOWLEDGMENTS ............................................................................................................. iii

TABLE OF CONTENTS ............................................................................................................... iv

LIST OF TABLES ......................................................................................................................... vi

LIST OF FIGURES ...................................................................................................................... vii

DESCRIPTION OF THESIS STRUCTURE ............................................................................... viii

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

Method .............................................................................................................................................8

Participants ...................................................................................................................................8

Apparatus .....................................................................................................................................8

Stimuli ........................................................................................................................................10

Procedures ..................................................................................................................................10

Data Analysis .............................................................................................................................11

Statistical Analyses ....................................................................................................................11

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

Anterior Activation Region ........................................................................................................13

Medial Activation Region ...........................................................................................................18

Posterior Activation Region .......................................................................................................19

Center of Gravity .......................................................................................................................19

Lingua-Palatal Contact Maps .....................................................................................................21

Discussion ......................................................................................................................................27

References ......................................................................................................................................31
LIST OF TABLES

Table 1  Dependent Measures for the Nonsense Word Elicitation Condition .........................15

Table 2  Dependent Measures for the Word Elicitation Condition ........................................16

Table 3  Dependent Measures for the Phrase Elicitation Condition ......................................17
LIST OF FIGURES

Figure 1. EPG sensor, microprocessor I/O device, PC representation of patterns ..........9
Figure 2. Areas of regional activation ...........................................................................12
Figure 3. Mean percent anterior activation in nonsense words across word position and vowel context ........................................................................................................14
Figure 4. Mean percent anterior activation in words across word position and vowel context .14
Figure 5. Mean percent anterior activation in phrases across word and vowel context ......18
Figure 6. Mean percent medial activation across task type and vowel context ............20
Figure 7. Mean percent medial activation by word position and vowel context.............20
Figure 8. Mean percent posterior activation across task type and word position ..........21
Figure 9. Average lingua-palatal contact in the high-front vowel context ..................22
Figure 10. Average lingua-palatal contact in the low-back vowel context .................22
Figure 11. Average lingua-palatal contact in the high-back vowel context ..................23
Figure 12. Lingua-palatal contact pattern for light [l] in nonsense words, high-front vowel .....24
Figure 13. Lingua-palatal contact pattern for dark [ɫ] in nonsense words, high-front vowel ......24
Figure 14. Lingua-palatal contact pattern for light [l] in words, high-front vowel .............25
Figure 15. Lingua-palatal contact pattern for dark [ɫ] in words, high-front vowel ..........25
Figure 16. Lingua-palatal contact pattern for light [l] in phrases, high-front vowel ..........26
Figure 17. Lingua-palatal contact pattern for dark [l] in phrases, high-front vowel ..........26
DESCRIPTION OF THESIS STRUCTURE

This thesis, *The Distinction between Lingua-Palatal Contact Patterns of English Light and Dark [ɫ]: A Precursor to Using Electropalatography in Second Language Instruction*, is part of a larger project aimed at explaining the role of electropalatography as it relates to second language acquisition. The body of this thesis is written as a manuscript suitable for submission to a peer-reviewed journal in speech-language pathology. Portions of this thesis may be submitted for publication elsewhere, with the thesis author being listed as one of multiple contributing coauthors. An annotated bibliography is presented in Appendix A and the informed consent document is included in Appendix B. A stimuli list is given in Appendix C and a compilation of all contact maps is presented in Appendix D.
Introduction

Electropalatography (EPG) is a system used to detect lingua-palatal contact during speech and provide visual biofeedback. The palatometer device consists of a thin pseudopalate that is custom-made for the subject, similar to an orthodontic retainer. The pseudopalate is covered with 124 gold-plated electrodes arranged from the alveolar ridge to behind the back molars. A wire extends from the front of the pseudopalate, out of the mouth, to a processing box. The contact pattern data are collected and converted from an analog to a digital signal, and the software then displays the contact patterns on a screen (Fletcher, McCutcheon, & Wolf, 1975). The EPG system gives dynamic visual feedback in real-time, which allows the speaker to monitor lingua-palatal contact and match their production of sounds to the model contact pattern (Dent, Gibbon, & Hardcastle, 1995).

Palatometry has been used successfully in the treatment of developmental speech disorders (Carter & Edwards, 2004; Gibbon & Paterson, 2006). In one study, EPG-based treatment was successful in remediation of misarticulated [t], [d], [s], and [ʃ] for 18 of 23 subjects (Dent et al., 1995). In a different study, EPG treatment was successful in remediating [s], [ʃ], [tʃ], and [l] in children with impaired articulation and/or phonology (Dagenais, 1995). Consequently, EPG can be used to help children acquire the sounds of their native language, especially if a child does not respond well to traditional articulation therapy. Dynamic palatometry can assist children with speech difficulties, whether or not the cause of these problems is known (Carter & Edwards, 2004).

Electropalatography may also be effective at helping to improve sound production for those with acquired speech disorders. This technology has been used to treat those with speech difficulties as a result of cleft palate (Gibbon et al., 2001), apraxia of speech (Bartle-Meyer,
Goozée, & Murdoch, 2009; Hardcastle & Edwards, 1992; Southwood, Dagenais, Sutphin, & Garcia, 1996), Parkinson’s disease (McAuliffe, Ward, & Murdoch, 2006), and dysarthria caused by traumatic brain injury (Kuruvilla, Murdoch, & Goozée, 2008). As such, electropalatography provides visual biofeedback support for these populations and allows them to re-learn proper sound production.

Similar to those with acquired and developmental speech disorders, learners of a second language (L2) often struggle to correctly produce the phonemes of the language they are learning. This is especially true if the phonemic and allophonic patterns of the L2 differ from the primary language (Flege, 1995). There are several theories which attempt to explain the reason for L2 phoneme production difficulties. The sound articulation patterns of the native language may cause interference to the individual’s articulation of sounds in the L2. A common example of this is with Japanese speakers learning English. In Japanese, there is no phonemic contrast between [l] and [r] as exists in English. Japanese speakers may not readily perceive this distinction in English and transfer the knowledge from their L1 to the pronunciation of L2 sounds. This may cause them to not differentiate between [l] and [r] sounds in their speech production and/or perception (Gibbon, Hardcastle, & Suzuki, 1991).

There are two prominent theories about the source of this problem. According to the Perceptual Assimilation Model, also known as PAM, as infants grow and develop, they start to learn the sounds of their native language (Best, 1994). For the first six months of life, infants are capable of distinguishing non-native phonemes through acoustic and phonetic features. However, the child shifts in development at around 8-10 months of age, when he or she begins to distinguish sounds based on perception of contrasts in the L1 and tunes out sounds that are not relevant to the native language. Therefore, when an L2 learner hears non-native sounds, they will
perceive the similarities between that phoneme’s articulatory features and those of a native phoneme. The unfamiliar phoneme is then assimilated into the native phoneme category that is most similar. The individual may perceive distinctions between the phonemes but identify the sound as a variant of the most similar native sound. This may be one reason for difficulties in learning the sounds of an L2, as the L2 learner may not be able to perceive the phonological differences between non-native sounds and L1 sounds. The degree to which language learners have difficulty assimilating new speech sounds varies depending on the relationship between the L1 and L2.

In the Speech Learning Model, or the SLM, Flege (1995) suggests that many L2 production errors are due to perceptual inaccuracies, similar to the PAM. The SLM differs from the PAM in that it explains these perceptual inaccuracies in terms of *perceptual equivalence* instead of in terms of assimilation. According to Flege, language learners perceptually equate L2 sounds with the L1 sound category that is most similar. The L1 and L2 share some phonemes that are the same. On the other hand, listeners perceive L2 sounds that are phonetically distant from a native sound as being “new” sounds. However, if an L2 sound is perceptually close to a native sound, the L2 sound is perceived as being “similar,” though not identical, to the native sound. Though learning a “new” sound may be more difficult initially, the “similar but different” sounds lead to difficulties in production and perception that persist longer. A foreign accent tends to occur when there is less perceptual distinction between sounds (Flege, 1995). Therefore, an important part of accent reduction therapy is helping L2 learners establish phonetic distinctions between similar phonemes.

The SLM theorizes that L2 learners will eventually establish new sound categories for those L2 sounds which are perceptually different and considered “new” compared to L1 sound
categories. However, because the speaker is not required to establish a new sound category for perceptually similar L2 sounds, they will continue to encounter difficulties and produce these similar sounds with an accent (Flege, Munro, & Mackay, 1995).

Another difficulty L2 learners face in correcting production errors is knowing how to physically modify their articulation to produce the correct sound. It is difficult to visualize the articulation of lingua-palatal and posteriorly produced sounds from outside the oral cavity. It is especially difficult to observe tongue movements during speech. These factors make it difficult for teachers or therapists to give salient models of articulation, instead giving students verbal explanations that may be vague or confusing. These barriers pose a challenge to both the learner and teachers, who in the past were forced to rely on verbal instruction, feedback, and perceptual features alone to correct L2 learners’ articulation errors (Gibbon et al., 1991).

In recent years, several studies have examined the application of EPG biofeedback for instruction of learners of a second language (Bright, 1999; Gibbon, et al., 1991, Isaacson, 2015; Schmidt, 1998). In Bright’s study, native Spanish-speaking participants demonstrated a significant reduction in foreign accent in English after participating in EPG therapy. Gibbon et al. (1991) studied EPG therapy with Japanese speakers learning English. The results showed that EPG therapy had a positive effect not only on the participants’ foreign accents, but also their perceptual abilities to distinguish the [r] and [l] phonemes. The therapy also proved useful in foreign accent reduction for native speakers of Thai learning English. Schmidt (1998) found that using EPG feedback to teach distinctions between the English phonemes [s]-[ʃ], [t]-[θ], and [l]-[i] to Thai speakers helped reduce foreign accent. All three of the participants improved articulation of English sounds and reported improvement in natural conversational settings as well (Schmidt,
Schmidt concluded that EPG therapy is a helpful tool for teaching distinctions between lingua-palatal consonants to Thai speakers learning English.

Therefore, EPG therapy may be a useful tool to teach correct phoneme production as well as to increase awareness of phonemic distinctions for L2 learners. This increased awareness may help prevent or overcome interference, in which the speaker incorrectly uses knowledge from the L1 to guide their production of L2 phonemes (Gibbon et al., 1991). It is also possible for L2 learners to achieve near-native production of L2 phonemic contrasts while still having difficulty perceiving these contrasts correctly (Smith, 2001). This shows that improvements in production after EPG therapy may occur independent of improvements in perception in some L2 learners.

Despite promising results of EPG therapy in Spanish, Japanese, and Thai, there is still insufficient research to support the use of EPG feedback in L2 instruction for other languages. Specifically, for the current project, more research is needed to examine the use of EPG therapy in teaching German sounds to native English speakers. Many English speakers have difficulty producing German phonemes. A significant difference between English pronunciation and German is that English uses three allophonic variations of [l], while German only uses two (the syllabic [l] exists in both languages). Besides syllabic [l], the other English [l] variations are commonly known as “dark” [ɫ] and “light” [l]. In the literature, light [l] is also sometimes referred to as “clear” [l]. The dark [l] is used in English words with word-final [l], like “pull” and “fill,” while the light [l] is found in words with word-initial [l], like “leap” and “left.” While English uses both the light and dark [l], German pronunciation only uses the light [l] (Recasens, Pallares, & Fontdevila, 1998). This difference can lead to interference errors when native English speakers are learning German as an L2, which dramatically increases the degree of foreign accent.
Several EPG studies have been conducted to examine the differences between light and dark [l] production. Narayan, Byrd, & Kaun (1999) used static palatography to distinguish the characteristics of liquids in the Tamil language. Static palatography is a low-tech version of palatography that uses carbon powder on the tongue to get a rough idea of the tongue contact patterns for different sounds. The success of this method in distinguishing liquids suggests that electropalatography may also be useful in detecting subtle differences between the light and dark [l] in English.

In another study, the ability of EPG to detect differences between light and dark [l] was compared to its ability to detect differences between bunched and retroflexed [r]. The liquid consonants [l] and [r] are similar in articulation and tongue placement. However, the variations of light and dark [l] were proven easier to perceive than bunched and retroflex [r] (Mielke, Baker, & Archangeli, 2016). The differences between light and dark [l] are simpler than those of bunched and retroflex [r]. Mielke et al. (2016) found that these differences between the allophonic variations of [l] are often shared by speech communities, while the variations of [r] are more idiosyncratic. The differences in production of light and dark [l] have also been shown to vary depending on dialect and language (Recasens, 2004). For instance, North American speakers tend to use both allophones, while speakers of Scot’s English tend to use dark [l]. The use of light and dark [l] in English may vary depending on the speaker’s dialect.

There are some distinguishing features between light and dark [l] that are already known. In a study by Narayan, Alwan (1997), four American native English speakers were tested using electropalatography and MRI images. These data were collected and analyzed while the participants produced both the light and dark allophonic variations of [l]. While results showed that individual participants use different tongue shapes for both light and dark [l], there were
some common characteristics in their productions of each allophone. All subjects had lingual contact along the midsagittal line from behind front incisors to the alveolar region. Light [l] had more lateral contact than dark [ɫ]. This study showed that lateral and anterior tongue contact is an important feature to note in the analysis of light and dark [l] production. Narayanan and Alwan’s study also showed that there was no significant difference between sustained [l] productions and those that occurred in natural contexts.

It is also important to understand the interaction between vowel context and [l] production. Vowel context has been shown to change the way [l] is produced (Recasens et al., 1998). The vocalized variant of dark [l] in some British dialects, for example, has been shown to occur more frequently with front vowels than with back vowels (Hardcastle & Barry, 1989). Recasens found that the distinction between light and dark [l] is best contrasted in the vowel context of [i] or [a] (Recasens, 2012). It is also significant to note that the syllabic [l] (as in the words “bottle,” “people,” and “tunnel”) can be produced both in the light or dark manner. The syllabic [l] occurs when the consonant forms an entire syllable on its own, without any vowels surrounding it. It is traditionally believed that the syllabic [l] is dark, however, this was shown to not always be the case, with syllabic [l] showing just as much variation between light and dark [l] as the nonsyllabic [l] (Barry, 2000).

The current study seeks to determine if the contact patterns for light and dark [l] are significantly different in terms of articulation. In particular, this study will identify the lingual-palatal contact patterns of light and dark [l] in English using EPG. This project will investigate several questions, including (a) Are the contact patterns of light and dark [l] (as determined by initial vs. final word position) visually distinct, (b) Does vowel context impact differences in contact patterns, and (c) Does elicitation context impact differences in contact patterns? This will
establish a base of knowledge to determine the visual differences between the two allophonic variations in English. The ultimate purpose of the study is to determine if these visual differences are significant enough to be taught using EPG feedback. If the contact patterns prove to be significantly different, further studies may be done to determine if EPG therapy can be used to teach L2 learners the difference between light and dark [ɫ]. For example, this type of EPG instruction could improve phonemic awareness and intelligibility of English speakers learning German as an L2, who often incorrectly use the dark [ɫ] when learning German by applying English allophonic rules.

**Method**

This study is part of a larger investigation examining the efficacy of implementing EPG biofeedback for L2 learning, focusing on whether contact patterns for light and dark [ɫ] differ adequately to assist in overcoming transfer of English allophonic rules to German.

**Participants**

Twelve adult male and female native English speakers (1 male, 11 female) who had no previous history of speech or language disorders participated in this study. The participants had no history of atypical development of their dentition, palate, or other anatomical structures of the vocal tract. Each participant read and signed an informed consent document approved by the Brigham Young University Institutional Review Board for Human Subjects Research prior to the start of data collection. The participants were compensated $30 for their participation in the study.

**Apparatus**

Before data collection began, participants were contacted via email to coordinate and schedule appointments at a local dental office to acquire a dental impression of their upper teeth
and palate. Participants were compensated $15 for this appointment. Each participant’s impression was collected from the dental office and delivered to SmartPalate International to create a customized EPG device. SmartPalate International created a relatively thin (2 mm) EPG sensor from the dental impression. The sensor appeared similar to an orthodontic retainer, in that it was customized to fit the unique shape of an individual’s teeth, extending from the alveolar ridge to the back molars (Fletcher et al., 1975). Each sensor contained 124 gold-plated electrodes which were arranged in a grid pattern across the surface of the pseudopalate, shown in Figure 1. Electrode data were processed by a microprocessor I/O device worn around the user’s neck, which then transferred contact pattern data via a USB cord to a PC computer. The instructor and L2 learner are able to observe their lingua-palatal contact patterns on a computer screen in real time.

Figure 1. EPG sensor, microprocessor I/O device, PC representation of patterns (www.completespeech.com).
**Stimuli**

The participants’ productions of the English light and dark [l] allophones were evaluated through a set of nonsense words in citation form, real words in citation form, and real words within phrases. The [l] consonant was embedded in a set of nonsense words across three vowel contexts ([i], [a], and [u]) in the initial and final word position. A list of real words was used, in both citation form and within phrases, which included the [l] consonant across the same three vowel contexts in the initial and final positions (e.g., – leap, loop, lock, peel, pool, ball). All words including [l] were in the single syllable consonant-vowel-consonant format. The nonsense words, real words, and phrases were presented to each subject via a set of five randomized lists, which were presented in random order. Participants were given a short break during between the recording sessions.

**Procedures**

Before collecting the data, participants were given time to insert the customized sensor and ensure proper fit and comfort. After correct fit was confirmed, the EPG processor was turned on and all electrodes were tested for functionality. Prior to data collection, participants were engaged in 15 minutes of conversation to allow time for motor adaptation to wearing the device. No data were collected during this time period.

After allowing for adaptation to the presence of the device in the mouth, the subjects participated in data collection for 45 minutes. During this time, they were asked to read nonsense words, real words, and phrases. The lingua-palatal contact data were then transferred to a PC and saved as a *.csv* file. The participants’ speech was recorded with an internal microphone within the EPG data processing unit (low-quality waveform) and an external high-quality microphone.
(high-quality waveform), and digitally saved as a .wav file on a PC hard drive. Participants were compensated $15 for the recording session.

**Data Analysis**

The original audio files of the speakers were spliced and then saved as smaller files based on the stimulus type and linguistic context. The onset and offset time points for each production of the target sound were identified and recorded in a text file to the nearest millisecond. If a participant did not produce the correct word or phrase, or if the onset and offset could not be identified, the production data were not included in the analysis. The time points recorded in a text file were then entered in a custom-designed MATLAB program that calculated the geometric shape of the lingua-palatal contact through a series of indices, the degree of activation in the anterior, medial, or posterior regions of the palate, and the lateral symmetry of the contact. A static measure of the contact pattern was extracted at 25% of total segment duration for word-initial targets and 75% of total duration for word-final. A series of two-dimensional contact-pattern maps were created for each of the target sounds using the activation level of each EPG electrode across a series of 20 ms time windows. The activation level of each electrode across all the participants was used to calculate a percentage of activation in the anterior, medial, and posterior regions of the palate and a center of gravity measure for the contact pattern (see Figure 2). The data from the light and dark [l] productions were then compared to determine if the EPG sensor could detect significant contact pattern differences between the two allophones.

**Statistical Analyses**

Analysis of the data collected in this study involved a repeated-measures analysis of variance (ANOVA) with three within-subject factors (vowel context, task type, and word position). The dependent measures included the percentage of activation in the anterior region of
the palate (N = 46 electrodes), medial region of the palate (N = 18 electrodes), posterior region of the palate (N = 50 electrodes), and the center of gravity, or COG, of the entire contact pattern (see Figure 3). The COG measure is based on the degree of electrode activation along the antero-posterior dimension, excluding the electrodes in the area of the dental arch and the lips. Each of the 14 rows of electrodes is given a power weighting, with the power weight of the second row being 14, the third row 13, the fourth row 12, etc. Thus, a contact pattern with more anterior activation will have a higher COG power than a contact pattern that is centered more posteriorly in the mouth.

The COG is calculated by the following algorithm:

\[ \text{COG} = \frac{\sum [A_r (P)]}{\sum (A_t)} \]

- \(A_r\) = percentage of electrode activation for each row
- \(A_t\) = percentage of total electrode activation
- \(P\) = relative power scale from 1 to 14

The ANOVA results include a measure of effect size, partial eta squared, or \(\eta^2\). In addition, pairwise comparisons for significant within-subject factors were calculated using General Linear Model repeated-measures contrasts with associated \(F\)-tests.

*Figure 2. Areas of regional activation.*
Results

Anterior Activation Region

The statistical analysis indicated that the speakers’ articulatory contact during productions of light and dark [l] in the anterior region of the palate was significantly different as a function of task type, $F(2,22) = 28.98, p < .0001, \eta^2_{partial} = .725$. Pairwise comparisons ($p < .001$) indicated that the highest degree of anterior activation occurred when the [l] phoneme is produced in nonsense ($M = 27.50\%$) and real words ($M = 26.01\%$), compared to spontaneous productions ($M = 12.69\%$). The degree of anterior activation also differed as a function of the word position of the target phoneme, $F(1,11) = 76.17, p < .001, \eta^2_{partial} = .874$. The anterior portion of the palate was contacted to a greater degree when [l] was in initial position ($M = 32.22\%$) of words, compared to final position ($M = 11.91\%$). There was no significant effect in the anterior region as a function of vowel context.

In addition, an interaction effect between task type, word position, and vowel context was found to be significant, $F(4,44) = 49.21, p = .011, \eta^2_{partial} = .251$. As shown in Figures 4-6, for all three task types the mean percentage of electrode activation in the anterior region was greater for light [l], when the [l] phoneme was in the initial position of words. However, for dark [l], when the [l] productions were in final word position, the pattern of anterior activation changed across task type. For the nonsense and real word tasks, the [l] productions had the most anterior activation when preceded by a low-back vowel (e.g., – ball). In the phrase task, the anterior activation was highest when preceded by a high-front vowel (e.g., – peel). For the dependent measure of anterior activation, no other statistical comparisons were found to differ significantly. Please refer to Tables 1 - 3 for a specific listing of the descriptive statistics associated with each measure.
Figure 3. Mean percent anterior activation in nonsense words across word position and vowel context.

Figure 4. Mean percent anterior activation in words across word position and vowel context.
### Table 1

**Dependent Measures for the Nonsense Word Elicitation Condition**

<table>
<thead>
<tr>
<th>Measures</th>
<th>Word Position</th>
<th>Vowel Context</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Center of Gravity</strong></td>
<td>Initial</td>
<td>High-front</td>
<td>10.63</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low-back</td>
<td>12.47</td>
<td>1.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-back</td>
<td>11.55</td>
<td>1.91</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>High-front</td>
<td>9.72</td>
<td>3.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low-back</td>
<td>10.63</td>
<td>4.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-back</td>
<td>9.74</td>
<td>3.60</td>
</tr>
<tr>
<td><strong>Anterior Electrode Activation</strong></td>
<td>Initial</td>
<td>High-front</td>
<td>39.81</td>
<td>11.62</td>
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<td></td>
<td></td>
<td>Low-back</td>
<td>37.31</td>
<td>12.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-back</td>
<td>37.81</td>
<td>11.04</td>
</tr>
<tr>
<td></td>
<td>Final</td>
<td>High-front</td>
<td>16.75</td>
<td>8.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low-back</td>
<td>20.11</td>
<td>10.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-back</td>
<td>13.18</td>
<td>10.36</td>
</tr>
<tr>
<td><strong>Medial Electrode Activation</strong></td>
<td>Initial</td>
<td>High-front</td>
<td>4.09</td>
<td>3.64</td>
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<td></td>
<td></td>
<td>Low-back</td>
<td>0.93</td>
<td>1.68</td>
</tr>
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<td>High-back</td>
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<td>0.67</td>
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<td></td>
<td></td>
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<td>High-back</td>
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</table>

*Note: These values are percentages of electrode activation in each region (anterior, medial, posterior) across task type. The number of electrodes in each region varies.*
### Table 2

**Dependent Measures for the Word Elicitation Condition**

<table>
<thead>
<tr>
<th>Measures</th>
<th>Word Position</th>
<th>Vowel Context</th>
<th>Mean</th>
<th>SD</th>
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<tr>
<td><strong>Center of Gravity</strong></td>
<td>Initial</td>
<td>High-front</td>
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<tr>
<td></td>
<td></td>
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<td>High-back</td>
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<td></td>
<td>Final</td>
<td>High-front</td>
<td>9.32</td>
<td>2.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low-back</td>
<td>11.35</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-back</td>
<td>10.88</td>
<td>2.36</td>
</tr>
<tr>
<td><strong>Anterior Electrode Activation(^a)</strong></td>
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<td></td>
<td>Low-back</td>
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<td>High-back</td>
<td>1.67</td>
<td>2.49</td>
</tr>
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<td></td>
<td>Final</td>
<td>High-front</td>
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<td>Low-back</td>
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</tbody>
</table>

*Note: \(^a\)These values are percentages of electrode activation in each region (anterior, medial, posterior) across task type. The number of electrodes in each region varies.*
Table 3

*Dependent Measures for the Phrase Elicitation Condition*

<table>
<thead>
<tr>
<th>Measures</th>
<th>Word Position</th>
<th>Vowel Context</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
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<td></td>
</tr>
<tr>
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</tr>
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</tr>
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<td>Low-back</td>
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<td></td>
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<td>High-back</td>
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<tr>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>High-back</td>
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<td>Low-back</td>
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<td>High-back</td>
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<td>Medial Electrode Activationa</td>
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<tr>
<td>Posterior Electrode Activationa</td>
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<td>High-front</td>
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<td>High-back</td>
<td>6.83</td>
<td>3.00</td>
</tr>
</tbody>
</table>

*Note:* *These values are percentages of electrode activation in each region (anterior, medial, posterior) across task type. The number of electrodes in each region varies.*
Medial Activation Region

The statistical analysis indicated that the speakers’ articulatory contact during productions of [l] in the medial region of the palate was significantly different as a function of task type, $F(2,22) = 11.688, p < .001, \eta^2_{\text{partial}} = .515$. The mean activation in the medial region was highest in the phrases task at 4.89%. The percentage activation for the nonsense words task and the words task were 1.71% and 2.19%, respectively. The percentage activation of lingua-palatal contact of electrodes also varied significantly by word position, $F(1,11) = 8.40, p = .015, \eta^2_{\text{partial}} = .433$. The mean percentage activation in the initial word position was 3.98% and in the final word position was 1.87%. A main effect was also found for vowel context, $F(2,22) = 17.07, p < .001, \eta^2_{\text{partial}} = .608$. The activation was highest in the high-front vowel context ($M = 4.36\%$), followed by the high-back ($M = 2.83\%$) and the low-back vowel context ($M = 1.60\%$).
In addition, an interaction effect between task type and vowel context was found to be significant, $F(4,44) = 3.19, p = .022, \eta^2_{\text{partial}} = .225$. As shown in Figure 7, the overall percent of medial activation and the degree of difference between vowel contexts was highest in the phrases task. An interaction effect between word position and vowel context was found to be significant, $F(2,22) = 2.76, p = .008, \eta^2_{\text{partial}} = .358$. As shown in Figure 8, the medial activation was highest when the [l] phoneme was produced in the initial position of words, especially in the high-front vowel context.

**Posterior Activation Region**

In the posterior region, the mean percentage activation of lingua-palatal contact of electrodes varied significantly by task, $F(2,22) = 14.89, p < .001, \eta^2_{\text{partial}} = .826$. The percent activation was highest in the phrases task ($M = 9.85\%$), and lower for nonsense words ($M = 5.56\%$) and words ($M = 4.88\%$). The mean percentage of activation in the posterior region also varied significantly by vowel context, $F(2,22) = 28.73, p < .001, \eta^2_{\text{partial}} = .723$. The activation was highest in the high-front vowel context ($M = 10.44\%$), and lower for the high-back ($M = 6.55\%$) and low-back ($M = 3.29$) contexts.

In addition, an interaction effect between task type and word position was found to be significant, $F(2,22) = 6.41, p = .006, \eta^2_{\text{partial}} = .368$. As shown in Figure 9, the overall percent of posterior activation was greatest in the high-front vowel context and the degree of difference between vowel contexts was highest in the phrases task.

**Center of Gravity**

The COG measure varied significantly by task type, $F(2,22) = 52.24, p < .001, \eta^2_{\text{partial}} = .826$. The COG was highest in the words ($M = 11.09$) and nonsense tasks ($M = 10.79$), compared to the phrases task ($M = 7.66$). The COG also varied significantly by vowel context, $F(2,22) =$
**Figure 6.** Mean percent medial activation across task type and vowel context.

**Figure 7.** Mean percent medial activation across word position and vowel context.
Figure 8. Mean percent posterior activation across task type and word position.

16.76, \( p < .001, \eta^2_{\text{partial}} = .604 \). The highest values were found in the low-back vowel context (\( M = 10.81 \)), followed by the high-back (\( M = 9.77 \)) and then the high-front context (\( M = 8.97 \)). In addition, a main effect of word position was also found, \( F(1,11) = 6.59, p = .026, \eta^2_{\text{partial}} = .375 \), with the COG highest in the initial position of words (\( M = 10.63 \)), compared to final position (\( M = 9.07 \)).

Lingua-Palatal Contact Maps

Figures 9-11 illustrate the average degree of lingua-palatal contact made during the production of \([l]\) when embedded in the three different vowel contexts. These data are an average of the \([l]\) productions collapsed across the different word positions, task types, and individual speakers. A color scheme with five varied shades of blue was used to represent how consistently a given electrode was activated during the production of the target sound.
Figure 9. Average lingua-palatal contact in the high-front vowel context.

Figure 10. Average lingua-palatal contact in the low-back vowel context.
Figure 11. Average lingua-palatal contact in the high-back vowel context.

Figures 12 through 17 illustrate the lingua-palatal contact patterns for the /l/ productions as a function of word position and task type for the high-front vowel context.
Figure 12. Lingua-palatal contact pattern for light [l] in nonsense words, high-front vowel.

Figure 13. Lingua-palatal contact pattern for dark [ɫ] in nonsense words, high-front vowel.
Figure 14. Lingua-palatal contact pattern for light [l] in words, high-front vowel.

Figure 15. Lingua-palatal contact pattern for dark [ɫ] in words, high-front vowel.
Figure 16. Lingua-palatal contact pattern for light [l] in phrases, high-front vowel.

Figure 17. Lingua-palatal contact pattern for dark [ɫ] in phrases, high-front vowel.
Discussion

The current study sought to investigate if EPG could be a useful tool in assisting L2 learners of German to acquire the allophonic contrast between the light and dark [ɫ] allophones. This study examined if EPG was able to show any quantitative or qualitative (visual) differences between the two allophonic variants of the phoneme /l/ that might be used to facilitate instruction with L2 learners. This information is needed to ascertain if further studies should be conducted to measure the effectiveness of EPG in teaching the difference between light and dark [ɫ] to non-native German learners and to help English-speaking L2 learners to avoid transferring their allophone rules to other languages which also lack the dark-light allophones.

This study also sought to examine how the lingua-palatal contact patterns might differ between light and dark [ɫ], as elicited in various tasks and vowel contexts. The results show that the allophonic variants of light and dark [ɫ] were found to have significant differences in anterior electrode activation as a function of vowel context. However, these differences were not visually distinct. Differences in regional electrode activation and COG were statistically significant as a function of task type. The anterior region had the highest mean activation values compared to the medial and posterior regional activation in each task. The visual differences in the contact patterns in the “words” task vs. the “phrases” task suggest that the allophone production may also change in relation to coarticulation of sounds in phrases, which approximate running speech more closely than words read from a list. This is important to consider when creating stimuli to be used in L2 learning.

However, the anterior and medial regional activation percentages, as well as the COG, of the [ɫ] productions suggest that the greatest differences occurred as a function of word position. The statistical analyses indicate that the lingua-palatal tongue contact patterns of light and dark
[l] differ significantly as a function of word position. This was expected considering that previous research has indicated that word position may be an important factor in measuring differences between phoneme productions (Recasens, 2012). Generally, there was a higher degree of activation and more anterior placement of the contact of the tongue tip for light [l] when the [l] phoneme is produced in the initial position, compared to the lingua-palatal contact patterns for the dark [l] produced in word final position.

When examining the qualitative data (the contact maps), the contact patterns between the two allophones of /l/ are visually distinct, with light [l] having increased anterior activation compared to dark [l]. Examples of these differences are illustrated in Figures 12 – 17. This is important because if the differences in placement are visually distinct to L2 learners, the EPG system may be a valuable source of real-time feedback to help L2 learners acquire the sound contrast and ultimately reduce their accent or improve their speech intelligibility. The learner views the visual feedback on a computer screen in real-time during running speech. Therefore, the visual differences must be distinguishable enough to be perceived in a very short period of time as the learner watches the screen.

These results suggest that further testing of EPG as a teaching tool for English speakers learning the pronunciation of the allophonic variants of light and dark [l] may be beneficial in future studies. Electropalatography has been effective in facilitating the L2 learning of specific “phoneme” contrasts, such as [l] - [r], [s] – [ʃ], [t]-[θ], and [l] - [i] (Bright, 1999; Gibbon et al., 1991; Schmidt, 1998). From preliminary studies, EPG technology also has the possibility of aiding L2 learners in their ability to produce the German allophonic sound variants of [x] and [ç] (Isaacson, 2015; Lester, 2017). The results of this study indicate that EPG has the possibility of
also providing L2 learners visually distinct feedback into the accurate production of light and dark [l].

The results also suggest that there may be subtle differences in posterior tongue placement that occurred further back than the device could capture. Furthermore, the EPG device does not give data about changes in tongue position or shape unless it is contacting the palate. Thus, there could be varying levels of tongue height in the oral cavity, below the palate, used in light and dark [l] production that cannot be visualized by the EPG sensors. The tongue may also be curling back or grooving at the midline, which would also not be captured using EPG.

Another limitation of this study is that it defined light and dark [l] as two distinct categories, although it has been shown that there is likely a continuous spectrum of degrees of darkness or lightness (Recasens, 2004).

It may be beneficial in future studies to use different types of instrumentation to capture the articulation patterns of light and dark [l] productions. Ultrasound technology may be able to more clearly show the movement of the entire tongue, including curling and horizontal and vertical movement within the oral cavity. Another possible option would be to use an NDI Wave electromagnetic articulograph to determine production differences between light and dark [l]. This technology utilizes sensors attached to the tongue, lips and jaw to track the precise movements of the articulators.

Despite these limitations, the current study contributed important information to aid understanding of the potential efficacy of using EPG in L2 learning and the specifics of how the allophonic contrast of light and dark [l] is articulated by native English speakers. This study also provided insight into differences in speech sound production across different task types and word positions. These findings may provide a foundation upon which future research using various
types of instrumentation might be used to track and aid in the acquisition of speech sounds in a speaker’s L2. Overall, it is hoped that these findings will improve L2 learning and teaching in the future.
References


Lester, K. E. (2017). *Quantifying lingua-palatal contact patterns of fricative productions by non-native students enrolled in a university German language course: An electropalatography study* (Master’s thesis). Brigham Young University, Provo UT.


APPENDIX A

Annotated Bibliography


*Objective:* This article discusses and refutes the claim that the English syllabic [l] is always pronounced as a dark [ɫ]. *Method:* The article first explains the difference between light and dark [ɫ], then defines syllabic [l]. The author presents research to show the acoustic and articulatory features of syllabic [l] along with phonological and phonetic aspects of its pronunciation. *Results:* The [l] is darker if placed before a consonant and lighter if placed before a vowel. Also, duration does not appear to be a differentiating factor between non-syllabic and syllabic [l]. *Conclusions:* Though it is commonly believed that syllabic [l] is always pronounced as a dark [l], research shows that syllabic [l] maintains a distinction between the light and dark productions just as non-syllabic [l] does. *Relevance to current study:* During testing, it is expected that participants may use either light or dark [l] when pronouncing the syllabic [l].


*Objective:* This chapter discusses how infants learn language-specific phonemic patterns that affect perception and production of phonemes. By adulthood, unfamiliar or non-native sounds are assimilated to the speaker’s native language categories, both in perception and production. *Method:* The author examines several studies about the phonological development in
young children through adulthood. The author focuses on speech perception, perceptual assimilation, and the developmental progression of speech perception in the native and non-native languages. Results: There is a developmental progression of perceptual learning. Findings show that young infants initially perceive nonlinguistic differences in speech sounds. As children develop, they better differentiate between native phonemic categories and begin to assimilate non-native sounds into these native categories based on their articulatory-gestural differences and similarities. Conclusions: The recognition and production of phonemes as linguistically meaningful units develops gradually as children expand their lexicon. The young child detects articulatory features of phonemes, which influences the development of both perception and production and helps the child acquire their native language. Relevance to current study: Adult speakers/listeners are skilled at distinguishing phonemes in their native language. When confronted with non-native phonemes or differences in pronunciation, speakers/listeners will assimilate these sounds into their native phonemic categories based on articulatory similarities. English speakers learning German will likely use English sounds or pronunciation patterns at times while speaking German.


Objective: The purpose of this study was to determine the effectiveness of using EPG technology in accent reduction therapy. Method: Three adult female native speakers of Spanish participated in EPG therapy focused on accent reduction and reaching target phonemes. Formal and perceptual tests of accent level were administered pre- and post-therapy. Results: The participants had a significant reduction in their foreign accent in English. Conclusions:
Palatometry-based therapy is a viable tool to help reduce a foreign accent. *Relevance to current study*: The current study is part of a larger project to determine the effectiveness of EPG therapy in reducing the foreign accent of English speakers learning German. The success of EPG therapy in one language group suggests that it may be an effective tool for many other L2 learners as well.


*Objective*: The purpose of this study was to determine the effectiveness of using EPG to treat ten children with persistent speech difficulties that were of unknown etiology. The authors sought to determine if the subjects benefited from EPG treatment, as well as if it was possible to develop predictive factors that would accurately rank the subjects based on amount of progress. *Method*: Ten subjects were tested to find baseline measures of their speech using word lists. The subjects then received therapy sessions using electropalatography (EPG) and were re-tested. Scores were based on correct productions of consonants from the word lists for each subject. *Results*: Each subject’s score increased. With all the scores combined, the change in scores was statistically significant. Initial ranking predictions were fulfilled, or only different by 1 place, for 4/10 subjects. *Conclusions*: None of the predictors of success were consistently reliable. Speech and language therapists seem to make appropriate referrals for EPG therapy, since all the subjects improved. However, therapists are not yet able to predict who will make the most progress with EPG therapy. No subgroups were identified to have more or to have less success with EPG therapy based on disorder category. *Relevance to current study*: It is possible to identify clients who would benefit from EPG use to improve articulation, though we cannot tell
how much they will improve. Therefore, it is likely that EPG therapy for English speakers learning German will have variable results depending on the learner.


**Objective:** This article evaluates treatment using EPG devices for articulation and phonological disorders. **Method:** The author presents results from studies of children with articulation or phonological problems. The author analyzes the results and provides suggestions for practical application in therapy. **Results:** For children with articulation problems, results showed that they may produce contact patterns that are more aberrant than what is noted perceptually. Those with phonological problems made significant progress in production of contrasted phonemes after EPG therapy. **Conclusions:** EPG remediation is beneficial to teach new articulatory gestures for children with articulation disorders. For children with phonological problems, it was found that using a motor approach to teach the phonetic inventory was effective. **Relevance to current study:** EPG devices can be successful in teaching speech sounds to those who struggle with perception and production of correct sounds. Speakers of English may benefit from a motor approach to learning German phonemes.


**Objective:** This article analyzes the use of EPG feedback in the treatment of speech disorders and what characteristics of the technology make it useful in therapy. **Method:** The author describes a study which evaluated the use of EPG therapy with children and young adults who have speech disorders. The effects of this treatment are evaluated and possible reasons for
success are suggested. **Results:** The 18 subjects who finished the treatment regimen were successfully able to produce perceptually normal target sounds in a therapy setting. The contact patterns for each subject varied from the others and from the modal pattern presented to them. **Conclusions:** Despite variation in contact patterns, each one had at least some of the characteristics of the modal contact pattern. It can be assumed that there is a range of normal variation in correct perceptual production of a sound. **Relevance to current study:** When collecting data about subject contact patterns, it is typical to have a small degree of variation in correct production of sounds. Both lingua-palatal tongue contact and acoustic features of the sounds must be considered.


**Objective:** The purpose of this chapter is to examine speech learning development over the lifespan and the benefits of beginning to learn and specifically pronounce the sounds of a second language early in one’s life. **Method:** The chapter begins by discussing general theories about foreign accent in L2 speech production. It then explains a model of L2 speech learning over the lifespan. The chapter also presents research about production and perception of L2 sounds and general questions about L2 phoneme learning. **Results:** L2 learners past a certain age of learning may rely on features of the L1 to understand sounds in the L2. Listeners may process sounds differently depending on the vowel context and syllable position. **Conclusions:** L1 features and patterns influence the pronunciation of the L2 in relatively older second language learners. **Relevance to current study:** It is likely that adult English speakers learning German will apply English pronunciation and patterns when producing the [l] sound. It might be difficult for
English speakers to produce solely a dark [l] in German because both light and dark [l] are prevalent in English pronunciation.


*Objective:* This article describes the purpose and function of continuous palatometry using a thin pseudopalate with electrodes embedded in it. The consistency of lingua-palatal contact patterns is assessed. *Method:* The article compares different methods for displaying lingua-palatal contact patterns and evaluates the variability of the patterns for each person. *Results:* There is a certain amount of variability for repetitions of each sound. *Conclusions:* An average contact pattern can be found between the slight variations in production for a sound. Overall, electropalatography (EPG) devices are effective at showing dynamic displays of lingua-palatal contact patterns during speech. *Relevance to current study:* EPG technology is an effective tool in studying speech articulation. It can be helpful in studying the variations in pronunciation of sounds in different languages.


*Objective:* This study evaluates the effects of EPG therapy on [t] and [s] production in those with articulation disorders related to repaired cleft palate. *Method:* Twelve subjects were randomly assigned to two different treatments. One group received four sessions of individual EPG therapy and four sessions of therapy without EPG. In the second group, subjects had four
sessions on non-EPG therapy first, followed by four sessions of EPG therapy. Results: 75% of subjects had improved articulatory patterns for [t] and [s] after EPG therapy. 92% saw no effect on articulation after non-EPG therapy. Three subjects (25%) did not respond to either treatment method. Conclusions: EPG therapy has a positive effect on many (though not all) cleft palate speakers with articulation errors. EPG therapy seems to be more effective than non-EPG therapy with subjects with cleft palate. Relevance to current study: EPG therapy is effective in improving articulation in a variety of circumstances, which may extend to foreign accent reduction.


Objective: This study aimed to monitor and change deviant productions of [r] and [l] in Japanese speakers learning English using an EPG device. Method: A pilot study was first carried out with two Japanese speakers living in England who had been learning English for about eight years. These speakers, a Japanese author of the study, and an English speaker all recorded the lingual consonant sounds of English while wearing an EPG device. The Japanese speakers also took part in perceptual tests with [r] and [l] minimal pairs. The Japanese speakers later participated in practice sessions, demonstrations, and explanations of correct pronunciation of [r] and [l] using EPG therapy. At the end, EPG recordings in English were made again to compare to the first recording. Results: Both Japanese students had difficulty perceiving the difference between minimal pairs. They both also made inconsistent articulatory errors in producing [r] and [l]. Conclusions: Both Japanese students produced transfer errors, which are errors influenced by their native Japanese articulation patterns. While they were using different strategies to produce each sound, they were not making a distinction in English. After therapy sessions with EPG, both
speakers improved their ability to perceive differences between [r] and [l] and fix pronunciation errors. *Relevance to current study:* Second language learners often have difficulty perceiving and producing distinctions between certain phonemes. EPG therapy can be effective in teaching and increasing awareness of these distinctions in L2 learners.


*Objective:* This article evaluates the responses of speech and language therapists from Scotland about the effectiveness of EPG therapy with their clients. *Method:* Ten speech and language therapists from Scotland who had used EPG in therapy over the period of ten years were surveyed with a questionnaire. This questionnaire asked for information about the client’s demographics, type of disorder, details of their EPG therapy, and the clinician’s perception of their progress with articulation after EPG therapy. *Results:* 87% of participants showed an improvement as a result of EPG therapy. The largest group (41%) showed moderate success after EPG therapy, meaning that some or all sounds targeted in therapy showed improvement and were used in speaking contexts. The therapists reported that 88% of participants had some difficulty generalizing sounds into everyday speech, with 48% having moderate difficulty. *Conclusions:* EPG therapy can be helpful at improving articulation for many clients. A common difficulty is generalization of correct pronunciation into spontaneous speech. This can be improved by employing techniques to continue practice of sounds in several contexts. *Relevance to current study:* EPG therapy may be helpful in improving articulation of German sounds. A potential difficulty for the application of EPG therapy to L2 learning could be generalization into spontaneous speech.

**Objective:** This study examines regularities in the production of [l] vocalization with the goal of identifying phonetic factors that influence it. This [l] vocalization is defined as a “vowelized” variant of the velar or “dark” [ɫ] that occurs non-syllabically. **Method:** Six speakers of different dialectal backgrounds were used in this study. Three speakers came from South East England, two from South East Australia, and one from the West Midlands of England. Because of education, the dialectal differences between the speakers were largely neutralized. Each subject wore an EPG device and recorded a list of sentences containing twelve words with post-vocalic [l] in syllable final clusters. **Results:** The presence or lack of vocalized [l] was influenced by the vowel context surrounding the [l] in each word. **Conclusions:** Vocalization of [l] occurs more frequently with front vowels than with back vowels. **Relevance to current study:** In analyzing contact pattern differences between light and dark [ɫ], it is important to consider the vowel context of test words.


**Objective:** The purpose of this study was to define native contact patterns for three German fricatives that could be used in the future to teach L2 learners of German. **Method:** Six native speakers of German currently living in the United States participated in this study. Each participant received a pseudopalate and speech recordings of word lists were collected from the participants while using the EPG device. **Results:** The study successfully described contact
patterns for three German fricatives. **Conclusions:** The three sounds were visually different from one another and EPG could be an effective tool for teaching these differences in future studies. **Relevance to current study:** The current study aims to determine if there is a significant visual difference in the contact patterns of the English light and dark [l]. The method of the current study may be similar to that of this study as they both seek to determine the usefulness of EPG technology in distinguishing between phonemes.


**Objective:** This study compares the allophonic variations of the American English [r] with the light/dark [l] allophone variations in English and other languages. **Method:** Twenty-seven American-English speakers were studied using ultrasound-based technology to compare allophonic variations of [r]. The results of this study were compared to the light/dark [l] variations found in seventeen languages. **Results:** Two of the speakers used only retroflex [r], sixteen used only bunched [r], and nine used both types according to individual sound patterns. The [l] allophonic patterns tend to be shared within speaking communities, and not as variable between individuals. **Conclusions:** Though [r] and [l] have a similar articulatory basis, the difference between light and dark [l] is more readily perceived than the difference between bunched and retroflex [r]. The allophonic patterns of [l] are simpler than those of [r] as well. Because of this, the [l] allophonic patterns tend to be shared among communities with [r] allophonic patterns are more idiosyncratic. **Relevance to current study:** Because allophonic patterns in light and dark [l] usage tend to be shared among speech communities, it can be expected that participants will have similar usage patterns during the current study in English.

Objective: This study analyzes the differences between light and dark [l] in the vocal tract, tongue shapes, and EPG contact patterns. Method: Four phonetically trained, native American English speakers participated in this study. MRI images and electropalatography contact patterns were collected and analyzed for each participant while producing both light and dark allophonic variations of [l]. Results: Participants had significantly different tongue shapes for both light and dark [l]. However, each participant’s tongue shape and contact patterns showed some common characteristics. Conclusions: All subjects had lingual contact along the midsagittal line from behind the front incisors and back to the alveolar region. Light [l] had more lateral contact than dark [l]. Relevance to current study: In the analysis of EPG contact patterns for English speakers in the current study, it will be important to examine the lateral and anterior tongue contact of both allophonic variations.


Objective: This study seeks to characterize the five different liquids present in the Tamil language in terms of articulatory and acoustic data. Method: Static palatography, MRI, and magnetometry technology are all used to analyze the static and dynamic articulation of liquids in Tamil based on a single speaker’s data. Results: Distinctions were found between allophonic variations of liquids in Tamil using several methods of study. Conclusions: The articulatory characteristics of Tamil were characterized using static palatography, MRI, and magnetometry. This information helps increase understanding of articulatory-acoustic mappings and features of
each allophone. **Relevance to current study:** The use of static palatography was successful in distinguishing the characteristics of liquids in Tamil. It follows that dynamic electropalatography may reveal subtle differences between liquids as well, such as light and dark [l].


**Objective:** The purpose of this study is to compare dialects with distinctively light and dark [l]s and identify any patterns or differences between dialects. **Method:** Five speakers of the Mallorqui dialect and five speakers of the Valencia dialect participated in this study. Each recorded seven repetitions of Catalan words containing the sound sequences [ili] and [ala] in a sentence context. EPG and acoustic data were collected for each participant. These results were also compared to data for the Eastern Catalan dialect and for German. **Results:** The speakers of the dialects containing dark [l] (Mallorqui and Eastern Catalan) had less dorsopalatal contact than those who use the light [l] (German and Valencia). Some of the dialects showed intermediate degrees of velarization for light [l] that were similar to a dark [l]. **Conclusions:** The degree of darkness of the [l] is a continuum, and not two distinctive categories. Some dialects have darker “dark” [l]’s than others and lighter “light” [l]’s. **Relevance to current study:** When testing English speakers in the current study, it is likely that the speakers will produce different degrees of darkness or lightness in the [l] phoneme compared to one another.


**Objective:** This study uses formant frequency data across 23 languages to compare [l] productions in different vowel contexts. These data are used to determine which languages use
dark [ɻ], light [ɻ], or both in the initial and final positions. Method: Speakers of 23 languages were recorded producing [ɻ] next to [i] and [a] both in the initial and final position. They were also recorded producing [ɻ] in an initial syllable intervocalic context. The sounds were produced within real words in short sentences. Results: Light and dark [ɻ] are best contrasted in the vowel context of [i] or [a]. Also, F2 frequencies can be used to determine the degree of darkness or lightness of the [ɻ] production. Conclusions: Languages and dialects can be categorized based on the presence or absence of light and dark [ɻ]. There appears to be intermediate darkness categories as well, which means that some “dark” [ɻ]’s may be lighter or darker than others. Relevance to current study: This study shows that the distinction between light and dark [ɻ] may be subtle and gradual depending on the language and dialect. There is room for variation between different productions of each allophone.


Objective: This study seeks to understand the effects of consonant and vowel context in coarticulation of VCV sequences, specifically involving the effects of [i] and [a] in relation to the [ɻ] phonemes in German and Catalan. Method: 5 male speakers of Eastern Catalan and 3 male speakers of German participated in the study. Each produced the VCV sequences [ili] and [ala] (symmetrical and asymmetrical) 5 times during recording sessions. Lingua-palatal contact data and acoustic data were collected for all participants and analyzed. Results: Catalan dark [ɻ] has more prominent C-to-V effects than the German light [ɻ], especially in the [i] context as compared to the [a] context. The German light [ɻ] also shows less vowel-dependent variability
than light [l] in other languages. Conclusions: Both languages require vocalic anticipation in producing [l] sequences. This trend is more prominent in Catalan than in German. Relevance to current study: The anticipation of vowel contexts may also cause significant differences in light and dark [l] production in English.


Objective: This study seeks to reduce the foreign accent of native Thai speakers learning English by using EPG feedback. Method: Three native adult speakers of Thai received EPG therapy to teach the differences between English [s]-[ʃ], [t]-[θ], and [l]-[i]. Results: All three participants improved articulation of English sounds using EPG feedback. The participants reported improvement in conversation outside of the clinic as well. Conclusions: EPG feedback is a helpful tool for foreign accent reduction when addressing consonants that involve lingual-palatal contact. Relevance to current study: The current study seeks to examine the feasibility of using EPG feedback to teach the difference between light and dark [l]. This would help English speakers learning German to reduce their foreign accent in German.
APPENDIX B

Informed Consent

Consent to be a Research Subject (speakers)

Introduction
The purpose of this research is to determine the effectiveness of a thin sensor placed over the top of the mouth to detect physical differences in how the “l” sound is said in English. This information will be used in future studies to examine the effectiveness of using visual feedback to assist native English speakers learning German as a second language. 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 an adult native English speaker and report no known history of a speech, language or hearing problems.

Procedures
Initially, participation in this study will involve approximately one hour of your time. During this time, you will be asked to visit a local licensed dental professional to have a dental mold taken of your upper teeth, which will be created at no cost to yourself. This mold will be used to create a sensor similar to an orthodontic retainer that fits over your upper teeth. Each participant will use their own custom-made sensor. You will then be asked to make recordings of your speech while wearing the sensor and reading words, phrases and participating in conversation. These recordings will take place in a sound booth located in a research lab in the John Taylor Building on the Brigham Young University campus. The recording session will take approximately 1 hour. The dental visit and recording sessions will involve about 2 hours of your time over the course of approximately 2 weeks.

Risks/Discomforts
The sensor used in this research may cause some minor discomfort to the gums or teeth during use. In addition, the participant may encounter some minor discomfort when the dental mold (which is used to create the sensor) is being made by a licensed dental professional. These sensors have been used for a number of years in the speech pathology community without any report of adverse events. The EPG sensor to be used in this study is commercially available and is currently being used in the BYU Speech and Hearing Clinic, as well as many other locations throughout the US.

Benefits
There are no direct benefits provided in this study.

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 for each hour of your participation in this study.

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: _________________________________________
APPENDIX C

Stimuli Used to Elicit Target Sounds

Please read the following phrases out loud.

1. The frog made a leap outside.
2. There is a leak in the tub.
3. Can you leave it there?
4. I ran the loop instead.
5. She bought a loom to weave.
6. His shirt is loose now.
7. Did you lock the door?
8. We saw it launch into space.
9. He broke the law there.
10. I cut my lip again.
11. Take the lid off.
12. I wrote a list for you.
13. She went to look for it.
14. He put a seal on it.
15. How do you feel now?
16. Throw the peel in the garbage.
17. There is a pool in the yard.
18. He broke the tool at work.
19. The air is cool now.
20. It is Fall next week.
21. He threw the ball far away.
22. She is tall now.
23. He took the pill at home.
24. I’ve had my fill of it.
25. She paid the bill there.
26. Don’t pull on it!
27. Are you full yet?
28. That was a dull class.

Please read the following words out loud.

1. leap
2. leak
3. leave
4. loop
5. loom
6. loose
7. lock
8. launch
9. law
10. lip
11. lid
12. list
13. look
14. seal
15. feel
16. peel
17. pool
18. tool
19. cool
20. Fall
21. ball
22. tall
23. pill
24. fill
25. bill
26. pull
27. full
28. dull

Please read the following nonsense words out loud.

1. lee
2. lah
3. loo
4. eel
5. ahl
6. ool
APPENDIX D

Contact Maps

Nonsense – Initial position – High-front vowel

Nonsense – Initial position – Low-back vowel