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Quantifying Lingua-Palatal Contact Patterns of Fricative Productions by Non-Native

Students Enrolled in a University German Language Course:

An Electropalatography Study

Kate Erin Lester

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

Quantifying Lingua-Palatal Contact Patterns of Fricative Productions by Non-Native Students Enrolled in a University German Language Course: An Electropalatography Study

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Master of Science

Electropalatography (EPG) is a computer-based tracking system designed to provide real-time visual biofeedback of articulatory contacts occurring during speech production. Historically, EPG technology has proven functional within the treatment and assessment of speech disorders however, application of EPG technology to assist in second language learning has remained limited. The present thesis is part of a larger study examining the effectiveness of using EPG as an advanced instructional tool for assisting second language (L2) learners of German. Fricative productions ([ç], [x], /s/, and /ʃ/) within real words were gathered from 12 native English speakers enrolled in a second semester university level course to learn German. Speech productions from student participants were compared against native German speakers' productions collected in a previous study, using electrode mappings, percentages of regional contact, and center of gravity measures. These measures revealed different patterns of palatal contact between fricative sounds, between individual subjects, and cross-linguistically. Fricative sound mappings varied visually as speakers generally produced [ç] and [x] with significantly less palatal contact than when producing /s/ and /ʃ/. Variation across individual subjects was identified as some produced sounds with nearly no posterior palatal contact while others produced sounds asymmetrically or with decreased overall contact. Cross-linguistic differences were apparent as non-native German speakers frequently contacted greater numbers of electrodes with greater force, compared to the natives. It is anticipated that the information included in this thesis will provide insights into the role of EPG technology as an instructional tool for L2 learners.

Keywords: Electropalatography, second-language acquisition, German, electrode mappings

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DESCRIPTION OF THESIS STRUCTURE

This thesis 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 with portions being 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 with the informed consent document presented in Appendix B. Additionally, a compilation of individual participant contact maps are presented in Appendix C.

Introduction

Electropalatography (EPG) is a computer-based tracking system designed to provide real-time visual biofeedback of articulatory contacts occurring during speech production.

Electropalatography utilizes an artificial pseudopalate or sensor customized to an individual's teeth and palatal contours, similar to an orthodontic retainer (Fletcher, 1992; Fletcher, McCutcheon, & Wolf, 1975). The device contains 124 gold-plated electrodes arranged systematically, extending from the alveolar ridge to the back molars. Wires exiting the mouth transmit the contact data to a small processing box for collection and transfer of those data to a computer. Computer software then transforms the electrode data into real-time visual representations of the articulatory contact patterns between the tongue and the palate, providing dynamic biofeedback to the speaker regarding their speech.

Visual biofeedback provided from EPG technology has thus far been primarily used in the evaluation and treatment of developmental and acquired speech disorders (Gibbon & Paterson, 2006). However, it is also effective in treating a number of communication disorders including apraxia of speech (Bartle-Meyer, Goozee, & Murdoch, 2009; Hardcastle & Edwards, 1992; Southwood, Dagenais, Sutphin, & Garcia, 1997), Parkinson's disease (McAuliffe, Ward, & Murdoch, 2006), dysarthria secondary to a traumatic brain injury (Kuruville, Murdoch, & Goozee, 2008), and disordered speech due to a partial glossectomy (Fletcher, 1988; Suzuki, 1989). Electropalatography technology has also been employed as a tool to explain the role of tongue movements within normal swallowing (Horn, Kuhnast, Axmann-Krcmar, & Goz, 2004).

Although functional for the assessment and treatment of many acquired communication disorders, EPG technology is more regularly used to assist children in acquiring speech sounds within their native language. Electropalatography may facilitate speech acquisition for children

who have developmental articulation disorders with no known etiology or who have persistent articulatory deficits that do not respond positively to traditional articulation therapy alone (Carter & Edwards, 2004; Dent, Gibbon, & Hardcastle, 1995). Liquid, fricative, stop, and affricate sound distortions are apparent in the speech of many typically developing children (Hardcastle & Barry, 1989; Narayanan, Byrd, & Kaun, 1999; Recasens & Pallares, 1999) even in the later stages of development (Paul & Norbury, 2010); however, for children who experience persistent difficulty, further intervention, such as EPG, may be warranted. The physical representations of palatal contacts generated from EPG may aid in the remediation of inappropriate fronting and backing of stops, /s/ and /ʃ/ fricative distortions, and /l/ and /r/ liquid contrasts which are amongst the most frequently distorted sound contrasts within the English language (Alwan, Narayanan, & Haker, 1997; Dagenais, 1991; Dagenais, 1995; Narayanan & Alwan, 1997; Traill & Litt, 1977).

Similar to the difficulty that many native English children encounter when learning to distinguish and accurately produce stop, fricative, and liquid contrasts, second language (L2) learners may also encounter difficulty developing the speech patterns of a specific language. Like children with speech sound disorders, some second language learners experience difficulty moving the tongue and supporting articulators in a native-like manner (Bright, 1999; Dent et al., 1995; Munro, 1992).

Some language learners acquire L2 articulatory movement patterns more readily when their native language and the desired L2 share similar speech sounds with similar articulation patterns (Flege, 1995). For these learners, a limited amount of practice and a traditional approach to language instruction (i.e., using auditory feedback) may be all that is necessary to acquire intelligible L2 speech. However, in instances where speech sounds, although similar

perceptually, have varying articulatory patterns achieving appropriate production may not be achieved through traditional language instruction alone due to several limitations.

First, traditional language instruction relies on the notion that awareness supersedes production (Cheng & Zhang, 2009; Crawford, 1995). General understanding of language learning assumes there must be strong correlation between perceiving speech sounds and being able to produce them. Thus, if language learners are unable to distinguish accurate productions from inaccurate productions perceptually, they will likely struggle to produce the sounds (Bright, 1999). However, when speech sounds within an L2 are similar to those within a speaker's native language, perceptually distinguishing between the two versions of the sound can be difficult with auditory information alone (Bright, 1999; Weiss & Wängler, 1985).

Several cross-language speech models, including the Perceptual Assimilation Model (PAM) and the Speech Learning Model (SLM), help to further explain the perceptual difficulties discussed above. The PAM model, proposed by Catherine Best in 1994, aims to predict the difficulties an L2 learner may have discriminating non-native sound contrasts by determining the patterns of assimilation of L2 sounds to the already established native-sound structure, patterns that are based on perceived phonetic similarity rather than phonemic inventory. There are six different patterns within the PAM model wherein sounds of non-native contrasts are assimilated. According to these patterns, many L2 learners will experience difficulty with *single-category assimilation* (divergence of speech sounds). If two non-native sounds are equally similar or discrepant from a native phoneme, they are difficult to perceptually discriminate (Best, 1994). Thus, L2 learners will frequently produce non-native speech sounds using articulatory patterns from within their native language resulting in decreased L2 intelligibility.

A second model, Jim Flege's (1995), SLM model is similar to the PAM model in that likewise suggests the perception of L2 sounds is significantly influenced by language transfer from an individual's native language. Flege suggests the nature of this language transfer is determined by the amount of perceived phonetic similarity between the sounds of an individual's first language (L1) and their L2. If an L2 sound is phonetically distant from a native sound, then it is perceived as a "new" sound and is thus easier to acquire because there is little language transfer from the speaker's native language. If an L2 sound is perceptually close to an L1 sound, it is considered "similar," thus making it more difficult to acquire the subtle differences between the two sounds because there is a high degree of language transfer from within the speaker's native language causing speech to be continually accented (Flege, 1995). Thus, to reduce the presence of this accenting, learners must establish L2 representations of language specific sounds that are separate from L1 representations.

In addition to the perceptual limitations of traditional language instruction, a second limitation is decreased visualization of some speech sounds. Specifically, sounds produced with posterior constriction are difficult to visualize because movements and patterns are not readily accessible. Speakers cannot readily identify appropriate tongue placements or recognize the use of supporting articulators when sounds are produced in the posterior portion of the oral cavity. In other words, L2 learners cannot produce language specific speech sounds with auditory information alone because they have decreased awareness of which articulators should be used and more importantly how they should be used (Gibbon, Hardcastle, & Suzuki, 1991).

The limitations of traditional therapy suggest additional means of instruction may be necessary for some L2 learners who experience persistent difficulty. Specifically, EPG instruction may be an alternative means to address the difficulties L2 learners encounter. The

visual biofeedback provided from EPG offers a more in-depth explanation of language specific speech sounds and provides L2 learners and their language instructors with a real-time visual display of speech movements, augmenting traditional language learning with additional biofeedback (Gibbon, Hardcastle, Crampin, Reynolds, Razzell, & Wilson, 2001; Michi, Yamashita, Imai, Suzuki, & Yoshida, 1993). EPG biofeedback could provide alternative means to “perception”, i.e. using visual or kinesthetic feedback to increase speakers’ awareness of speech sounds.

The complicated nature of the EPG device and processing unit, as well as the relatively high cost of creating a customized sensor, may have limited the use of EPG for L2 instruction in the past. Additionally, these factors may have limited the amount of research evaluating the efficacy of using EPG for L2 learning. However, a recently developed EPG system (SmartPalate International), utilizing a relatively thin pseudopalate sensor and a smaller processor at a considerably lower cost, has allowed EPG to be more readily accessible. Although there is anecdotal evidence indicating the effectiveness of the new EPG device, the amount of empirical data is limited.

Nevertheless previous research, although narrow in scope and quantity, has revealed positive outcomes such as increased ability distinguishing sound contrasts and accent reduction when augmenting second language learning with EPG visual biofeedback. Positive outcomes are evidenced through the research of Fiona Gibbon and her colleagues who used EPG to facilitate native Japanese speakers’ ability to produce the English /l/ and /r/ contrast (Gibbon et al., 1991). Evaluation of pre- and post- EPG instruction speech samples from within this study revealed improved accuracy and consistency when distinguishing the American sound contrast, indicating increased understanding of articulatory movements.

Evidence supporting EPG use within second language learning additionally comes from Amy Bright's research amongst native Spanish speakers learning English and from Anna Schmidt's evaluation of Thai speakers learning English (Bright, 1999; Schmidt, 1998). Bright's analysis revealed accent reduction and increased articulatory awareness following one month of EPG instruction, which findings Schmidt also supported. Specifically, Schmidt's research showed decreased accent and increased ability distinguishing sound contrasts when EPG instruction was implemented.

Although the benefits of EPG instruction seem apparent within these studies, EPG's role in second language learning has not been fully documented. Aside from these three languages (Japanese, Spanish, Thai), there is little research to support use of EPG in additional languages, such as German.

Many native English speakers experience difficulty producing German sounds in a native-like manner. Specifically, the German fricatives [x], [ç], /s/, and /ʃ/ are difficult for non-native speakers to produce correctly or without an accent. Of particular difficulty for non-native German speakers are the allophones for the German <ch> sound, namely *ich*-Laut and *ach*-Laut ("Laut" being the German equivalent of "sound"). These two sounds are both fricatives, but the sounds are produced with a constriction at a different location within the vocal tract. The *ach*-Laut or [x] is a voiceless velar fricative, while the *ich*-Laut or [ç] is a voiceless palatal fricative. These allophones present in a complementary manner, as each phone occurs in specified phonetic environments. The [x] fricative is utilized following non front (central/back) vowels and the [ç] fricative occurs in all other environments, including after front vowels (Macfarland & Pierrehumbert, 1991). Correct usage of these phonemes has proven difficult for native English speakers learning German, as they require production of a non-native sound with simultaneous

phonetic context evaluation. [x] is present in Scottish English while [ç] occurs in some English words but neither phone occurs in the same contexts within the English language as they do within German therefore, they are frequently misarticulated by non-native speakers as the English fricative /ʃ/ or the stop /k/ (Moulten, 1962). Fortunately, many of the sounds that L2 learners find difficult to acquire (e.g., [x], [ç], /s/, and /ʃ/) also have relatively high degrees of lingua-palatal contact that can be tracked by the EPG sensor.

This high degree of lingua-palatal contact would facilitate collection of normative data which would need to be obtained prior to using EPG as an L2 instructional tool for English speakers learning German. A first task would be to determine how native English speaking students learning German as an L2 are producing German sounds. These data can then be used to identify which sounds are being articulated in a non-native manner and to identify how non-native students' patterns vary from the patterns of native speakers. Specifically, such data might allow determination as to whether students are assimilating German sounds with English sounds or if students are using an articulatory pattern that is unique to both languages. These data could then be used to develop an EPG instructional curriculum to help students acquire German sounds or reduce their accent by "fine-tuning" the articulation of sounds. Articulatory contact patterns have rarely been compared cross-linguistically to determine which language specific speech sounds are frequently disordered. In addition, a limited number of visual displays portraying how contact patterns affect L2 speech intelligibility have been generated.

Thus, this study will quantify lingua-palatal contact patterns of fricative productions using EPG. Specifically, this study will evaluate the contact patterns of native English students learning German as an L2 as they produce [x], [ç], /s/, and /ʃ/. Contact patterns will then be used for comparison with native-German patterns (Isaacson, 2015). Cross-linguistic comparison will

generate visual displays of geometric shape, area of lingua-palatal contact, and activation levels during speech production.

Method

This study is part of a larger study examining the efficacy of implementing EPG biofeedback for second language learning.

Participants

Twelve adult Brigham Young University students ranging in age from 17-25 years old were recruited as participants for this study. All participants were currently enrolled in a second semester university course to learn German as a second language. In other words, each participant had completed one introductory semester of German. Participants were native speakers of English and did not have any known diagnosis of atypical development of their dentition, palate, or other anatomical structures of the vocal tract. Additionally, participants reported no history of speech or language disorder. Each participant read and signed an informed consent document, and prior approval was obtained from the Brigham Young University Institutional Review Board for Human Subjects Research prior to data collection (see Appendix B). The subjects were compensated \$40 for their participation in the study.

Apparatus

Prior to the initiation of data collection, participants were contacted via email to coordinate and schedule dental appointments at a local dental office where they acquired 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.

From this impression, SmartPalate International created a relatively thin (2 mm) EPG sensor. The sensor was similar to an orthodontic retainer, in that it was individually customized to fit the contours of an individual's teeth, extending from the alveolar ridge to the back molars (Fletcher, 1992; Fletcher et al., 1975). The sensor contained 124 gold-plated electrodes arranged in a grid pattern across the surface of the pseudopalate. Electrode data are processed by a microprocessor I/O device worn around the user's neck, which then transfers contact pattern data via a USB cord to a PC computer. The instructor and L2 learner are able to observe their linguopalatal contact patterns on a computer screen in real time.

Stimuli

Students' productions of the following German sounds were evaluated; [x], [ç], /s/, and /ʃ/. Sounds were embedded within both real and nonsense words with the real words being produced within the carrier phrase "*ich sage das Wort ____*". (I say the word ____). Target sounds were assessed in multiple phonetic contexts; initial, medial, and final. However, not all positions will be evaluated within this thesis and not all sounds were assessed in each context since [x] and [ç] are context specific sounds. In particular, [x] occurs posteriorly in the oral cavity and therefore does not follow front vowels, while [ç] occurs more anteriorly in the oral cavity and does not follow central or back vowels (Mangold, 2000). In addition to multiple phonetic contexts, multiple tokens were collected. Three tokens of each word were collected. These words were randomized and presented to each subject to read aloud via physical printouts. Prior to data collection, subjects were familiarized with stimuli via a voice recording presenting the desired production of each word. Students were given approximately a 5-minute break after producing approximately 50% of the words. Please refer to Table 1 below for a full review of the stimuli.

Table 1

German Words Used to Elicit Target Sounds

Target Sound	German Word
[ç]	mich sich dich
[x]	fluch such buch fach dach mach
/ʃ/	fisch tusch wasch
/s/	miss fluss lass

Procedures

Prior to data collection, the fit and functioning of the sensor were evaluated. Participants were instructed to insert their customized sensor and to verify it had clicked into place without being painful or loose. Two participants reported loose fitting sensors, which were secured using dental adhesive. The EPG processor was then activated and all electrodes were determined functional. Before beginning data collection a period of motor adaptation took place. Participants engaged in 15 minutes of conversational English to allow them to adapt to the physical presence of the sensor in their mouth, during which time no data were collected.

Following the adaptation period, participants produced the target stimuli during one 60-minute session of data collection while seated in a sound-attenuating booth. The lingua-palatal contact data were transferred to a PC and saved as a *.csv* file. In addition, the participants' speech was recorded via 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. At the conclusion of the session, participants were instructed to remove the EPG sensor and produce the target stimuli without the sensor in place. These data were only saved as audio *.wav* files. This data set was not evaluated in the current study.

Data Analysis

The original audio files were spliced and saved as smaller files based on the stimulus type and linguistic context. For each speaker production, the onset and offset time points of the target sound were then identified and recorded in a text file to the nearest millisecond. The onset of each fricative sound was identified by locating the time point during which there was a distinct increase in diffuse noise energy, while the offset was identified by locating the time point during which there was a distinct decrease in diffuse energy. If the beginning or end of a sound production could not be distinguished or if the participant clearly produced an incorrect word, then the data for that production would not be included in further analyses. In total, three productions were excluded. The time points recorded in a text were then used as input to 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. Using the activation level of each EPG electrode across a series of 20 ms time windows, a series of three-dimensional contact-

pattern maps were created for each of the target sounds. Additionally, the activation level of each electrode was used to calculate percentage of regional activation and center of gravity measures. These data were then compared to those of native German speakers, gathered in a previous thesis (Isaacson, 2015).

Measurement Reliability

To ensure the accuracy of the segmented sounds and time points, 10% of all tokens were analyzed by an additional rater and then correlated with the original rater's time points for these tokens.

Results

Patterns of palatal contact made by the L2 learners of German are reported descriptively. Electrode mappings, percentage of regional activation, and center of gravity (COG) measurements are provided for each of the fricative sounds analyzed. Mappings provide a visual representation of the average level of lingua-palatal contact made during the production of individual sounds. A blue color scheme with four varied shades was used to represent the different levels of contact. An example of an electrode mapping can be seen in Figure 1. The percentage of regional activation reports the average electrode activation within certain regions of the palate; front, central, left and right anterior (LA, RA), left and right medial (LM, RM), and left and right posterior (LP, RP). Figure 2 shows a palatal mapping with the indicated regions. Finally, the COG reveals where the weight or majority of the electrode contact is being made. The COG measure was computed by taking the sum of the percentage of activation of each row multiplied by a relative power scale, divided by the total degree of activation across the EPG sensor. The power scale was distributed from 1 to 14 across the posterior 14 rows of the EPG sensor (excluding the initial row of sensors that measure lip contact). Thus, the power weight of

the 2nd row was 14, the 3rd row was 13, the 4th row was 12, etc. The middle four sensors of rows 8, 13, 14, and 15, as well as the central region were excluded from the COG calculation because of the relatively limited contact of the electrodes due to the shape of the dental arch and the nature of the fricative productions. Thus, the computation of the COG measure was as follows:

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

A_r = percentage of electrode activation for each row

A_t = percentage of total electrode activation

P = relative power scale from 1 to 14

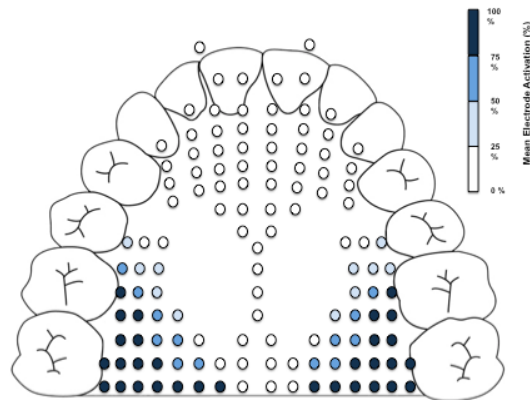


Figure 1. Example electrode mapping.

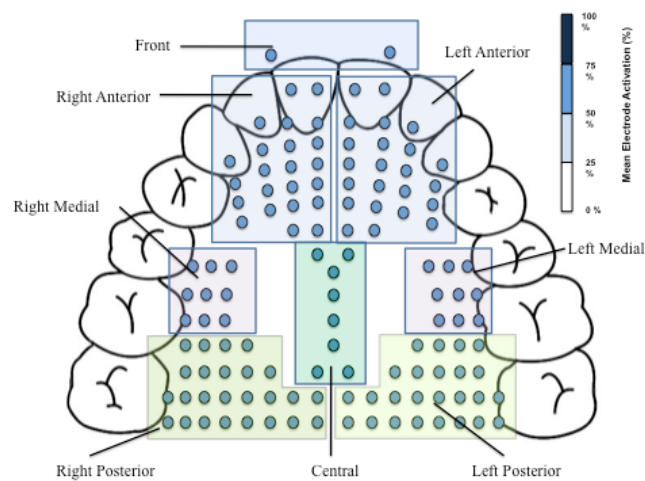


Figure 2. Areas of regional activation.

ach-Laut, [x]

The [x] phoneme, or *ach*-Laut, which is produced in the posterior region of the oral cavity, was evaluated in the context of both high and low-back vowels. Figures 3 and 4 display electrode mappings of [x] in the respective vowel contexts. Participants appeared to utilize a greater degree of posterior lingua-palatal contact with minimal to no contact in the central, medial, and anterior regions. Specifically, the percentage of regional activation for [x] in the high-back vowel context revealed LM = 18%, RM = 19%, LP = 44%, and RP= 48%.

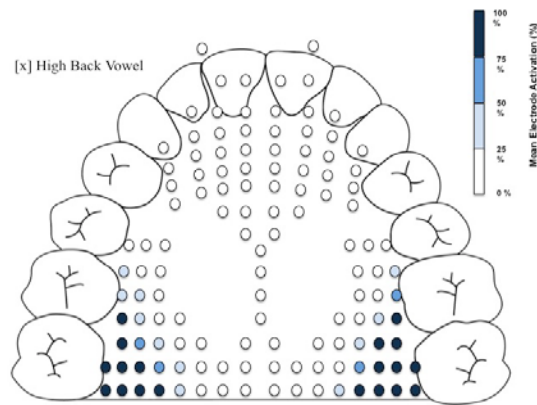


Figure 3. Electrode mapping for [x] in the high-back vowel context.

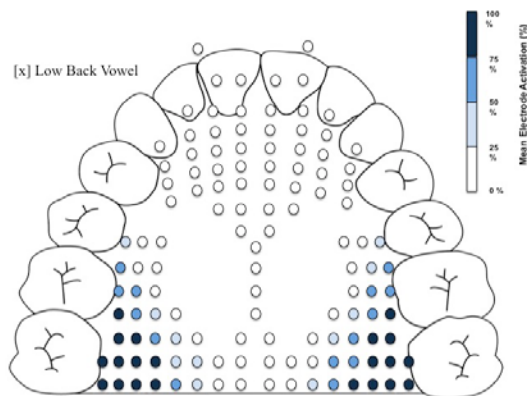


Figure 4. Electrode mapping for [x] in the low-back vowel context.

Medial and posterior electrode activation increased for [x] in the low-back vowel context with LM = 34%, RM = 31%, LP = 54%, and RP = 57%. Figures 5 and 6 display the percentages of regional activation for all the palatal regions for both high and low-back vowel contexts. COG for [x] in the high-back vowel context was 3.411. COG for [x] in the low-back vowel was 3.68.

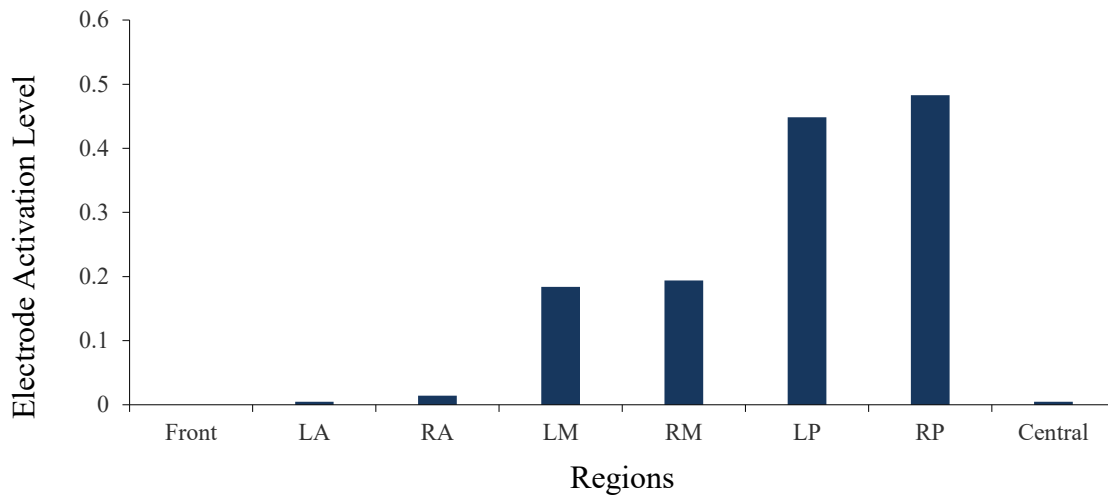


Figure 5. Percentage of regional activation for [x] in the high-back vowel context.

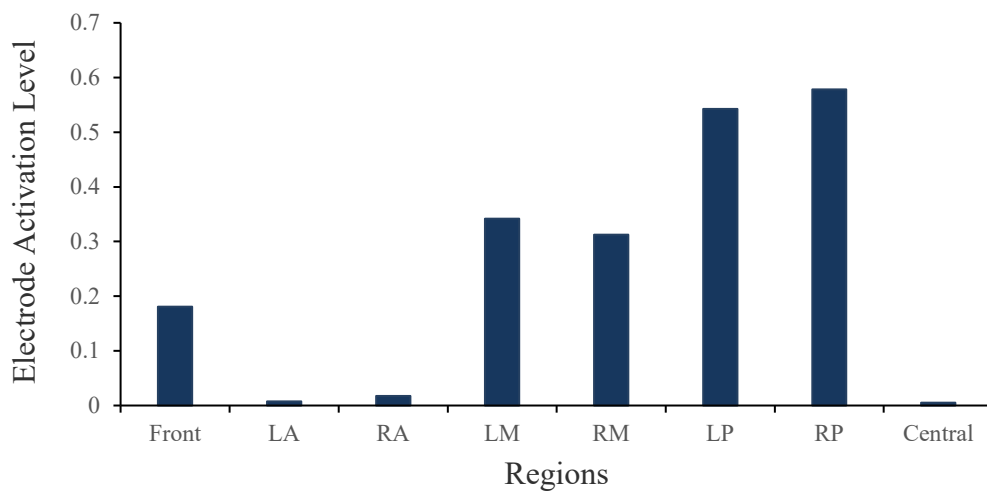


Figure 6: Percentage of regional activation for [x] in the low-back vowel context.

ich-Laut, [ç]

The electrode mapping of [ç] or *ich*-laut, the allophonic counterpart to [x], is shown in Figure 7. Similar to [x], the subjects' production of [ç] revealed a heightened degree of posterior lingua-palatal contact. However, the sounds could be distinguished in that [ç] had increased levels of medial and anterior contact. The percentage of regional activation for [ç] was LA = 12%, RA = 15%, LM = 92%, RM = 94%, LP = 79%, and RP = 84%. Detailed percentage of regional activation measures for [ç] are provided in Figure 8. The COG for [ç] was 4.97.

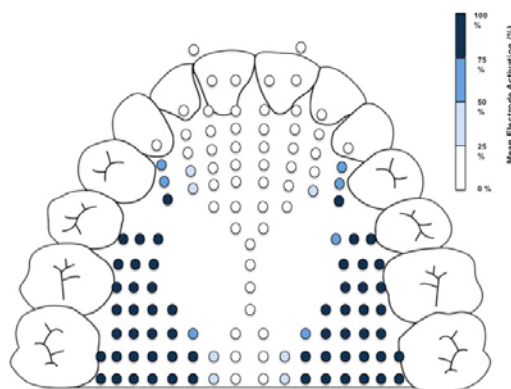


Figure 7. Electrode mapping for [ç].

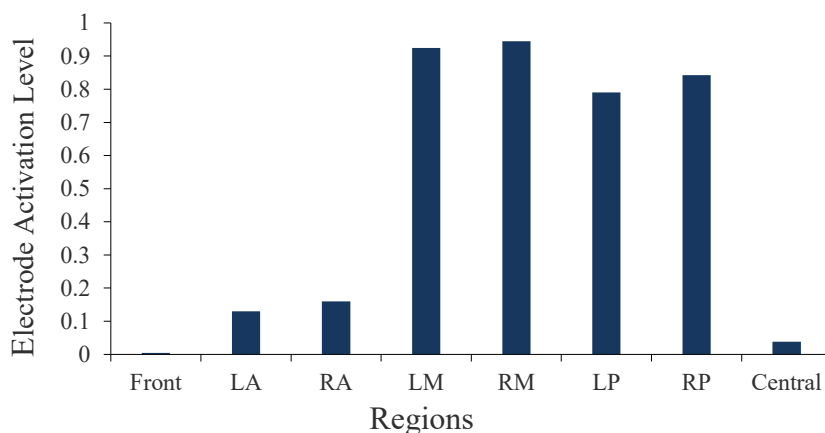


Figure 8. Percentage of regional activation for [ç].

Voiceless Palatal Fricative, /ç/

The electrode mapping of /ç/ is shown in Figure 9. /ç/ was produced by subjects with a minimal degree of anterior lingua-palatal contact and a moderate degree of medial and posterior contact. The percentage of regional activation for /ç/ was LA = 11%, RA = 14%, LM = 62%, RM = 64%, LP = 59%, and RP = 64%. Detailed percentages of regional activation measures for /ç/ are provided in Figure 10. Subjects' productions of /ç/ appeared similar to their productions of [ç] in that there was anterior lingual movement. However, they differed in that they did not contact the medial electrodes with as high of frequency. The COG for /ç/ was 4.77.

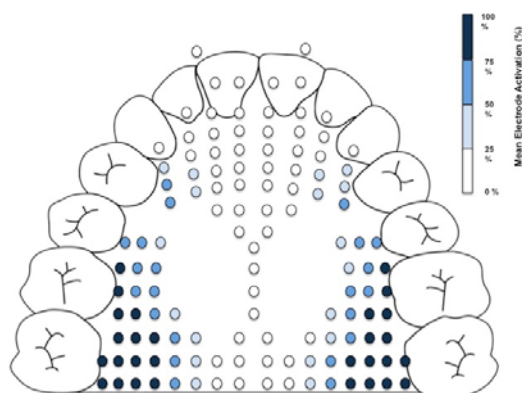


Figure 9. Electrode mapping for /ç/.

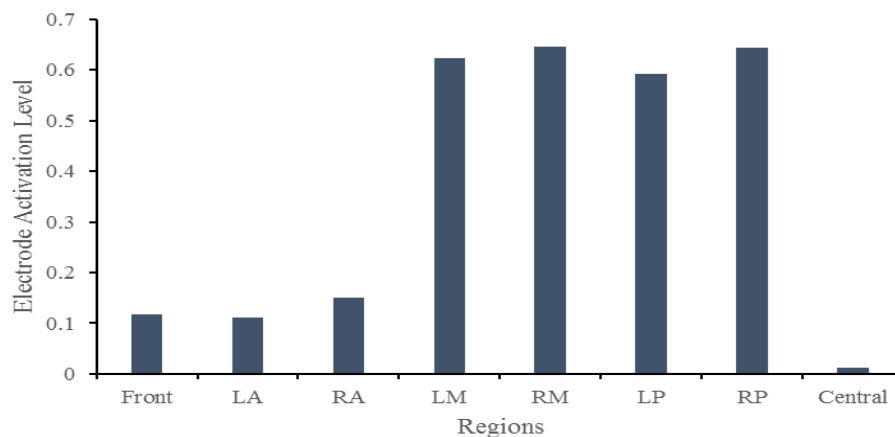


Figure 10. Percentage of regional activation for /ç/.

Voiceless Alveolar Fricative, /s/

The electrode mapping of /s/ is shown in Figure 11. Subjects produced /s/ with the highest degree of anterior lingua-palatal contact. Although there was not complete anterior contact, the majority of electrodes were contacted. Additionally, when producing /s/ subjects used a high degree of medial lingua-palatal contact and a moderate degree of posterior contact. Percentage of regional activation for /s/, presented in Figure 12, were LA = 43%, RA = 43%, LM = 73%, RM = 78%, LP = 45%, and RP = 47%. COG for [ç] was 6.52.

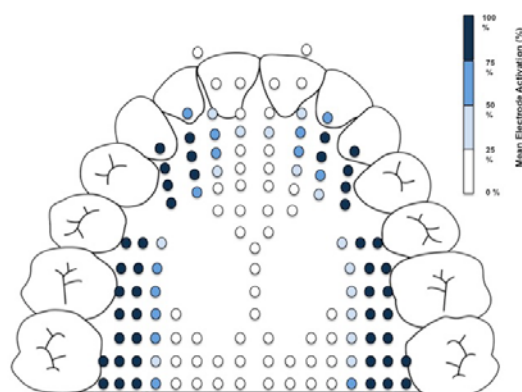


Figure 11. Electrode mapping for /s/.

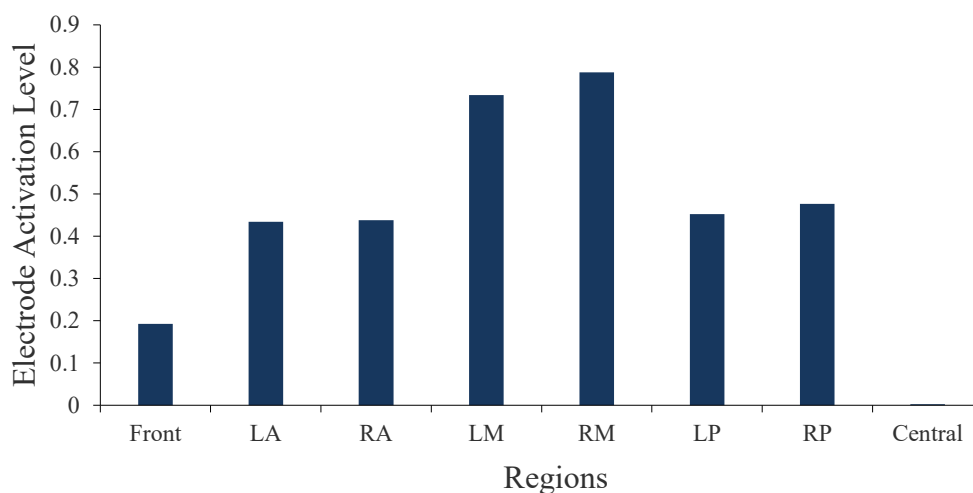


Figure 12. Percentage of regional activation for /s/.

Discussion

The purpose of this study was to quantify the lingua-palatal contact patterns of native English students learning German as an L2 as they produced fricative sounds [x], [ç], /s/, and /ʃ/. The EPG data collected revealed distinct patterns of lingua-palatal contact for each fricative sound. The contact patterns for [x] showed contact was highest in the posterior regions, while the remaining fricatives had contact patterns highest in the medial regions. This is likely due to [x] being produced in the posterior portion of the oral cavity, while the other sounds require anterior tongue excursion for production. The /s/ phoneme exhibited the highest level of anterior regional palatal contact. Again, this likely corresponds to the tongue placement required for the production of /s/. Center of gravity measurements support these findings, with [x] produced posterior in the oral cavity, followed by /ʃ/, [ç], and /s/ as the most anterior. These sound-specific differences in palatal contact could be attributed to factors such as tongue height or tongue excursion.

The results also showed significant variation between native German production patterns and the non-native L2 learners participating in the current study. Through comparison to data collected in a previous thesis analyzing native German speakers' productions of /ʃ/, [ç], and [x] (Isaacson, 2015), non-native speakers generally produced German fricatives with greater lingua-palatal contact, resulting in a reduced width in the central groove during production. Figure 13 displays the differences in lingua-palatal contact between the native and non-native speakers in terms of percentages of regional activation while Figures 14, 15, and 16 present lingua-palatal contact mappings. This use of increased palatal contact in comparison to native speakers may explain the difficulty L2 learners of German commonly have in producing the [ç] and [x] allophones in a native-like manner, often stopping the fricatives similar to a /k/ phoneme

(Moulten, 1962). In accordance with the SLM and PAM models of language learning (Best, 1994 and Flege, 1995), this difference in production abilities may be a result of non-native speakers having difficulty perceiving [ç] and [x] from their native English phoneme /k/.

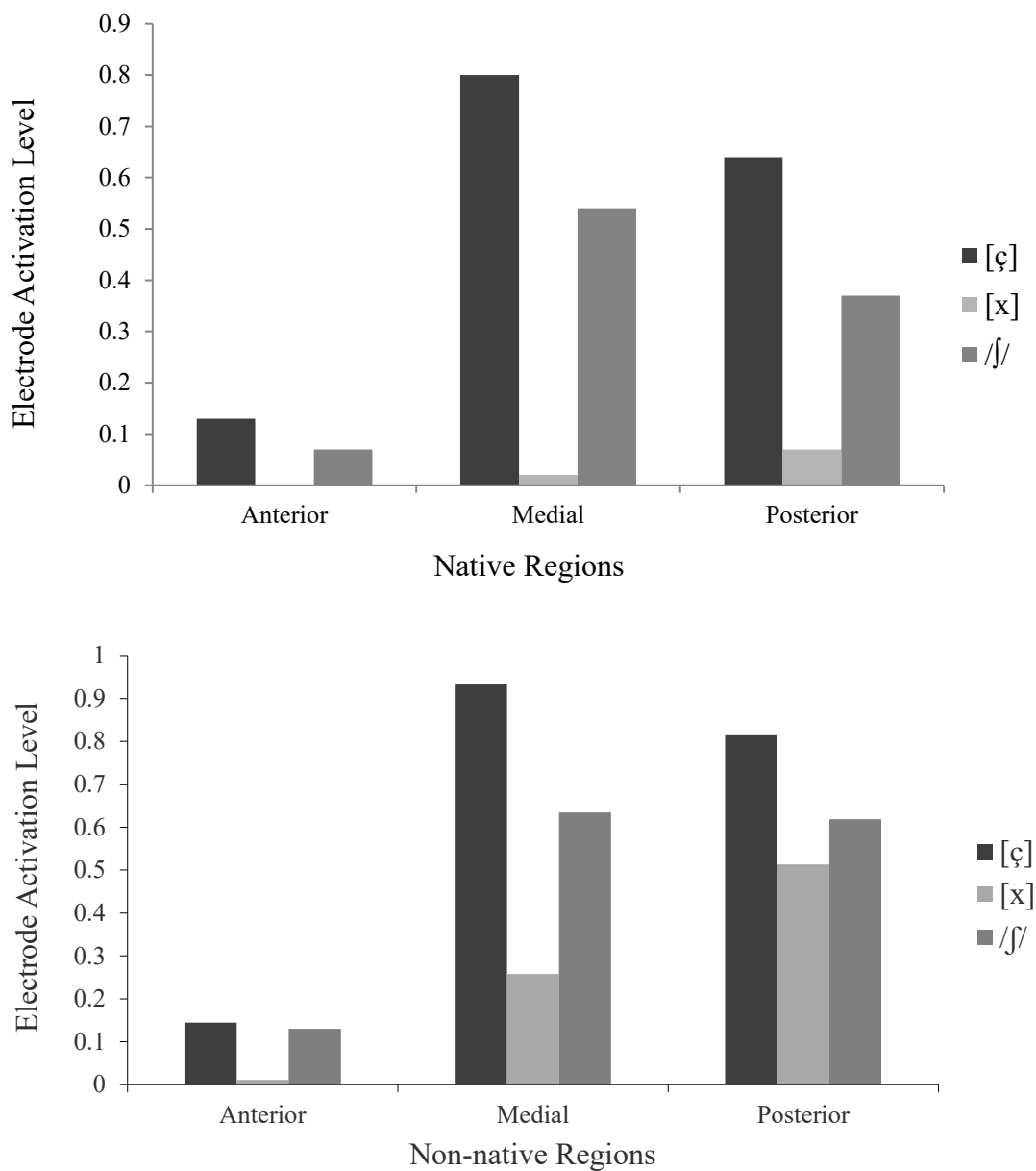


Figure 13. Comparison of native (Isaacson, 2015) and non-native percentages of regional activation.

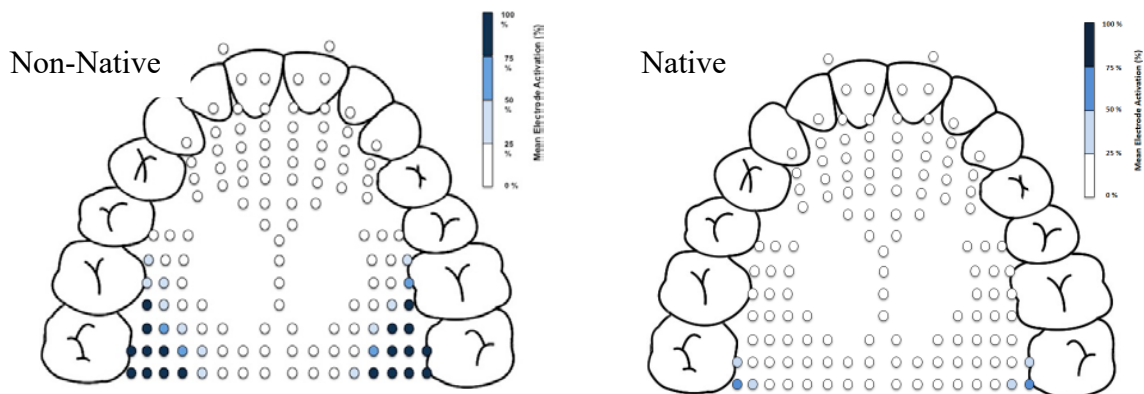


Figure 14. Non-Native vs. native (Isaacson 2015) [x] high-back vowel

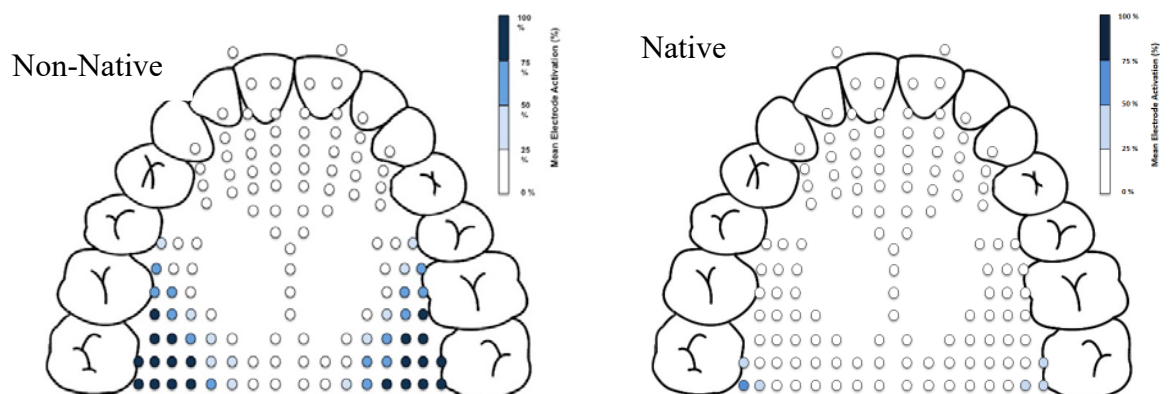


Figure 15. Non-Native vs. native (Isaacson 2015) [x] low-back vowel

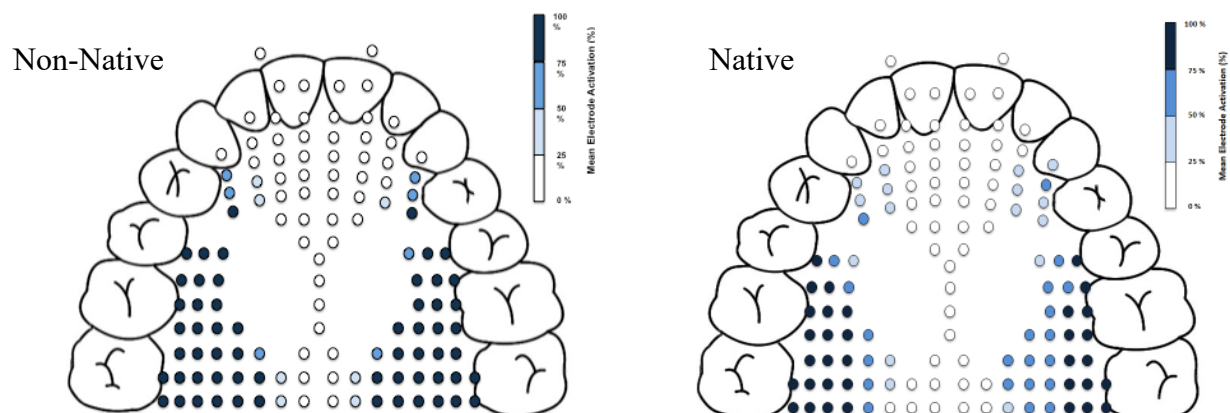


Figure 16. Non-Native vs. native (Isaacson 2015) [ç].

When comparing native and non-native contact patterns of the /ʃ/ fricative the electrode mappings revealed patterns of contact that were more closely related than those of the other fricative sounds. As shown in Figure 17, both native and non-native speakers of German contacted similar electrodes with nearly the same level of frequency. These similarities are likely due to the presence of the /ʃ/ phoneme in both languages allowing for direct language transfer (Best, 1994).

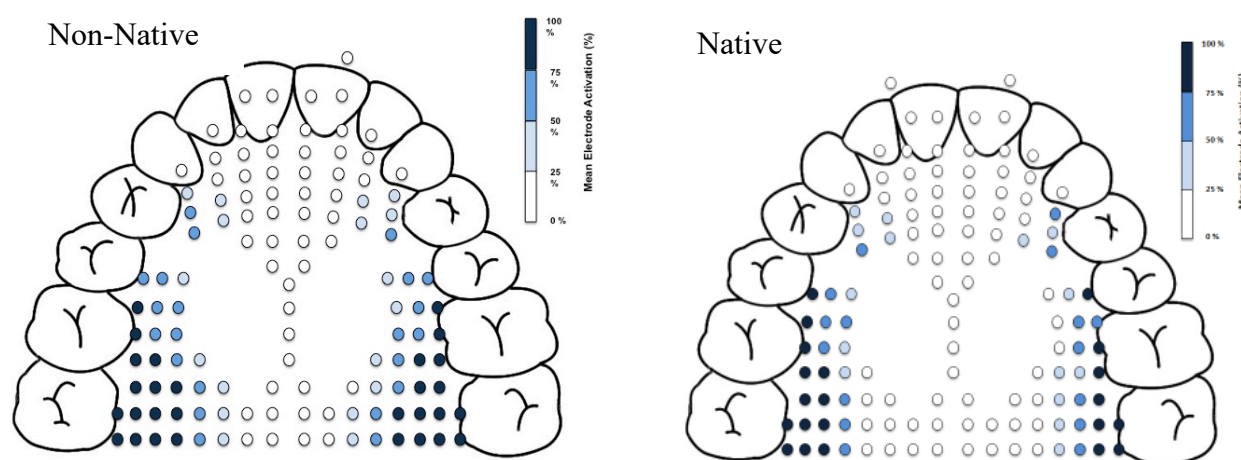


Figure 17. Non-Native vs. native (Isaacson, 2015) /ʃ/.

As shown by the sound-specific electrode mappings created for each subject presented in Appendix C, the patterns of lingua-palatal contact varied across each L2 speaker. In particular, subjects 4, 7, and 9 exhibited patterns that differed in comparison to the remainder of the subject pool. Subject 4's electrode activation mappings for each sound revealed decreased overall lingua-palatal contact and decreased frequency of palatal contact. In general, this subject appeared to use decreased lingua-palatal contacts, more similar to the native speakers' patterns for some sounds. This subject's production of [x], shown in Figure 18, closely resembled the

native production of this sound both visually and in terms of the percentages of region activation. Subject 4's more native-like manner of production may be due to increased proficiency with sound specific contact patterns, however, there continued to be discrepancies when compared to the native production of this sound, indicating continued difficulty mastering the L2.

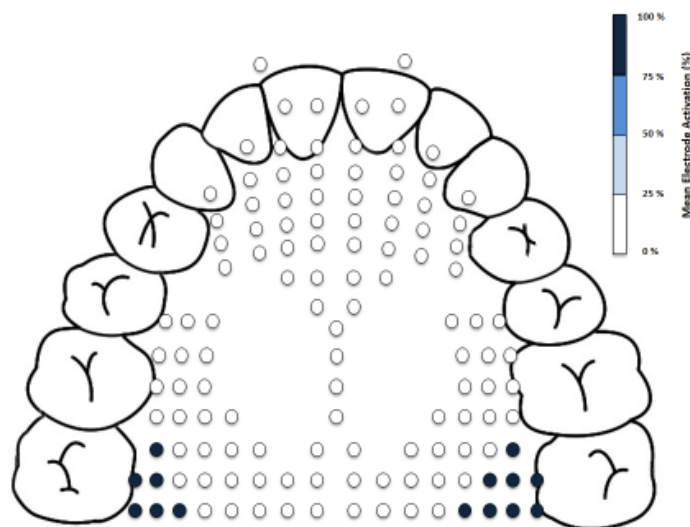


Figure 18. Subject 4's electrode mapping of [x].

Subject 7 also exhibited asymmetrical lingua-palatal contact patterns. As shown in Figure 19, subject 7's electrode mappings revealed increased contact on the right side of their hard palate. This subject produced sounds with greater right-sided lingua-palatal contact while the remaining native and non-native subjects' productions were judged to be fairly symmetrical. This right sided imbalance may be attributed to learned speech behavior that may also be present in their production of English fricatives. The asymmetrical contact patterns may also be a result of poor adaptation to the EPG device. Previous research findings vary in regards to EPG adaptation. Some researchers have reported no overt speech differences following only five

minutes of adaptation, while many others claimed some speakers may never fully adapt to the pseudopalate, even after an extended adaptation period (Barrett, 2012; Gibbon et al., 1991).

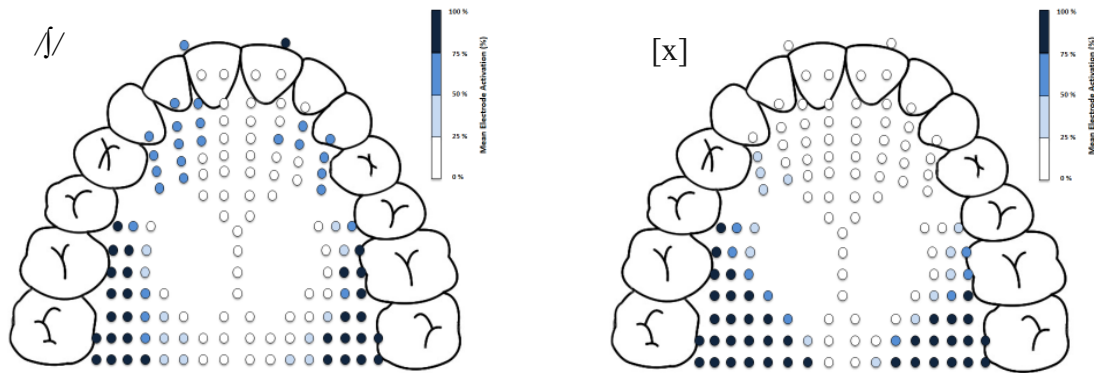


Figure 19. Subject 7's electrode mappings, right-sided excursion

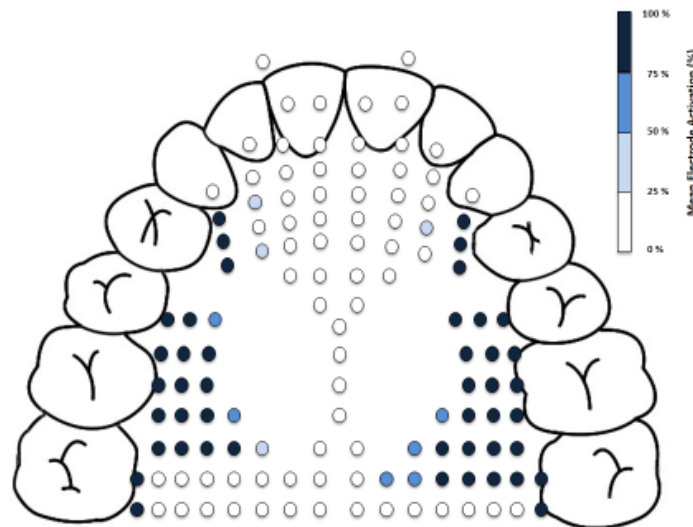


Figure 20. Subject 9's electrode mapping of [ç], decreased posterior activation.

Subject 9's electrode mapping for [ç], shown above in Figure 20, indicated little to no posterior lingua-palatal contact. This pattern of contact differs from the majority of speakers who exhibited a relative increase in posterior contact.

Furthermore, in addition to the previously mentioned individual differences, another interesting difference was revealed in the subjects productions of the /s/ phoneme. The majority of subjects produced /s/ with palatal contact patterns that were more representative of the English /l/. Subjects appeared to be brushing (stopping) their tongues slightly against the alveolar ridge. Typically, a narrow central groove would be expected and would appear on the electrode mappings along the alveolar ridge. However, the individual participant mappings, shown in Appendix C, reveal more complete contact along this ridge when producing /s/. This may be due to the fact that the contact pattern was extracted at the maximal point of contact during the fricative and not in the middle of the sound. Thus, as the speaker tapped the tip of their tongue lightly against the alveolar ridge at the beginning or end of the sound, it would be this contact pattern that would have been extracted. It may be beneficial in future research to extract contact patterns from the /s/ productions near the 50% duration time point rather than at the point of maximal contrast.

The current study only evaluated 12 subjects as they produced fricative sounds during one session of data collection therefore, it may be beneficial to increase the number of participants. Additionally, it would be beneficial to quantify production patterns from a variety of sound classes (i.e., obstruents, stops, affricates) across an increased number of data collection periods to account for sound class variables and increased familiarity with the task.

Further research is necessary to quantify the articulatory patterns of individuals across age ranges and across varied levels of proficiency. The current study only included students age

17-25 within an introductory level course (second semester) at Brigham Young University. While these participatory guidelines reduced confounding variables, current results may be limited to individuals within this age range and level of German proficiency.

Although continual research may be necessary to more fully understand the efficacy of using EPG as an instructional tool for second language acquisition, the current study provides a reliable basis for which future research may expand upon. Specifically, the palatal contact mappings created within this study and the collection of percentages of regional activation and COG measures provide multiple avenues for future research.

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APPENDIX A: Annotated Bibliography

Bartle-Meyer, C. J., Goozée, J. V., & Murdoch, B. E. (2009). Kinematic investigation of lingual movement in words of increasing length in acquired apraxia of speech. *Clinical Linguistics & Phonetics*, 23, 93-121. doi:10.1080/02699200802564284

Objective: This chapter discusses the use of EPG technology to describe the areas of the tongue that are involved in the production of speech. Additionally, it reviews cases in which EPG has been utilized to promote its use in treating individuals with apraxia of speech. *Method:* The authors evaluated lingua-palatal contact patterns in single words, phrases, and connected speech. They gathered mappings of these contact patterns and used them to indicate the need for having bio-feedback when trying to instruct clients to produce a particular path of movement at a particular speed. *Results:* Implementation of EPG allows therapists and their clients to gather information as to the interaction of the tongue, jaw, and other articulators during speech. These interactions can be used to develop specific instructions for facilitating improved understanding and performance of the desired speech behavior. *Conclusions:* Understanding and seeing articulatory interactions through the use of EPG technology can facilitate increased intelligibility as individuals with apraxia of speech are provided with a reproducible model for speech movements and rates. *Relevance to current study:* EPG technology can be used to quantify lingua-palatal contact patterns.

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 this study was to evaluate the effectiveness of using EPG therapy to reduce accent within Spanish speakers learning English. *Method:* Participants of this study included three adult females who were native speakers of Spanish learning English. Connected speech samples were collected from the participants (before and after EPG therapy) and reviewed by native speakers of English who rated the overall intelligibility of the sample with emphasis placed on particular sound classes. A formal accent test was also conducted. *Results:* The presence of an accent went from 59% to 16%. *Conclusions:* The visual feedback provided from EPG therapy is useful in accent reduction of L2 learners. *Relevance to current study:* EPG instruction is linked to positive outcomes for second language learners however these outcomes have not yet been evaluated in relation to the German language.

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: This study explores the effectiveness of using EPG treatment on children with persistent speech disorders. It aimed to determine whether children benefited and to identify what factors may be used in predicting what client types would benefit from this treatment. *Method:* There were eight males and two females ranging from 7 – 14 years of age with a diagnosed speech disorder employed for this study. Each child underwent 10 weeks of EPG articulation therapy. Prior to therapy and at the conclusion of therapy, speech samples were gathered with and without the palate inserted. Perceptual judgments and EPG readings were used to determine each child's rate of improvement. Age, diagnosis type, oral-motor structure, therapy schedule and therapy targets were considered to provide a predictive outcome to each child.

Results: Compilation of data indicated acoustic and perceptual improvements in consonant production for all participants. Predictive factors were determined to be reliable measures for prognosis and awareness and motivation were discovered to be additional factors. *Conclusions:* EPG appears to be a beneficial approach for a range of speech disorders and several predictive factors are present. Continued assessment and identification of factors would be beneficial.

Relevance to current study: EPG technology can facilitate speech development in children who have long-standing speech sound disorders, despite typical physical and intellectual development.

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: The aim of this study was to determine the effectiveness of electropalatography (EPG) in diagnosing and remediating articulation and phonological disorders in children.

Method: Authors presented instrumentation options, EPG speech training procedures, and considerations for client candidacy. Additionally, reviews of articulation and phonological disorder treatments utilizing EPG were presented. *Results:* Study indicated some children present with systematic differences in their articulatory posture warranting re-evaluation of the effectiveness of EPG with these children. Phonological treatment with EPG was determined to be effective when teaching sound inventories rather than eliminating processes. Teaching children articulator positions may facilitate generalization of rules and sound combinations.

Conclusions: EPG provides information about potential causes of speech problems and proves to be an effective method for remediating speech disorders. *Relevance to current study:* EPG's

unique ability to quantify lingua-palatal contacts allows for the identification of abnormal patterns or varied manners of speech sound production.

Dromey, C., Nissen, S., Nohr, P., & Fletcher, S.G. (2005). Measuring tongue movements during speech: Adaptation of a magnetic jaw-tracking system. *Speech Communication, 48*, 463-473. doi: 10.1016/j.specom.2005.05.003

Objective: The purpose of this study was to determine if tongue movements during speech could be measured using a device commonly used for tracking jaw movement. *Method:* Tongue movements were tracked using The BioResearch Associates JT-3 jaw tracking instrument. Each subject was fitted with a tongue magnet and a corresponding headset. Data was collected before and after insertion and acoustic analysis was performed on the acoustic properties of voiceless fricatives. *Results:* Production of fricatives appeared to be unaffected by the presence of a magnet. *Conclusions:* Jaw-tracking devices were capable of recording tongue movements, however limitations were noted. Limitations to this method included the inability to separate two points in space, reliance on steady head position, and small magnet size. Jaw-tracking devices may be useful for basic and applied research however, more advanced instrumentation would be ideal. *Relevance to current study:* More specific tracking instruments, such as EPG, should be used for research pertaining specifically to the varied speech production patterns of second language learners.

Fletcher, S. G. (1988). Speech production following partial glossectomy. *Journal of Speech and Hearing Disorders 53*, 232-238.

Objective: The purpose of this study was to evaluate the speech of individuals following partial removal of their tongue. Changes in dimensions and patterns of articulation to compensate for their excised tongue tissue were main areas of investigation. *Method:* The subjects for this study included three speakers with varying degrees of partial glossectomy. Each subject was asked to produce pre-determined sound targets while EPG and acoustic recordings were gathered.

Results: Evaluation of contact patterns and acoustics revealed articulation was shifted to parts of the vocal tract for some speakers while metrical properties (width) were maintained.

Intelligibility appeared to have decreased however, it was still sufficient for communication when compensatory articulatory contacts were utilized. *Conclusions:* This study showed

compensatory articulatory patterns could be developed to achieve intelligible speech. EPG technology may be beneficial in teaching or describing these compensatory strategies. *Relevance to current study:* EPG technology has proven functional in quantifying and teaching compensatory speech production patterns, thus it may also prove functional in quantifying the articulatory patterns of second language learners of German.

Fletcher, S. G. (1992). *Articulation: A physiological approach*. San Diego, CA: Singular Publishing Group, Inc.

Within this publication the author discusses a physiologically-based approach to teaching and learning appropriate articulation. He explicitly discusses the use of palatometry and the benefits that can come from using such instrumentation. Fletcher outlines the use and underlying features of EPG technology. He explains the three dimensions in which articulatory events are portrayed by EPG technology and discusses their application in teaching speech as a motor skill. Fletcher defends the use of EPG technology and identifies numerous bio-feedback benefits that come

form utilizing this alternate approach to teaching and learning articulation. Numerous explanations of the design and benefits of EPG technology are presented. In relation to the current study, EPG technology provides biofeedback that could be beneficial for the instruction of second language learners.

Gibbon, F., Hardcastle, W. J., Crampin, L., Reynolds, B., Razzell, R. & Wilson, J. (2001) Visual feedback therapy using electropalatography (EPG) for articulation disorders associated with cleft palate. *Asia Pacific Journal of Speech, Language and Hearing*, 6, 53-58.

Objective: Primary reasoning for this study was to evaluate the effectiveness of using EPG technology in the treatment of articulation disorders secondary to cleft palate. *Method:*

Developers of this study used 12 randomly selected children with repaired cleft palates as participants. Participants were randomly assigned to one of two treatment groups. Group A completed 4 weeks of EPG based articulation therapy followed by 4 weeks of traditional therapy while Group B completed 4 weeks of traditional therapy followed by 4 weeks of EPG based therapy. Specifically, contact patterns for /s/ and /t/ were evaluated. *Results:* EPG based treatment revealed normal palatal contact for 75% of participants while traditional therapy appeared to have no affect on articulatory patterns for 92% of participants. 25% of participants failed to respond to either the EPG based or the traditional treatment. *Conclusions:* EPG therapy is more effective in improving the articulation of those with cleft palate compared to traditional therapy. Additionally, although EPG therapy proved beneficial to many it may not be effective for all. *Relevance to current study:* EPG technology can be used for multiple purposes, aside from basic articulation remediation. Second language instruction may be one of these additional purposes.

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: This study was designed to evaluate the use of EPG technology in second language learning. Specifically, researchers aimed to explain the /l/ and /r/ distinction that is frequently difficult for Japanese individuals learning English as a second language. *Method:* Japanese individuals learning English as a second language were the subjects for this study. Their ability to identify and distinguish the difference between /l/ and /r/ sound classes not found in Japanese were evaluated using acoustic instruction alone and biofeedback instruction using EPG. *Results:* The study revealed distinguishing /l/ from /r/ was very difficult for these second language learners when provided acoustic instruction alone. With the addition of biofeedback from EPG technology the second language learners more appropriately distinguished these two sounds. *Conclusions:* Implementation of EPG technology may help to facilitate second language learning. Specifically, EPG may help second language learners more readily distinguish sound classes that may be particularly difficult. *Relevance to current study:* EPG technology appears beneficial in remediating the difficulties second language learners of English experience with the /l/ and /r/ contrast. Thus, EPG technology may also be beneficial in helping second language learners of German distinguish between the ich-laut and ach-laut sound contrast.

Gibbon, F. E., & Paterson, L. (2006). A survey of speech and language therapists' views on electropalatography therapy outcomes in Scotland. *Child Language Teaching and Therapy*, 22, 275-292. doi: 10.1191/0265659006

Objective: The purpose of this study was to evaluate speech therapists' views as to the effectiveness of using electropalatography as a therapy technique in the treatment of school-age children with articulation difficulties. *Method:* An EPG questionnaire developed by a small group of speech-language therapists was distributed to 10 therapists who had treated a total of 60 school-age individuals using EPG therapy between the years 1993 and 2003. The questionnaire gathered information relating to demographics, therapy details (how many sounds targeted, number of sessions, etc.), type of speech sound disorder, and relative outcomes for each child. *Results:* Completion of the questionnaire revealed the most frequently targeted speech sounds amongst participants of EPG therapy were /t/, /s/, and /d/. A large degree of the participants were determined to have improved their articulation and increased their self-awareness following the implementation of EPG treatment. Although there appeared to be improvement for many of the participants, generalization of improved articulation was not widely exhibited. *Conclusion:* Implementation of EPG technology appeared to improve articulation in hard to treat cases and may be a beneficial for some clients. Due to the decreased likelihood for generalization of skills, speech therapists who utilize EPG should employ additional measures to promote generalization. *Relevance to the current study:* Some professionals believe EPG technology is beneficial for facilitating appropriate speech sound productions in cases where traditional articulation therapy has proven unsuccessful. Thus, EPG may also be beneficial for cases where traditional language (auditory) instruction has not shown positive outcomes.

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.

This chapter aimed to discuss the use of EPG technology in identifying and describing the articulatory patterns of individuals with apraxic speech. The authors argue that explanation of speech patterns and misarticulated sounds is difficult using perceptual measures alone. They present EPG technology as one way in which to overcome perceptual drawbacks and facilitate increased understanding and treatment of apraxia of speech. EPG appeared useful in describing the temporal and spatial characteristics of sounds within speakers with apraxia. Misdirected articulatory contacts, distorted spatial patterns, omission of target sounds, and seriation problems could all be better explained through use of the EPG technology. Implementation of EPG technology for the identification and treatment of individuals with apraxia of speech appeared beneficial however, EPG may not be appropriate for all. Special considerations should be employed to determine candidacy. This information is important for the current study because EPG technology has been used to quantify the lingua-palatal contact patterns of individuals with apraxia of speech, thus it could also be used to quantify the patterns of second language learners.

Hei Yan, C., Murdoch, B. E., Goozée, J. V., & Scott, D. (2007). Electropalatographic assessment of tongue-to-palate contact patterns and variability in children, adolescents, and adults.

Journal of Speech, Language & Hearing Research, 50, 375-392. doi:10.1044/1092-4388

Objective: This study investigated the normal development of tongue-to-palate contact throughout maturation. Additionally, it analyzed contact variability related to change and stability. *Method:* Children and adults (48) ranging from 6 – 38 years participated. All participants were Australian English speakers with no history of speech, language, or hearing impairment. Participants were fitted with a pseudopalate and underwent a one-week desensitization period in which they were encouraged to converse with the palate inserted at their

leisure (> 20 min). Data was collected as subjects repeated short sentences five times. It was analyzed by evaluating frames of maximum contact to quantify electrodes activated and identify closure and constriction. *Results:* Major changes occurred with tongue-to-palate contact for the 6-11 years age group. Adolescents appeared to reduce these changes and exhibited more refinement of articulatory control. As age increased, palatal contact reduced and place of articulation became more consistent. *Conclusions:* This study concluded that visual inspection is not an accurate representation of tongue-to-palate contact. This method suggested adult and child contact patterns resembled one another, but through EPG analysis it is concluded that there appears to be a maturation trend. Age was the major difference in tongue-to-palate contact although gender was found to show some influence. *Relevance to current study:* EPG technology can provide a more in depth quantification of contact patterns compared to visual inspection alone. Thus, to determine variations between native and non-native speaker's production patterns it is imperative to use instrumentation such as EPG to gather more representative information.

Horn, H., Kuhnast, K., Axmann-Krcmar, D., & Goz, G. (2004). Influence of orofacial dysfunctions on spatial and temporal dimensions of swallowing movements. *Journal of Orofacial Orthopedics*, 5, 376-388.

Objective: The primary purpose of this study was to analyze the sequence of swallowing movements in the presence of lip or tongue abnormalities through the use of electromagnetic articulography to advance diagnosis and treatment options. *Method:* This study included 31 subjects. They were observed during reflexive swallows and also during swallow trials of 20mL water. Resulting swallows were analyzed spatially and temporally. *Results:* There were found to be fewer significant temporal differences while spatial differences were more prevalent.

Maximum contact differences were noted at the point of palate separation and continued to the end of the swallow. *Conclusions:* Electromagnetic articulography can be used in identification and treatment of lingual dysfunction. *Relevance to current study:* Even within the complex sequence of swallowing, lingual dysfunction can be identified using electromagnetic articulography therefore EPG technology can likely identify contact patterns within non-native speech.

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: This study was designed to compare timing and spatial measures of speech, captured by EPG technology, between a group of individuals with dysarthria and a group of non-impaired individuals. *Method:* The subjects for this study included 11 individuals with dysarthria secondary to a severe traumatic brain injury and 10 sex and age matched individuals with no known neurological impairments. The dysarthria group included severity levels from mild to severe. Subjects were fitted with artificial palates and EPG recordings were conducted as they produced speech at the syllable and sentence levels targeting specific speech sounds at a habitual rate and loudness. *Results:* Comparison of the EPG contact patterns across groups indicated articulatory slowness, impaired accuracy, impaired coordination of articulatory movements, and impaired speech motor control amongst the individuals with dysarthria. Spatial differences also appeared more prevalent amongst the dysarthric group. *Conclusions:* EPG revealed individuals with dysarthria utilize different spatial and temporal features in speech production compared to typical individuals. These differing features may account for their perceived speech deficits.

Relevance to current study: EPG technology can quantify the timing and spatial measures of speech, which is one of the first components necessary before using EPG as a tool for second language instruction.

Macfarland, T., & Pierrehumbert, J. (1991). On ich-Laut, ach-Laut and structure preservation.

Phonology, 8, 171-180.

Objective: The purpose of this article was to explore the defining characteristics amongst the common German contrast ich-Laut and ach-Laut. *Method:* Authors of this article evaluated the usage of the contrast throughout German language to establish rule-based usage. *Results:* Ich-laut or [ç] is a voiceless palatal fricative while ach-laut or [x] is a voiceless velar fricative. These allophones present in a complementary manner as each phone occurs in specified phonetic environments. The [ç] fricative is utilized following front vowels and the [x] fricative is utilized following back vowels. *Conclusions:* The rule-based system behind this contrast is difficult for non-native speakers to acquire. *Relevance to current study:* The German contrast ich-Laut and ach-Laut is frequently distorted amongst non-native speakers, however it has a high-degree of lingua-palatal contact that can be quantified using EPG thus providing biofeedback that may reduce these distortions. Additionally, EPG technology has not been evaluated as an instructional tool for German specifically, therefore it would be beneficial to evaluate EPG's role in teaching this difficult sound contrast.

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: The purpose of this study was to use electropalatography to describe the speech patterns of individuals with Parkinson's disease. Lingua-palatal contacts and consonant imprecision were the main areas of interest. *Method:* A Parkinson's group and a control group were utilized within this study. Each subject was asked to read aloud a carrier phrase ('I saw a --- today') targeting specific sounds (initial /l/, /s/, and /t/) while wearing an artificial palate. Phonetic transcriptions and description of errors were completed for each production in addition to explanation of tongue-palate contact patterns and spatial palatal indices. *Results:* Interpretation of the perceptual transcriptions and the EPG contact patterns revealed that the Parkinson's and control groups differed in their rate of undershooting articulatory contacts. Individuals with Parkinson's disease appeared to more frequently undershoot consonant productions however the EPG revealed many of these individuals still reached the appropriate contact but utilized reduced force and impaired timing. *Conclusions:* Evaluation of these results indicated that EPG technology could be useful for training lingua-palatal contact pressure levels and timing for individuals with Parkinson's disease. Previously, EPG has mainly been utilized to teach contact areas, however it may also serve a function in teaching timing gestures and contact force. *Relevance to current study:* EPG technology has been used to quantify the lingua-palatal contact patterns of individuals with Parkinson's, thus it could also be used to quantify the patterns of second language learners.

Michi, K., Yamashita, Y., Imai, S., Suzuki, N., & Yoshida, H. (1993). Role of visual feedback treatment for defective /s/ sounds in patients with cleft palate. *Journal of Speech, Language, Hearing Research, 36*, 277-285.

Objective: Authors of this study aimed to evaluate the effectiveness of using visual feedback when treating distorted /s/ due to cleft palate. *Method:* This study used six individuals with similar ages, misarticulation patterns, and velopharyngeal function. They were divided into two groups and participated in either EPG therapy or traditional therapy. *Results:* Participants treated with EPG therapy revealed increased speech intelligibility compared to individuals who participated in traditional therapy. *Conclusions:* Visual feedback is beneficial for increasing awareness of tongue placement and friction throughout sound production. *Relevance to current study:* Biofeedback can facilitate the accurate production of /s/, therefore it may also be able to facilitate the accurate production of German sounds that are frequently distorted by native English speakers learning German.

Moulton, W.G. (1962). The sounds of English and German. Chicago, IL: University of Chicago Press.

The author of this book reviews the sounds of English and German and aims to describe the contrasts between the two languages. Several sound contrasts that are particularly difficult when learning German as a second language are discussed however, the author's discussion of the common German contrast *ich-Laut* and *ach-Laut* is of particular interest. The author reveals that difficulty with this contrast is likely due to having to produce a non-native sound while simultaneously evaluating the context. Several German sounds are particularly difficult for native English speakers. These sounds are ideal targets as they readily identify varied articulatory contact patterns to between native and non-native speakers of German.

Nissen, S. L., & Fox, R. A. (2005). Acoustic and spectral characteristics of young children's fricative production: A developmental perspective. *Journal of the Acoustical Society of America*, 118, 2570-2578. doi: 10.1121/1.2010407

Objective: This study explored the relationship between acoustics and perception by examining the production of voiceless fricatives. *Method:* The subject pool for the study was composed of 30 children (3 to 6 years) and 10 adults. All subjects were English speaking, had no history of speech, language, or hearing deficits, and were required to pass a hearing and oral/motor exam. Additionally, all had typical dentition and test appropriate articulation on the Goldman Fristoe Test of Articulation (GFTA). Single syllable words (CV) consisting of the voiceless fricatives /f, θ, s, ʃ/ followed by one of the following vowels /i, a, u/ were inserted in a carrier phrase ('This is a -') and used for this study. Subjects identified target productions via picture identification. Recordings of productions were collected and analyzed using discriminant analysis to identify fricative durations, normalized amplitude, spectral moments, and spectral slope. *Results:* Acoustic analysis indicated spectral slope and variance aided in the classification of voiceless fricatives. Spectral variance appeared to be the most informative measure as it was the only measure to identify all four places of articulation. Evidence of differing spectral parameters was identified between children and adults. *Conclusion:* This study concluded that age can influence the place of articulation, suggesting development of sibilant contrast continues to develop into adulthood. *Relevance to current study:* Acoustic analysis can be used as an additional measure for the quantification of articulatory contact patterns.

Pena-Brooks, A., & Hedge, M. N. (2007). Assessment and treatment of articulation and phonological disorders in children. Austin, TX: Pro.Ed.

The aim of this text is to educate professionals on the assessment and treatment of articulation and phonological disorders within the childhood population. Within the text the authors describe sound classes, articulation patterns and treatments to increase intelligibility. Of particular interest is the authors discussion of obstruents; the obstruent sound class contains stops, fricatives, and affricates made with complete closure or narrow constriction of the oral cavity, stopping the airstream or producing a friction noise. Knowledge of sound classes and production patterns is essential in identifying target sounds with ideal levels of lingua-palatal contact.

Ritterbusch, R., LaFond, L., & Agustin, M. (2006). Learner difficulties with German case:

Implications from an action research study. *Die Unterrichtspraxis/ Teaching German*, 39, 30-45. doi: 10.1111/j.1756-1221.2006

Objective: This article aimed to describe why many English speakers learning German as a second language demonstrate poor performance with the German case marking system. It intended to identify potential sources for case marking difficulty and provide pedagogical practices that might enhance second language learners performance. *Discussion:* Perhaps the complexity of the German case marking systems results in poor performance of second language learners. One form can indicate case, number, and grammatical gender, making acquisition and use of forms difficult. Reliance on word order and tendency to assign the role of agent using a “first noun strategy” may also hinder performance. *Method:* The subject pool for this study included 60 adult, native speakers of English. Participants completed a rating scale to self-evaluate their performance and understanding of German case and to gauge their level of opinion regarding case importance. Additionally, they completed a proficiency test in which they completed sentences and supplied the correct form of definite articles. *Results:* There appeared to

be a strong correlation between learner performance on the proficiency test and the self-assessment (i.e., those who rated their skills higher demonstrated better performance). These findings indicate transfer of skills learned in native language and the use of metalinguistic awareness (knowledge of rules) and grammatical competence (ability to produce language) can facilitate second language learning. Communicative instruction is not complete enough, explicit grammar instruction of German case is necessary to achieve native like speech. *Relevance to current study:* Knowledge of the German case marking system is essential in understanding the difficulty many native speakers of English experience when learning German sound contrasts.

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: The purpose of this study was to evaluate the development of a standardized grouping of palatometric articulation files. *Method:* This study utilized 20 native English speakers. Speakers were equipped with a pseudopalate to produce vowel consonant vowel (VCV) nonsense words with an initial schwa, palatal consonants (15), and corner vowels /i/, /α/, and /u/. EPG electrode activation was recorded throughout production, with the highest level of activation being used to develop a speaker variability index. *Results:* Consonants coarticulated with /u/ revealed greater variability than those coarticulated with the remaining vowels. Additionally, speakers who exhibited variability within one vowel context generally revealed variability within all vowel contexts. *Conclusions:* The study indicates that there is great articulatory variability between and within speakers, revealing that some degree of variability is normal. *Relevance to current study:* Varied lingua-palatal contact patterns may be typical to

some degree. Thus it is important to consider the degree of variation when determining how non-native German productions vary from native productions.

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 purpose of this study was to use EPG technology to assist in the teaching of native Thai speakers who were learning English as a L2. *Method:* The subjects for this study were three adult, native speakers of Thai, with normal bilateral hearing. Subjects were equipped with a pseudopalate and asked to utilize it for a two-week period prior to data collection to decrease negative effects. Participants were recorded saying consonant vowel (CV), VCV, and VC nonsense syllables in English, including the following English sounds: /t, d, k, g, ʃ, l, n, s, z, and f/. Participants were seen bi-weekly for 24 weeks. *Results:* All participants demonstrated the ability to accurately produce targeted sound contrasts. Participants also reported that the visual feedback was helpful throughout therapy. *Conclusions:* EPG technology is useful in teaching difficult sound contrasts however, generalization is not always evident. Additional practice with motor patterns is required to generalize accurate productions to all contexts. *Relevance to current study:* EPG technology has shown positive outcomes for the instruction of native Thai speakers learning English, thus EPG may also show positive outcomes when used as an instructional tool for learning German. However, EPG has not been evaluated in relation to German, therefore this research is warranted.

Southwood, M. H., Dagenais, P. A., Sutphin, S. M., & Garcia, J. M. (1996). Coarticulation in apraxia of speech: A perceptual, acoustic, and electropalatographic study. *Clinical Linguistics and Phonetics* 11, 179-203. doi: 10.3109/02699209708985190

Objective: This study was designed to explain the anticipatory coarticulation patterns in the speech of individuals with apraxia. *Method:* Subjects for this study were one adult individual with apraxia of speech and one normal control individual. Subjects were presented a carrier phrase ('say --- again') to produce repetitions of words containing specific vowels (/i/, /ɑ/ and /u/). These repetitions were produced at varying rates including slow, habitual, and fast. *Results:* The study revealed the individual with apraxia of speech to have EPG contact patterns that were variable and often inappropriate for the vowel, compared to those of the normal comparison subject. This indicated that the apraxic patient's coarticulatory gestures that differ in all rate conditions may be identifiable and then treated using EPG technology. *Conclusions:* Evaluation of the results within this study conclude that EPG technology may be valuable in identifying abnormal coarticulatory patterns that may be present in the speech of individuals with apraxia. *Relevance to current study:* EPG technology can be used to quantify the lingua-palatal contact patterns of individuals with apraxia, thus it could also be used to quantify the patterns of second language learners.

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: The purpose of this study was to evaluate the articulatory contacts of individuals with glossectomy and cleft palate using EPG technology. *Method:* The subject pool for this study was

comprised of 28 Native Japanese individuals, 25 being cleft palate cases and 3 being glossectomy cases. Japanese productions of VCV syllables were recorded. *Results:* The study revealed that individuals with glossectomies exhibited varied intelligibility although palato-lingual contact was limited. Additionally, individuals with cleft palate presented with three classes of misarticulations: lateral misarticulation, nasopharyngeal articulations, and palatalized articulations. *Conclusions:* This study indicates that EPG technology could be expanded from simply a diagnostic and treatment tool to a tool that can assess articulatory contact patterns under a variety of physical conditions. *Relevance to current study:* EPG technology can assess the physical conditions of contact patterns to identify differences prior to treatment of disorders. This identification should take place with second language instruction as well. In other words, the physical conditions of contact patterns should be obtained prior to using EPG as a tool for L2 instruction.

APPENDIX B: Informed Consent

Consent to be a Research Subject (speakers)

Introduction

The purpose of this research is to examine the effectiveness of using visual feedback to assist native English speakers learn 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 learner of German who is currently enrolled in a course in German language instruction 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. You will be asked to visit a local licensed dental professional to have an 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 your upper teeth. You will be asked to make recordings of your speech while producing German speech sounds and reading German words. These recordings will take place in a sound booth located in a research lab on the Brigham Young University campus.

These recordings will then be examined and if it is determined that your German pronunciation might improve by using visual feedback from a thin sensor placed over your hard palate, you will be asked to participate in the follow-up portion of the study. You will then be asked to use the sensor while practicing your pronunciation of common German words. You will practice for one hour and 20 minutes each week for four consecutive weeks in a computer lab on the BYU campus. You will be trained on the use and care of the sensor prior to the initial session of pronunciation practice. At the beginning, end, and four weeks following your pronunciation practice ends you will be asked to make recordings of your speech in a sound booth while reading a series of everyday German words. The dental visit, pronunciation practice, and recording will involve approximately 9 hours of your time over the course of approximately 3 months.

Risks/Discomforts

There are no known risks associated with participation in this study.

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 you participate in this study.

Participation

Participation in this research study is voluntary. You have the right to withdraw at anytime 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.

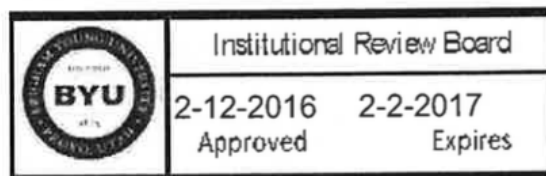
Questions about your Rights as Research Participants

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.

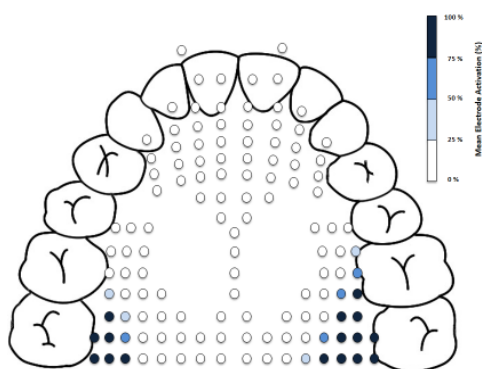
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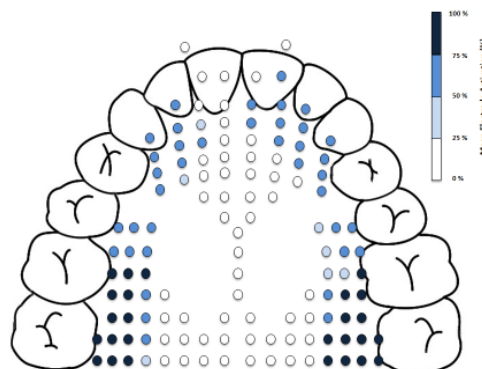


APPENDIX C: Individual Participant Contact Maps

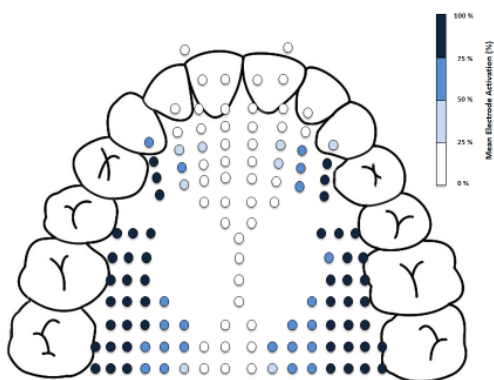
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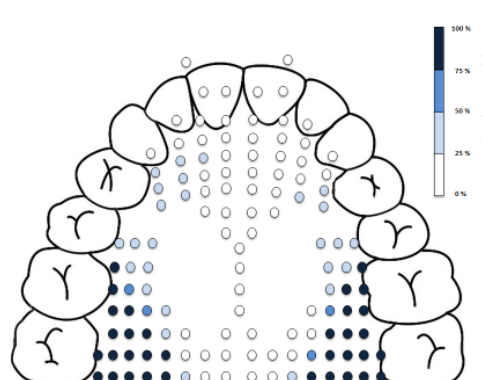
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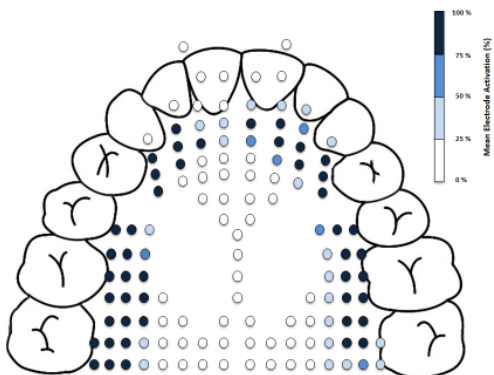
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[ç]

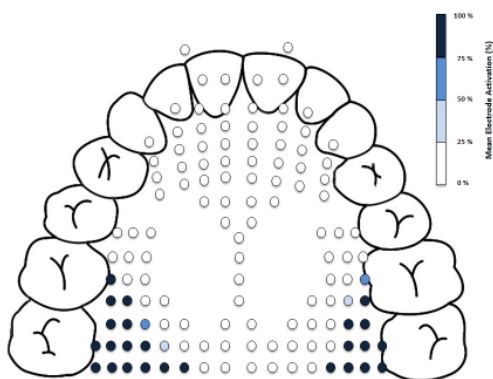


[ɤ] low-back vowel

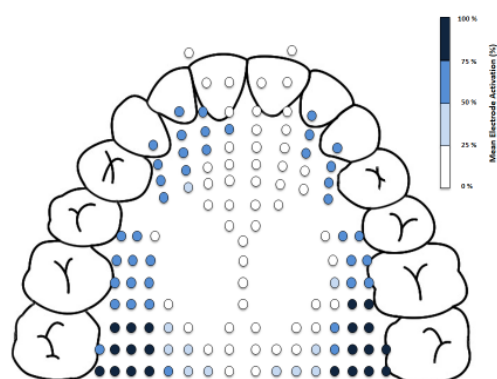


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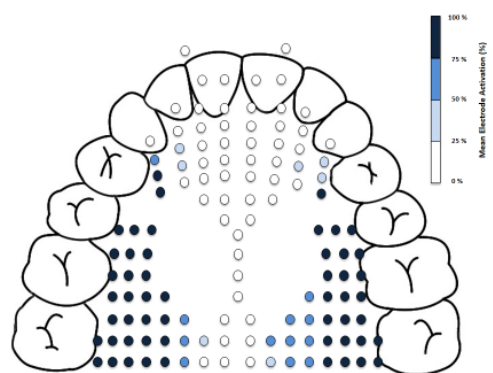
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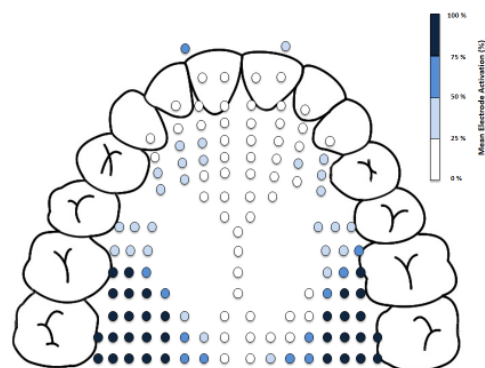
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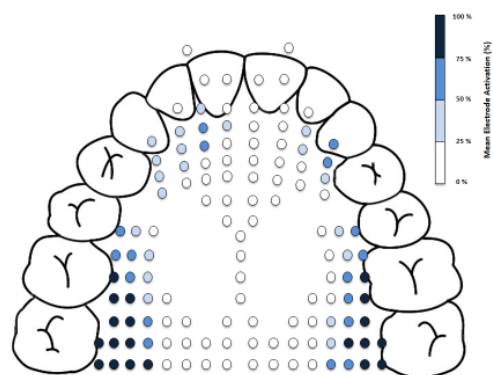
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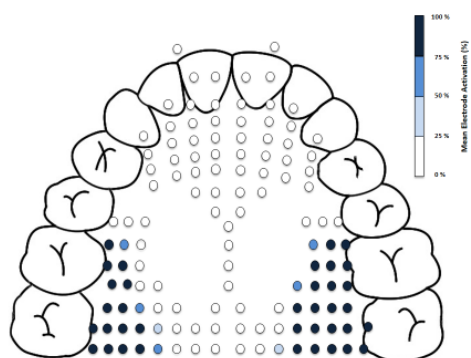


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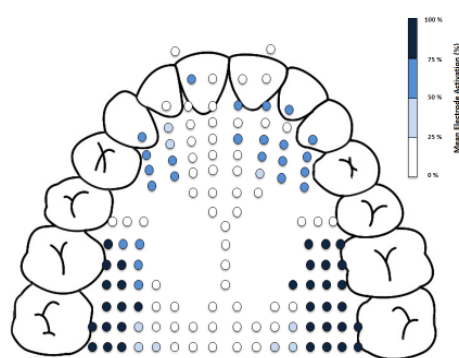


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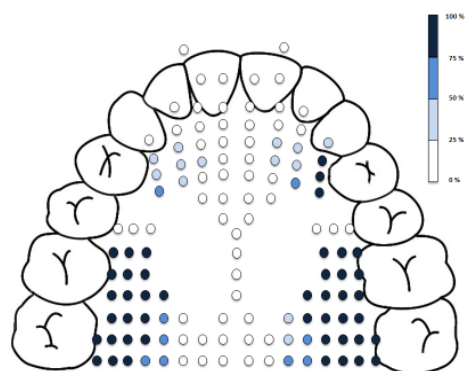
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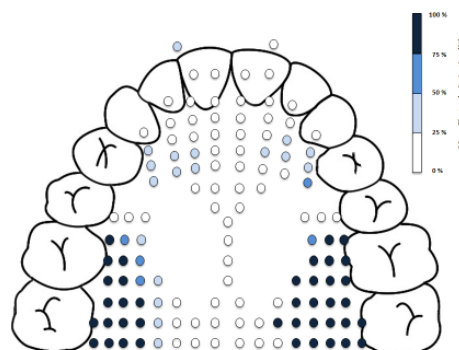
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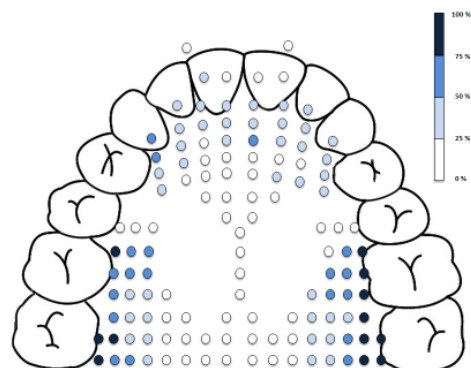
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[ɛ]

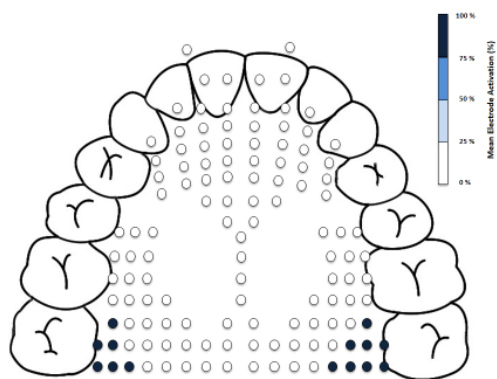


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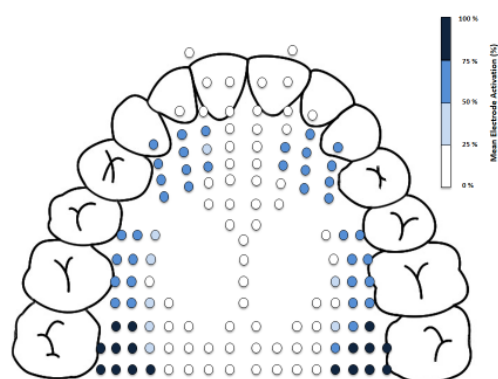


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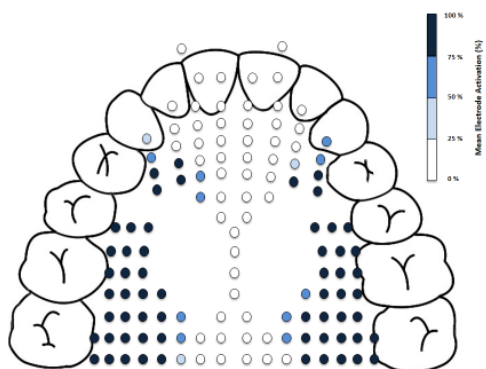
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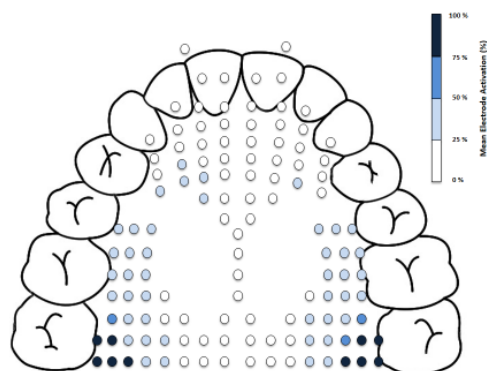
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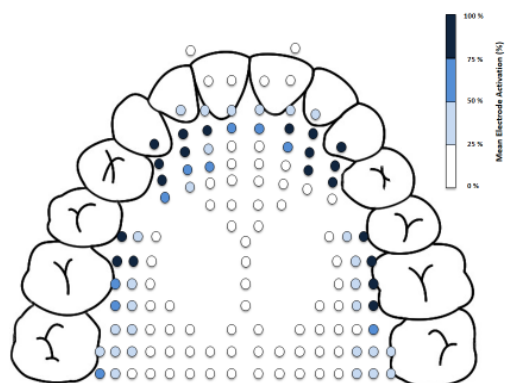
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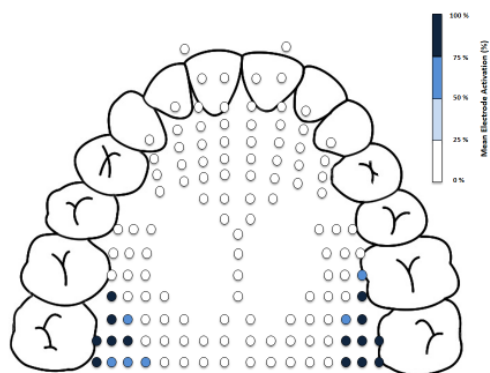


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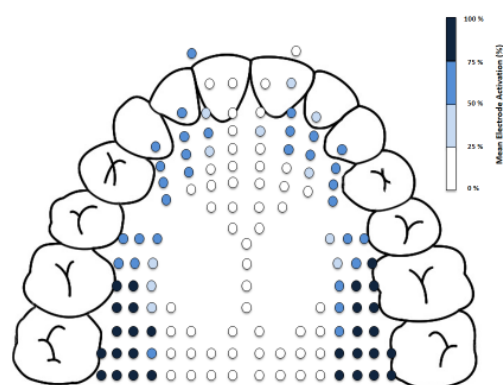


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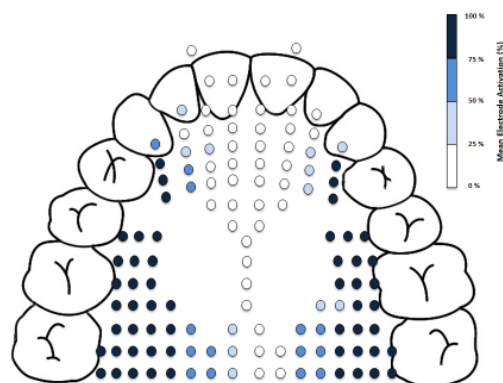
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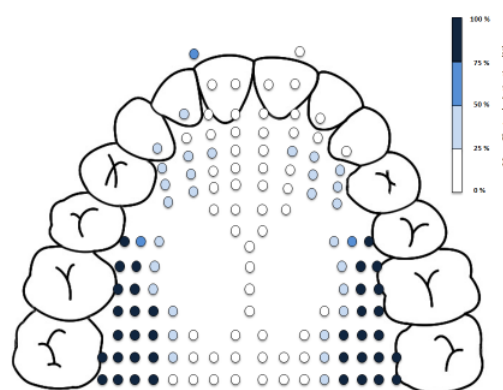
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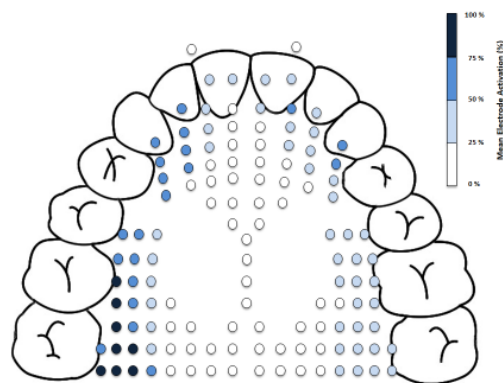
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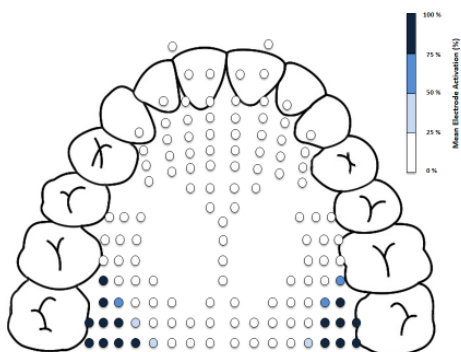


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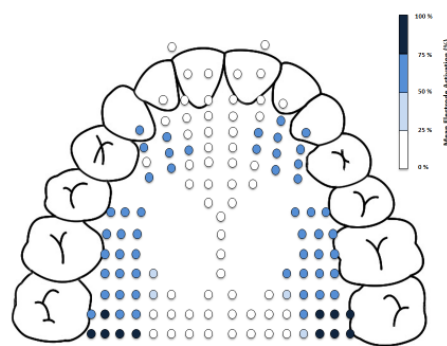


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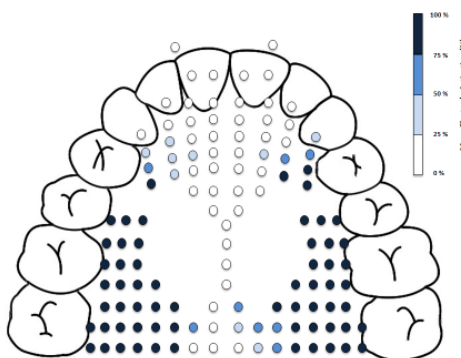
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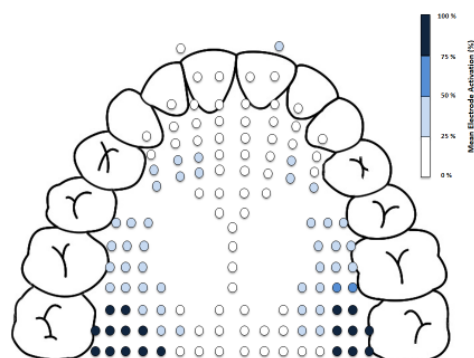
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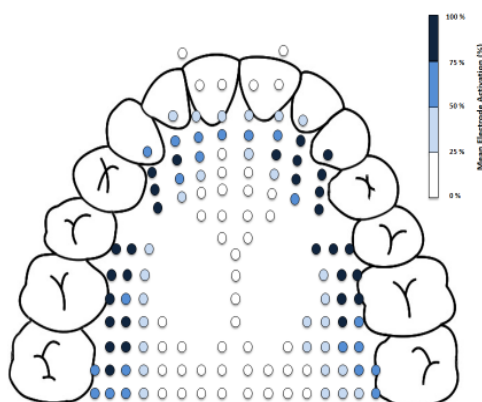
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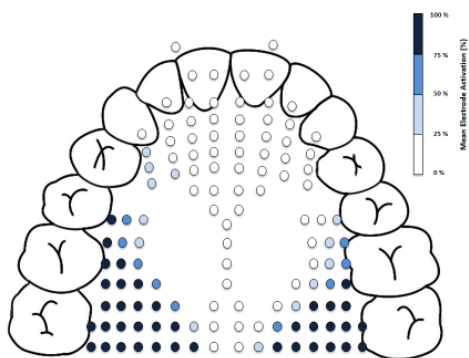


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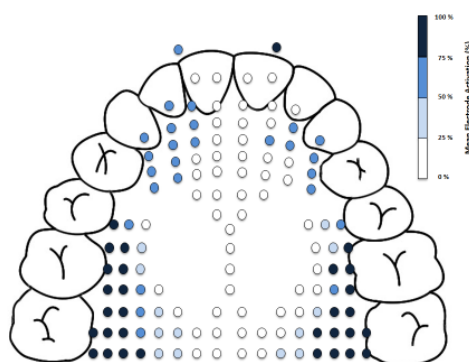


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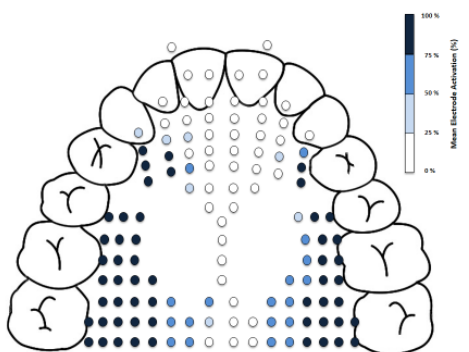
Subject 7



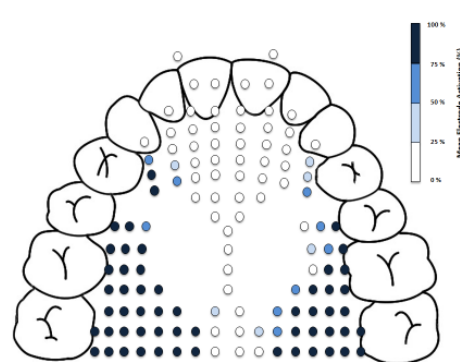
[x] high-back vowel



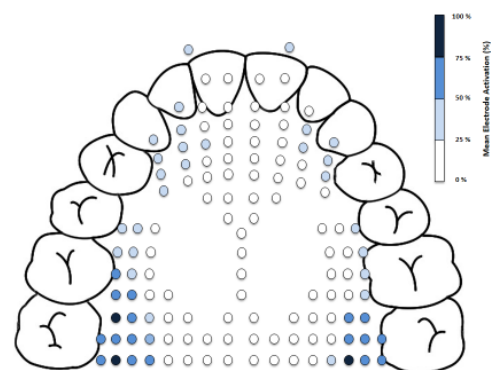
/j/



[ç]

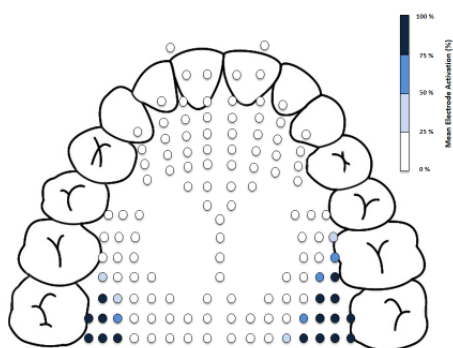


[x] low-back vowel

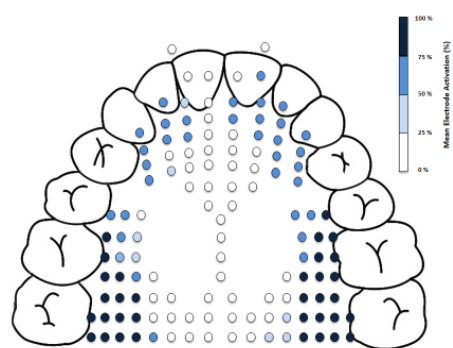


/s/

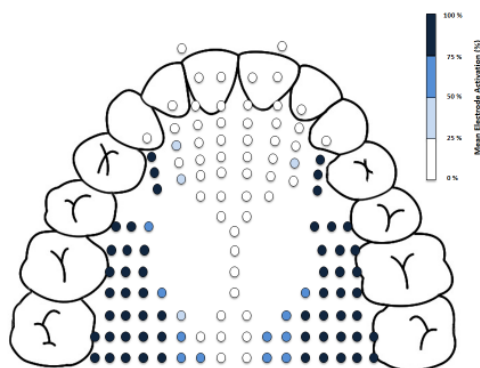
Subject 8



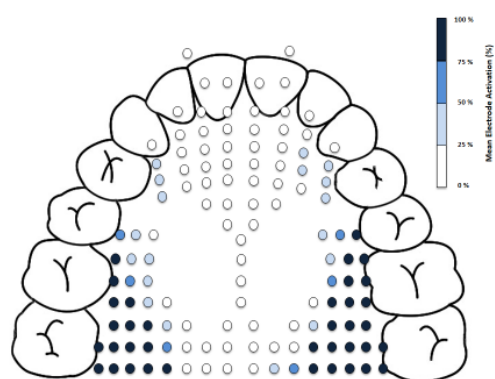
[x] high-back vowel



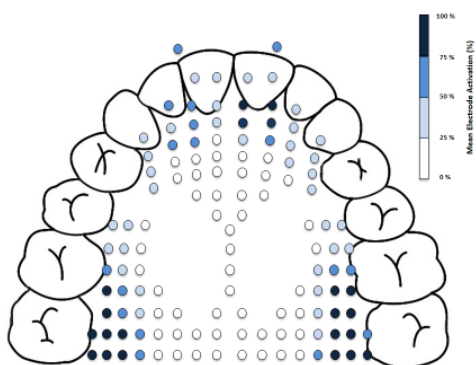
/ʀ/



[ç]

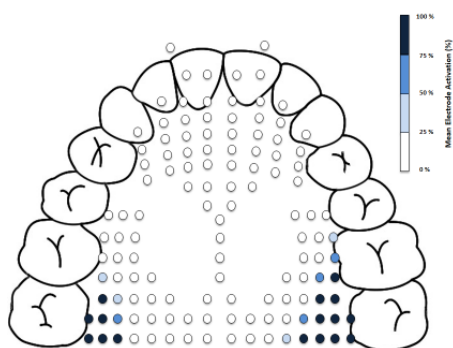


[ɤ] low-back vowel

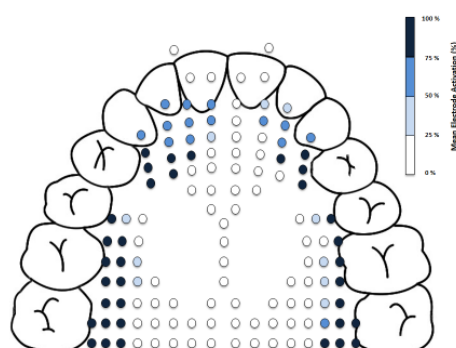


/s/

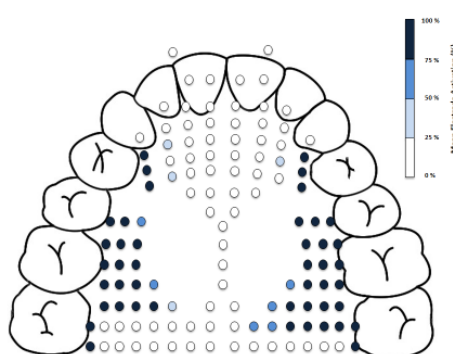
Subject 9



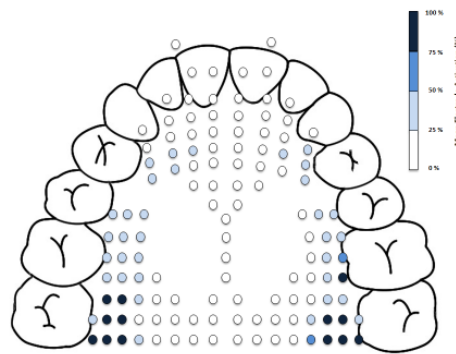
[x] high-back vowel



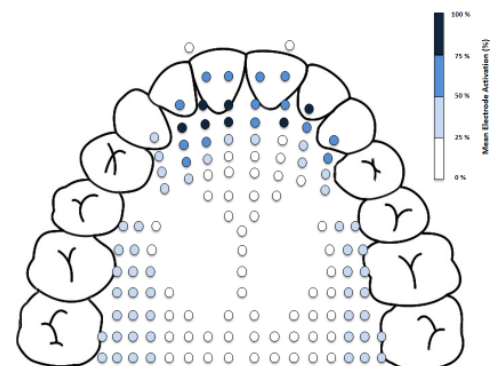
/ɪ/



[ç]

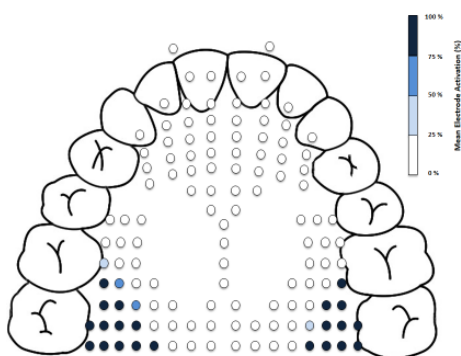


[x] low-back vowel

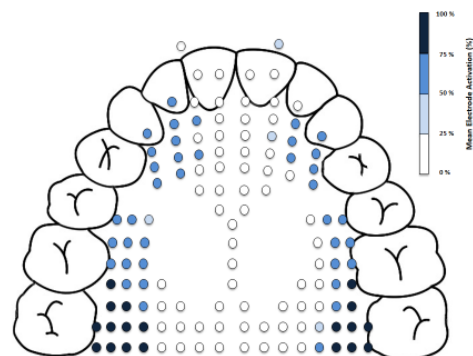


/s/

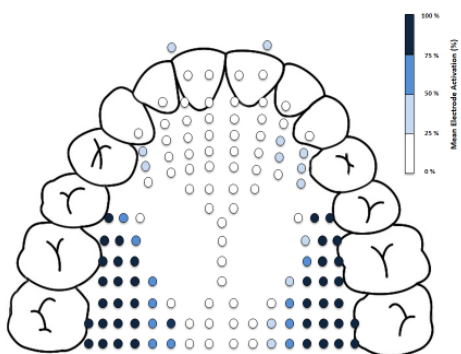
Subject 10



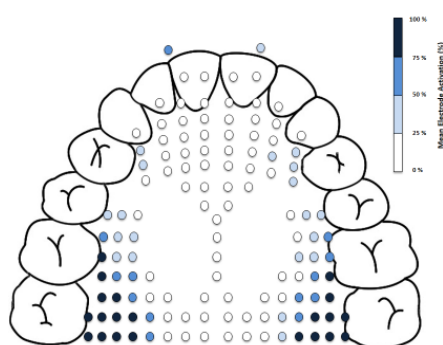
[x] high-back vowel



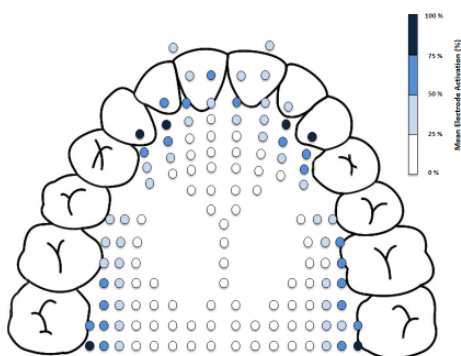
/ʃ/



[ç]

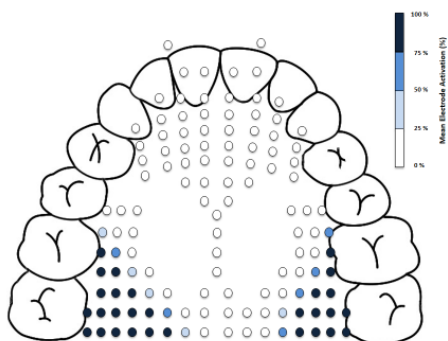


[ɣ] low-back vowel

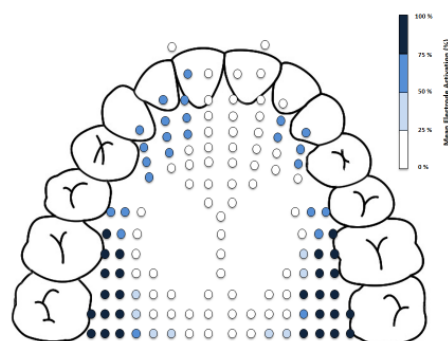


/s/

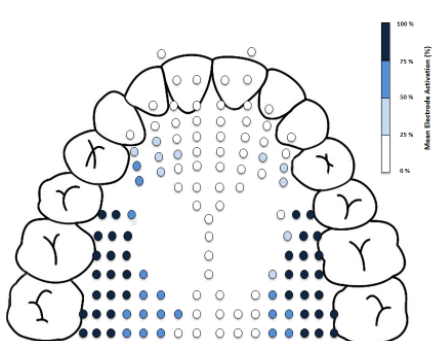
Subject 11



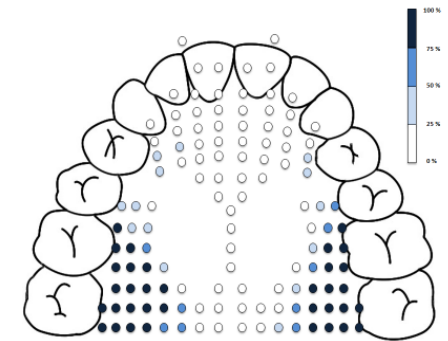
[x] high-back vowel



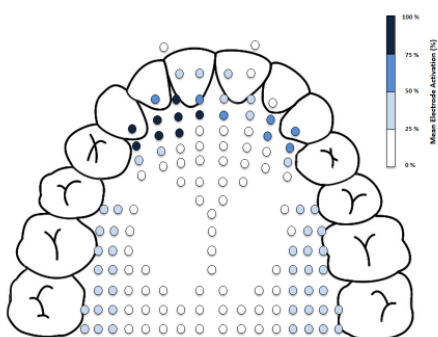
/j/



[ç]

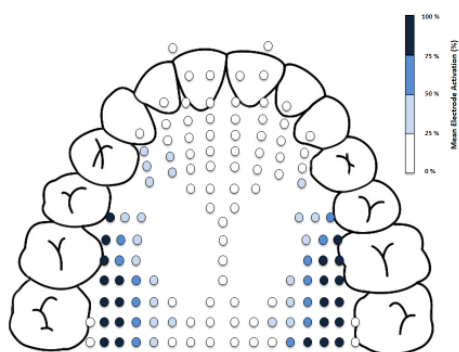


[x] low-back vowel

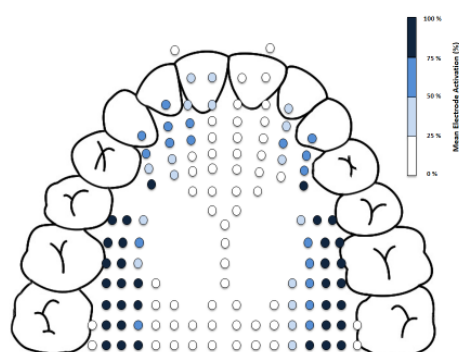


/s/

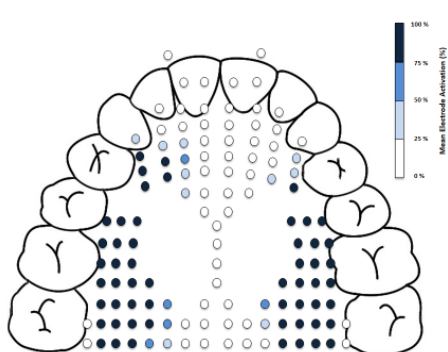
Subject 12



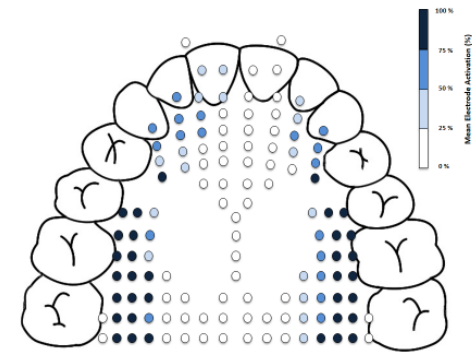
[x] high-back vowel



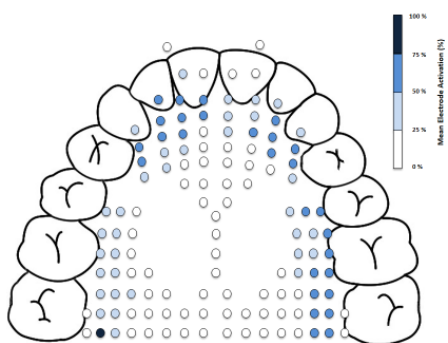
/i/



[ɛ]



[ɤ] low-back vowel



/s/