An Ultrasound Analysis of Tswefap Back Consonants

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1 Introduction

Tswefap is a grassfields Bantu (Bamileke) language spoken in Batoufam, Cameroon. This paper is part of a series of descriptive and theoretical analyses of Tswefap undertaken for a fieldwork methodology seminar. The focus for this paper is to identify the place of articulation of back consonants in Tswefap using ultrasound imaging and SSANOVA. Data for this analysis were collected in an urban setting from one adult male native speaker of Tswefap, a Berkeley undergraduate named Guy Tchatchouang (born 1975). Mr. Tchatchouang grew up in Douala, where he spoke Tswefap and French. Extensive language contact in Douala has resulted in lots of loanwords from French used in Tswefap, as well as frequent code-switching in the speech of Tswefap speakers from that region.

bilab.	lab.dent.	alv.	postalv.	pal.	**velar**	**lab.vel.**	**uv.**	**phar.**	**glot.**
p / b		t / d			**k / g**			kp / gb	ʔ
m		n		ɲ	ŋ			ŋm	
	pf / bv	ts / dz	tʃ / dʒ						
	f / v	s	ʃ / ʒ		**ɣ***	**χ* / ʁ***	**ʕ***	**ʁw**	**h**
			l		j (“y”)			w	

Table 1: Presumed consonant phoneme inventory of Tswefap

Table 1 illustrates the Tswefap consonant inventory assumed in prior research. All included consonants are a result of several months of transcription during elicitation. The Tswefap

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consonant inventory includes a number of dorsal and laryngeal fricatives, which we will refer to collectively as “back”. Considering the proximity of back places of articulation and difficulties in identifying fricatives from just acoustics, Table 1 shows the maximal number of possible consonants based on just perception and transcription during elicitation. Bolded symbols indicate the consonants that will be used for comparison in this study; asterisks indicate the hypothesized phonemes in question. Table 2 explains the correspondence between a Tswefap phoneme in IPA with the graphemes we will use in this paper to represent it.

ʃ	ʒ	tʃ	dʒ	ɲ	ŋ	ɣ	j	χ	ɾ	ʕ	ŋm	ʁw	ʔ
sh	zh	ch	j	ny	n	g	y	r	r	r?	nm	rw	’

Table 2: Orthographic correspondences between IPA and Tswefap as used in this paper. Tone will not be represented orthographically in this paper.

The voiced velar stop (/g/) lenites to a voiced fricative (potentially the velar [ɣ], as lenition to the same place of articulation is likeliest) intervocalically, especially in fast or casual speech. Because of this phonological process, we label instances of what we believe is [ɣ] as the underlying phoneme: /g/. This allophony (and others) is illustrated in Table 3 below.

phon. context	/g/ ‘g’	/ʁ/ ‘r’
word-initial	[g] gaɣmənəp “sky”	[ʁ] rə “do”
word-final	[k] tɔg “dig”	
intervocalic	[g∼ɣ] cəgə “surpass”	[ʁ∼ʕ] mbara “male”
postnasal	[g] ngwak “salt”	[g∼g^h] məngə “I do”
prenasal	[k∼ɣ] pagnyu “red wine”	
	/ʕ/	/ʁw/ ‘rw’
word-initial		[ʁw] rwu “big”
word-final	[k∼∅] pɛkaʕ “plate”	
intervocalic	[ʕ] lɔʕɔ “stone”	[gw] momənɡwɔ “I am grinding”

Table 3: Hypothesized allophony in Tswefap. Proposed phonemes are in slashes, and orthographic representation is in single quotes. “Postnasal” refers to the consonant occurring after the nasal TAM prefix that attaches to verbs. “Prenasal” refers to the consonant occuring before the nasal prefix of a following morpheme.

There also appears to be a borrowed phoneme from French, the uvular fricative /ʁ/, based on exclusive occurrences in loanwords from French (or English), such as [tʁosi] ‘trousers’ or [matʁesi] ‘mattress’. The acoustics of the audio recordings show that our speaker does not voice these productions, but /ʁ/ surfaces as [χ] since the four instances of this phoneme recorded for the study all follow voiceless stops.

Besides the French fricative and what might be a voiced velar stop, there is possibly an additional back fricative that occurs word-initially or intervocalically. After a nasal prefix, it becomes the voiced velar stop [g]. This occurs regularly in verb conjugations like “I am doing" and "I am marrying", where "do" and "marry" are fricative-initial verbs but become [g]-initial when following the auxiliary and aspect nasal prefix [məŋ]. It is difficult to perceive where this fricative is articulated, but for simplification purposes, it will be labeled 'r' throughout this paper and for analysis. It may well be that this fricative is the uvular fricative /ʁ/, since the devoiced French fricative occurs in a very specific context, or that it is the velar fricative /ɣ/.

The last two fricatives that we study in this paper are a potential pharyngeal fricative [ʕ], which seems to occur only between low back vowels, as in lɔʕɔ "stone", and a labiovelar fricative which occurs before back rounded consonants, as in rwu "big". This fricative sometimes surfaces just as [w], and other times has very clear frication. It is possible, however, that it is merely the uvular fricative, which we label 'r', preceding a rounded vowel (resulting in labialization).

The outstanding questions regarding Tswefap back consonants, therefore, are as follows:

1. Are the phones we have marked as intervocalic 'g' and 'r' produced at significantly different places of articulation?
2. Is the phone that we have marked as /ʕ/ significantly different from intervocalic 'r'?
3. Is the phone that we have marked 'rw' significantly different from 'r'?
4. What phone does 'g' become when it occurs before a nasal consonant?

Attempts to classify or categorize these fricatives using only naked perception or the acoustics have been unsuccessful, in part due to the difficulty of perceiving contrasts in the back of the vocal tract, the researchers' unfamiliarity with these kinds of contrasts, as well as the interesting morpho-phonological processes that affect the surface form of each phoneme. Therefore, an internal imaging technique that could accurately show us where constrictions were being made in the vocal tract would be useful for the identification of the phones in the Tswefap inventory.

Ultrasound is an effective technique in this situation because it provides a midsagittal image of the length of the tongue. This method is preferable to other techniques, such as electromagnetic midsagittal articulography (EMMA), because of its non-invasive nature, and it is also more cost-effective and simple to operate compared to newer techniques like MRI. Ultrasound images can tell us more definitively the place of articulation of hard-to-perceive back consonants in many of the elicited Tswefap words.

We use smoothing spline ANOVA (SSANOVA) to compare tongue curve shapes (Davidson 2006). Velar, uvular, and pharyngeal back consonant productions should produce significantly different tongue contours, distinctly visible in the smoothing spline images.

2 Methods

The speaker recorded a word list in a sound-attenuated booth. He wore a headset for stabilizing the ultrasound transducer, in order to maintain consistency between productions for comparable data. A list of eighty-four words was displayed on a screen in English, and the speaker self-timed recording the Tswefap translations. Since there are often multiple Tswefap words for an English word, an experimenter sat inside the booth to consult with the speaker and confirm whether previous elicitations were properly glossed in English, in order to elicit the proper Tswefap word with a back consonant.

The recordings were time-aligned to a series of ultrasound images represented as individual frames. At 30 fps, each word had between twenty and forty frames. From these frames, the one representing the midpoint of the fricative was selected for contour extraction using the software EdgeTrak. These contours were run through a smoothing spline ANOVA (Mielke 2013) that can be used to visualize comparisons of tongue contours based on any kind of variable (including phoneme, hypothesized place of articulation, and phonetic context).

3 Results

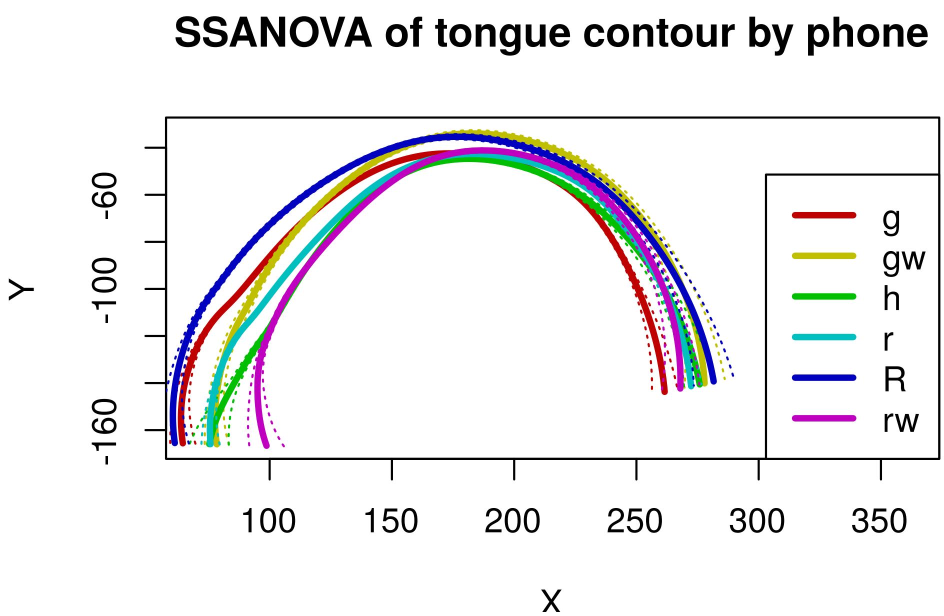

Figure 1: SSANOVA of tongue contours by phone (i.e., hypothesized underlying phoneme); anterior is to the left.

The figures in this section are the smoothing spline ANOVA results of the tongue contours. In each image, the anterior portion of the vocal tract is to the left, and posterior is to the right. The spline itself is the thick solid line, and the fainter, dotted lines of the same color on either side represent confidence intervals. Where the confidence intervals are narrower, we can be more certain that the tongue's contour exists at that space in the polar coordinate plane (measured in pixels on the X and Y axes).

Figure 1 above represents tongue contours, categorized by hypothesized phone. It is clear that phones marked 'g' (velar stops, intervocalic fricativized 'g', and postnasal obstruentized fricatives, all indicated by the red line) have a more anterior place of articulation than those marked 'r' (uvular fricatives, indicated by the cyan line). The uvular fricative and the labiovelar fricative 'rw' (violet line) have similar contours. Both are not as anterior as the navy line that represents the /ʁ/ from French; this is likely because this phone occurs mostly immediately following the alveolar stop /t/ and is fronted as a result. Finally, the glottal fricatives should have the least amount of constriction, which the green line does show. However, this figure has plotted the means of each phone's contour. The fact that the contours for 'g', 'r', and 'rw' overlap so much with 'h' warrants further analysis.

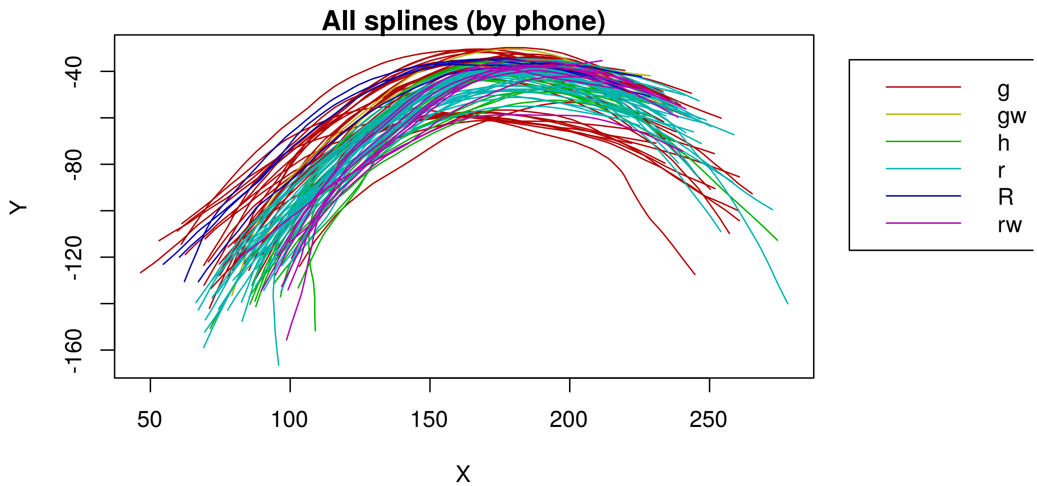

Figure 2: All traces of tongue contours by phone (i.e., hypothesized underlying phoneme); anterior is to the left.

Figure 2 illustrates all of the contour traces, also grouped by phone. Now, it can be seen that there are two distinct kinds of 'g' (maroon lines). One is the fully articulated 'g' that occurs word-finally or after a nasal prefix as a stopped /r/. The other is the reduced 'g' that occurs intervocalically or syllable-finally before a morpheme boundary – this 'g' often lenites to a fricative or disappears altogether. Our next analysis will look in more detail at the phonetic contexts (intervocalic versus word-initial, etc.) that influence how a phoneme will surface.

The most striking thing seen in Figure 3 is that when the phoneme /g/ occurs before a nasal (navy line), as in the word for 'red wine' (pagnyu), it often reduces to the point of

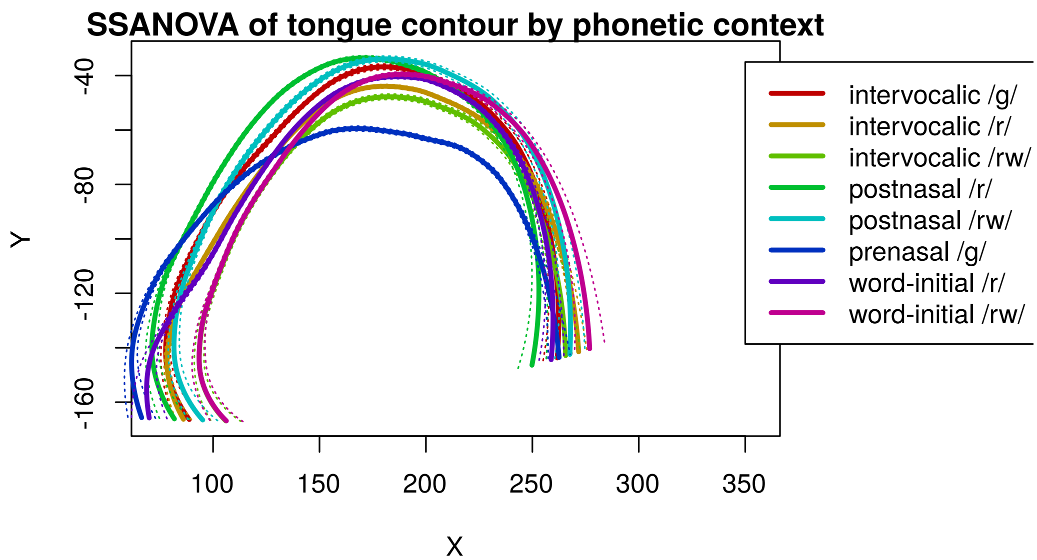

Figure 3: SSANOVA of tongue contours by phonetic context (e.g., intervocalic /g/, which is visibly reduced, or prenasal /g/, which is deleted.

having no constriction whatsoever. Also, the two highest and most anterior constrictions belong to postnasal /r/ and /rw/, which surface as velar stops.

Figures 4 and 5 plot all intervocalic fricatives except the voiceless glottal fricative /h/, which is not easily confusable with the other back fricatives[1]. In Figure 4, which groups by phonetic context, the red line, which is highest, represents intervocalic /g/, which is realized as a reduced fricative (e.g. sɔmbəgə 'seven'). It is clearly distinct from the green and blue lines, which represent back fricatives initially all transcribed as /r/. This indicates that there are only two distinct places of articulation, velar and uvular.

In Figure 5, which groups by preceding vowel, we can see that the vowel that precedes the fricative does not seem to greatly affect the place of articulation of the fricative, since all the lines seem to overlap. This is relevant for the question of whether vowel context affects particular proposed phonemes, so the next analysis will be limited to just contours of two phonemes, /ʕ/ and /ʁ/.

Lastly, Figure 6 plots tongue contours for back fricatives by preceding vowel. The blue contours represents tongue shape during articulation of the consonant initially transcribed as /ʕ/, since it occurs only in the ɔ_ɔ environment. Despite that consonant having been transcribed as pharyngeal, its articulation does not display a contour that curves up farther back in the mouth than the maroon clump of contours, which represent uvular fricatives

[1]The lines plotted in this figure are limited to intervocalic contexts, despite what is displayed in the legend; this was due to a computing error

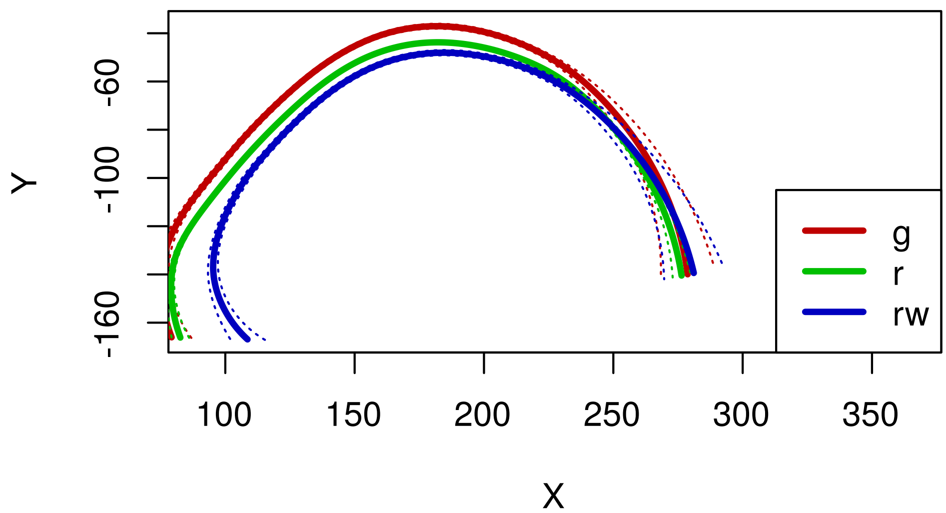

Figure 4: SSANOVA of tongue contours of only intervocalic fricatives, grouped by phonetic context; anterior is to the left

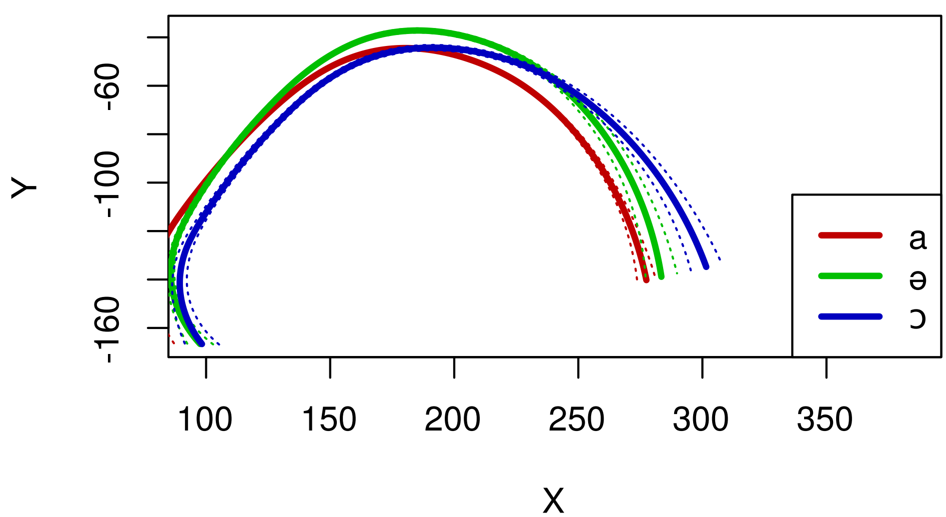

Figure 5: SSANOVA of tongue contours of only intervocalic fricatives, grouped by preceding vowel; anterior is to the left.

in the a_a environment. Rather, it overlaps with the uvular contours. If there were a pharyngeal phone in Tswefap, the blue contour's highest point would have a lower x value and higher y value than is shown in Figure 6. Therefore, what was transcribed as /ʕ/ should be transcribed instead with /ʁ/, and Tswefap has no phonemic pharyngeal fricative.

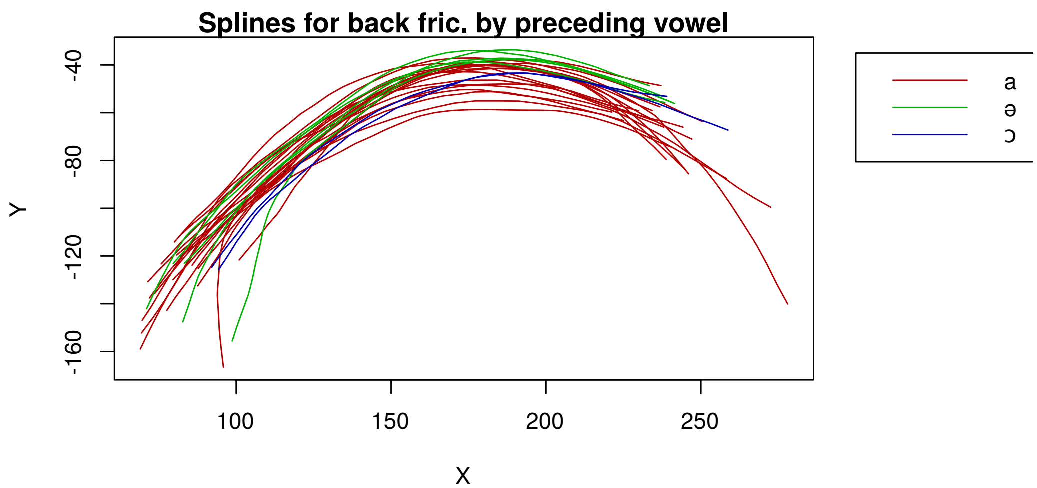

Figure 6: All traces of tongue contours of only uvular and pharyngeal fricatives, grouped by preceding vowel; anterior is to the left. The overlap of all the traces indicates that "pharyngeal" fricatives are made at the same place of articulation as uvular ones.

4 Discussion

Based on the SSANOVA results, we can answer the questions first posed in the introduction:

1. Yes, the phones that we marked as 'g' and 'r' are produced at significantly different points in the vocal tract. 'g' is clearly more anterior than 'r' (and 'rw') when in an intervocalic context.

2. The phone that we have marked as /ʕ/ is not significantly different from intervocalic 'r', and it seems like the difference is only due to vowel context.

3. 'rw' is not significantly different from 'r', but it reduces sometimes to just 'w', which is what we hear in words like rub "they". This could just be due to the rounded following vowel context.

4. 'g' before a nasal consonant fricativizes sometimes, but the constriction in SSANOVA (Figure 3) is so low as to be considered deletion. This is clear as well from the acoustics.

In addition, we found that the glottal fricative happens to map closely to the velar fricative, which indicates that it may be a voiceless velar fricative, or have some kind of velar constriction. This may also be due to coarticulation with the labialized vowel just following many of the /h/-initial words in the word list.

We do have a few remaining questions for future work:

1. How can we account for the aspirated [g] as in ngh 'do' and nghngh 'play'? Is it an allophone of something we have missed, or does it occur in free variation with the unaspirated variants?
2. By what process does labialized 'r' before /u/ lenite to just /w/?
3. Is deleted /g/ the same as no constriction whatsoever for glottal stop as in ra'a 'peanut shell'?

To answer these questions, further ultrasound analysis may be done, in addition to more research in the articulatory constraints and influences on lenition.

Finally, the table below illustrates the phones identified in the transcriptions of each Tswefap word, according to the results of our SSANOVA.

Phoneme (label)	Allophone	Context	Example word
r	r (vd uvular fric)	word initial	rap 'ten'
r	r (vd uvular fric)	intervocalic at word morpheme boundary	ma ru 'I laughed'
r	r (vd uvular fric)	intervocalic not at word morpheme boundary	wara 'all'
r	g(h)	stopped 'r' after nasal prefix (sometimes aspirated)	momənga 'I am opening my eyes'
r	rw ∼ w (vd labiovelar fric)	word initial before back rounded vowels	rwu 'big'
r	gw (vd labiolized velar stop)	stopped 'rw' after nasal prefix (sometimes aspirated?)	moməngɔ 'I am grinding'
g	ɣ (vd velar fric)	syllable final and at morpheme boundary, pre-nasal (sometimes reduced)	pagnyu 'red wine'
g	k (vless velar stop)	word final (more like [k] and sometimes aspirated	fog 'to pull'
g	g ∼ ɣ	intervocalic, not at morpheme boundary, usually reduced	sombəgə 'seven'
h	h ∼ ħ	word initially and intervocalic at morpheme boundary, no allophony	hop 'eight'
r	ɾ (vd uvular fric)	only in loanwords from French and English	latrɛ 'light'

Table 4: New classification of back fricative phonemes and their allophony.

Although the SSANOVA results are quite clear, the researchers acknowledge the limitations of this kind of statistical test. All words and their corresponding tongue contours were coded by hand, and, with the orthography we have been using to study Tswefap not very standardized, the likelihood of statistical error is not insignificant.

5 Conclusion

This study has demonstrated that ultrasound is a useful and effective way to study articulation. The ultrasound images are able to show us back consonant articulations that are difficult to determine just from acoustics, and the smoothing spline ANOVA indicate accurately where place of articulation is statistically significantly different between phones.

For our study of Tswefap, this confirms that velar and uvular places of articulation are different, and helps us to solidify our consonant inventory. It also has given us reason to collapse the previously-identified pharyngeal and labiovelar places of articulation to allophonic variation on the uvular place of articulation.

Looking forward in the research and documentation of Tswefap, the recommendation based on the results of this study is to use the “g” and “r” and “h” to represent their representative phonemes in orthography, and to use “g” for reduced/fricativized /g/ and stopped/obstruentized /r/.

References

[1] Lisa Davidson, *Comparing tongue shapes from ultrasound imaging using smoothing spline Analysis of variance*, Journal of the Acoustical Society of America 120:407415, 2006.

[2] Jeff Mielke *tonguessanova.r [R script]* 2014. Online: `http://phon.wordpress.ncsu.edu/lab-manual`, accessed May 3, 2016.