Dorsal consonant place and vowel height in Cochabamba Quechua*

Gillian Gallagher, New York University

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Abstract

The current study quantifies the effects of dorsal stops and fricatives on surrounding vowels in Cochabamba Quechua. The traditional description of high vowels [i u] surrounding velar stops and mid vowels [e o] surrounding uvular stops is confirmed in Experiment 1. The lowering effect of uvulars is found for both preceding and following vowels, at both midpoint and onset/offset. In Experiment 2, spirantized dorsal stops are found to maintain the uvular-velar contrast following front vowels, and vowel height effects are predictable. Following back vowels, there is no evidence of a uvular-velar contrast in fricatives, though both high and mid vowels are found. Additionally, there is high variability across speakers in the production of a given lexical item, suggesting that the contrast in fricatives is unstable.

1 Introduction

This paper presents an acoustic study of the effects of uvular consonants on surrounding vowels in Cochabamba Quechua. Uvular consonants in Quechua are described as lowering the high vowels /i u/ to mid vowels [e o] or [ɛ ɔ] (Bills et al. 1969; Adelaar with Muysken 2004; Hoggarth 2004; Laime Ajacopa 2007), e.g., /q'ipij/ → [q'epij] 'to carry'. Similar patterns are seen in many languages with uvulars or other post-velar consonants, including Eskimo-Aleut languages (Rischel 1972; Dorais 1986), many Interior Salish languages (Bessell 1998), Nuu-chah-nulth (Wakashan) (Wilson 2007), Chilcotin (Athabaskan) (Cook 1983, 1993; Bird 2014), Aymara (de Lucca 1987; Adelaar with Muysken 2004) and many varieties of Arabic (McCarthy 1994; Shahin 2002; Zawaydeh 1998; Al-Ani 1970; Butcher and Ahmad 1987).

Lowering effects of uvulars range in magnitude, from full lowering to a mid-vowel to insertion of a schwa-like glide at the transition between vowel and consonant. In Quechua, lowering is described as affecting the entirety of the vowel, both immediately preceding and following a uvular stop, e.g., /huq'u/ [hoq'o] 'damp', and preceding a cluster with a uvular as C_2, e.g., /sunqu/ [sɔNqo] 'heart'. Typologically, then, the lowering effects of uvulars in Quechua are quite strong. One of the goals of the current study is to quantify the effects of intervocalic uvular stops on preceding and following vowels by comparing high vowels surrounding velar stops, e.g., /ʎik'ij/ 'to tear', to those surrounding uvular stops, e.g., /liq'i/ 'hat', verifying and augmenting the available descriptions.

The second goal of the current study is to explore a less well-described area of Quechua dorsal-vowel interactions. Uvular and velar stops spirantize to fricatives in pre-consonantal or final position in Cochabamba Quechua (and in other Quechua varieties), and spirantized uvular fricatives should trigger the same lowering effects as uvular stops, e.g., /suqtɑ/ [sɔχtɑ] 'six'.

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Experiment 2 examines the distribution of vowel height preceding dorsal fricatives and the evidence for a contrast between uvular and velar fricatives.
Experiment 1, which looks at stops, confirms the existing descriptions. Experiment 2, which looks at fricatives, presents a more complex picture with evidence for both high and mid vowels preceding dorsal fricatives, but only mixed evidence for a contrast between uvular and velar fricatives themselves. The paper is organized as follows. Background on Quechua is given in Section 2, followed by a discussion of the research questions motivating the current study in Section 3. Experiment 1 is presented in Section 4 and Experiment 2 in Section 5. Section 6 discusses the results and concludes.

2 Quechua background

The data for the current study are drawn from Quechua speakers from the Cochabamba department of Bolivia. Cochabamba Quechua is a variety of South Bolivian Quechua (Lewis et al. 2014), classified in group IIC of the Quechua language family (Torero 1964), along with many varieties of southern Peruvian Quechua, including Cuzco Quechua. The description of the phonological effects of uvular consonants on vowels holds across this subgroup of the language family, though the results of the acoustic study here may be specific to Cochabamba Quechua. The phonemic consonantal inventory of Quechua is given in Table 1 (Rowe 1950; Cusihuamán 1976; Bills et al. 1969); of particular interest are the three uvular consonants [q q^h q’] which contrast with their velar counterparts [k k^h k’]. In Cochabamba Quechua the plain uvular stop /q/ is realized as a voiced sonorant [ʁ] (Bills et al. 1969).

	labial	dental	postalveolar	velar	uvular	glottal
plain	p	t	tʃ	k	q	
aspirate	p^h	t^h	$tʃ^h$	k^h	q^h	
ejective	p’	t’	tʃ’	k’	q’	
fricative		s				h
nasal	m	n	ɲ			
liquid		l ɾ	ʎ			
glide	w		j			

Table 1: Quechua consonant inventory.

Quechua is described as having three underlying vowels /i u ɑ/, which surface as tense in open syllables and lax in closed syllables. In addition to the tense/lax alternation, the high vowels are reported to lower to mid vowels - /i/ surfaces as [e] or [ɛ], /u/ surfaces as [o] or [ɔ] - in the vicinity of a uvular consonant (Bills et al. 1969; Adelaar with Muysken 2004; Hoggarth 2004; Laime Ajacopa 2007). The low central vowel /ɑ/ is not reported to be affected by consonantal context. Lowering is reported for vowels both immediately preceding and following a uvular (1a,b), as well as those preceding a consonant cluster with a uvular in C_2 (1c). The description of vowel lowering by word-initial uvulars is supported by the acoustic study in Holliday (under review), which finds that vowels following uvulars are produced as mid throughout their duration.

(1)	a.	/q’ipij/	[q’epij]	‘to carry’
		/q^{h}iʎu/	[q^{h}eʎu]	‘lazy’
		/qusɑ/	[ʁosɑ]	‘husband’
		/q’usɲi/	[q’ɔsɲi]	‘garbage’
	b.	/liq’i/	[leq’e]	‘hat’
		/siq’uj/	[seq’ɔj]	‘to smack’
		/huq’u/	[hoq’o]	‘damp’
		/muq’ij/	[moq’ɛj]	‘to want, love’
	c.	/irqi/	[ɛrʁe]	‘son’
		/p’isqu/	[p’ɛsʁo]	‘bird’
		/sunqu/	[sɔNʁo]	‘heart’
		/urqu/	[ɔrʁo]	‘mountain’

While in native Quechua words the distribution of vowel height is predictable given the consonantal context, loanwords from Spanish may have mid vowels in unconditioned environments. Spanish loans with mid vowels may be borrowed into Quechua with high vowels, e.g., Spanish [trigo] Quechua [riwu] ‘wheat’, Spanish [eskwela] Quechua [iskwila] ‘school’, but many speakers produce Spanish loans with mid vowels and other non-native segments or structures. As the majority of Quechua speakers have some knowledge of Spanish and contact with Spanish speakers, most Quechua speakers have at least some experience with mid vowels outside of a uvular context. Holliday (under review) finds, however, that the vowel space of Quechua-Spanish bilinguals is quite different in the two languages, suggesting that speakers maintain distinct phonetic systems.

The vowel lowering pattern above interacts with another allophonic process in Bolivian Quechua: the spirantization of the plain dorsal stops /k q/ to voiceless fricatives in pre-consonantal or final position (Bills et al. 1969; Adelaar with Muysken 2004; Laime Ajacopa 2007).[1] The ternary laryngeal contrast in Quechua stops and affricates is limited to pre-vocalic context, so only the plain stops /k q/ may occur in the environment for spirantization. Bills et al. (1969) report that spirantized dorsal stops contrast for place, [x] vs. [χ], and that uvular stops trigger lowering of the preceding vowel, e.g., /ʎikʎɑ/ [ʎɪxʎɑ] ‘small shawl’, /tʃiqnin/ [tʃɛχniŋ] ‘he hates’. While Laime Ajacopa (2007) is explicit that there are four post-velar consonants (i.e., three stops and a fricative), he transcribes the fricative using the <j> symbol (the orthographic representation of the dorsal fricative in Spanish), and is silent about spirantization of the velar stop or effects of the dorsal fricative on vowels. In his description of Cuzco Quechua, Cerron-

[1] Laime Ajacopa (2007) states that spirantization is optional in final position, where stops and fricatives alternate freely. Spirantization in pre-consonantal position is then implied to be obligatory.

Palomino (1994) is explicit that both dorsals spirantize in pre-consonantal and final position, maintaining a place contrast, but is silent about the effects of these segments on preceding vowels.

Standard Bolivian Quechua orthography represents neither spirantization nor vowel lowering. In pre-consonantal and final position, dorsal fricatives are represented with the same symbols as for stops <k> and <q>, and only three vocalic symbols are used <i>, <u> and <a>. Informal work with Cochabamba Quechua speakers has revealed that the pronunciation of vowels preceding dorsal fricatives is unclear. Forms that are orthographically represented with uvulars, like <suqta>, are reported to be acceptable pronounced as either [suχtɑ] or [soχtɑ].

In sum, while descriptions are clear that the dorsal stops are realized as fricatives in pre-consonantal and final position, it is not entirely clear (i) whether dorsal stops retain the contrast between uvular and velar place when spirantized and (ii) whether vowels show the same height allophony preceding dorsal fricatives as they do preceding dorsal stops.

3 Research questions

This paper addresses two descriptive questions about the system of vowel and dorsal consonant contrasts in Cochabamba Quechua. First, the effects of intervocalic uvular and velar stops on preceding and following vowels are quantified. Second, the existence of a place contrast between pre-consonantal dorsal fricatives is examined, as well as the distribution of vowel height preceding these fricatives. With respect to both of these questions, only the high vowels /i u/ are analyzed; the low vowel /ɑ/ is not examined in the current study.

The description of the effects of dorsal stops on surrounding vowels is clear in the literature, and the acoustic analysis done here serves to verify the analysis and explore phonetic details that may not have been captured in previous, impressionistic analyses. To confirm the lowering effect of uvulars on both preceding and following vowels, intervocalic uvular and velar stops are examined and the formant structure of surrounding vowels is analyzed, e.g., /l**iq'i**/ 'hat' is compared to /ʎ**ik'i**j/ 'to tear'. Only intervocalic stops are looked at. Differences between intervocalic stops and initial or medial (in C_2 of a cluster) stops are left for future work.

In addition to assessing the lowering effect of uvulars in general terms, two more specific questions are addressed. First, the magnitude of the lowering effect of uvulars is compared between preceding and following vowels. Gick & Wilson (2006) report that in some languages, uvulars have a stronger impact on preceding vowels, while in other languages following vowels are more strongly affected. In Nuu-chah-nulth (Wakashan), high front vowels preceding uvulars have a schwa-like offglide, but are not fully lowered /iq/ → [i^{ə}q]. High front vowels following uvulars, however, are lowered to a mid vowel /qi/ → [qe] or [qɛ]. This pattern is largely confirmed in the detailed auditory, acoustic and articulatory analyses in Wilson (2007). In Chilcotin (Athabaskan), the reverse pattern is found (Cook 1983, 1993; Bird 2014). The high front vowel is slightly lowered when it precedes a uvular /iq/ → [ɪq], but following a uvular only a schwa-like offglide is found without any lowering of the following vowel /qi/ → [q^{ə}i]. Bird (2014) further finds that retraction triggered by the pharyngealized series of consonants in

Chilcotin extends further leftwards than rightwards from the triggering segment. Directional asymmetries in the effects of post-velar consonants on surrounding segments are also found in studies of several Arabic dialects (Shahin 2002; Zawaydeh 1998; Al-Ani 1970; Butcher and Ahmad 1987), where effects on preceding segments are typically found to be stronger than effects on following segments.

Second, the magnitude of the lowering effect of uvulars is compared between the midpoint of the vowel and the offset (for preceding vowels) or onset (for following vowels) of the vowel. The descriptions of lowering in Quechua suggest that this process is categorical, contrasting with what is found in other languages, like Nuu-chah-nulth or Chilcotin, where a uvular results in a transitional glide as opposed to full lowering of a vowel. Gick & Wilson (2006) and Wilson (2007) show that the transitional glide between a high front vowel and a uvular is likely the result of biomechanical, articulatory pressures. Uvulars require a back tongue body and a retracted tongue root, while a high front vowel requires a high front tongue body and an advanced tongue root. If the effects of uvulars on surrounding vowels are solely due to biomechanical pressures, the expectation is that the portion of a vowel that is closer to the consonantal closure should be more affected by the consonant than the midpoint of the vowel. Effects of a uvular on the entirety of a surrounding vowel, as found in Holliday (under review), would support the analysis of Quechua as having a truly phonological, allophonic alternation in vowel height. A further observation on this point is that Quechua uvulars are reported to have the same effects on both front and back vowels. From an articulatory perspective, only the high front vowel is in conflict with a uvular constriction. A high back vowel like /u/ is not articulatory antagonistic with a uvular, and is not expected to be affected if only biomechanical pressures are at issue (Wilson 2007). The asymmetry between back and front vowels is clearly seen in languages like Nuu-chah-nulth where only the high front vowel /i/ is modified in the vicinity of uvulars, /u/ and all other vowels are unaffected (Wilson 2007). The three research questions to be addressed with respect to the effects of intervocalic uvulars and velars on surrounding high vowels are summarized in (2).

(2) Research Question 1: Are vowels preceding and following uvulars lower (higher F1) than vowels preceding and following velars?

Research Question 2: Are preceding or following vowels more affected by consonantal place?

Research Question 3: Are vowels more affected by consonantal place at onset (following vowels) and offset (preceding vowels) than at midpoint?

With regards to the dorsal fricatives and their effects on preceding vowels, there are several possible scenarios, schematized in (3). The first possibility (3a) is the most transparent: there is a surface contrast in fricative place that has a predictable effect on the preceding vowel. A second possibility is that fricatives contrast for place, but have a smaller effect on preceding vowels than stops do (3b). Wilson (2007) finds that Nuu-chah-nulth /χ/ has no effect on preceding vowels, though uvular stops do effect preceding vowels. A second set of possibilities is that the place contrast in fricatives is neutralized on the surface. If this is true, vowels may still show variation in height reflecting either an underlying contrast in fricative place or a reanalysis of vowel height as phonemic in Quechua (3c). Alternatively, vowels may show no variation in height (3d).

(3) a. Scenario 1 – surface contrast in fricatives, uvulars lower preceding vowels
[…uxC…] vs. […oχC…]

b. Scenario 2 – surface contrast in fricatives, small/no effect of uvulars on preceding vowels
[…uxC…] vs. […uχC…] or […uᵊχC…]

c. Scenario 3 – no surface contrast in fricatives, but both high and mid vowels are found
[…uxC…] vs. […oxC…]

d. Scenario 4 – no surface contrast in fricatives, no contrast in vowel height
[…uxC…] or […uᵊχC…] or […oχC…]

The three research questions to be addressed with respect to the dorsal fricatives and preceding vowels are summarized in (4).

(4) Research Question 1a: Are both high and mid vowels found before dorsal fricatives?

Research Question 1b: Is there a place contrast between uvular and velar fricatives?

Research Question 2: Given positive answers to Questions 1a,b, are uvular fricatives preceded by mid vowels and velar fricatives by high vowels?

The questions outlined in this section are addressed in two sets of acoustic analyses, one looking at stops, presented as Experiment 1 in Section 4, and the other looking at fricatives, presented as Experiment 2 in Section 5. The data for both analyses were collected together, but the analyses are presented as separate experiments because the questions and methods differ substantially.

4 Experiment 1 – vowels surrounding uvular and velar stops

4.1 Participants

Eleven native speakers of Quechua participated in the experiment. All participants were recruited in the town of Anzaldo, Bolivia in the Cochabamba department; participants were all from Anzaldo or surrounding communities. The participants were nine females and two males. The males were both 18 years of age, and the females ranged from 18 to 37. All participants had some knowledge of Spanish, but all reported that they spoke Quechua more frequently than they spoke Spanish and that they were more comfortable speaking Quechua than Spanish, considering it their primary language. The age that participants began learning Spanish ranged from 9 to 19.

4.2 Materials

The stimuli were Quechua words that contained an intervocalic velar or uvular stop, either ejective or aspirate, preceded and followed by the high vowels /i u/. Aspirate and ejective stops were used instead of plain stops because the plain uvular stop in Cochabamba Quechua is realized as an approximant, and thus is neither comparable to the plain velar stop nor easily segmentable from surrounding vowels. To arrive at the set of stimulus words, given in Table 2, all of the forms with an intervocalic /k' q' k^h q^h/ preceded and followed by the high vowels /i u/ were extracted from the Laime Ajacopa (2007) dictionary. A native Quechua speaking RA from Cochabamba then checked this list to remove words that she judged would be unfamiliar to native speakers, and added any more words that she could think of. As there were not a great number of words with the desired strings, all of the words that contained these strings were included in the stimulus set. Consequently, the resulting stimulus set is not balanced for V_1, V_2 or place of articulation. Words with a uvular surrounded by high vowels were particularly rare, so two additional words /miq'a/ and /uq^{h}arij/ were also included. There are 10 words with velar stops, of which V_1 = /i/ in 6 items, V_1 = /u/ in 4 items, V_2 = /i/ in 3 items and V_2 = /u/ in 7 items. In the 7 words with uvular stops, V_1 = /i/ in 3 items, V_1 = /u/ in 4 items, V_2 = /i/ in 2 items, V_2 = /u/ in 3 items and V_2 = /a/ in 2 items.

velar		**uvular**	
hik'uj	'hiccup, gulp'	huq'u	'damp'
huk'utɑ	'sandal'	liq'i	'hat'
huk'utʃɑ	'mouse'	luq'u	'deflated'
ʎik'ij	'to tear (cloth)'	miq'ɑ	'hollow'
mik^{h}uj	'to eat'	muq'ij	'want, love'
mik'i	'damp'	siq'uj	'to smack'
muk'u	'type of chicha'	uq^{h}ɑrij	'to take out'
rik^{h}urij	'to appear'		
sik'ij	'to uproot'		
uk^{h}u	'body'		

Table 2: Stimuli with a uvular or velar stop in the context of a high vowel, phonemic transcription.

Each word was presented both in isolation and in a unique carrier phrase (see Appendix A for a list of carrier phrases). Carrier phrases were designed so that the target word always had initial stress (stress in Quechua is fixed on the penultimate syllable). Verbs were always in the 3rd person singular present, which is marked with the suffix [-n] e.g., [mik^{h}un] 'he eats', and were always phrase final. Nouns and adjectives were phrase medial and were either unsuffixed or suffixed with the 3rd singular possessive [-n], e.g., [uk^{h}un] 'his body'.

4.3 Procedure

A native Quechua speaking RA from Cochabamba, Bolivia conducted the experiment. The RA pronounced a target word in isolation, and the participant was asked to repeat the word twice, with a pause between the repetitions. The RA then produced the target word in a carrier sentence, and the participant was asked to repeat the sentence. In the case of disfluencies, which were rare, the participant was asked to repeat the target word or sentence again. No Spanish was used in conducting the experiment.

The stimuli for Experiment 1 were randomized with the stimuli for Experiment 2, and all stimuli were presented to participants together in a single session.

4.4 Analysis

Target words were segmented for V_1 and V_2, as in Figure 1. Vowels were segmented based on the onset and offset of F2. V_1 was always clearly segmentable from the preceding consonant, but V_2 was often followed by the glide [j] (the infinitival marker for verbs). In such cases of a final diphthong, the end of V_2 was designated as the middle of the vowel+glide period. The presence of the final palatal glide resulted in higher F2 values for back vowels (β = -320.81, SE = 56, t = -5.73), indicating a fronting effect, but did not affect F1 in back vowels nor F1 or F2 in front vowels.

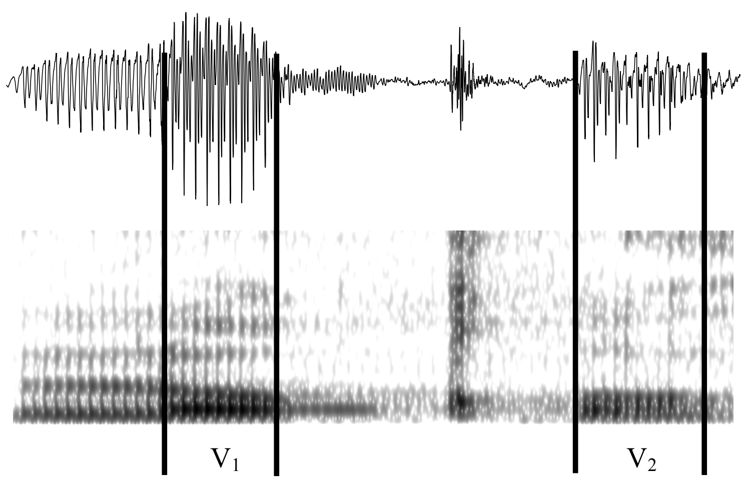

Figure 1: Waveform and spectrogram for /luq'u/ 'deaf', with segmented V_1 and V_2.

Preceding and following high vowels were measured for F1 and F2, at midpoint (50%) as well as at offset (90%) of V_1 and onset (10%) of V_2. All analysis was done in Praat version 5.2.43 (Boersma & Weenink 1992-2014).

Formant values were analyzed separately for front and back vowels. Isolation words and words in carrier phrases were also analyzed separately. All statistical models were Linear Mixed Models (LMMs) fit in R (http://www.r-project.org/) using the *lmer* function in the languageR package (Bates & Maechler 2008). All models have centered, contrast coded predictors and maximal random effects structures; t values of ± 2 are considered significant (Gelman & Hill 2006). Vowel plots were created using the vowels package for R (Kendall & Thomas 2012).

29 vowels in isolation words and 21 vowels in words in carrier phrases were removed from analysis either due to disfluency or because they were voiceless and had unclear formant

structure. The number of tokens that were included in the analysis for each place/backness combination for each measure is given in Table 3.

	isolation				carrier phrase			
	uvular		velar		uvular		velar	
	back	front	back	front	back	front	back	front
V_1	84	66	82	128	42	31	42	61
V_2	60	43	141	63	30	22	72	31

Table 3: Tokens included in the analysis of medial stops, by place, vowel backness and isolation/carrier phrase.

4.5 Results

4.5.1 Preceding vowels

Vowels preceding uvular and velar consonants are distinct from one another, both at midpoint (50%) and offset (90%) of the vowel. Vowels preceding uvulars are lower – have a higher F1 – than vowels preceding velars, for both front and back vowels. There are also differences in F2. High vowels tend to be more peripheral than mid vowels, though this difference is more pronounced for front vowels than back vowels, and is both smaller and more variable across speakers than the distinction in F1. Figure 2 shows the vowel space (non-normalized across speakers) before uvulars and velars at midpoint and offset of vowels in isolation words.

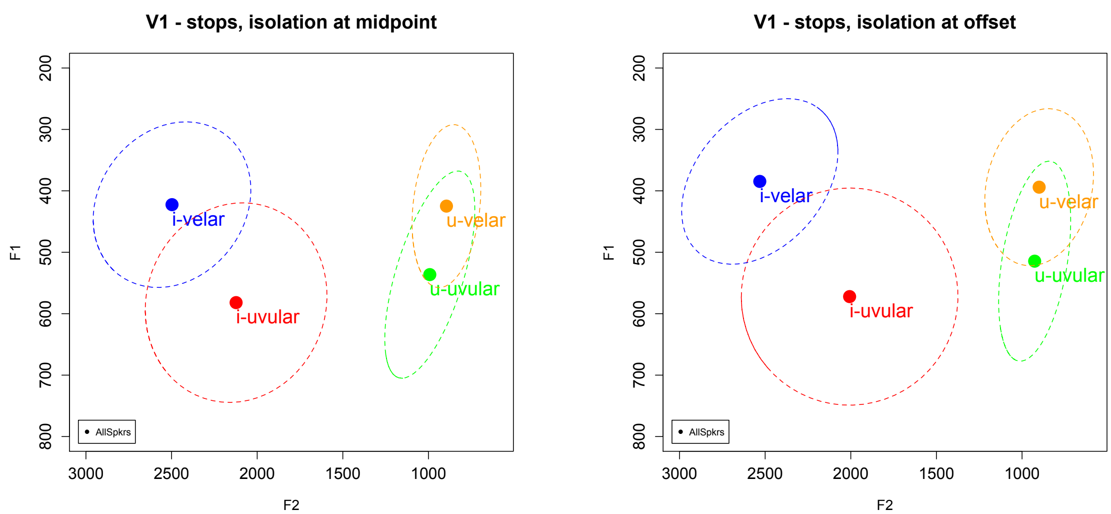

Figure 2: F1 and F2 for vowels /i u/ in V_1 in isolation words, plotted by consonantal context, at vowel midpoint (left) and vowel offset (right). Values represent averages across speakers.

LMMs were fit to F1 and F2 values at midpoint and offset. For each model, there was a predictor of consonantal context, comparing vowels preceding velars and those preceding uvulars. At vowel midpoint, F1 differs by consonantal context for front vowels (β = 160.8, SE = 15.49, t = 10.38) and back vowels (β = 112.39, SE = 16.91, t = 6.65), as does F2 (front: β = -362.99, SE = 91.85, t = -3.95; back: β = 93.69, SE = 43.83, t = 2.14). At vowel offset, differences in F1 by consonantal context are also found for both front (β = 190.56, SE = 18.59, t = 10.25) and back (β

= 121.41, SE = 13.77, t = 8.82) vowels, but differences in F2 are only found for front vowels (β = -525.69, SE = 91.54, t = -5.74); back vowels do not show a significant difference in F2 between uvular and velar contexts (β = 22.89, SE = 43.90, t = 0.52).

To test for differences between vowel midpoint and vowel offset in the magnitude of consonantal context effects, additional LMMs were fit with F1 or F2 as the dependent variable and predictors of timepoint (midpoint or offset), consonantal context and their interaction. The crucial question is whether the interaction between timepoint and consonantal context is significant. This interaction is significant for F1 and F2 in front vowels (F1: β = -28.58, SE = 12.55, t = -2.28; F2: β = 153.79, SE = 43.72, t = 3.52) and for F2 but not F1 in back vowels (F1: β = -8.64, SE = 12.71, t = -0.68; F2: β = 71.55, SE = 34.83, t = 2.05). The interactions for front vowels arise because the effects of consonantal context on a preceding front vowel is larger at vowel offset (velar context F1 = 385, F2 = 2531 vs. uvular context F1 = 572, F2 = 2007) than at vowel midpoint (velar context F1 = 423, F2 = 2497 vs. uvular context F1 = 582, F2 = 2123). For back vowels, the significant interaction for F2 is found because F2 values differ by consonantal context significantly at midpoint but not at offset, consistent with the models reported above.

For the midpoint and offset formant values of isolation words, the data from individual speakers were evaluated for conformance to the overall pattern. At midpoint, all speakers show significant differences (based on a Welch, two sample t-test) for F1 and F2 in front vowels and for F1 in back vowels. Ten out of eleven speakers also show signficiant differences in F2 in back vowels, but the direction of difference is consistent with the overall pattern for all speakers. At vowel offset, all speakers show significant differences for F1 in front and back vowels. All speakers are consistent with the overall pattern for F2 in front vowels, though one speaker shows a non-significant effect in the expected direction. Ten out of eleven speakers have non-significant differences in F2 for back vowels, but one speaker has a significant difference with lower F2 preceding velars than uvulars. The full results for individual speakers are reported in Appendix B.

The pattern for preceding vowels in words in carrier phrases is similar to that seen for isolation words. Both front and back vowels show distinct F1 and F2 values depending on the following vowel. Figure 3 shows the vowel space at the midpoint.

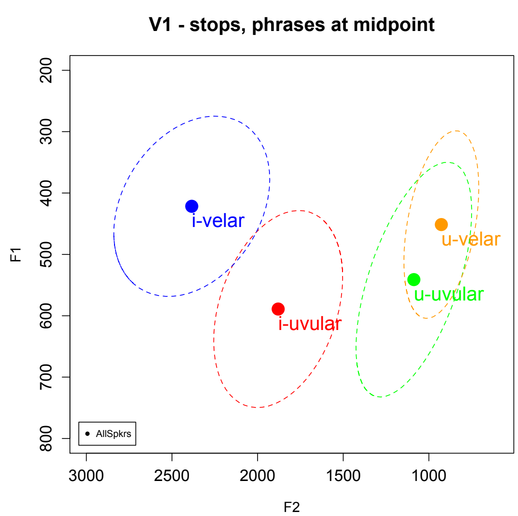

Figure 3: F1 and F2 at midpoint for front and back vowels in V_1 in words in carrier phrases, plotted by consonantal context. Values represent averages across speakers.

Two LMMs confirm that F1 differs by consonantal context for front vowels (β = 167.90, SE = 25.90, *t* = 6.48) and back vowels (β = 90.44, SE = 18.95, *t* = 4.77) in carrier phrases. F2 also differs by consonantal context for both front vowels (β = -509.95, SE = 75.55, *t* = -6.75) and back vowels (β = 158.89, SE = 59.63, *t* = 2.67). The average formant values for all preceding vowel measurements are given in Table 4.

	isolation, midpoint		isolation, offset		carrier phrase, midpoint	
	velar	uvular	velar	uvular	velar	uvular
front	F1 = 422 F2 = 2497	F1 = 582 F2 = 2123	F1 = 385 F2 = 2531	F1 = 572 F2 = 2007	F1 = 422 F2 = 2385	F1 = 589 F2 = 1880
back	F1 = 425 F2 = 895	F1 = 536 F2 = 992	F1 = 394 F2 = 900	F1 = 514 F2 = 926	F1 = 451 F2 = 927	F1 = 541 F2 = 1088

Table 4: F1 and F2 values for front and back vowels in V_1, averaged across speakers.

4.5.2 Following vowels

Like preceding vowels, vowels following uvular and velar consonants show distinct F1 values, but only front vowels show a difference in F2. The vowel space for following vowels at onset (10%) and midpoint (50%) is shown in Figure 4.

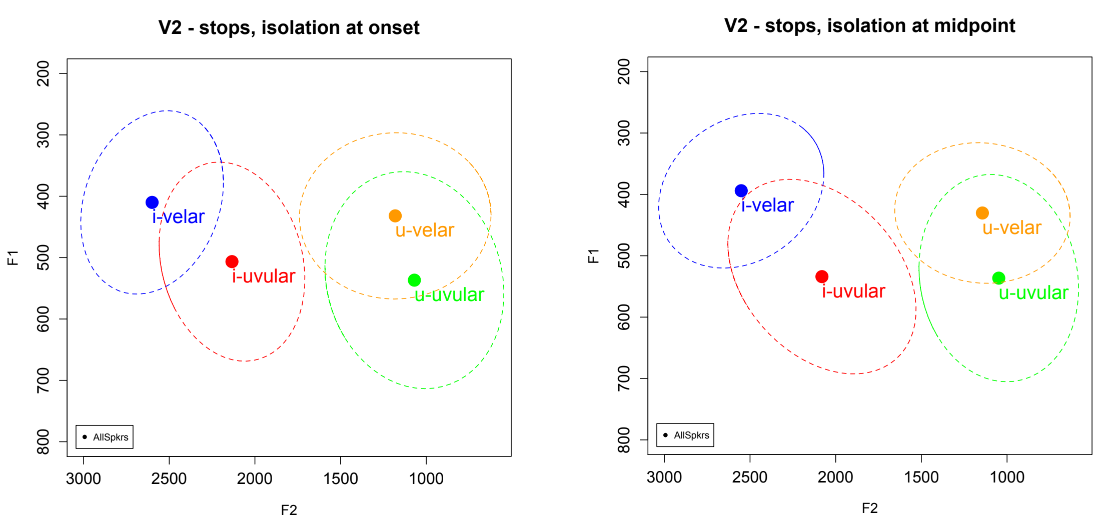

Figure 4: F1 and F2 for front vowels in V_2 in isolation words, plotted by consonantal context, at vowel onset (left) and vowel midpoint (right). Data is pooled across speakers.

As for preceding vowels, LMMs were fit to F1 and F2 values at onset and midpoint. At vowel onset, F1 differs by consonantal context for front vowels (β = 95.88, SE = 18.23, t = 5.26) and back vowels (β = 106.23, SE = 19.44, t = 5.46). F2 differs for front vowels (β = -469.46, SE = 74.53, t = -6.30) but not for back vowels (β = -116.88, SE = 160.96, t = -0.73). At vowel midpoint the pattern is the same, differences in F1 by consonantal context are found for both front (β = 138.81, SE = 16.51, t = 8.41) and back (β = 105.54, SE = 17.49, t = 6.03) vowels, as well as for F2 in front vowels (β = -462.20, SE = 84.46, t = -5.47) but not back vowels (β = 100.8, SE = 129.5, t = -0.78).

To test for differences in the effects of consonantal context between onset and midpoint, a second set of analyses was done with timepoint and consonantal context as predictors. These analyses were only done for F1 and F2 in front vowels, as F2 was not found to differ by consonantal context for back vowels. The interaction between timepoint and consonantal context is significant for F1 in front vowels (β = 43.19, SE = 17.02, t = 2.54), but not for back vowels (β = 0.27, SE = 12.15, t = 0.02), and is also not significant for F2 in front vowels (β = 5.65, SE = 71.42, t = 0.08). The interaction for F1 in front vowels arises because the effect of consonantal context on the height of a following front vowel is actually larger at midpoint (velar context F1 = 394, F2 = 2551 vs. uvular context F1 = 534, F2 = 2080) than at vowel onset (velar context F1 = 410, F2 = 2600 vs. uvular context F1 = 507, F2 = 2134).

For the onset and midpoint formant values of isolation words, the data from individual speakers were evaluated for conformance to the overall pattern. At onset, all speakers are consistent with the overall pattern for F1; differences are significant for four out of eleven speakers for front vowels and eight out of eleven speakers for back vowels. Ten out of eleven speakers are consistent with the overall pattern for F2 in front vowels, though this difference is significant for none. All speakers are consistent with the overall pattern for F2 in back vowels. At midpoint, all speakers are consistent with the overall pattern. Differences in F1 are significant for eight out of eleven speakers for front vowels and back vowels, and differences in F2 in front vowels are significant for seven out of eleven speakers. The full results for individual speakers are reported in Appendix B.

The pattern for following vowels in words in carrier phrases is similar to that seen for isolation words for front vowels, but differs for back vowels. For front vowels, both F1 and F2 are affected by consonantal context, but there is no distinction in either F1 or F2 for back vowels. Figure 5 shows the vowel space at the midpoint of vowels for words in carrier phrases.

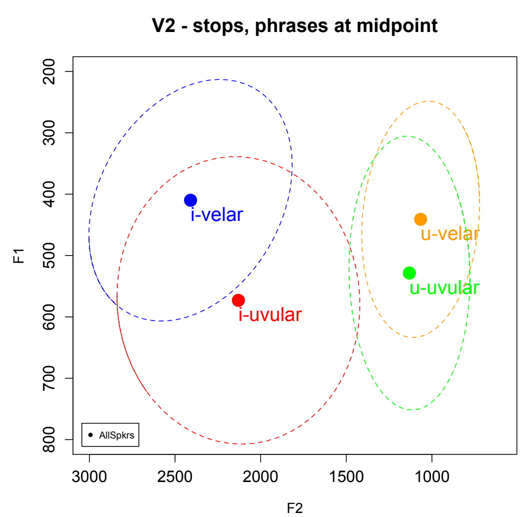

Figure 5: F1 and F2 at midpoint for front and back vowels in V_2 in words in carrier phrases, plotted by consonantal context. Values represent averages across speakers.

LMMs find that F1 differs by consonantal context for front vowels (β = 164.21, SE = 32.49, t = 5.05) but not for back vowels (β = 90.04, SE = 50.74, t = 1.78). For F2, there is also a significant difference for front vowels (β = -282.14, SE = 97.41, t = -2.90) but not for back vowels (β = 54.63, SE = 67.32, t = 0.81).

The average formant values for all following vowel measurements are given in Table 5.

	isolation, onset		isolation, midpoint		carrier phrase, midpoint	
	velar	uvular	velar	uvular	velar	uvular
front	F1 = 410 F2 = 2600	F1 = 507 F2 = 2134	F1 = 394 F2 = 2551	F1 = 534 F2 = 2080	F1 = 410 F2 = 2409	F1 = 573 F2 = 2130
back	F1 = 432 F2 = 1181	F1 = 536 F2 = 1069	F1 = 430 F2 = 1144	F1 = 536 F2 = 1048	F1 = 441 F2 = 1066	F1 = 529 F2 = 1132

Table 5: F1 and F2 values for front and back vowels in V_1, averaged across speakers.

4.5.3 Comparison of preceding and following vowels

The magnitude of consonantal context effects on preceding and following vowels was directly compared in a separate set of analyses. Based on the analyses above, which look at preceding and following vowels separately, both preceding and following vowels are strongly affected by consonantal context throughout the duration of the vowel.

To directly compare the consonantal effects on preceding and following vowels, a series of LMMs were fit with dependent variables of F1 or F2 and predictors of consonantal context, vowel position (preceding or following) and their interaction. One set of models compared vowels at their midpoints, and another set of models compared preceding vowels at offset with following vowels at onset. The crucial question for each model is whether the interaction term is significant, as this would indicate a difference in the effect of consonantal context between preceding and following vowels.

Comparing vowel midpoints in isolation words, the interaction term is significant for F2 in back vowels (β = -193.11, SE = 43.73, t = -4.416) and approaches significance for F1 in front vowels (β = -34.12, SE = 17.26, t = -1.98). The significant interaction for back vowels in F2 arises because the direction of the consonantal effect differs for preceding and following vowels. For preceding vowels, F2 is lower in the velar context (velar context F2 = 895, uvular context F2 = 992), indicating that vowels preceding velars are further back than vowels preceding uvulars. For following vowels, however, F2 is lower in the uvular context (velar context F2 = 1144, uvular context F2 = 1048), indicating that vowels following uvulars are more retracted than vowels following velars. The near significant interaction for front vowels arises because the effect of consonantal context is bigger for preceding vowels than following vowels. Preceding vowels show a 160 Hz difference by context (velar context F1 = 422, uvular context F1 = 582), while following vowels show a smaller, 140 Hz difference (velar context F1 = 394, uvular context F1 = 534).

Comparing onset and offset, the interaction term is similarly significant for F1 in front vowels (β = -89.85, SE = 23.85, t = -3.77) and for F2 in back vowels (β = -134.22, SE = 49.09, t = -2.73). The significant interaction for F1 in front vowels arises again because the magnitude of the effect of consonantal context is larger for preceding than following vowels: 187 Hz difference for preceding vowels (velar context F1 = 385, uvular context F1 = 572) compared to a 97 Hz difference for following vowels (velar context F1 = 410, uvular context F1 = 507). For F2 in back vowels, the interaction is again due to a difference in the direction of the effect: vowels are backer preceding velars than uvulars (velar context F2 = 900, uvular context F2 = 926) for preceding vowels, but following vowels are backer following uvulars than velars (velar context F2 = 1181, uvular context F2 = 1069).

For vowels in words in carrier phrases, the interaction is not significant for any measure.

4.6 Discussion

Uvular or velar consonantal place was found to affect F1 in surrounding vowels in the predicted direction: both front and back vowels are lower surrounding a uvular consonant than following a velar consonant. Comparison of consonantal effects at midpoint and vowel onset/offset suggest that lowering in the context of a uvular reflects a lower target for vowels in this context, as opposed to gradient effects of coarticulation with the dorsal consonant.

Comparing preceding and following vowels to one another, the effects of consonantal context are comparable for back vowels, but preceding front vowels are affected more strongly than following front vowels.

The results of Experiment 1 are consistent with a description of Quechua as having allophonic lowering of both preceding and following vowels in the context of a uvular stop.

5 Experiment 2 – vowels preceding dorsal fricatives

Having established the effects of uvular and velar stops on preceding vowels, words with dorsal fricatives are now examined. It was found in Experiment 1 that uvular stops are preceded by mid vowels and velar stops by high vowels. The acoustic properties of dorsal fricatives and preceding vowels are analyzed in two ways in Experiment 2. First, the orthographic representation of dorsal consonants as either uvular or velar is used to test for differences in the spectral energy of the fricative and formant structure of the preceding vowel. Second, items are classified based on whether the vowel falls into the high or mid range, given the results of Experiment 1.

5.1 Participants

The participants were the same individuals who completed Experiment 1.

5.2 Materials

The stimuli for Experiment 2, given in Table 6, were words with a dorsal fricative in preconsonantal position, preceded by a high vowel /i u/. The items in this list were chosen using the same method as described for the stops in Experiment 1, by consulting the Laime Ajacopa (2007) dictionary and a native Cochabamba Quechua speaker. The stimuli here are given in the phonemic transcription implied by the orthography. In the surface acoustic form, items with <k> should have a velar fricative [x] and a preceding high vowel [i u] and items with <q> should have a uvular fricative [χ] and preceding mid vowel [e o], though the actual status of these fricatives and preceding vowels is subject to analysis in the current study.

V_1 = /i/		**V_1 = /u/**	
tʃikʎaj	'to choose'	tʃuktʃɑ	'hair'
likrɑ	'shoulder, wing'	ʎuktʃij	'to touch'
ʎikʎɑ	'shawl'	pukʎaj	'to play'
piktʃuj	'to chew coca'	suksuj	'to consume'
tikraj	'to turn over'	tʃuqʎu	'corn-on-the-cob'
tʃiqtʃij	'to smile'	tʃuqru	'dry, hard'
tʃiqnij	'to hate'	luqt'u	'deaf'
tʃ'iqtʃi	'grey'	ʎuqsij	'to leave'
piqtuj	'to mix'	muqtʃ'ij	'to rinse'
riqsij	'to know'	ɲuqtu	'brain'
siqsij	'to sting'	ɲuqtʃ'ɑ	'daughter-in-law'
		puqtʃu	'unit of measure'
		suqtɑ	'six'
		t'uqsij	'to point, prick'
		t'uqpi	'crazy'
		uqʎaj	'to hug'

Table 6: Fricative stimuli with a dorsal fricative preceded by a high vowel /i/ or /u/.

5.3 Procedure

The procedure was the same as for Experiment 1. The stimuli for Experiment 1 and Experiment 2 were presented randomized together, in a single session.

5.4 Analysis

Target words were segmented for V_1 and the target fricative, as in Figure 6.

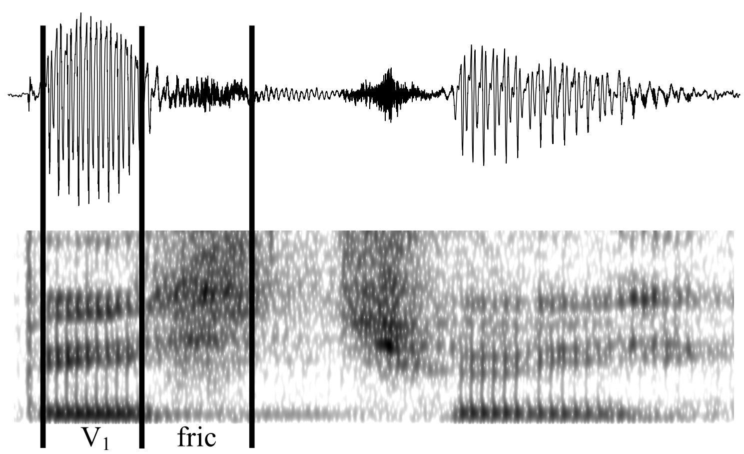

Figure 6: Waveform and spectrogram for target stimulus /piktʃuj/ 'to chew coca', with segmented V_1 and fricative.

V_1 was measured for F1 and F2 at midpoint (50%). Fricative duration was measured, along with the first two spectral moments (Forrest et al. 1988), mean and variance. As in recent work looking at sibilant fricatives (Jesus & Shadle 2002; Lousada et al. 2012; Koenig et al. 2013), a low frequency cutoff of 500 Hz was used in analyzing the spectra to filter out low frequency noise due to carry-over voicing from the preceding vowel. Spectral moments were taken over a window centered at the midpoint of the fricative; the duration of the window was 10% of the duration of the fricative. Several previous studies have found that uvular and velar fricatives are distinguished by spectral mean, with uvulars having a higher spectral mean than velars (Gordon et al. 2002; Gordon & Applebaum 2006), and by duration, with uvulars being shorter than velars (Gordon et al. 2002). Taff et al. (2001) and Mayes (1979) have also found differences in spectral mean, though not variance, between uvular and velar stop bursts. All analyses were done in Praat version 5.2.43 (Boersma & Weenink 1992-2011).

Formant values were analyzed for an effect of consonantal place, separately for front and back vowels, by fitting Linear Mixed Models, as in Experiment 1. Spectral moments and duration measures in fricatives were also compared by consonantal place.

Coding of tokens as uvular/velar was done in two ways. First, the orthographic representation was used. Second, vowels were classified as either high [i u] or mid [e o] based on the results at midpoint for preceding vowels for each speaker in Experiment 1, and fricatives were then coded as uvular or velar based on the preceding vowel. These two coding methods were used because native speaker consultants were not confident about the status of a given fricative as uvular/velar or a given vowel as high/mid, and so confidence in the orthographic representation was not high, and also because the orthographic coding did not reveal strong distinctions in either vowel or fricative categories.

The coding of vowels as high or mid based on Experiment 1 was done as follows. Front vowels were classified by computing the Euclidian distance ($\sqrt{((F1_j-F1_k)^2+(F2_j-F2_k)^2)}$) from the mean of that speaker's front vowel preceding a velar and a uvular. The vowel was classified as high if it was closer to the mean of a vowel preceding a velar and as mid if it was closer to the mean of a vowel preceding a uvular. Back vowels were classified as high or mid based solely on whether the vowel was closer to the the mean F1 preceding a velar or uvular. Euclidian distance was not used for back vowels because back vowels preceding fricatives had a higher F2 overall than back vowels preceding stops (mean F2 stops = 943, mean F2 fricatives = 1119, $p < 0.0001$). The result of this difference in F2 was that many vowels with a very low F1 but a relatively high F2 were classified as mid by the Euclidian distance metric, and the resulting high and mid categories preceding fricatives looked quite strange. The reason for the higher F2 in vowels preceding fricatives is likely due to the high number of words in this set with initial palatal consonants, [ʎ] or [ɲ], which have a fronting effect on the following vowel.

Because speaker F1 did not distinguish back vowels before uvular and velar stops in either F1 or F2, classification of back vowels before fricatives was not done for this speaker.

As in Experiment 1, some tokens were removed from analysis in Experiment 2 for the following reasons (i) disfluency, (ii) the vowel and/or fricative could not be reliably segmented from the surrounding segments or (iii) the fricative was produced as a stop (69 tokens). The total number of tokens that were analyzed are summarized below in Table 7.

	isolation				phrase			
	uvular		velar		uvular		velar	
	back	front	back	front	back	front	back	front
V_1	257	132	85	110	126	66	42	52
fricative	184	95	61	87	111	58	39	46

Table 7: Tokens included in the analysis for Experiment 2, by place, vowel backness and isolation/carrier phrase.

5.5 Results

5.5.1 Orthographic coding

When coded orthographically, uvular and velar fricatives were found to have a significant effect on the height of preceding front and back vowels, though neither measures of duration nor spectral properties differentiated between the fricatives themselves.

5.5.1.1 Vowels

While both front and back vowels do differ by consonantal context, there is substantial overlap between height categories. In particular, the high vowels, preceding an orthographic velar, are almost completely overlapped by the mid vowels. The vowel space at midpoint for words in isolation and those in carrier phrases is shown in Figure 7.

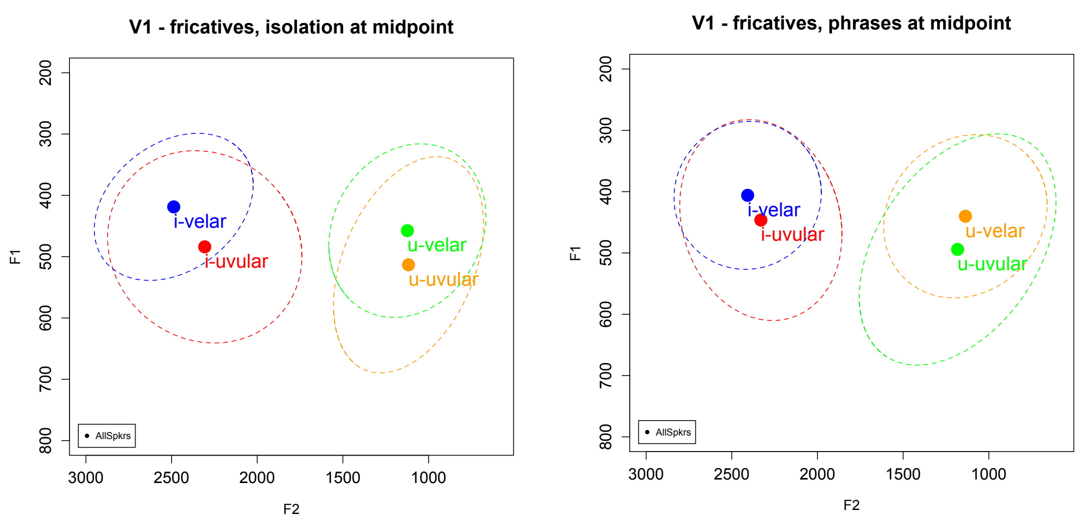

Figure 7: F1 and F2 at midpoint for front and back vowels preceding dorsal fricatives, in words in isolation and carrier phrases, plotted by consonantal context. Values represent averages across speakers.

For vowels produced in words in isolation, F1 differs by consonantal context for both front (β = 65.15, SE = 19.25, t = 3.39) and back vowels (β = 60.80, SE = 23.78, t = 2.56), and F2 differs by consonantal context for front vowels (β = -180.90, SE = 66.48, t = -2.72) but not back vowels (β = 67.10, SE = 74.80, t = 0.90). In carrier phrases, F1 also differs by context for both front (β = 39.09, SE = 19.04, t = 2.05) and back vowels (β = 54.58, SE = 24.49, t = 2.23), and F2 does not differ for either front (β = -82.19, SE = 63.05, *t* = -1.30) or back vowels (β = 46.72, SE = 109.42, *t* = 0.43).

Looking at individual speakers, seven out of eleven speakers show significant effects of consonantal context for front vowels (F3, F4, F5, F7, F9, M1 and M2), and six out of eleven for back vowels (F2, F3, F4, F7, F9 and M1).

5.5.1.2 Fricatives

Neither duration nor spectral properties of fricatives are distinguished by orthographic place of articulation.

The duration of uvulars and velars is not significantly different in either isolation words (β = -4.16, SE = 3.83, *t* = -1.08) or phrases (β = -5.25, SE = 5.64, *t* = -0.93). The mean duration of uvulars is 89 ms in isolation and 69 ms in carrier phrases, and the mean duration of velars is 92 ms in isolation and 74 ms in carrier phrases.

The spectral mean of fricatives is slightly lower for uvulars than for velars, as would be expected, but these differences are not significant in isolation (front vowels: β = -354.5, SE = 389, *t* = -0.91; back vowels: β = -160.88, SE = 101.01, *t* = -1.59) or in carrier phrases (front vowels: β = -88.8, SE = 348.1, *t* = -0.26; back vowels: β = -268.32, SE = 176.19, *t* = -1.52). Variance in spectral energy also does not differ significantly by consonantal context either in isolation (front vowels: β = 18.53, SE = 101.65, *t* = 0.18; back vowels: β = -181.05, SE = 95.79, *t* = -1.89) or in carrier phrases (front vowels: β = 66.15, SE = 114.74, *t* = 0.56; back vowels: β = -178.95, SE = 171.50, *t* = -1.04) . Spectral mean and variance for isolation words and words and in carrier phrases are shown in Figures 8 and 9.

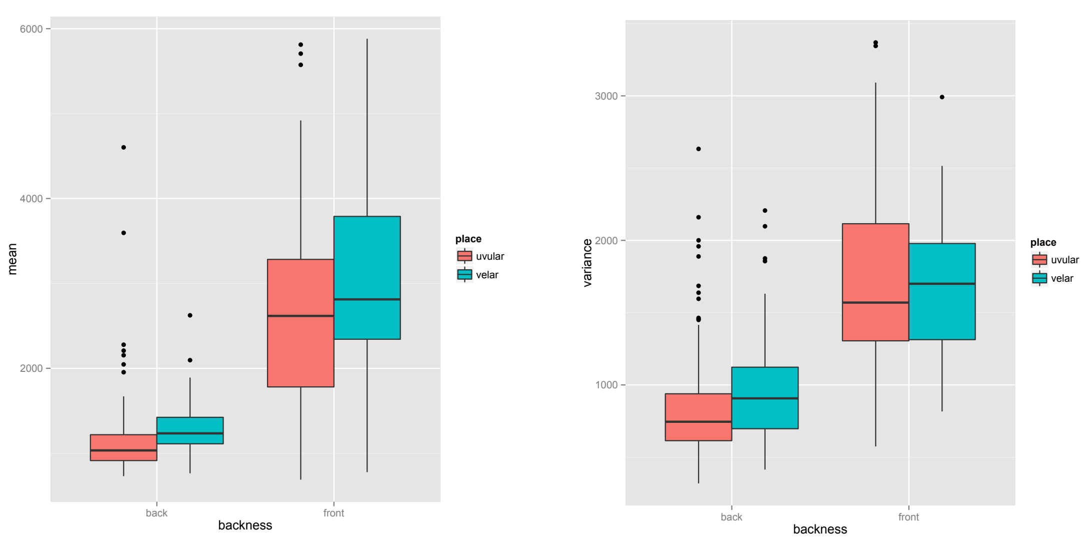

Figure 8: Spectral mean and variance for fricatives in isolation words, by preceding vowel backness and orthographic place of articulation.

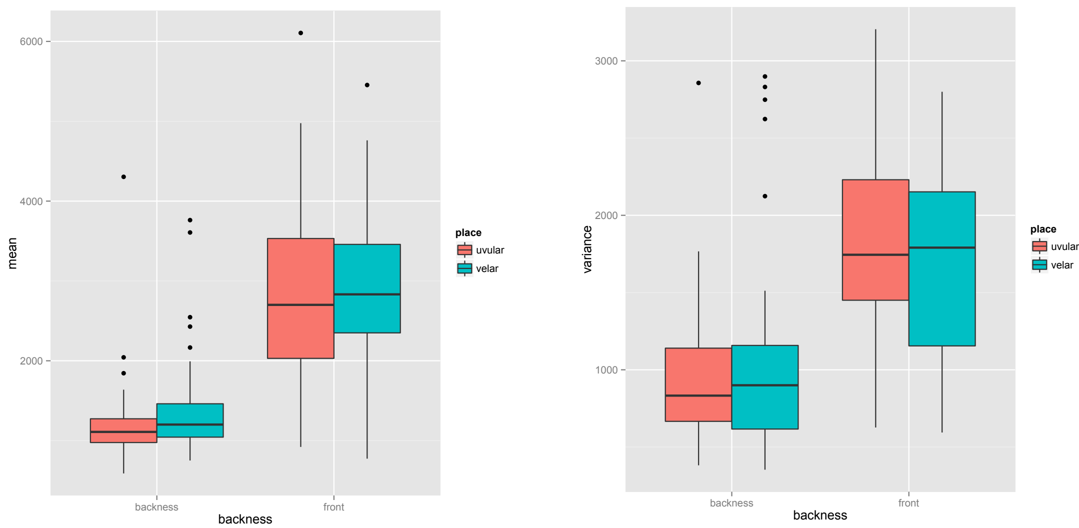

Figure 9: Spectral mean and variance for fricatives in words in carrier phrases, by preceding vowel backness and orthographic place of articulation.

5.5.2 Coding based on Experiment 1

This section reports the results when vowels are coded as high or mid based on the results of Experiment 1. When vowels are coded based on their formant values, high and mid vowels are found for almost all speakers, for both front and back vowels, and these categories (unsurprisingly) are less overlapped than when orthographic labels are used. Coding fricatives based on preceding vowel also results in distinct uvular and velar categories emerging for fricatives following front vowels, but not those following back vowels.

5.5.2.1 Vowels

In isolation words, nine out of eleven participants showed evidence of having both high and mid front vowels preceding dorsal fricatives; speakers F4 and M1 have only high vowels preceding fricatives. Nine out of ten participants showed evidence of both high and mid back vowels preceding dorsal fricatives; speaker F2 has only high vowels preceding fricatives. The vowel space at midpoint for vowels preceding fricatives in isolation words is shown in Figure 10 on the left, and for carrier phrases on the right.

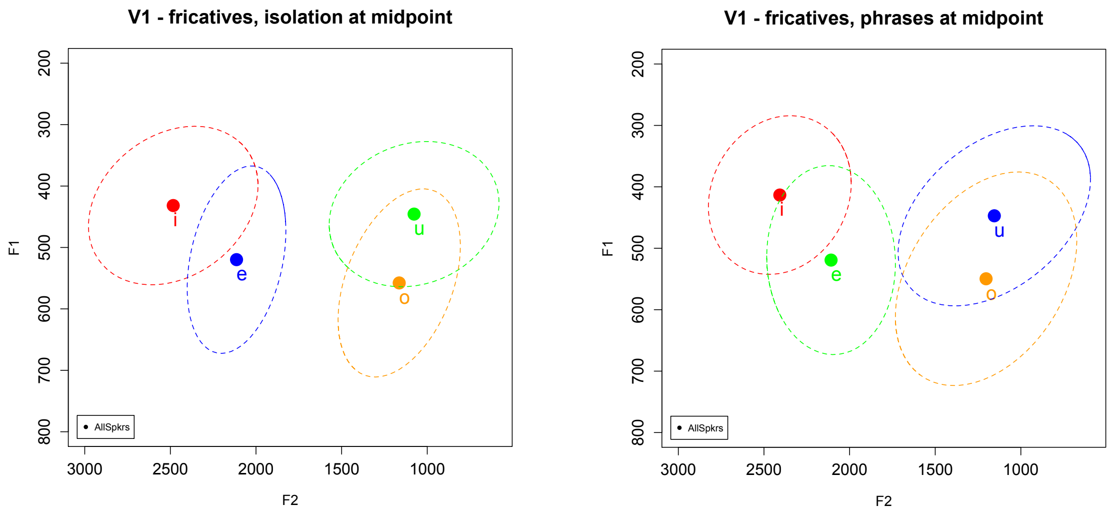

Figure 10: Vowel space for vowels preceding dorsal fricatives at midpoint, for words in isolation (left) and words in carrier phrases (right).

While most speakers have both high and mid vowels before dorsal fricatives, there is substantial variation in which lexical items are produced with which vowel height. Figures 11 and 12 show the proportion of speakers that have a high or a mid vowel for a given item. Since each target item was elicited twice in isolation from each speaker, some speakers have a high vowel in one token and a mid vowel in the other. These speakers are categorized as "split" in the Figures. Figure 11 presents data from the 9 speakers that have both high and mid front vowels, and Figure 12 presents data from the 9 speakers that have both high and mid back vowels. Looking at the front vowels in Figure 11, three words are consistent across all speakers. All speakers have a high vowel in /piktʃuj/ 'to chew coca' and /tikraj/ 'to flip over' and all speakers have a mid vowel for /riqsij/ 'to know'. These three words are also consistent with the orthographic representation. Other words show variation across speakers, though high vowels are more common overall. Looking at the back vowels in Figure 12, /uqʎɑj/ 'to hug' has a high vowel for all speakers, inconsistent with the orthography, and /suqta/ 'six' has a mid vowel for all speakers, consistent with the orthography. High vowels are more frequent for four items (/pukʎɑj/ 'to play', /tʃuktʃa/ 'hair', /muqtʃʼij/ 'to rinse' and /puqtʃu/ 'unit of measure') and mid vowels are more frequent for all remaining words.

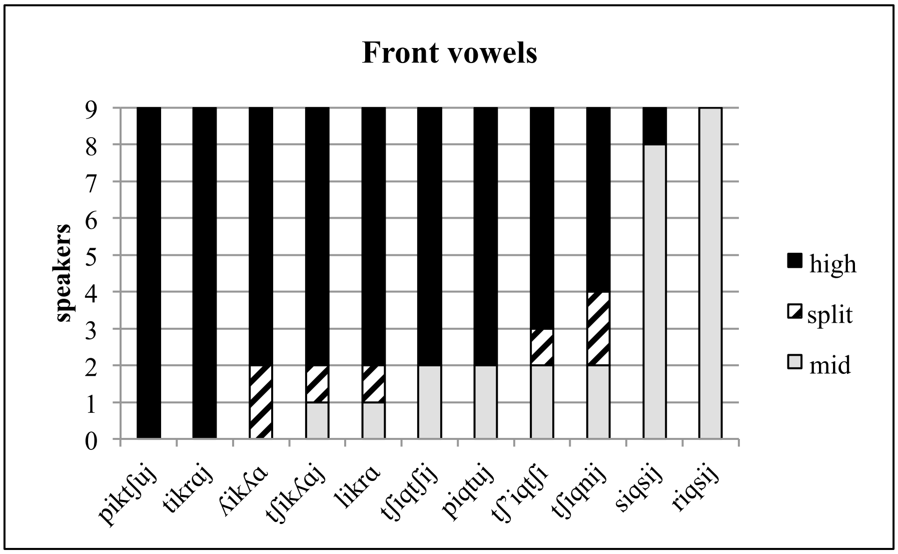

Figure 11: Proportion of lexical items with front vowels that are produced by speakers with mid vowels, high vowels, or split.

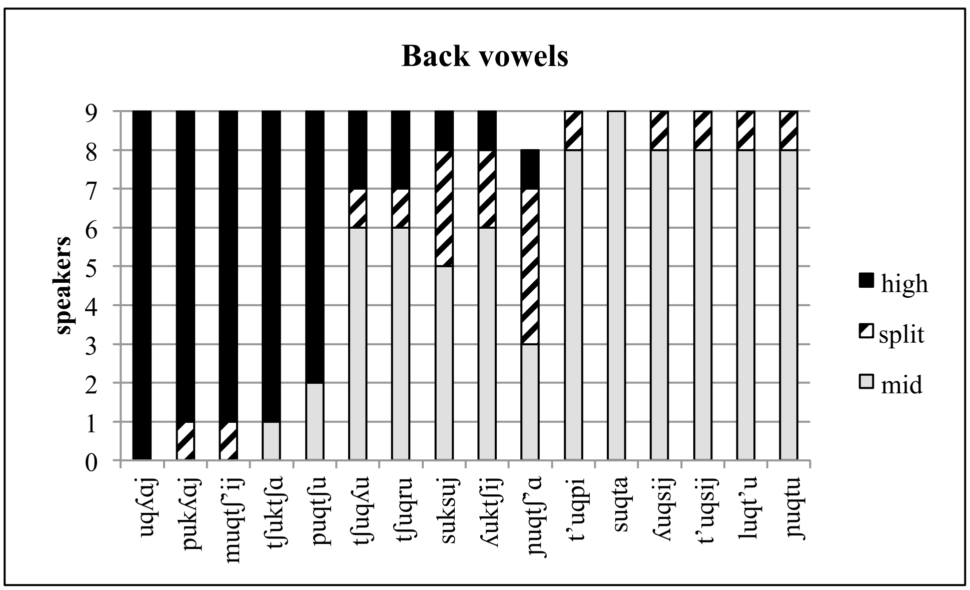

Figure 12: Proportion of lexical items with back vowels that are produced by speakers with mid vowels, high vowels, or split.[2]

Overall, the formant based coding of vowels as high or mid arrives at more sensible looking categories than the orthographic representation does. Specifically, many vowels that precede an orthographic uvular are phonetically high. Looking at the item-specific data in Figures 11 and 12 above, it can be seen that while the distribution of vowel height is not entirely inconsistent with orthographic labels, there are many words that show mismatches. For front vowels, the items /tʃiqtʃij/, /piqtuj/, /tʃ'iqtʃi/ and /tʃiqnij/ have an orthographic uvular, but are produced with majority high vowels. For back vowels, the items /uqʎaj/, /muqch'iy/ and /puqtʃu/ have an

[2] For speaker M2, both tokens of /ɲuqtʃ'ɑ/ were too noisy to be measured.

orthographic uvular, but are produced with majority high vowels. The items /suksuj/ and /ʎuktʃij/ show the opposite pattern, with an orthographic velar but majority mid vowels.

5.5.2.2 Fricatives

When fricatives are classified as uvular or velar based on the preceding vowel, significant differences in spectral energy emerge for fricatives following front vowels but not for those following back vowels. No differences in duration are found. Spectral mean in the dorsal fricative was found to be higher following the high front vowel [i] than following the mid front vowel [e] (β = 778.5, SE = 350.5, t = 2.22). No such differences are seen for back vowels, however; the spectral mean in the dorsal fricative is not significantly higher following the high back vowel [u] than following the mid back vowel [o] (β = 58.12, SE = 89.83, t = 0.65). The second spectral moment, variance, does not show significant differences by preceding vowel for either front vowels (β = 155.2, SE = 150.1, t = 1.03) or back vowels (β = 13.68, SE = 62.47, t = 0.22). Average mean and variance in fricatives by preceding vowel is shown in Figure 13.

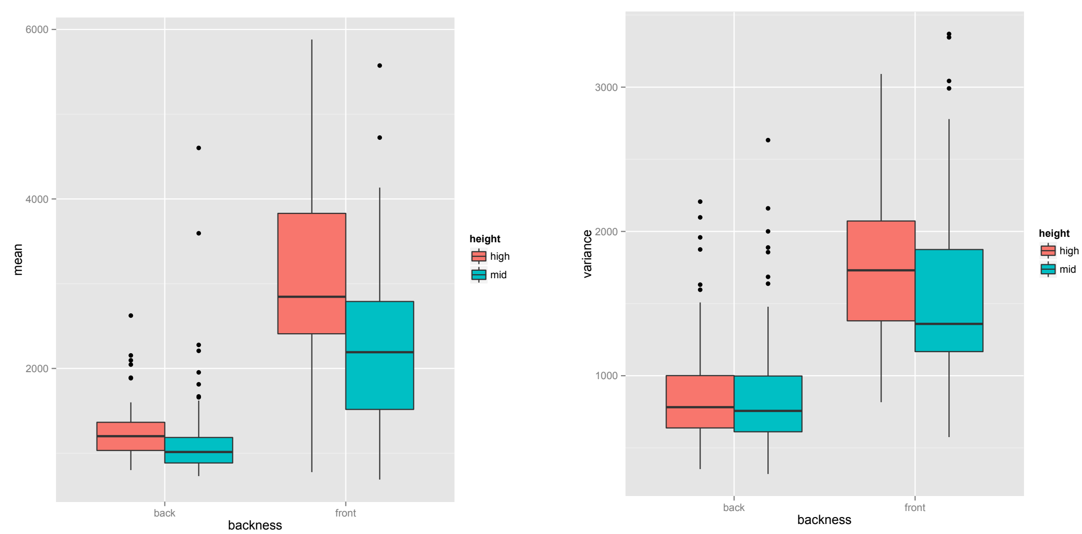

Figure 13: Spectral mean (left) and variance (right) of fricatives in isolation words following high and mid front vowels and high and mid back vowels.

The results of individual speakers were examined for consistency with the overall pattern for spectral mean, the measure that shows the strongest effect of vowel height. For front vowels, all speakers have a higher spectral mean for fricatives following high vowels than those following mid vowels, consistent with the overall pattern. This difference is significant (based on a Welch two sample t-test, reported in Appendix B) for four of the nine speakers (F2, F3, F5 and F9). For back vowels, eight of nine speakers also have a higher spectral mean in fricatives following high vowels than following mid vowels; this difference is significant for two speakers, F7 and M1.

In carrier phrases, the pattern of spectral mean in fricatives is similar to that in isolation words as seen in Figure 14. For both front and back vowels, fricatives following high vowels have a higher spectral mean than fricatives following mid vowels. This effect is more pronounced for front vowels (β = 585.7, SE = 316.1, t =1.85) than for back vowels (β = 121.8, SE = 103.8, t =1.17), though neither effect is significant. Spectral variance is also not significantly different by vowel height for either front vowels (β = 155.8, SE = 140.8, *t* =1.11) or back vowels (β = 33.03, SE = 82.06, *t* =0.40).

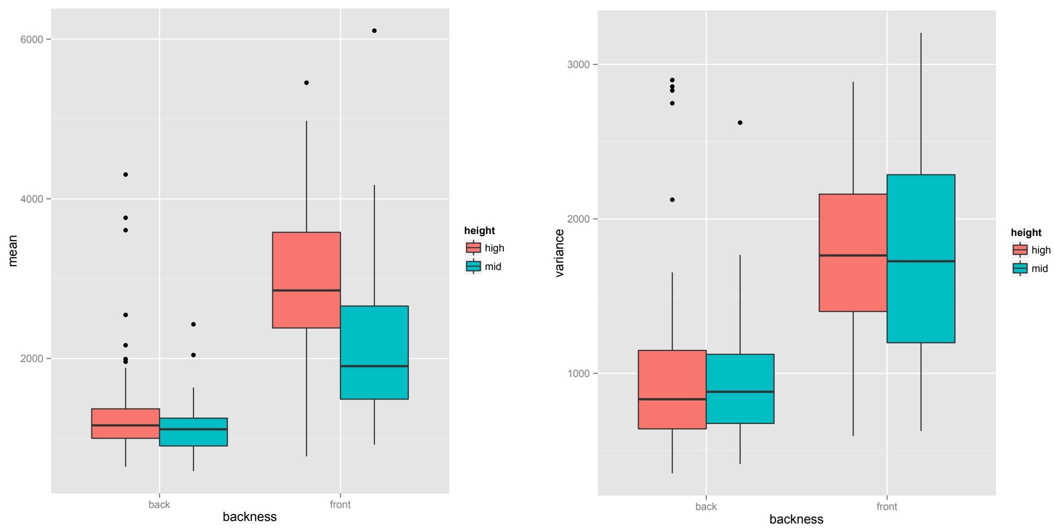

Figure 14: Spectral mean (left) and variance (right) of fricatives in words in carrier phrases following high and mid front vowels and high and mid back vowels.

5.7 Discussion

While both high and mid vowels were found preceding dorsal fricatives, the evidence that this vocalic difference is correlated with a difference in fricative place is mixed. For front vowels, the difference in vowel height correlates with a difference in spectral energy, suggesting that the high front vowel is followed by the velar fricative [x] and the mid front vowel is followed by the uvular fricative [χ]. For back vowels, however, there is no such correlation between vowel height and spectral mean, suggesting that both the high back vowel and the mid back vowel are followed by the same dorsal fricative (the status of this fricative as [x] or [χ] cannot be determined from the available measures, because the spectral means are so different following front and back vowels).

The patterning of the front vowels is consistent with a transparent analysis of the interaction between spirantization and vowel lowering: Quechua has a phonemic contrast between uvular and dorsal place in stops and in fricatives that result from spirantization, and uvulars cause allophonic lowering of a preceding high vowels. The patterning of the back vowels is not consistent with this synchronic analysis, however. While there is no evidence for a contrast between uvular and velar fricatives, there is evidence for both high and mid back vowels preceding a dorsal fricative. This finding suggests that height is not allophonic for back vowels in this environment.

To further complicate matters, the distribution of height for both front and back vowels is not consistent across lexical items, either within or across speakers. This high variability suggests that the representation of lexical items as containing a high vowel/velar consonant or a mid vowel/dorsal consonant is inconsistent, in turn suggesting that this contrast is unstable.

5 General Discussion

The study presented in this paper had two goals. The first was to verify the impressionistic description of vowel height allophony in the vicinity of uvular stops, and to augment this description with quantified acoustic data. The results of Experiment 1 were as expected given the existing descriptions of Quechua. Vowels were found to be high preceding and following velar stops and to lower substantially preceding and following uvular stops. Preceding and following vowels are both strongly affected by the consonantal context for the duration of the vowel, consistent with allophonic lowering to a mid vowel target surrounding a uvular stop. A slight asymmetry between preceding and following vowels was found: the difference between front vowels preceding a uvular or velar is slightly larger than the difference following a uvular or velar. This directional asymmetry is small, and doesn't contradict a mid vowel target for both preceding and following vowels.

The second goal of the study was to determine whether dorsal fricatives, which result from spirantization of dorsal stops in pre-consonantal or final position, contrast for place, and whether dorsal fricatives trigger the same height allophony in preceding vowels seen for stops. The results of Experiment 2 were less clear than those of Experiment 1. The orthographic representation of words as containing a uvular or velar fricative was not a good predictor of either the spectral shape of the fricative or the height of the preceding vowel. When vowels were coded for height by their formant values, both high and mid vowels were found preceding dorsal fricatives, and spectral differences by vowel height were found for fricatives following front vowels but not back vowels. Across participants, there was little consistency about which lexical items were produced with a mid vowel and which were produced with a high vowel.

The results of Experiment 2 suggest that the place distinction in dorsal fricatives is undergoing a merger and is not fully contrastive in the language any longer. For front vowel+fricative sequences, the results are consistent with a uvular-velar place contrast in fricatives and vowel lowering preceding the uvular consonant. The inconsistency in productions of individual lexical items across speakers, however, suggests that this system is not stable. For back vowel+fricative sequences, there is no evidence for a contrast in fricative place, though there is evidence of both high and mid vowels. This pattern suggests one of two analysis. One possibility is that vowel height is simply variable in back vowels preceding dorsal fricatives. Perhaps as a result of the absence of a place contrast in dorsal fricatives, speakers are uncertain of the height of the preceding vowel, leading to variability. Alternatively, speakers may have reanalyzed – or be in the process of reanalyzing – vowel height as contrastive in this context, albeit with variability in lexical representations.

The results of both experiments reveal strong differences in vowel height which are partially predictable by consonantal context. To further explore the status of vowel height and dorsal place in the synchronic Quechua grammar, more work is needed to determine what cues speakers use to classify vowel+dorsal sequences and what distributional restrictions on vowel height and consonantal place Quechua speakers are sensitive to.

Appendix A Carrier phrases

Experiment 1

1.	hik’uj	wawa jakuta uqjaspa **hik’un**
	‘gulp’	‘The child gulps down the water’.
2.	huk’uta	hwanpa **huk’utan** p’itisqa kasqa
	‘sandals’	‘Juan’s sandals were broken.’
3.	huk’utʃa	jana **huk’utʃa** usqajta ajqin
	‘mouse’	‘The black mouse escapes quickly.’
4.	huq’u	mamaj **huq’u** tʃuktʃanta tʃ’akitʃin
	‘damp’	‘My mother dries her wet hair.’
5.	liq’i	hwanpa **liq’in** mesapi
	‘hat’	‘Juan’s hat is on the table.’
6.	luq’u	tʃaj **luq’u** siki q^{h}ari asin
	‘defeated’	‘That smug bastard is laughing.’
7.	ʎik’ij	maria puʎiranta **ʎik’in**
	‘tear’	‘Maria tore her skirt.’
8.	mik’i	hwan **mik’i** p’atʃanta uq^{h}arin
	‘wet’	‘Juan takes off his wet clothes.’
9.	mik^{h}uj	hwan antʃa hajata **mik^{h}un**
	‘to eat’	‘Juan ate a lot of sour things.’
10.	miq’a	wawas **miq’a** runtuta mik^{h}unku
	‘hollow’	‘The children ate hollow eggs.’
11.	muk’u	hwan muk’u aq^{h}ata toman
	‘type of chicha’	‘Juan drinks *muk’u* chicha.’
12.	muq’ij	tʃaj wawa misk’ita **muq’in**
	‘want, love’	‘That child wants sweets.’
13.	rik^{h}urij	sapa p’untʃaw hwan q^{h}atupi **rik^{h}urin**
	‘appear’	‘Every day Juan appears in the market’
14.	sik’ij	doktor hwanpa kirunta **sik’in**
	‘to uproot’	‘The doctor extracted Juan’s tooth.’
15.	siq’uj	hwan q^{h}iʎa kawaʎuta **siq’un**
	‘to slap’	‘Juan slapped the lazy horse.’
16.	uk^{h}u	hwanpa **uk^{h}un** nanan
	‘body’	‘Juan’s body hurts.’
17.	uq^{h}arij	mamaj papata uq^{h}arin
	‘to take out’	‘My mother takes out the potatoes.’

Experiment 2

1.	tʃikʎaj	hwan sara muhuta sumaqta **tʃikʎan**
	‘to choose’	‘Juan chose the corn seeds well.’

2.	tʃiqnij	tʃaj warmi hwanta **tʃiqnin**
	'to hate'	'That woman hates Juan.'
3.	tʃiqtʃij	maria tata felipewan **tʃiqtʃin**
	'to smile'	'Maria smiles at Tata Felipe.'
4.	tʃuktʃa	warmiq **tʃuktʃan** yana yanaʎa
	'hair'	'The woman's hair is very black.'
5.	tʃuqʎu	tʃaj **tʃuqʎu** antʃa hak'a
	'corn-on-the-cob'	'That corn-on-the-cob is very ripe.'
6.	tʃuqru	hwan **tʃuqru** t'antasta aqʎarqa
	'hard'	'Juan chose hard bread.'
7.	tʃ'iqtʃi	hwan **tʃ'iqtʃi** pantaluyuq tusun
	'grey'	'Juan dances in grey pants.'
8.	likra	tʃaj p'isquq **likran** antʃa hatun
	'wing'	'That bird's wing is very big.'
9.	luqt'u	warmi **luqt'u** wawanta q^hawan
	'deaf'	'The woman looks after her deaf child.'
10.	ʎikʎa	mamajpa **ʎikʎan** antʃa k'atʃitu
	'shawl'	'My mother's shawl is very pretty.'
11.	ʎuktʃij	warmi ujanta **ʎuktʃin**
	'to touch'	'The woman touches her face.'
12.	ʎuqsij	hwan paqarinɲa wasinmanta **ʎuqsin**
	'to leave'	'Juan left his house in the morning.'
13.	muqtʃ'ij	wawa siminta yakuwan **muqtʃ'in**
	'rinse'	'The child rinses their mouth with water.'
14.	ɲuqtʃ'a	ɲuqaq **ɲuqtʃ'aj** maj k'atʃita
	'daughter-in-law'	'My daughter-in-law is very beautiful'
15.	ɲuqtu	hwan uwiha **ɲuqtu** kankata mik^hun
	'brain'	'Juan eats roasted lamb brain.'
16.	piktʃuj	sapa p'untʃaw hwan kukata **piktʃun**
	'to chew coca'	'Ever morning Juan chews coca.'
17.	piqtuj	warmi p^hiritawan kesotawan **piqtun**
	'to mix'	'The woman mixes cheese and *phiri*.'
18.	pukʎaj	wawaj wasij qajʎapi **pukʎan**
	'to play'	'My child plays near my house.'
19.	puqtʃu	maria huk **puqtʃu** sarata manukun
	'unit of measure'	'Maria asked for one unit of corn.'
20.	riqsij	hwan ansaldo prowinsiata sumaqta **riqsin**
	'to know'	'Juan knows the province of Anzaldo well.'
21.	siqsij	hwanpa ɲawin **siqsin**
	'to sting'	'Juan's eye stings.'
22.	suksuj	$jarq^h$aj aʎqu lawata **suksun**
	'to consume'	'The hungry dog consumes the soup.'

23. suqta — ɑʎqu **suqta** t’uʎusta mik^{h}urqa
‘six’ — ‘The dog ate six bones.’

24. tikraj — hwan p’uɲuta majʎajtawan **tikran**
‘to turn over’ — ‘Juan washed the jug and turned it over.’

25. t’uqpi — hwan **t’uqpi** runata mask’an
‘crazy’ — ‘Juan is looking for a crazy person.’

26. t’uqsiy — hwan k^{h}itʃkawan p^{h}ukutʃuta **t’uqsin**
‘to prick’ — ‘Juan pricked the balloon with a needle’

27. uqʎaj — wawa mamanta **uqʎan**
‘hug’ — ‘The child hugs their mother’

Appendix B Statistical results and averages by speaker

		F1			F2		
		uvular	velar	*p*	uvular	velar	*p*
F1	front	490	368	< 0.01	2211	2498	< 0.01
	back	471	397	0.13	941	898	0.14
F2	front	526	431	< 0.02	1961	2625	< 0.0001
	back	509	426	< 0.05	999	951	0.57
F3	front	521	352	< 0.0001	1873	2315	< 0.0001
	back	500	355	< 0.0001	947	781	< 0.0002
F4	front	640	458	< 0.001	2297	2630	< 0.02
	back	574	453	< 0.002	1034	919	< 0.04
F5	front	612	449	< 0.001	2039	2508	< 0.0001
	back	620	446	< 0.001	1075	890	< 0.01
F6	front	580	475	< 0.01	1968	221	< 0.001
	back	483	442	< 0.05	856	880	0.69
F7	front	669	472	< 0.0001	2181	2500	< 0.01
	back	624	473	< 0.0001	1001	885	< 0.02
F8	front	680	513	< 0.0001	2169	2673	< 0.001
	back	648	498	< 0.0001	1186	967	< 0.01
F9	front	655	439	< 0.001	2089	2764	< 0.001
	back	557	462	< 0.02	1016	877	< 0.03
M1	front	498	325	< 0.0001	2719	2530	< 0.01
	back	440	358	< 0.001	896	887	0.80
M2	front	530	347	< 0.0001	1849	2234	< 0.01
	back	468	362	< 0.0001	958	913	0.53

Table B1: V_1 stops, isolation words at midpoint

		F1			F2		
		uvular	velar	*p*	uvular	velar	*p*
F1	front	487	339	< 0.01	1987	2664	< 0.0001
	back	489	339	< 0.01	911	823	< 0.01
F2	front	420	405	< 0.02	1833	2656	< 0.0001
	back	503	436	< 0.04	958	975	0.87
F3	front	519	312	< 0.0001	1808	2358	< 0.001
	back	469	340	< 0.0001	893	804	0.08
F4	front	639	401	< 0.001	2142	2651	< 0.01
	back	563	411	< 0.0001	939	980	0.37
F5	front	630	416	< 0.001	1823	2487	< 0.0001
	back	576	399	< 0.001	931	1001	0.44
F6	front	618	411	< 0.001	1857	2291	< 0.01
	back	444	417	0.13	837	762	0.27
F7	front	598	445	< 0.01	2221	2629	< 0.01
	back	574	429	< 0.01	917	868	0.34
F8	front	653	470	< 0.001	1951	2768	< 0.0001
	back	622	453	< 0.0001	1060	978	0.14
F9	front	654	396	< 0.0001	1975	2536	< 0.0001
	back	550	434	< 0.01	958	1001	0.57
M1	front	490	309	< 0.001	2776	2620	< 0.05
	back	450	346	< 0.001	914	830	0.29
M2	front	486	313	< 0.0001	1702	2223	< 0.001
	back	429	327	< 0.001	879	883	0.94

Table B2: V_1 stops, isolation words at 90%.

		F1			F2		
		uvular	velar	*p*	uvular	velar	*p*
F1	front	560	371	< 0.01	1844	2076	0.45
	back	545	407	0.06	1437	1074	0.37
F2	front	489	414	0.24	1828	2149	0.42
	back	541	430	< 0.01	1205	1035	0.39
F3	front	471	374	0.06	1823	1795	0.91
	back	444	391	< 0.04	1303	931	0.21
F4	front	569	467	0.15	1841	1985	0.75
	back	642	452	< 0.01	1504	969	0.16
F5	front	558	470	< 0.01	1651	1911	0.52
	back	593	481	< 0.0001	1397	1089	0.27
F6	front	466	445	0.46	1651	2002	0.19
	back	499	444	0.14	1180	970	0.39
F7	front	559	498	0.10	1777	2080	0.40
	back	608	466	< 0.02	1405	1121	0.40
F8	front	538	463	< 0.05	1724	2192	0.15
	back	580	466	< 0.04	1387	1079	0.21
F9	front	483	406	0.10	1797	2051	0.37
	back	564	442	< 0.04	1421	1106	0.41
M1	front	445	358	< 0.01	1648	2013	0.43
	back	457	381	0.14	1081	1046	0.89
M2	front	394	361	0.31	1818	1821	0.99
	back	444	358	< 0.04	1330	967	0.33

Table B3: V_2 stops, isolation words at 10%.

		F1			F2		
		uvular	velar	*p*	uvular	velar	*p*
F1	front	519	386	< 0.01	1953	2712	< 0.0001
	back	552	388	< 0.0001	1012	1336	0.09
F2	front	548	396	0.08	2111	2472	0.15
	back	509	447	0.12	1072	1286	0.09
F3	front	453	345	< 0.02	2010	2315	0.07
	back	471	390	< 0.001	1052	992	0.08
F4	front	543	425	0.08	2507	2741	0.08
	back	654	467	< 0.001	1009	1173	0.07
F5	front	629	451	< 0.01	1929	2565	< 0.001
	back	606	483	< 0.0001	1015	1121	0.07
F6	front	534	417	< 0.01	1812	2248	< 0.001
	back	497	423	< 0.001	928	1069	0.11
F7	front	612	395	< 0.0001	1955	2538	< 0.01
	back	588	457	< 0.001	1083	1152	0.61
F8	front	562	454	< 0.02	1974	2789	< 0.01
	back	595	469	< 0.01	1149	1249	0.36
F9	front	558	375	< 0.02	2085	2828	< 0.001
	back	530	427	0.10	1247	1231	0.96
M1	front	481	343	0.08	2620	2688	0.27
	back	429	381	< 0.02	994	1023	0.79
M2	front	421	336	< 0.02	2062	2188	< 0.04
	back	449	374	0.05	979	1003	0.84

Table B4: V_2 stops, isolation words at 50%.

	front			back		
	high	mid	*p*	high	mid	*p*
F1	3125	2835	0.43		n/a	
F2	2979	1020	< 0.0001		n/a	
F3	3406	1925	< 0.0001	1094	1032	0.50
F4		n/a		1355	1111	0.60
F5	2605	2012	< 0.02	1161	1092	0.41
F6	2704	1856	0.13	1251	1217	0.74
F7	2544	1668	0.06	1315	949	< 0.0001
F8	2678	3587	0.21	1338	1118	0.19
F9	4027	1381	< 0.01	1214	1088	0.17
M1		n/a		1252	1002	< 0.01
M2	3409	2544	0.19	1165	1659	0.19

Table B5: Spectral mean at midpoint.

References

Adelaar, William with Pieter Muysken. 2004. *The languages of the Andes*. Cambridge: Cambridge University Press.

Al-Ani, Salman H. 1970. *Arabic phonology: An acosutical and physiological investigation*. The Hague: Mouton.

Bates, Doug and Martin Maechler. 2010. lme4: Linear mixed effects models using S4 classes. http://CRAN.Rproject.org/package=lme4.

Bessell, Nicola. 1998. Local and non-local consonant-vowel interaction in Interior Salish. *Phonology* 15: 1-40.

Bills, Garland and Rudolph C Troike; Bernardo Vallejo. 1971. *An Introduction to Spoken Bolivian Quechua*. Austin:University of Texas Press.

Bird, Sonya. 2014. "Chilcotin flattening" revisited: A phonetic investigation of Tsilhqut'in retraction effects. Poster presented at *LabPhon 14*, NINJAL, Japan.

Boersma, Paul and David Weenink. 1992-2011. Praat: doing phonetics by computer. Version 5.1.30, available at www.praat.org.

Butcher, Andrew and Kusay Ahmad. 1987. Some acoustic and aerodynamic characteristics of pharyngeal consonants in Iraqi Arabic. *Phonetica* 44:156-172.

Cerrón-Palomino, Rodolfo. 1994. *Quechua sureño diccionario unificada Quechua-Castellano Castellano-Quechua* [Unified dictionary of southern Quechua, Quechua-Spanish Spanish-Quechua]. Lima: Biblioteca Nacional del Perú.

Cook, Eung-Do. 1983. Chilcotin flattening. *Canadian Journal of Linguistics* 28:123-132.

Cook, Eung-Do. 1993. Chilcotin flattening and autosegmental phonology. *Lingua* 91:149-174.

Cusihuamán, Antonio. 1976. *Diccionario Quechua: Cuzco-Collao*. Lima: Ministerio de Educación and Instituto de Estudios Peruanos.

de Lucca, Manuel. 1987. *Diccionario practico Aymara-Castellano Castellano-Aymara* [Practical dictionary Aymara-Spanish Spanish-Aymara]. Cochabamba:Los Amigos del Libro.

Dorais, Louis-Jacques. 1986. Inuktitut surface phonology: A trans-dialectal survey. *International Journal of American Linguistics* 52:20-53.

Gelman, Andrew & Jennifer Hill. 2006. Data analysis using regression and multilevel/hierarchical models. Cambridge: Cambridge University Press.

Gick, Bryan and Ian Wilson. 2006. Excrescent schwa and vowel laxing: Cross-linguistic responses to conflicting articulatory targets. In Louis Goldstein, Doug Whalen and Catherine Best, eds., *Laboratory Phonology 8*, 635-659. Berlin: Mouton de Gruyter.

Hoggarth, Leslie. 2004. *Contributions to Cuzco Quechua grammar*. Bonn: Bonn Americanist Studies.

Holliday, Nicole. under review. Vowel systems of Bolivian Quechua/Spanish bilinguals.

Kendall, Tyler and Erik Thomas. 2012. Vowels: Vowel manipulation, normalization and plotting. http://cran.r-project.org/web/packages/vowels/index.html

Laime Ajacopa, Teofilo, et al. 2007. *Diccionario Bilingüe, Iskay Simipi Yuyayk'ancha: Quechua – Castellano Castellano –Quechua*. La Paz, Bolivia.

Lewis, M. Paul, Gary F. Simons & Charles D. Fennig (eds.). 2014. *Ethnologue: Languages of the World*, *17th edition*. Dallas, TX:SIL International. Online at www.ethnologue.com.

McCarthy, John J. 1994. The phonetics and phonology of Semitic pharyngeals. In Patricia Keating, ed., *Phonological structure and phonetic form: Papers in laboratory phonology III*, 191-233. Cambridge: Cambridge University Press.

Rischel, Jørgen. 1974. *Topics in West Greenlandic Phonology*. Copenhagen: Akademisk Forlag.

Rowe, J.H. 1950. Sound patterns in three Inca dialects. *International Journal of American Linguistics* 16:137-248.

Shahin, Kimary N. 2002. *Postvelar harmony*. Amsterdam: John Benjamins.

Torero, Alfredo. 1964. Los dialectos Quechuas [The dialects of Quechua]. *Anales Científicos de la Universidad Agraria* 2:446-478.

Wilson, Ian. 2007. The effects of post-velar consonants on vowels in Nuu-chah-nulth: Auditory, acoustic and articulatory evidence. *The Canadian Journal of Linguistics* 52: 43-70.

Zawaydeh, Bushra. 1998. Gradient uvularization spread in Ammani-Jordanian Arabic. In Elabbas Benmamoun, Mushira Eid and Niloofar Haeri, eds., *Perspectives on Arabic linguistics XI*, 117-141. Amsterdam: John Benjamins.