Individual variation in lexical palatalization:
Articulatory evidence from Scottish Gaelic*

Jae-Hyun Sung · Diana Archangeli · Samuel Johnston · Ian Clayton · Muriel Fisher · Michael Hammond · Andrew Carnie**

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** Yonsei University, Department of English Language and Literature (Jae-Hyun Sung, jsung@yonsei.ac.kr), University of Arizona, Department of Linguistics (Diana Archangeli, Samuel Johnston, Muriel Fisher, Michael Hammond, Andrew Carnie, {dba;sjcjohnston;murielf;hammond;carnie}@email.arizona.edu), University of Nevada, Department of English (Ian Clayton, iclayton@unr.edu)

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1. Introduction

Palatalization refers to a type of coarticulation in which the place of articulation of some sound is closer to the palate than otherwise expected, triggered by adjacent palatal segments. Palatalization is found in many languages (Bateman 2007), and is one of the well documented phenomena in the literature in terms of its relation to different types of higher-level linguistic structures in individual languages, especially in phonological and morphological aspects.

One aspect of palatalization is that it can either emerge as a lexical process governed by language-specific, obligatory rules (lexical palatalization), or as a post-lexical process that appears to be language-universal, optional and coarticulatory (post-lexical palatalization). For instance, /s/ in the English word *press* becomes palatalized in *pressure*, one of its derivatives. This /s/-to-[ʃ] palatalization in *press-pressure* exists as an obligatory rule in English phonology, in which failing to palatalize /s/ to [ʃ] results in an ill-formed realization of the word (i.e., *[pɹɛsjɚ]). In this regard, palatalization in *press-pressure* is a lexical process. When it comes to the English phrase *miss you*, however, the /s/-to-[ʃ] palatalization is optional, in which one may or may not palatalize /s/ (i.e., [mɪsju] or [mɪʃu]), or may palatalize /s/ to various degrees (i.e., [mɪsʲu] or [mɪʃu]). In the case of palatalization in *miss you*, palatalization is a post-lexical process. This paper examines palatalization that exists as a lexical process in Scottish Gaelic (Gàidlig, henceforth SG), an endangered language in Scotland which belongs to the Goidelic branch of the Celtic languages and has Manx and Irish Gaelic as sister languages (Simons & Fennig 2018).

The consonant inventory in the Gaelic language is shown in Table 1. Plain and palatalized coronal consonants excluding /j/ and /ðʲ/ will be the focus of this study.

<Table 1> The consonant inventory in Gaelic (Ladefoged et al. 1998)

	Plain			Palatalized			Velarized	Glottal
	Lab.	Cor.	Vel.	Lab.	Cor.	Vel.	Cor.	
Stop	p^h p	t^h t	k^h k	p^{hj} p^j	t^{hj} t^j	k^{hj} k^j		
Nasal	m	n			n^j		(n^ɣ)	
Fricative	f v	s	x ɣ	f^j	ʃ	ç ɣ^j		h
Rhotic		ɾ			ð^j		ɾ^ɣ	
Approx.		j						
Lateral		l			l^j		l^ɣ	

SG exhibits complex consonant mutation, in which consonants undergo various phonological changes depending on their morphological contexts (Macaulay 1992, Ladefoged et al. 1998, Gillies 2002, Stewart 2004). As illustrated in (1), consonant mutation is prevalent throughout SG morphology. Although they show some sign of lenition, the patterns of consonant mutation in SG appear extremely idiosyncratic, in that there is no difference in underlying phonological representation between unmutated and mutated forms. In other words, there is no phonological motivation involved in mutation processes in SG. In this regard, consonant mutation in SG is considered highly lexicalized.

(1) Consonant mutation in SG (Sung 2015)[1)]

a. *<u>m</u>àgach* /m/ 'frog' - *do <u>mh</u>àgach* [v] 'your frog'

b. *<u>f</u>alt* /f/ 'dog' - *a <u>fh</u>alt* (silent) 'his dog'

c. *<u>d</u>oras* /t/ 'door' - *ath <u>dh</u>oras* [ɣ] 'next door'

d. *<u>s</u>ad* /s/ 'Toss!' - *<u>sh</u>ad* [h] 'tossed'

Palatalization in SG serves as a type of this lexicalized consonant mutation, but appears to be a relatively transparent case among various types of mutation (Stewart 2004). (2) shows that palatalization occurs in SG for different consonant types and in various morphological contexts. As illustrated in (2), palatalization in SG is marked with an adjacent orthographic 'i' that typically precedes a target segment.

1) All SG orthography herein is italicized for readers' convenience.

However, this orthographic ‘i’ shown in palatalized forms is not phonological in that ‘i’ is not phonologically nor phonetically realized and only exists in the SG orthography.

(2) Lexical palatalization in SG (Sung 2015)

a. *ard* /t/ ‘high’ - *airde* [t^j] ‘highest’
b. *òg* /k/ ‘young’ - *òige* [k^j] ‘younger/youngest’
c. *gob* /p/ ‘beak’ - *guib* [p^j] ‘beak’s’
d. *dun* /n/ ‘fort’ - *duin* [n^j] ‘forts’

The fact that there is no phonological palatalization trigger in SG palatalization raises an interesting question: will palatalized consonants in SG words show similar articulatory behavior to that typically observed in other languages such as English? Palatalization without phonological motivation may lead to phonetic patterns that are different from that with a phonological trigger. An investigation of palatalization without phonological motivation, like SG palatalization, will shed light on the question how different sources of palatalization are at play in the articulatory behavior of palatalized consonants.

Moreover, this paper explores potential morphological effects by comparing the articulation of palatalized consonants from morphologically derived and inherent words. As illustrated in (3), derived palatals refer to those resulted from the aforementioned palatalization process (i.e., [t^j] and [n^j] from /t/ and /n/ respectively), whereas inherent palatals are the underlying palatals (i.e., [t^j] and [n^j] from /t^j/ and /n^j/ respectively). Comparisons of palatalized consonants in derived and inherent words will address the question whether palatalized consonants resulting from two different sources are articulatorily distinct or neutralizing.

(3) Inherent and derived palatals in SG (Sung 2015)

a. *cait* ‘cat’s’, /t/→[t^j], derived
ait ‘humorous’, /t^j/→[t^j], inherent
b. *cinn* ‘grow’, /n/→[n^j], derived
sinn ‘we’, /n^j/→[n^j], inherent

Although consonant mutation in the Gaelic languages is fairly well documented

(Macaulay 1992, Ladefoged et al. 1998, Gillies 2002, Stewart 2004), there is only a handful of experimental, quantitative studies on consonant mutation to date (Archangeli et al. 2011b, 2014, Hammond et al. 2017 on Scottish Gaelic, and Bennett et al. 2017 on Irish Gaelic). With palatalization being one of the consonant mutation processes in SG, this study is the first attempt to quantitatively examine plain (unmutated) and palatalized (mutated) consonants in SG using ultrasound imaging.

The goal of this study is to add to our understanding of consonant mutation in SG by exploring the articulatory properties of palatalization in this language. In the subsequent section, the experimental design of the study will be discussed.

2. Methods

2.1. Participants

Twenty-six native speakers of SG who live on the Isle of Skye, Scotland, were recruited for the production experiment, without regard to gender or particular dialects. All participants were SG-English bilinguals, but have been exposed to SG from birth, and have continued to use SG on a daily basis. Ten (six females and four males, ages 19-60) out of 26 speakers were selected based on the quality of their ultrasound tongue images[2)], and the data from those 10 speakers, whose demographic information is shown in Table 2, were analyzed for this study.

2) Ultrasound imaging tends to result in various qualities of images depending on the speakers' biological and physical traits such as age, gender, and weight. Two of the co-authors checked the ultrasound recordings and selected 10 speakers whose images were of a good quality for data labeling, extraction and analysis.

<Table 2> Participants

Speaker	Gender	Age	L1 Dialect
S5	m	19	Uist
S7	f	34	Lewis
S10	f	50	Uist
S12	m	26	Lewis
S13	m	43	Uist/Lewis[3]
S15	f	50	Lewis
S17	m	60	Lewis
S23	f	51	Skye
S25	f	57	Lewis
S26	f	59	Skye

2.2. Materials

All test words were retrieved from an SG dictionary and verified by one of the co-authors who is a language teacher and also native speaker of SG. Among 112 Gaelic words and phrases used in the production experiment,[4] 16 items were selected for palatalization of coronal segments in various contexts. All multisyllabic words have the primary stress on the first syllable except for *am Basteir* with the primary stress on the second syllable. Table 3 shows the test words based on their phonological and morphological conditions. No pair of morphologically inherent and derived words was available for /s/ as no words with derived palatal /s/ were approved by our native speaker consultant.

3) S13 speaks two dialects of SG due to the fact that his parents speak different dialects.

4) This study was carried out as part of a larger project on SG (Arizona Scottish Gaelic project at the University of Arizona, NSF #BCS0921685 & #BCS11443818) which investigates phonological and morphological properties of the language using multiple instrumental and experimental techniques.

<Table 3> Stimuli

Target	Condition	Word	IPA Transcription	Gloss
/t/	plain	*cat*	[kʰaʰt]	‘cat’
	derived palatal	*cait*	[kʰaʰtʲ]	‘cat’s’
	inherent palatal	*ait*	[aʰtʲ]	‘humorous’
	plain	*bad*	[pat]	‘place’
	inherent palatal	*phògamaid*	[fo:kamɪtʲ]	‘we would kiss’
/s/	plain	*cas*	[kʰas]	‘foot’
	inherent palatal	*achlais*	[axlɪʃ]	‘armpit’
/n/	plain	*ceann*	[kʰʲawn]	‘head’
	derived palatal	*cinn*	[kʰʲiɲ]	‘grow’
	inherent palatal	*sinn*	[ʃiɲ]	‘we’
/l/	plain	*Gall*	[kawl]	‘lowlander’
	derived palatal	*Goill*	[kˠiʎ]	‘lowlander’s’
	inherent palatal	*ainmeil*	[ɛɲɛməʎ]	‘famous’
/ɾ/	plain	*ministear*	[miɲiʃtʲɛɾ]	‘minister’
	derived palatal	*ministeir*	[miɲiʃtʲiɾ]	‘minister’s’
	inherent palatal	*am Basteir*	[ampaʃtʲiɾ]	‘(name of mountain)’

2.3. Procedures

This study used ultrasound imaging to examine the articulatory properties of palatalized consonants in SG. Despite its short tradition in linguistics, ultrasound imaging technology has been used effectively for various studies in speech production, including but not limited to language documentation (e.g., Davidson 2006, Scobbie et al. 2008, Archangeli et al. 2011a, Mielke et al. 2011), the investigation of language-universal articulatory behavior (e.g., Gick et al. 2004, Zharkova & Hewlett 2009), and the use of ultrasound for speech development and speech-impaired population (e.g., Bernhardt et al. 2005, Adler et al. 2007). Compared to other experimental methods in articulatory studies such as X-Ray, MRI, or Electropalatography (EPG), ultrasound is relatively inexpensive, minimally invasive, and portable (Gick 2002, Stone 2005). In addition, ultrasound imaging is now widely acknowledged as an excellent method for phonetic fieldwork investigating the articulatory aspects of speech, and the phonetic and phonological behavior of speech sounds.[5] The merit of ultrasound makes it a natural candidate to conduct the current study, which requires articulatory data collection in multiple locations.

The articulatory data for this study was collected with a SonoSite TITAN portable ultrasound unit and a C-11/7-4 11-mm broadband curved array transducer. The machine generates 30 frames per second, equivalent to approximately 15-20 ultrasound tongue images per word. The ultrasound images were concurrently recorded with audio, and the visual and audio data were synchronized, creating an ultrasound tongue movement video as a result.

Most experiment sessions were conducted in Sabhal Mòr Ostaig, a college and language institute on the Isle of Skye, Scotland. Some sessions took place in Staffin for the speakers who could not come to the college. Participants were instructed to read out the words presented on a computer screen at a normal speaking rate. Because most participants were older (50+ years old) speakers, each experiment session was divided into three 5-minute blocks, and participants were allowed to take a break between blocks for their comfort. During each participant's break, two research assistants checked and assured that all the equipment, especially the ultrasound transducer, is in place for the following experiment block. All the instructions were given in English.[6)]

During the course of the experiment, head movement was limited with a head stabilizing device made by the Arizona Phonological Imaging Lab, shown in Figure 1. Participants were instructed to sit comfortably in front of the device, and place his or her chin on the ultrasound transducer which was immobilized by the device. While maintaining the contact between the chin and the transducer throughout the experiment, participants were also expected to place their forehead onto the cotton pad, which further helped participants minimize their head movements.[7)] As illustrated in Figure 1, the device was also clamped onto the desk throughout the entire experiment session.

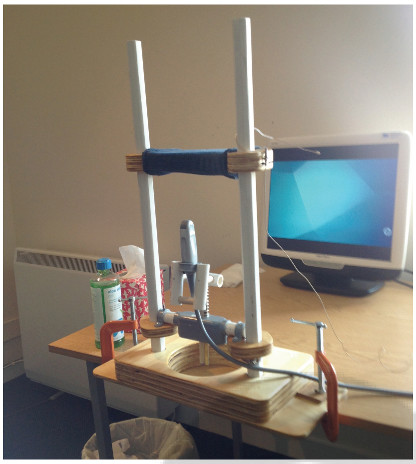
As is typical with fieldwork, there were unavoidable disruptions that affected the

5) See Stone (2005) for further details of ultrasound imaging techniques and procedure for speech research, and Davidson (2005) for the use of ultrasound imaging to address phonological questions.

6) Prior to the experiment, all participants had a brief language questionnaire interview with one of the co-authors (a native speaker of SG). This helped them stay in the Gaelic mode during the experiment session, even though the instructions were given in English.

7) Gick et al. (2005) pointed up the importance of having a headrest to minimize speakers' head movements under field data collection conditions.

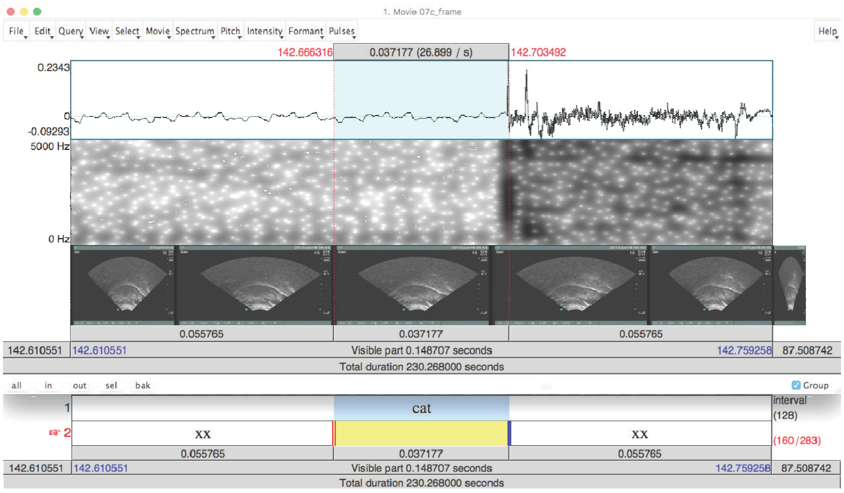
quality of the audio recordings during the experiment sessions, such as cars pulling up, birds chirping, and bagpipes. Since the primary focus of this study is the articulatory properties of target segments, these disruptions were considered to have minimal impact on the quality of the tongue movement recordings.



<Figure 1> Head stabilizing device

2.4. Measurements

Image frames corresponding to the test words were identified and extracted. For frame identification, this study used UltraPraat, a modified version of Praat (Boersma & Weenink 2011) created by the Arizona Phonological Imaging Lab (Archangeli et al. 2013). As presented in Figure 2, UltraPraat enables us to view ultrasound tongue images and their corresponding acoustic signals simultaneously. Image frames of target segments were identified based on the corresponding acoustic signals. For frames of interest, this study identified and extracted the gestural peaks of target consonants in plain and palatalization conditions. In case of the stop consonants, a gestural peak was considered to be the last full image frame before the stop release of the consonant, as shown in Figure 2. For all other consonants, the image frame from the midpoint of the acoustic signal of the consonant was identified as gestural peak.

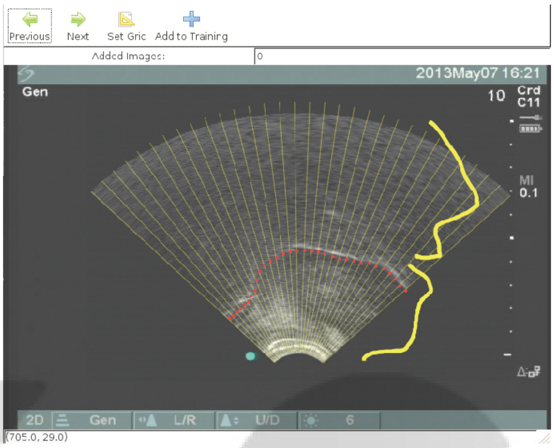


<Figure 2> UltraPraat

Once the image frames of interest were identified, the tongue curves shown were labeled using AutoTrace, a python- and Matlab-based data extraction script introduced in Fasel & Berry (2010). Figure 3 shows an example of manual data extraction from an ultrasound tongue image. The tongue is expected to be located beneath the bright curve in the center of the image (which is a reflection caused by the abrupt change in density). Tongue tip is to the right, and a profile is hand-drawn on the image frame. The data points (shown as dots; 32 data points per image) were placed beneath the bright curve.

Given that the ultrasound machine produces 30 frames per second and it takes approximately 20 seconds for a trained researcher to label one tongue image (Berry 2012), this type of data extraction is expensive, resulting in a great deal of ultrasound studies with relatively few speakers and inconclusive results. This cumbersome process appears to leave no way to conduct a large-scale study using ultrasound imaging. Due to the labor-intensive nature of the study, this study limits the scope of investigation to the gestural peaks of coronal consonants in control and palatalization environments, resulting in one image frame per token, and 10 speakers analyzed for this study.

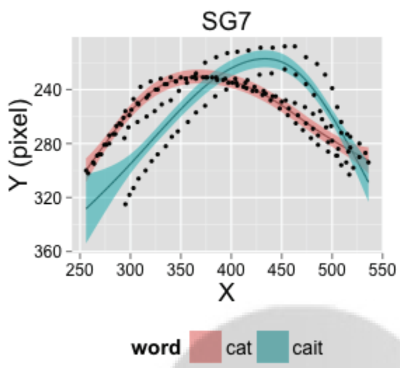
To correct for head movement during data collection, raw tongue contours extracted from the ultrasound recordings were adjusted using a Matlab script. First, tongue-at-rest positions between tokens of interest were identified and extracted for each speaker. Second, the angles of the tongue-at-rest positions were identified so that the positions corresponded with each other. Then the angles of raw tongue contours for target consonants were adjusted to match the angles of adjacent tongue-at-rest contours.



<Figure 3> Data extraction using AutoTrace

The extracted and adjusted tongue contours were statistically analyzed using Smoothing Spline ANOVA (henceforth SSANOVA, Gu 2002, Davidson 2006). SSANOVA has been used in recent ultrasound studies (Archangeli & Berry 2010, Mielke et al. 2011, Kochetov et al. 2013 among many) to test whether two sets of tongue contours from one speaker are significantly different and generate plots of means of tongue contours and confidence intervals for the sets of contours. The sets of tongue contours are considered significantly different when the confidence intervals (95%) for the two sets do not overlap, equivalent to $p<.05$. Figure 4 presents an example of SSANOVA analysis from the SG data in this study, which presents a comparison of two averaged tongue curves, plain and palatalized final /t/'s in SG.

The x-axis in Figure 4 represents position along the tongue, where the leftmost endpoint is the tongue root and the rightmost endpoint is the tongue tip. The y-axis represents raw tongue height in pixels. As shown in Figure 4, tongue positions of plain and palatalized /t/, represented by red and blue curves respectively, do not overlap in the tongue front nor in the back region. This suggests that there is significant difference in /t/'s in palatalizing and non-palatalizing conditions. In the subsequent sections in which the results from the ultrasound experiments will be presented, whether there is significant difference between two averaged tongue curves on SSANOVA plots will be used to determine whether speakers are able to articulate the difference between two conditions.

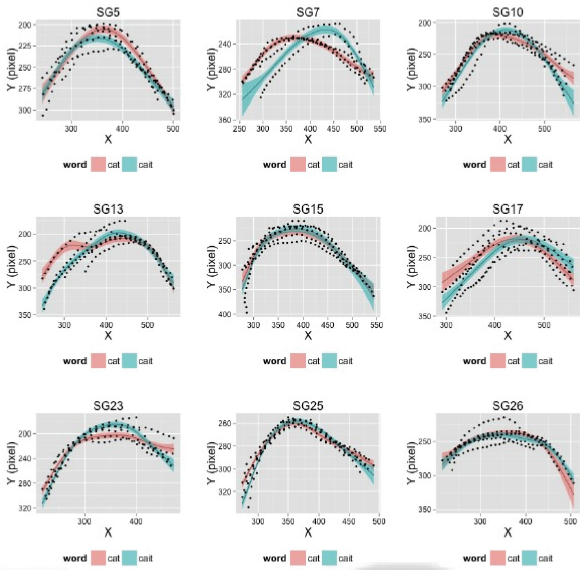


<Figure 4> A sample SSANOVA plot of tongue contours. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Axis values correspond to pixels.

3. Results[8)]

3.1. Plain vs. palatalized

8) All the data presented in this paper only contain each speaker's correct pronunciations of the test words based on their intuition. Mispronunciations and stuttered productions were excluded from the analysis.

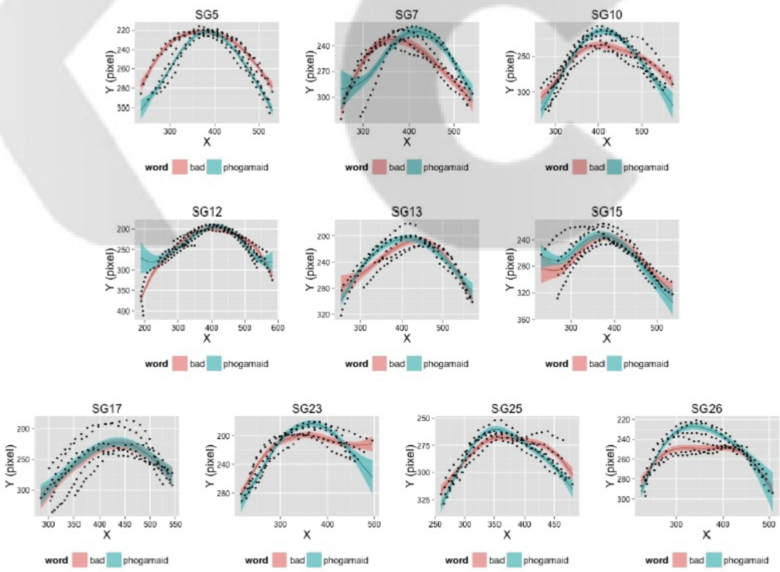


<Figure 5> SSANOVA plots of tongue contours of plain (red) vs. palatalized (blue) /t/ from *cat* and *cait*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

Figures 5 and 6 present comparisons of plain vs. palatalized /t/ from the SG words *cat* and *cait*, and *bad* and *phògamaid*, respectively. As illustrated in Figure 5, roughly half of the speakers (SG5, SG7, SG13, and SG23) produced significantly different tongue contours for /t/ in plain (*cat*) and palatalizing (*cait*) contexts. Some speakers, e.g., SG7 and SG23, show similar articulatory distinction between plain and palatalized consonants. However, the way speakers make such articulatory distinction is generally not uniform across speakers. For instance, in Figure 5, SG5 showed a higher tongue curve in the plain condition, whereas SG23 showed a lower tongue curve in the same context. The gestural patterns in Figure 5 exemplify speaker-specific variation.

Figure 6 demonstrates that /t/s in plain and palatalizing contexts yield articulatorily distinct patterns which are more robust than those in Figure 5. Two thirds of the speakers (SG5, SG7, SG10, SG13, SG23, SG25, and SG26) maintain some kind of gestural distinction between two contexts. Again, the way these seven speakers articulate the plain (*bad*) - palatalized (*phògamaid*) contrast exhibits some individualized patterns. SG5 is different from all other speakers in that he is the only speaker who showed a higher tongue curve in the tongue dorsum for the plain condition. Given that SG5 is noticeably younger than all other speakers (see Table 2) who maintained the plain-palatalized contrast, the idiosyncratic pattern observed here may show an articulatory sign of sound change in progress, which needs further examination with more data.

While the tongue contours in Figure 6 show variation across speakers, there also seems to be a common trait shared among some speakers. SG10, SG23, and SG26 all showed a higher tongue dorsum in the palatalizing condition. These three speakers belong to the same age group, and the pattern is not shown in Lewis speakers (S15 and S25) in the same age group (see Table 2). Thus, this potentially suggests a ‘palatal’ gesture for palatalized /t/ shared by SG speakers in this age/dialect group.

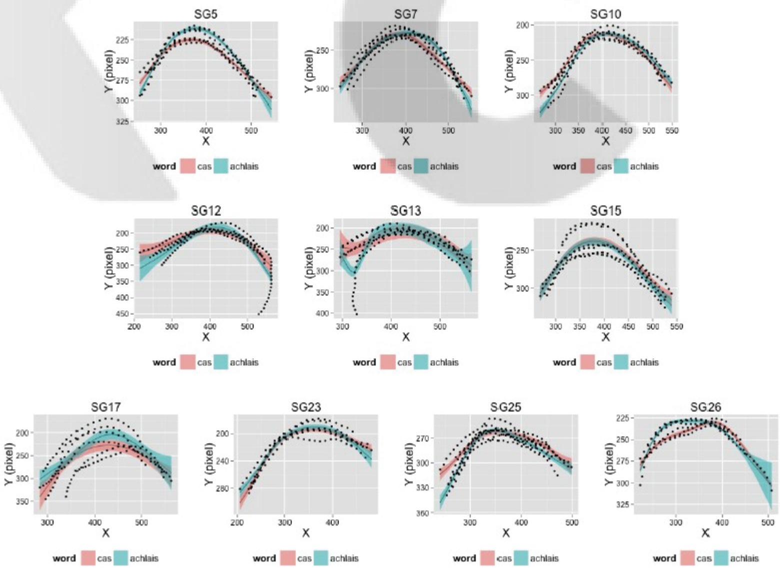


<Figure 6> SSANOVA plots of tongue contours of plain (red) vs. palatalized (blue) /t/ from *bad* and *phògamaid*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data

points. Where fewer data points are available, the shared area is larger.

Note that the plain vs. palatalized /t/ contrast is made differently across words, in which the *bad-phògamaid* (Figure 6) comparisons generate more robust contrast than the *cat-cait* ones (Figure 5). Four out of 9 speakers showed significantly different tongue gestures in the *cat-cait* contrast, whereas seven out of 10 did so in the *bad-phògamaid* contrast. It merits further examination with a larger pool of SG words whether the difference comes from word-specific or orthographic knowledge.

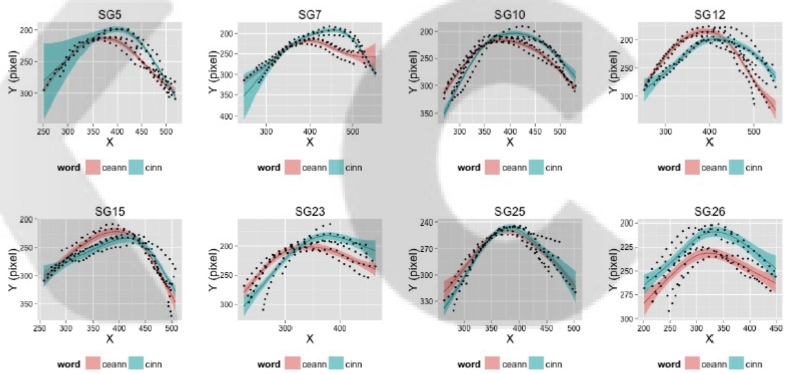
Figure 7 presents comparisons of plain vs. palatalized /s/ from the SG words *cas* and *achlais*. Here, the articulatory distinction between plain and palatalized /s/ is not as robust as that between plain and palatalized /t/. Only three speakers (SG5, SG7, and SG26) showed articulatory contrast between plain and palatalizing contexts. As stated in the above-discussed findings, however, the gestural patterns here also yield a clear sign of speaker specificity. Despite that they all showed a higher tongue curve in the palatalizing context, the way SG5, SG7, and SG26 articulate the contrast is slightly different from one another.



<Figure 7> SSANOVA plots of tongue contours of plain (red) vs. palatalized (blue) /s/ from *cas* and *achlais*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them

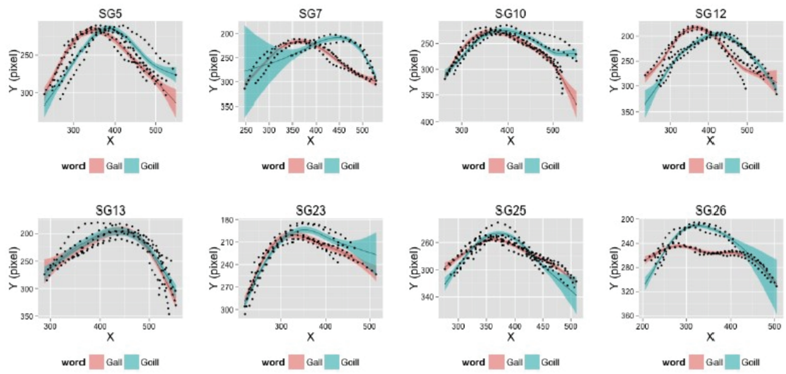
are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

Figures 8 through 10 show comparisons of plain vs. palatalized sonorants, in the order of plain vs. palatalized /n/, /l/, and /ɾ/. In contrast to the plain vs. palatalized obstruents, speakers tend to make more distinct tongue gestures that differentiate sonorants in plain and palatalizing contexts. As illustrated in Figure 8, all speakers except for SG25 articulated the contrast between plain and palatalized /n/. Moreover, those speakers made a higher tongue curve in the front region of the tongue, which is, presumably, the common articulatory gesture for palatalized /n/ shared by SG speakers. The fact that SG10, SG12, and SG23, all of whom differ by dialect, showed similar articulatory contrast further supports the existence of a universal 'palatal' gesture for palatalized /n/.



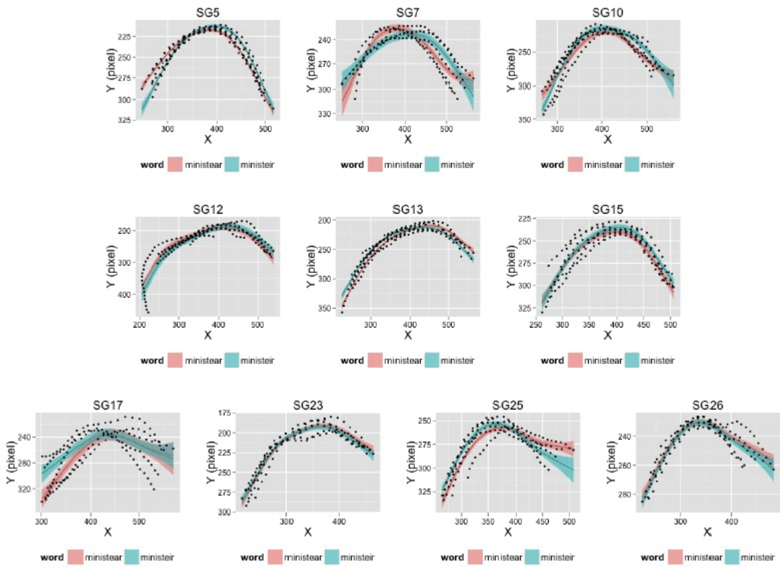
<Figure 8> SSANOVA plots of tongue contours of plain (red) vs. palatalized (blue) /n/ from *ceann* and *cinn*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

Similar to the plain vs. palatalized /n/ contrast, the majority of SG speakers maintained articulatory distinction between plain and palatalized /l/, as shown in Figure 9. All speakers except for SG13 differentiated /l/s in two contexts in their articulation. The universal trend observed in Figure 9 is also found in those who made a significant contrast, in which speakers consistently showed a higher tongue contour in the front region of the tongue in the palatalizing context. This suggests that the 'palatal' gesture is shared among different sonorants.



<Figure 9> SSANOVA plots of tongue contours of plain (red) vs. palatalized (blue) /l/ from *Gall* and *Goill*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

In contrast to the above-discussed patterns in plain vs. palatalized sonorants, Figure 10 exhibits a distinct pattern of articulatory contrast, in which the majority of speakers did not distinguish [ɾ]'s in two contexts. This might have resulted from several factors. First, the SG words used for the plain vs. palatalized [ɾ] contrast, *ministear* and *ministeir*, are remarkably similar to each other in terms of phonological and orthographic shape. Due to the extreme similarity between two words, speakers might have misread the words, and their mispronunciation could have gone unnoticed. Second, the acoustic signals for word-final /ɾ/ in SG, which were the basis of corresponding ultrasound image frames, were not always straightforward to identify. In addition, the ultrasound machine employed in this study generates 30 frames per second, which is not ideal for the analysis of flaps. In this study, word-final /ɾ/ in SG very often did not generate clear acoustic and auditory signals, and was frequently confused as background noise. Such potential problems in data collection and extraction processes could be avoided in future studies with production experiments conducted in sound-attenuated environments.



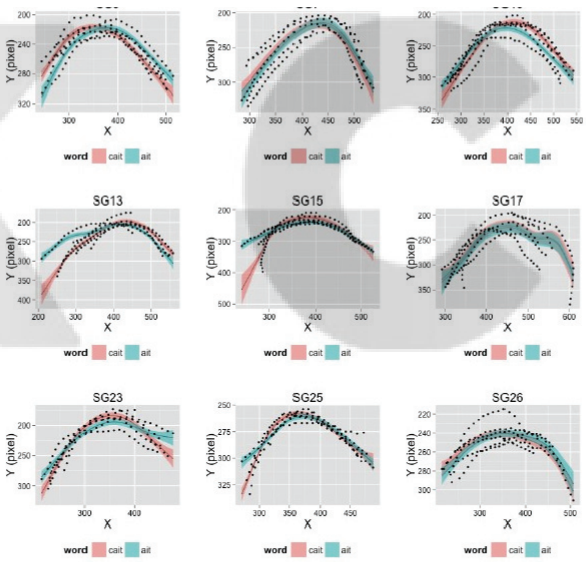
<Figure 10> SSANOVA plots of tongue contours of plain (red) vs. palatalized (blue) /ɾ/ from *ministear* and *ministeir*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

On the whole, the phonemic distinction between plain and palatalized consonants is manifested as distinct tongue gestures by speakers, allowing some degree of idiosyncratic patterning across speakers and target segments. The findings from this section are summarized in Table 4. The subsequent section will discuss articulatory differences in palatal(ized) consonants from morphologically derived and inherent words.

<Table 4> A summary of plain vs. palatalized consonants: asterisk (*) represents significant difference, and N/A refers to no data due to the poor quality of ultrasound tongue images.

Speaker / Segment	SG5	SG7	SG10	SG12	SG13	SG15	SG17	SG23	SG25	SG26
/t/ (‘*t*’)	*	*		n/a	*			*		
/t/ (‘*d*’)	*	*	*		*			*	*	*
/s/	*	*								*
/n/	*	*	*	*	n/a	*	n/a	*		*
/l/	*	*	*	*		n/a	n/a	*	*	*
/ɾ/	*	*	*				*			

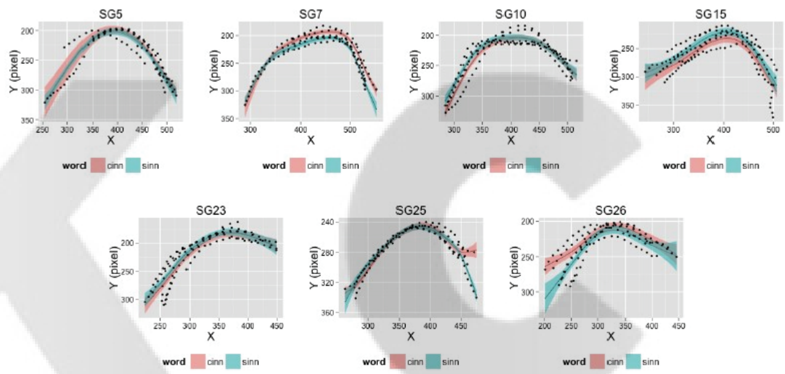
3.2. Derived vs. inherent palatals



<Figure 11> SSANOVA plots of tongue contours of derived (red) vs. inherent (blue) palatals from *cait* and *ait*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

Figure 11 presents comparisons of palatalized /t/s from the morphologically derived word *cait* (derived from *cat*) and the morphologically inherent word *ait*, in which two words form a near-minimal pair. According to the gestural patterns observed here, palatalized /t/s from two morphologically different words are neutralizing in production. As noted earlier in the case of ministear and ministeir (Figure 10), however, it is possible that the articulatory neutralization is an artifact of orthographic similarity between two words.

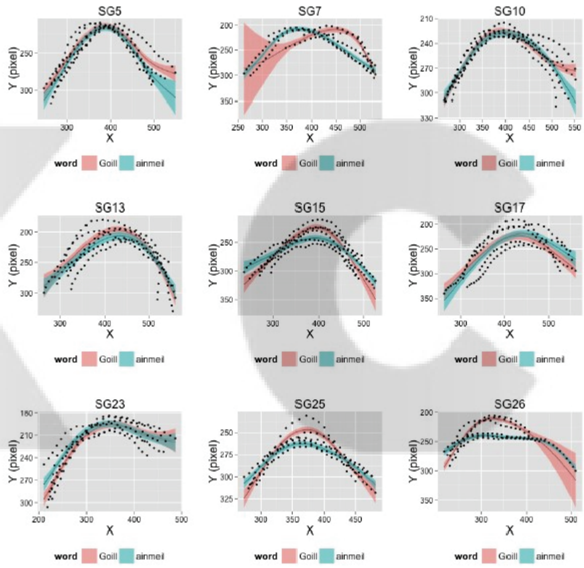
Figure 12 shows comparisons of palatalized /n/s from the derived word *cinn* (derived from *ceann*) and the inherent word *sinn*, which is only minimally different from *cinn*. Again, with the exception of SG7 and SG26, there seems no sign of articulatory contrast between two words. This further disconfirms potential morphological effects in lexical palatalization in SG.



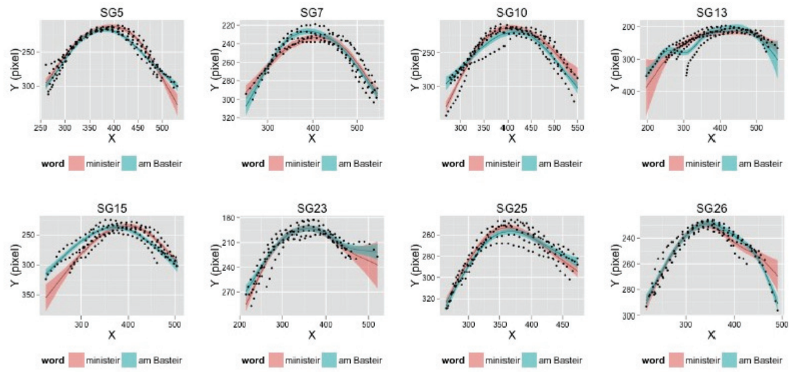
<Figure 12> SSANOVA plots of tongue contours of derived (red) vs. inherent (blue) palatals from *cinn* and *sinn*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

In contrast to the previous two comparisons, Figures 13 and 14 demonstrate comparisons of two words that are phonologically distinct from each other, which are *Goill* (derived from *Gall*) vs. *ainmeil* (morphologically inherent) (Figure 13), and *ministeir* (derived from *ministear*) vs. *am Basteir* (morphologically inherent) (Figure 14). Based on the patterns illustrated in Figure 13, phonological dissimilarity seems to be at play to some extent. Roughly half of the speakers (SG7, SG15, SG25, and

SG26) showed significantly different tongue contours between two words. Moreover, those who maintained an articulatory distinction exhibit some common trend, in which they showed a higher tongue curve in the derived context. It is not clear, however, whether the trend represents a greater degree of palatalization in the derived environment, or word-specific properties of /l/ in the SG word *Goill*. Figure 14 adds weight to the claim that the patterns in Figure 13 might simply show word-specific properties. Despite the orthographic dissimilarity between *ministeir* and *am Basteir*, most speakers did not produce any significant difference between two conditions. It is also possible that this serves as evidence that /ɾ/ in SG simply does not become palatalized.



<Figure 13> SSANOVA plots of tongue contours of inherent (red) vs. derived (blue) palatals from *ainmeil* and *Goill*. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.



<Figure 14> SSANOVA plots of tongue contours of inherent (red) vs. derived (blue) palatals from am Basteir and ministeir. Tongue tip is to the right, and dotted lines represent 95% confidence interval. Thick lines are averaged tongue curves, and shades around them are confidence intervals of the averaged curves (95%). Dots represent the data points. Where fewer data points are available, the shared area is larger.

In sum, comparisons of palatal(ized) consonants from morphologically derived and inherent words disconfirm the potential role of morphology in the articulation of SG palatalization. In other words, different morphological statuses of individual SG words do not manifest as different articulatory gestures. The findings from this section are summarized in Table 5.

<Table 5> A summary of derived and inherent palatals: asterisk (*) represents significant difference, and n/a refers to no data due to the poor quality of ultrasound tongue images.

Segment \ Speaker	SG5	SG7	SG10	SG12	SG13	SG15	SG17	SG23	SG25	SG26
/t/ (‘*t*’)	*		*	n/a	*					
/n/				n/a	n/a		n/a			*
/l/		*		n/a		*			*	*
/ɾ/	*	*		n/a		*	n/a			

4. Discussion and Conclusions

<Table 6> A summary of the results: asterisk (*) represents significant difference, and n/a refers to no data.

Condition / Speaker	plain vs. palatalized						derived vs. inherent			
	/t/		/s/	/n/	/l/	/ɾ/	/t/	/n/	/l/	/ɾ/
	‘t’	‘d’								
SG5	*	*	*	*	*	*	*			*
SG7	*	*	*	*	*	*			*	*
SG10		*		*	*	*	*			
SG12	n/a			*	*		n/a	n/a	n/a	n/a
SG13	*	*		n/a			*	n/a		
SG15				*	n/a				*	*
SG17				n/a	n/a	*		n/a		n/a
SG23	*	*		*	*					
SG25		*			*				*	
SG26		*	*	*	*			*	*	

Taken together, the results show a clear sign of articulatory contrast between plain and palatalizing environments across various coronal consonants, and neutralization among morphologically different sources of palatalization. A summary of all SG results in this study is presented in Table 6. As summarized in Table 6, the results from 10 speakers indicate that native SG speakers are aware of the plain vs. palatalized contrast and articulate such contrast, which supports previous claims on the phonemic plain vs. palatalized contrast in SG (Borgstrøm 1941, Ternes 1973, Lamb 2003).

While the plain vs. palatalized contrast is consistently manifested by tongue gestures, however, it is not clear how palatalization is represented in each speaker’s linguistic mind. The gestural patterns observed in Figures 5 through 14 do not show what is typically expected in the articulation of palatalized consonants, in which one would expect to see the tongue curve get closer to the palate than that in the plain condition.[9] According to the idiosyncratic patterns herein, it is possible that native

9) This palatal gesture has been reported in several other articulatory studies on palatalization in related and unrelated languages, e.g., Kochetov (2002), Sung (2015), Bennett et al.

SG speakers are not interested in creating a 'palatal' gesture for consonants in palatalization conditions as long as they maintain some degree of plain vs. palatalized contrast. Some idiosyncratic patterns observed in this paper suggest a possibility that speakers may possess "individualized" palatalization grammar and articulate it. As noted in the previous section, while SG5 consistently shows a higher tongue tip in the palatalization context allowing some degree of variation, SG7 tends to create articulatory distinction between plain and palatalization contexts somewhat randomly.

Table 6 also demonstrates substantial variability across consonant types in plain vs. palatalized, and derived vs. inherent contrast. As noted earlier, plain vs. palatalized differences are more robust in sonorants (/n, l, ɾ/) than obstruents (/t, s/). The driving force behind such difference merits further investigation, and needs to be examined with other lenition processes or coarticulatory phenomena involving both obstruents and sonorants in SG.

Although it is a well-known phenomenon, consonant mutation in SG is poorly studied in an experimental perspective. This study adds to the small literature on the articulatory properties of Gaelic languages, pointing to the importance of instrumental, experimental documentation research for endangered languages. The gestural characteristics observed in this study offer insight into how lexical palatalization in SG manifests as differences in tongue gestures. Moreover, the findings from this study provide empirical evidence for articulatory realizations of consonant mutation, and further support an increasing body of literature on individual variation in speech production.

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<Abstract>

Individual variation in lexical palatalization:

Articulatory evidence from Scottish Gaelic

Jae-Hyun Sung, Diana Archangeli,
Samuel Johnson, Ian Clayton, Muriel Fisher,
Michael Hammond, and Andrew Carnie

This paper discusses the articulatory characteristics of palatalized consonants in Scottish Gaelic (Gàidlig, henceforth SG), an endangered language spoken in Scotland. Palatalization is a notable lexicalized process in SG, which is considered as part of the complex consonant mutation processes in the language. With only a handful of instrumental, experimental studies on the language that exist, this paper is the first attempt to quantitatively examine the articulatory patterns of plain and palatalized consonants, and palatalized consonants from different morphological sources in SG using ultrasound imaging. The gestural patterns from 10 SG speakers show some degree of the universal 'palatal' gesture, represented by a higher tongue tip or dorsum than otherwise expected. However, the articulatory distinction between plain and palatalizing conditions is not at all uniform across speakers and target segments. In addition, palatalized consonants from different morphological sources do not differ markedly. The findings from this paper add to the growing literature on individual variation in phonology, and point to the importance of language documentation research using modern instrumental and experimental techniques.

Keywords: palatalization, articulation, ultrasound imaging, language documentation, Scottish Gaelic

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