Phonetic vs. phonological rounding in Athabaskan languages*

Sharon Hargus, University of Washington

1 Introduction

Vowel-to-vowel (VCV) coarticulation (Öhman 1966 and much subsequent work) and vowel harmony represent the phonetic and phonological ends of a phenomenon whereby properties of vowels are predictable from other vowels within a word. The subject of this article deals with a predictable property of the vowel system of Deg Xinag, Rounding Assimilation, which has received no mention from previous Deg Xinag linguists, perhaps because it is "simply coarticulation". The main task of this article is to bring evidence to bear on the question of whether Rounding Assimilation is phonetic (VCV coarticulation) or phonological (neutralizing assimilation). Various kinds of evidence from within Deg Xinag, including results of an acoustic study, suggest that Rounding Assimilation is phonological. In keeping with the conference theme, some images and discussion of the lip gestures involved in producing rounded vowels in Deg Xinag are also provided. Data from the related language Babine-Witsuwit'en is also presented, showing an absence of Rounding Assimilation in one of the contexts where it occurs in Deg Xinag. Babine-Witsuwit'en sheds light on how and why Rounding Assimilation may have developed historically in Deg Xinag.

2 Deg Xinag

2.1 Phonological contrasts

Deg Xinag (DX) (a.k.a. Ingalik, Deg Hit'an) is an Athabaskan language of western Alaska, with the vowel inventory shown in (1).

(1) Deg Xinag vowel phonemes

full	*reduced*	*full*
	ʊ	
e	ə	o
	a	

In acoustic study of quality and quantity contrasts among the Deg Xinag vowels (8-speaker sample), Hargus 2010 confirmed the general validity of the transcriptional symbols shown in (1), with /ʊ/ having an allophone closer to [ŏ] when adjacent to a uvular (the reduced vowels are shorter in duration than the full vowels).

Deg Xinag (Yukon dialect) has the syllable-initial inventory of consonants in (2).

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(2) Deg Xinag syllable-initial consonant phonemes

p p^h		t t^h t’			k k^h k’	q q^h q’	ʔ
	tθ $tθ^h$ tθ’	ts ts^h ts’	ʦ̱ $ʦ̱^h$ ʦ̱’	ʧ $ʧ^h$ ʧ’			
		tɬ $tɬ^h$ tɬ’					
	θ ð	s z	ʂ ʐ	ʃ		χ ʁ	h
		ɬ					
m		n			ŋ		
v		l		j			

2.2 Rounding Assimilation

As discussed in Hargus 2010, auditory impressions suggest that the contrast between /ə/ and /ʊ/ is neutralized as [ʊ] before a round vowel (/ʊ/ or /o/) if a uvular or laryngeal consonant intervenes:

(3) Rounding Assimilation
/ə/ → [ʊ] / ___ {uvular, laryngeal} {ʊ, o}

Illustrative of Rounding Assimilation, the forms in (4) all contain /k/- unspecified object and /ə/- imperfective (Hargus and Tuttle 1997). In (4)a., a laryngeal consonant intervenes between /ə/- imperfective and a round vowel, and Rounding Assimilation has applied, whereas in (4)b. an alveolar consonant intervenes, blocking Rounding Assimilation:

(4) [ə] ~ [ʊ] alternations[1]

a. [kʊ̲hoo̯n]	/k/- unspecified object + /ə/- imperfective + /(h)oo̯n/ ‘sg. eat’	‘he/she is eating’
b. [kə̲soo̯n]	/k/- unspecified object + /ə/- imperfective + /s/- 1s subject + /(h)oo̯n/ ‘sg. eat’	‘I’m eating’

Rounding Assimilation apparently does not iterate across the word, unlike rounding harmony in other languages (Kaun 2004). All of the forms in (5) contain /k/- unspecified object, /ə/- imperfective, and the verb stem -[q’ʊʦ̱]:

(5) Some forms of the imperfective verb paradigm of -/q’ʊʦ̱/ ‘chew (object)’

a. /k-ə-q’ʊʦ̱/	[kʊq’ʊʦ̱]	‘he/she is chewing’
b. /k-ə-s-q’ʊʦ̱/	[kəsq’ʊʦ̱]	‘I’m chewing’
c. /k-χ-ə-q’ʊʦ̱/	[kəχʊq’ʊʦ̱]	‘they’re chewing’

Rounding Assimilation has applied in the third person singular form in (5)a., where a single uvular consonant separates imperfective /ə/- from the round vowel of -/q’ʊʦ̱/. Rounding Assimilation has not applied in the first person singular subject form in (5)b. because it contains a subject prefix, /s/- ‘I’, creating a cluster before the underlying round

[1]The data in this section is transcribed in accord with auditory impressions.

vowel. In (5)c., we see evidence for lack of iteration of Rounding Assimilation. The third person plural subject prefix /χ/- is followed by imperfective /ə/-, which has undergone Rounding Assimilation. /χ/- is preceded by epenthetic [ə], which has not undergone Rounding Assimilation, even though separated from a round vowel by a single uvular consonant.[2]

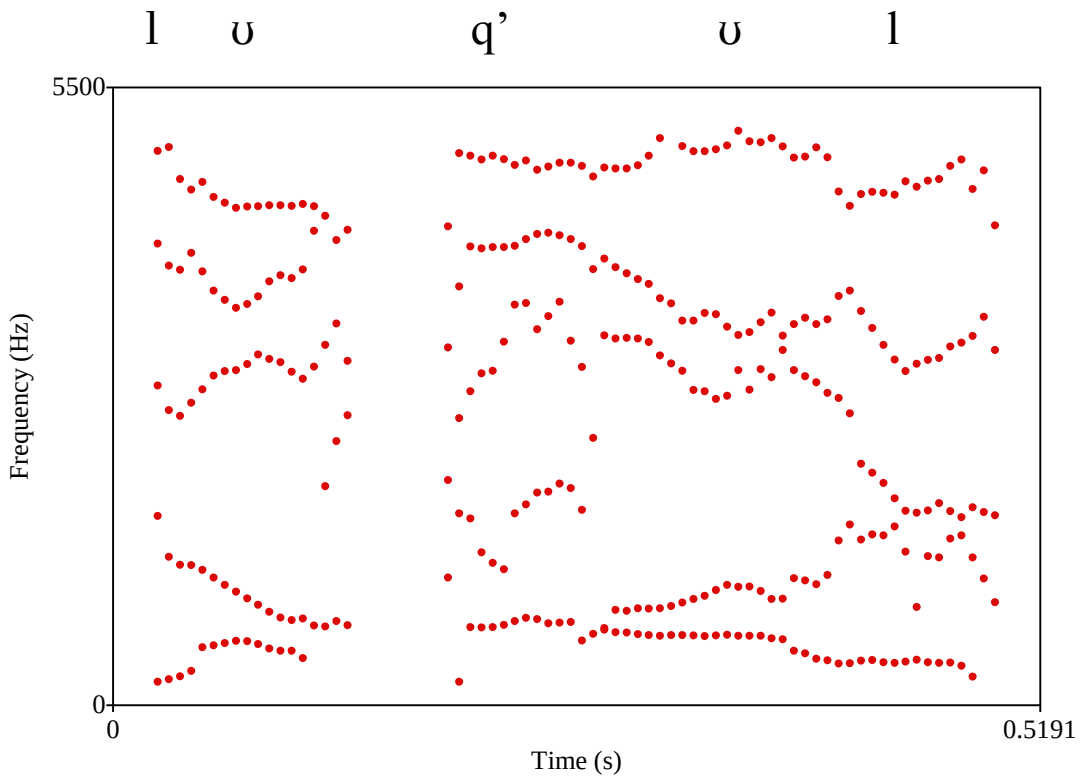
Apart from mention in Hargus 2010, Rounding Assimilation has not been noted in the literature on Deg Xinag phonology. Krauss 1962 provides great detail about vowel allophones but no mention of Rounding Assimilation. In Kari 1978, [jʊχʊn̥] 'you (pl.)' is transcribed *yixunh* (where <i> represents /ə/ and <u> represents [ʊ] in the local orthography (Krauss 1962, Kari 1974)). Various Deg Xinag short stories (e.g. Rock 1998) contain spellings such as *ghihoɬ* 'he/she is walking', which, according to my auditory impressions should be transcribed ([ʁʊhoɬ]). In Deacon et al. 2007 the output of Rounding Assimilation is inconsistently transcribed.[3]

Perhaps previous field linguists failed to take note of Rounding Assimilation because it is coarticulation rather than neutralization. When Rounding Assimilation takes place, the rounding on the vocalic target of RA increases—that is, F2 apparently decreases—as the vowel approaches the uvular or laryngeal consonant, as can be seen in the spectrogram of [lʊqʼʊl] 'white (object)' in (6). At issue is whether the vowel of the first syllable is rounded ([ʊ]) or not ([ə]). At the left edge of the vowel, the first three formants are more or less evenly spaced, as is characteristic of [ə]. At the right edge of the vowel, the second formant is closer to the first formant than the third, characteristic of a rounded vowel. The more extreme rounding at the right edge of the vowel—lowering of F2—is consistent with the apparent lack of iteration of Rounding Assimilation seen in (5)c. It is difficult to say whether the assimilation in rounding only takes place at the right edge of the vowel from inspection of spectrograms like (6), because the vowel which undergoes Rounding Assimilation is short and unstressed and typically lacks a clear F2 target.

[2]Possibly, Rounding Assimilation does not interate because the triggering round vowel must be stressed. Stress typically falls on final or stem syllables in Deg Xinag (Hargus 2005).

[3]Transcriptions were altered after I pointed out the likely existence of Rounding Assimilation to the principal compiler (letter from Sharon Hargus to Alice Taff, 9-13-04).

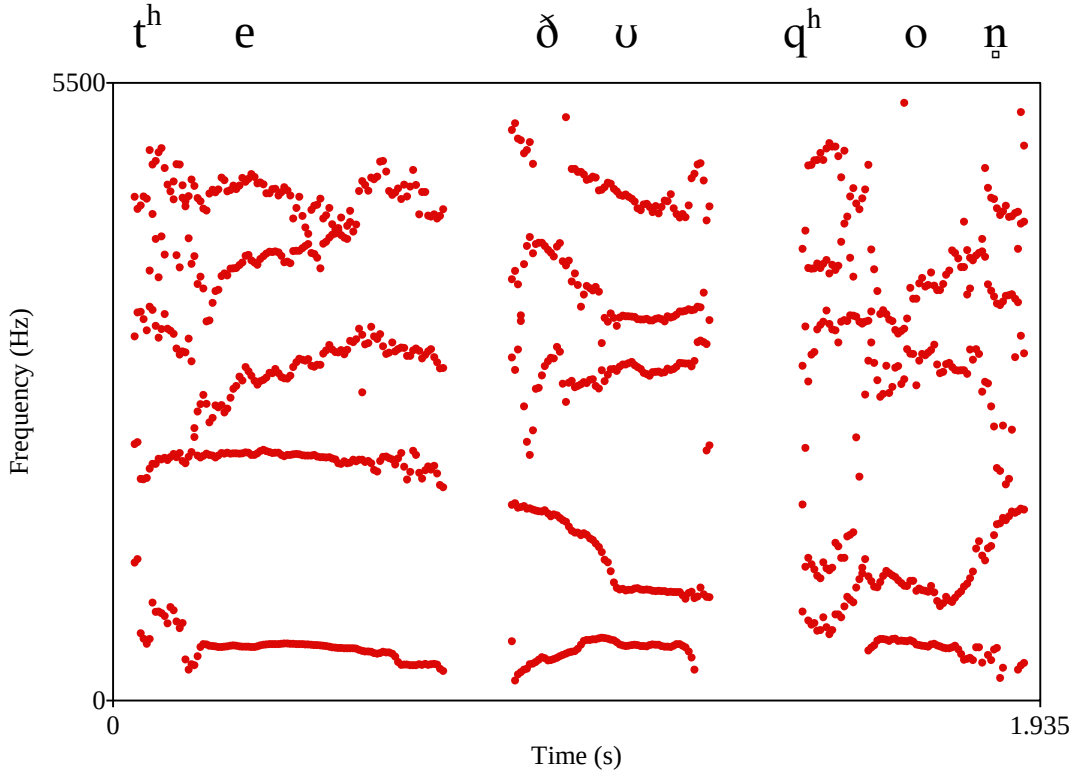
(6) Spectrogram of [lʊqʼʊl] ‘white (object)’ (female speaker LH)



However, other facts suggest that Rounding Assimilation is a phonological phenomenon. (1) Rounding Assimilation does not apply in fast speech only. Consider the production of [t^{h}e ðʊq^{h}o̥n̥] ‘there is water (in container)’ in (7). This sentence consists of two words, [t^{h}e] ‘water’ and [ðʊq^{h}o̥n̥] ‘there is (in container)’, but in this production the speaker has a roughly 150 msec. pause between the first word and the second, and an over 200 msec. pause between the two syllables of the final word.[4]

[4]During our recording for the experiments described below, I had just asked this speaker to repeat this sentence, and she repeated it slowly, syllable by syllable.

(7) Slow-speech production of [tʰe ðʊqʰo̰n̰] ‘there is water (in container)’



(2) One feature of the idiolect of AJ, a native speaker of Deg Xinag, was ‘o-unrounding’; that is, she often had [ɑ] corresponding to other speakers’ [o], as in -[ʁoʔ] ‘body hair, fur’, AJ -[ʁɑʔ]. The sentence in (8) is taken from a project during which we recorded the texts in Chapman 1914 (Kari 1981):

(8) A sentence from *Yixgitsiy Dranh Itltsenh Dong* (Raven made light long ago), recorded by AJ

Vanhtoniy	*nigughun’*	*getiy*	*vugho’* [vʊʁɑʔ]	*dengath.*
ruff	wolf	really	its fur	it’s long

‘It had a wolf ruff with very long fur.’

Even in such cases, however, when a prefix preceded her [ɑ] < /o/, a word like [vʊʁɑʔ] contained a round vowel in the first syllable. This is also suggestive of the phonological status of Rounding Assimilation: the trigger need not even be present phonetically.

2.3 An acoustic study of Rounding Assimilation

Given previous linguists’ transcriptions of vowels in RA contexts as unrounded, an acoustic study was undertaken to determine whether or not the vowels identified as rounded by subjective listening are in fact rounded or unrounded. If it could be shown that the output of Rounding Assimilation is present in the middle of a vowel, rather than

only found at the right edge of a vowel, this would strengthen the case for a phonological interpretation.[5]

2.3.1 Hypotheses

Fant 1973:28 noted that the acoustic correlate of the lips being 'relatively close and protruded (small lip-opening area)' is 'F1+F2+F3 lower than with a larger lip-opening and the same tongue articulation.' Results of my previous acoustic study of Deg Xinag vowels (Hargus 2010) showed that /ʊ/ has significantly lower normalized F2 than /ə/ in two measured contexts, uvular__alveolar and alveolar__uvular.[6] Vowels in Rounding Assimilation contexts are therefore predicted to have significantly lower F2 if they are rounded.

Hypotheses (9)a.-e. investigate whether or not there are differences in F2 among reduced vowels in non-final syllables. Hypothesis (9)f. tests whether or not vowels in non-final syllables which are predicted to undergo Rounding Assimilation are different from the vowel of the perambulative prefix, with underlying /ʊ/.

(9) Predictions concerning rounding contrasts among reduced vowels in Deg Xinag. 'Q' = uvular, 'H' = laryngeal, 'K' = velar, 'C' = any other consonant
a. ʊ̲Q{ʊ,o} vs. ə̲Q{ə,a}: [ʊ] predicted to have significantly lower F2
b. ʊ̲H{ʊ,o} vs. ə̲H{ə,a}: [ʊ] predicted to have significantly lower F2
c. ʊ̲Q{ʊ,o} vs. ʊ̲H{ʊ,o}: predicted not to differ in F2
d. ʊ̲Q{ʊ,o} vs. ə̲K{ʊ,o}: [ʊ] predicted to have significantly lower F2
e. ʊ̲Q{ʊ,o} vs. ə̲CQ{ʊ,o}, for C = alveolar: [ʊ] predicted to have significantly lower F2, higher F1
f. ʊ̲Q{ʊ,o} vs. perambulative q'ʊ̲: predicted not to differ in F2

For experiments which vary the following consonant and control for following vowel quality, the hypotheses above are probably too crude. For hypothesis (9)d., we might expect lowered F2 anyway before the intervening uvular as compared with velar (cf. Ladefoged and Maddieson 1996: 36). Similarly for (9)c., laryngeals are generally transparent to vowel quality (Steriade 1987), but in some languages appear to have formant lowering effects (e.g. Klallam, Montler 1998; see also Rose 1996).

Because rounding appears to increase at the right edge of the vowel (2.2), these hypotheses were tested at 50% and 75% of vowel duration.

2.3.2 Methods

A master word list was developed and presented to 5 speakers, 3 male and 2 female, for recording. Because the target vowel was in all cases relatively short, a concern was that results might be skewed by place of articulation effects from adjacent consonants. Therefore, the place of articulation of the preceding consonant was balanced

[5]Manuel and Krakow 1984 found anticipatory coarticulation into vowel steady-state in Swahili, but this seems atypical of VCV coarticulation cases.

[6]/ʊ/ also had higher normalized F1 than /ə/, perhaps for reasons unrelated to the rounding difference. The measured allophone of /ʊ/ was [ŏ], and the quality of peripheral mid vowels in Deg Xinag is lower- rather than higher-mid (Hargus 2010).

in testing each of the hypotheses in (9), and prefixes containing a labial consonant were not used on the word list.

Each hypothesis was tested with 9-15 comparison pairs per speaker. Because of idiolectal differences, some adjustments to the word list were made during the recording. If a speaker didn't recognize a particular word, it was not recorded, leading to inter-speaker differences in the number of comparison pairs for a particular experiment. However, in all cases statistical tests were performed by comparing words with equal numbers of preceding and following consonant places of articulation for a speaker.

Recordings were made on a Sound Devices 702 compact flash recorder with an external microphone, either AT 4041 or Shure MX184, at a sampling rate of 44,100 Hz. At least two repetitions of each word were recorded from each speaker, but generally only one repetition of each token was measured.

Recordings were downsampled to 11,025 Hz for measurement. The token containing the longest and/or loudest target vowel whose formants could be most completely analyzed was selected for measurement. Using Praat (5.1.30), the beginning and end of the target vowel were marked, as were the 50% and 75% points in the vowel. The duration of the vowel was measured, along with the lowest three formants, using Maximum Formant settings of 5000 Hz for male speakers and 5500 Hz for female speakers.

The measured data was analyzed with repeated-measures ANOVA for the group of five speakers, using each speaker's mean formant value as the dependent measure. At the individual level, the data was analyzed with factorial ANOVA. In both cases, the post hoc test used was Bonferroni/Dunn. Because of the need to balance the place of articulation of the consonants preceding the targets of Rounding Assimilation, the ə̲Q{ʊ,o} words used to compare with ə̲Q{ə,a} might be slightly different than (e.g.) those compared with əCQ{ʊ,o} for a particular speaker. Therefore, each hypothesis was tested in a separate experiment, and there was some overlap in the data used to test the hypotheses. [7]

2.3.3 Results

2.3.3.1 Rounded vs. unrounded vowel, intervening uvular consonant

Vowels before a single uvular consonant + rounded vowel were predicted to have lower F2 relative to unrounded vowels. The average duration of the vowels measured in this context was .078 sec. before rounded vowels and .081 sec. before unrounded vowels.[8]

A graph of F1 x F2 in this context is shown in (10). As in (6), F2 is lower at the right edge of the vowel than at vowel midpoint. F2 was significantly lower before a round vowel at both 50% ($F[1,4] = 86.882$, $p = .0007$) and 75% of vowel duration ($F[1,4] = 88.177$, $p = .0007$). There were no significant differences in F1 or F3 at either measurement point.

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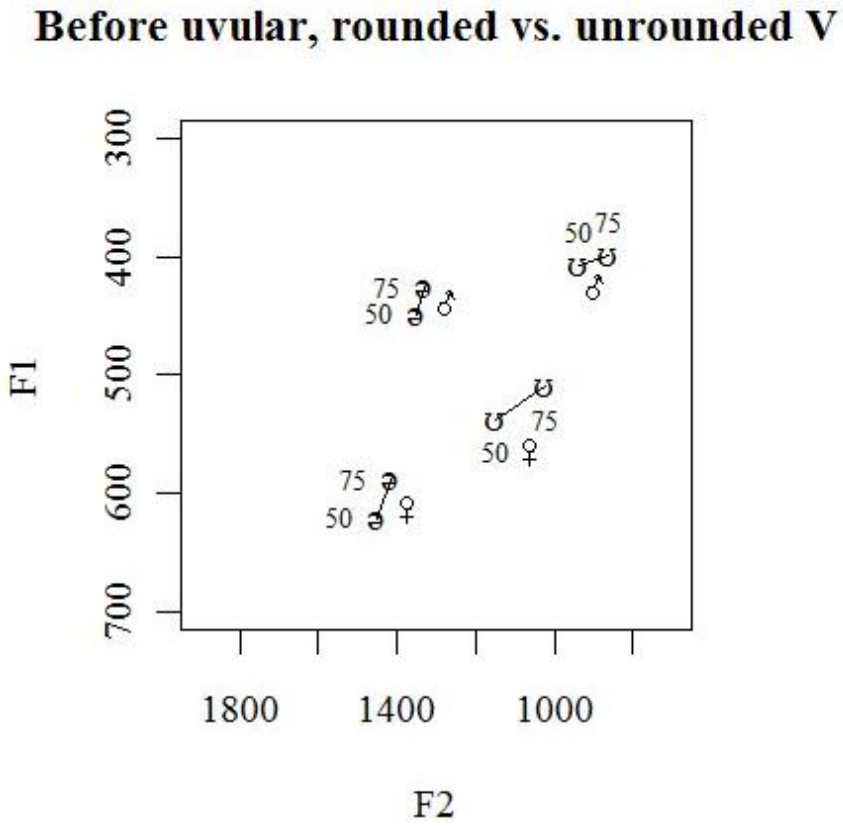
[7]For the same reason—balanced but not controlled preceding place of articulation—the formant data was not normalized. In the experiments described in Hargus 2010, the preceding and following consonant was controlled for and data was normalized using the Nearey normalization.

[8]Here and elsewhere, these durations are averages of each speaker's average duration for the category.

(10) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). 'ə' graphs F1 and F2 before unrounded vowels; 'ʊ' graphs F1 and F2 before rounded vowels.



At the individual level, F2 was significantly ($p < .0001$) lower before round vowels at both 50% and 75%. With respect to F1, for two speakers /ʊ/ had significantly lower F1 at both positions measured, for two speakers only at 75%. The fifth speaker had no significant differences in F1 between the two vowels. There were no significant differences in F3.

The acoustic evidence that Rounding Assimilation takes place in this context is supported by qualitative video evidence from one speaker which shows that rounding begins during the target vowel and continues through the uvular consonant into the triggering round vowel. This discussion of lip gestures in Deg Xinag is based on parameters identified by Linker 1982 in her study of lip positions English, Cantonese, Finnish, French and Swedish vowels. From 24 measures of lip shape, Linker identified a small number of parameters involved in the distinction between rounded and unrounded vowels in each language. For English, the most important parameter is 'horizontal opening' (p. 102), whereas for Swedish, with a more complex inventory of rounded vowels, there are three crucial parameters: (1) 'horizontal opening, front view area, and protrusion', (2) 'the ratio of horizontal opening, front view area (and vertical opening) to protrusion', and (3) 'vertical opening, front view area and protrusion'. The identification of lip gestures is an extremely complex topic and the remarks offered here for Deg Xinag must be considered very impressionistic and preliminary. For example, qualitative

inspection of images cannot reveal whether a parameter is fundamentally lip protrusion or the ratio of lip protrusion to vertical opening.

(11) shows the positions of the lips during production of [sʊqʼʊθ] ‘my neck’.[9] Here and elsewhere, the frontal and sagittal video frames are from different productions of the same word. The leftmost frames show lip positions at about 50% and 75% of the prefix vowel,[10] and the rightmost frame shows the most extreme lip rounding in the underlying round vowel. It can be seen, especially from the sagittal view, that the most extreme lip rounding during [sʊqʼʊθ] is achieved during the second (underlying round) vowel.

(11) Speaker ED, showing lip positions on the vowels of [sʊqʼʊθ] ‘my neck’

[sʊ̲]- (50%) [sʊ̲]- (75%) [qʼʊ̲θ]

(12) shows lip positions during production of a word with unrounded vowels, [səq^{h}aʔ] ‘my foot’. Comparing the first vowel of [sʊqʼʊθ] with the first vowel of [səq^{h}aʔ], even at

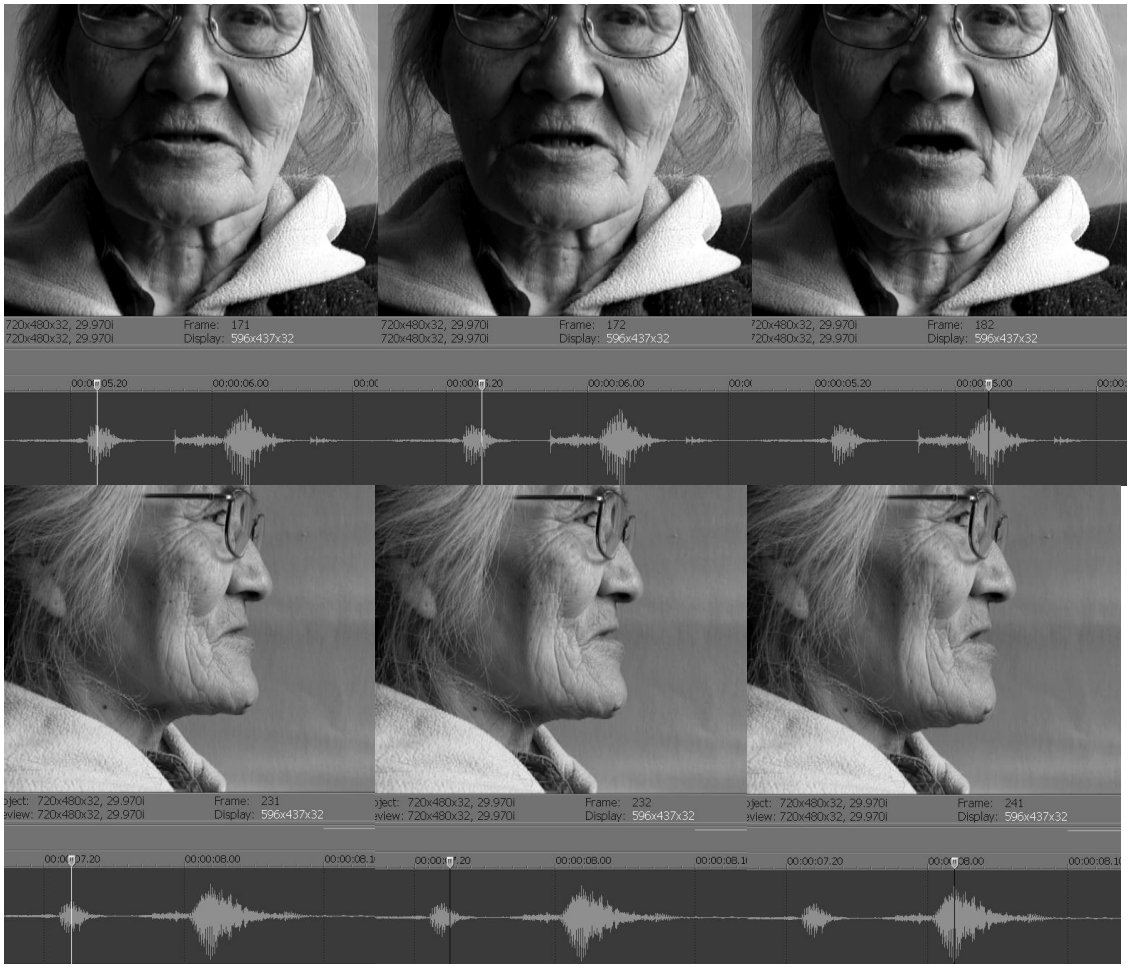
[9]The speaker was seated a fixed distance from the camera lens, about 27.5”, and the same level of zoom was used throughout. The camera used was the Casio EX-F1. Images are from video shot at 30 frames per second.

[10]The ‘75%’ image is one video frame advanced (about 30 msec.) from the ‘50%’ image.

50% of the prefix vowel, we see a smaller horizontal opening in the frontal views of the vowels of [sʊqʼʊθ], and more lip protrusion in the sagittal views.

(12) Speaker ED, showing lip positions on the vowels of [səq^{h}aʔ] ‘my foot’

[sə̲]- (50%) [sə̲]- (75%) [q^{h}a̲ʔ]



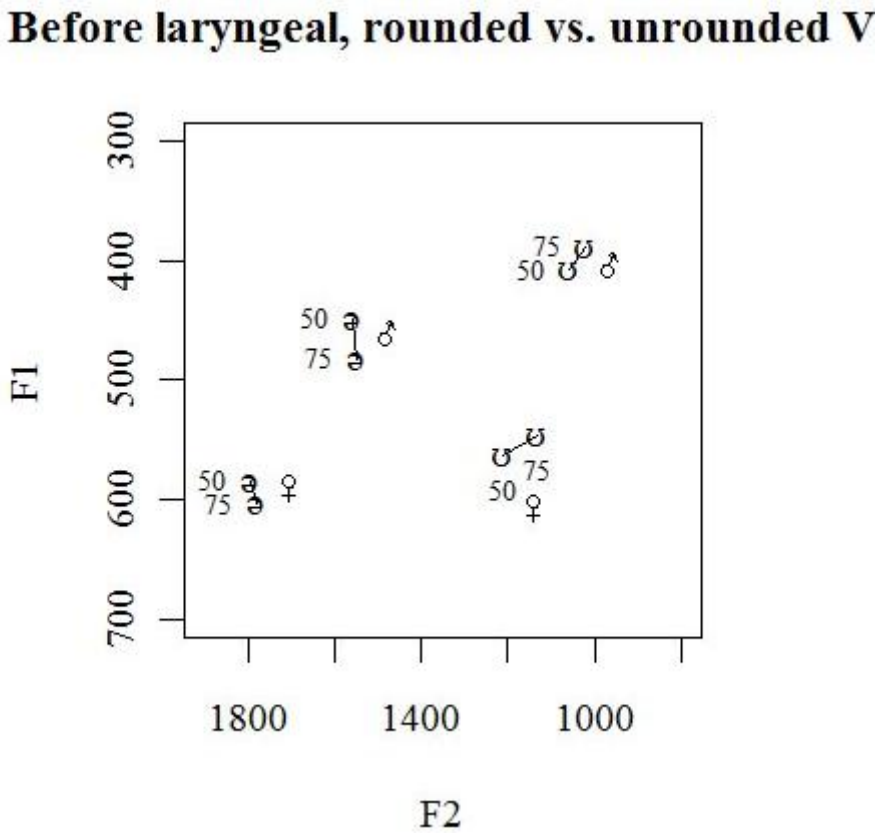
Based on the images in (11)-(12), Deg Xinag lip rounding seems to involve smaller horizontal opening (as seen in the frontal view) and greater lip protrusion (as seen in the sagittal view).

2.3.3.2 Rounded vs. unrounded vowel, intervening laryngeal consonant

Vowels before a single laryngeal consonant + rounded vowel were predicted to have lower F2 relative to unrounded vowels. The average duration of the vowels measured was .083 sec. before a rounded vowel vs. .081 sec. before an unrounded vowel.

A graph of F1 x F2 is shown in (13). F2 was significantly lower before a round vowel than before an unrounded one at both measurement points (50%, ($F[1,4] = 251.933$, $p < .0001$); 75% , ($F[1,4] = 71.600$, $p = .0011$). F1 was significantly lower at 75% ($F[1,4] = 15.095$, $p = .0178$) but not at vowel midpoint. There were no significant differences in F3.

(13) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). 'ə' graphs F1 and F2 before unrounded vowels; 'ʊ' graphs F1 and F2 before rounded vowels.



For each individual, F2 was significantly lower before a rounded than unrounded vowel both at 50% and 75% of vowel duration (p ranged from < .0001 to .0003). F1 was significantly lower before a round vowel at both measurement points for one speaker (50%, p = .0416; 75%, p = .0023). There were no significant differences in F3.

The images in (14) show Rounding Assimilation across a laryngeal consonant. If Deg Xinag lip rounding gestures are primarily smaller horizontal opening (frontal images) and lip protrusion (sagittal images), as suggested in 2.3.3.1, then the prefix vowel in [kʊhoŋ̊] is nearly as round as the stem vowel.

(14) Speaker ED, showing lip positions on the vowels of [kʊ̲hoŋ̥] ‘he/she is eating’
[kʊ̲]- (50%) [kʊ̲]- (75%) [hoŋ̥]

Comparing (14) with the lack of Rounding Assimilation across an alveolar in (15), notice that the degree of rounding in the underlying round vowels seems comparable. In contrast, the non-final (unrounded) vowel in [kəsoŋ̥] has greater horizontal and vertical opening than the final (rounded) vowel.

(15) Speaker ED, showing lip positions on the vowels of [kəson̥] ‘I’m eating’

[kə̲]- (50%) [kə̲]- (75%) [son̥]

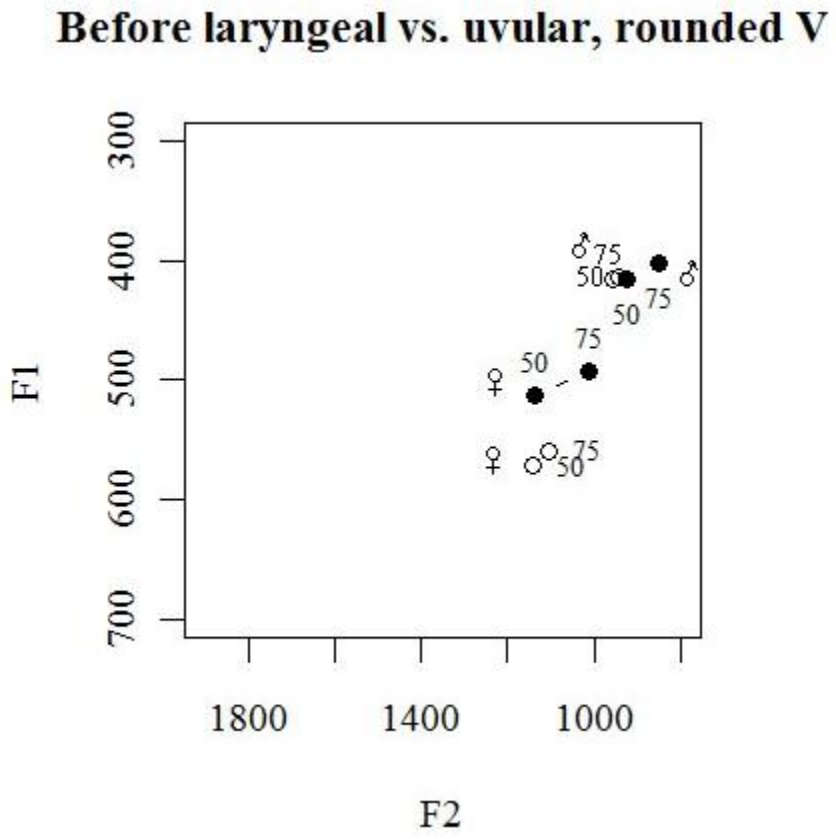
2.3.3.3 Uvular vs. laryngeal consonant before rounded vowel

Vowels before a single laryngeal consonant + rounded vowel were predicted not to differ in F2 relative to vowels before a single uvular consonant + rounded vowel. The average duration of the vowels measured was .094 sec. before a laryngeal vs. .080 sec. before a uvular.[11]

A graph of F1 x F2 is shown in (16). There were no significant differences in F1 or F3 at either measurement point, nor were there significant differences in F2 at vowel midpoint. However, at 75% of vowel duration F2 was significantly lower before a uvular than before a laryngeal ($F[1,4] = 13.284$, $p = .0219$).

[11]Some speakers had relatively long durations before a laryngeal consonant as a result of variation in the production of [ʔ], which was often realized as laryngealization of the preceding vowel rather than a silent period.

(16) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). The solid circles graph F1 and F2 before a uvular; the open circles graph F1 and F2 before a laryngeal consonant.



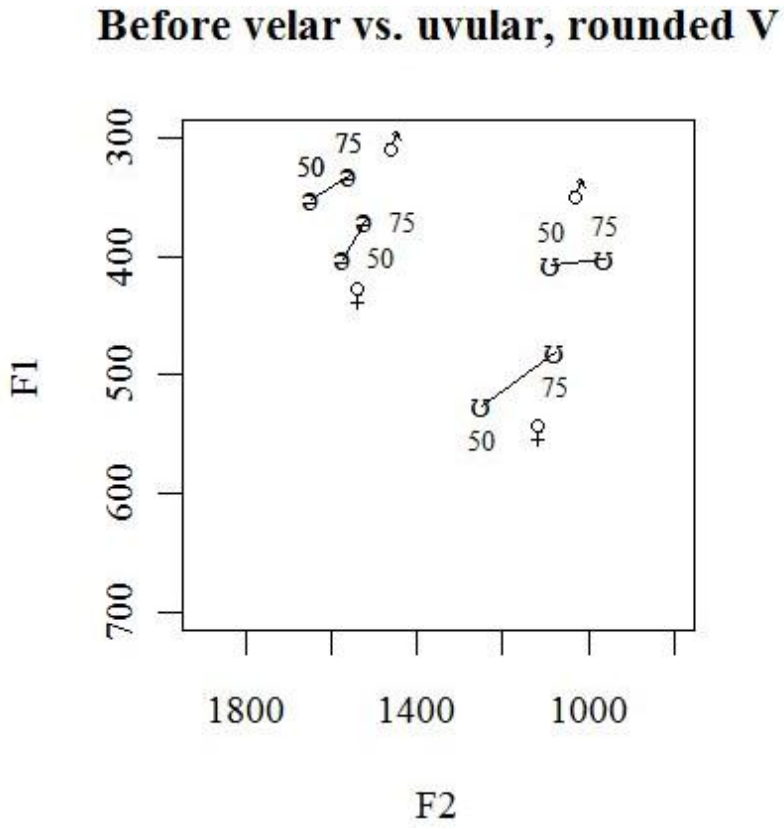
For three individuals, results were as predicted: F2 was not significantly lower before a uvular than before a laryngeal at either measurement point. For two speakers, F2 was significantly lower before a uvular at 75% of vowel duration, but not at 50%. For another speaker, F1 was significantly lower before the uvular at both measurement points.

2.3.3.4 Uvular vs. velar consonant before rounded vowel

Vowels before a single uvular consonant + rounded vowel were predicted to have lower F2 relative to vowels before a single velar consonant + rounded vowel. The average duration of the vowels measured was .068 sec. before a uvular vs. .065 sec. before a velar.

A graph of F1 x F2 is shown in (17). F2 is significantly lower before a uvular at both measurement points (vowel midpoint, $F[1,4] = 50.304$, $p = .0021$; 75% of vowel duration, $F[1,4] = 104.483$, $p = .0005$). F1 is significantly higher before the velar at both 50% ($F[1,4] = 18.439$, $p = .0127$) and 75% of vowel duration ($F[1,4] = 44.605$, $p = .0026$). There were no significant differences in F3.

(17) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). 'ə' graphs F1 and F2 before a velar; 'ʊ' graphs F1 and F2 before a uvular.



For each individual, F2 was significantly lower before a uvular than before a velar both at vowel midpoint (p ranged from < .0001 (3 speakers), .0008 (1 speaker), and .0053 (1 speaker)) and at 75% of vowel duration (p < .0001). All speakers also showed significantly higher F1 before the uvular than before the velar at at least one measurement point. For two speakers, F3 was significantly lower before a velar at 75% of vowel duration.

Video evidence suggests that the crucial gesture which underlies rounded reduced vowels in Deg Xinag may be lip protrusion as opposed to (lack of) horizontal opening. Compare the images of [səŋoo̯] 'my mother' in (18) with [sʊqʼʊθ] in (11). The lateral and vertical compression in the frontal 50% and 75% images of [səŋoo̯] is similar to that seen in the non-final vowel of [sʊqʼʊθ]. However, notice the lack of lip protrusion at 50% and 75% in the sagittal views of [səŋoo̯]. Although Linker 1982 found that a factor related to lip protrusion was relevant only in the languages in her study with front rounded vowels, she also noted (p. 97) that 'languages differ greatly in the lip gestures they use to make the same acoustic distinctions among vowels.'

(18) Speaker ED, showing lip positions on the vowels of [səŋoˌŋ] ‘my mother’

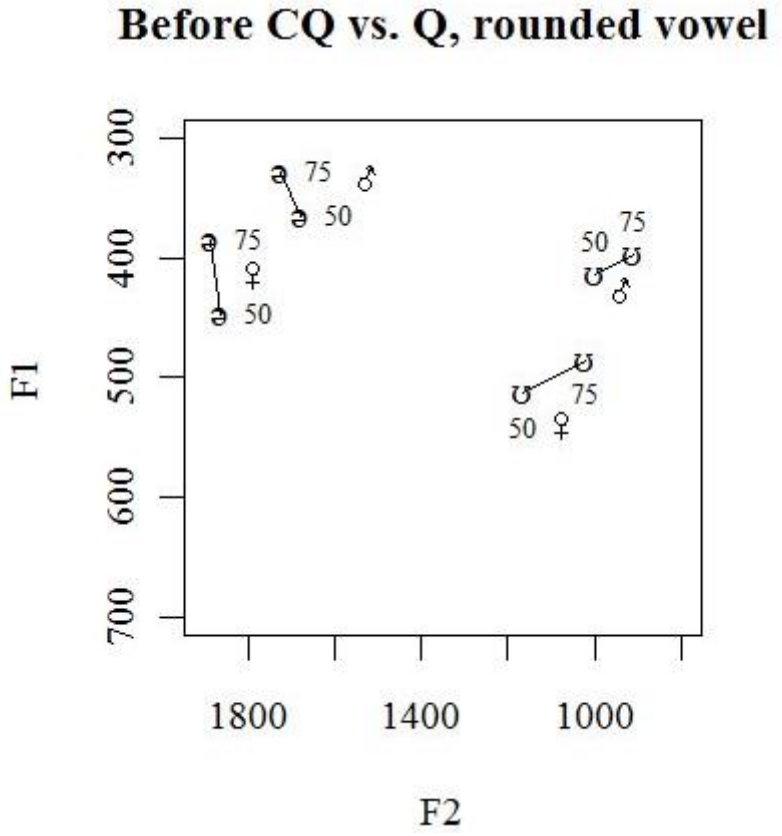
[sə̲]- (50%) [sə̲]- (75%) [ŋoˌŋ]

2.3.3.5 Single uvular consonant vs. cluster containing uvular before rounded vowel

Vowels before a single uvular consonant + rounded vowel were predicted to have lower F2 and higher F1 relative to vowels before a cluster of alveolar + uvular before rounded vowel. The average duration of the vowels measured was .083 sec. for reduced vowels before clusters and .082 sec. for reduced vowels before single uvular consonants.

A graph of F1 x F2 is shown in (19). F2 was significantly higher before the cluster at both 50% ($F[1,4] = 296.091$, $p < .0001$) and 75% of vowel duration ($F[1,4] = 216.353$, $p = .0001$). F1 was significantly lower before the cluster at both 50% ($F[1,4] = 36.750$, $p = .0037$) and 75% of vowel duration ($F[1,4] = 29.447$, $p = .0056$). There were no significant differences in F3 at either measurement point.

(19) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). 'ə' graphs F1 and F2 before a CQ cluster; 'ʊ' graphs F1 and F2 before a uvular (Q).

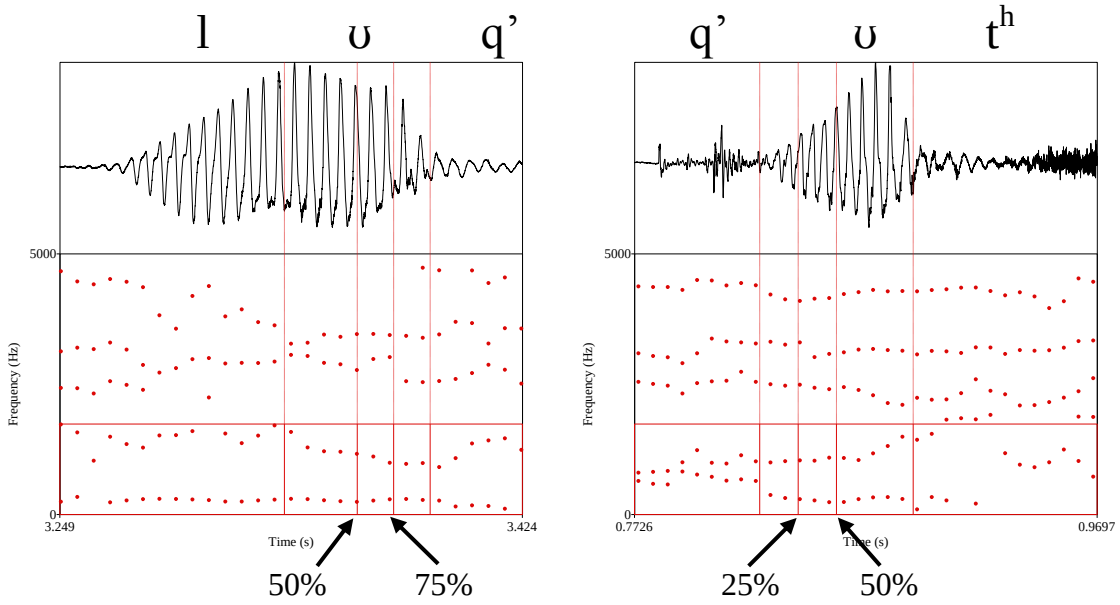


For each individual, F2 was significantly lower before the single uvular than the cluster both at vowel midpoint and at 75% of vowel duration. F1 was significantly lower before the cluster at both measurement points for two speakers, only at 75% for another two speakers, and at neither measurement point for the fifth speaker. There were significant differences in F3 for two speakers (higher before the cluster for one speaker at both points; lower before the cluster for another speaker at 75%).

2.3.3.6 Underlying /ʊ/ vs. [ʊ] derived via Rounding Assimilation

The final experiment tested for differences in F2 between the underlying round vowel of the perambulative prefix, /q'ʊ/-, and round vowels which result from Rounding Assimilation when a uvular follows the target of assimilation. Because the uvular precedes rather than follows the round vowel of the perambulative prefix, measurement points in this experiment were at 25% and 50% of vowel duration for the vowel of the perambulative prefix vs. 75% and 50% of vowel duration for the output of Rounding Assimilation, as shown in (20).

(20) Vowel duration and measurement points in standard Rounding Assimilation token (left) vs. perambulative prefix token (right) (male speaker JD). The outermost dashed lines delimit the measured vowels.



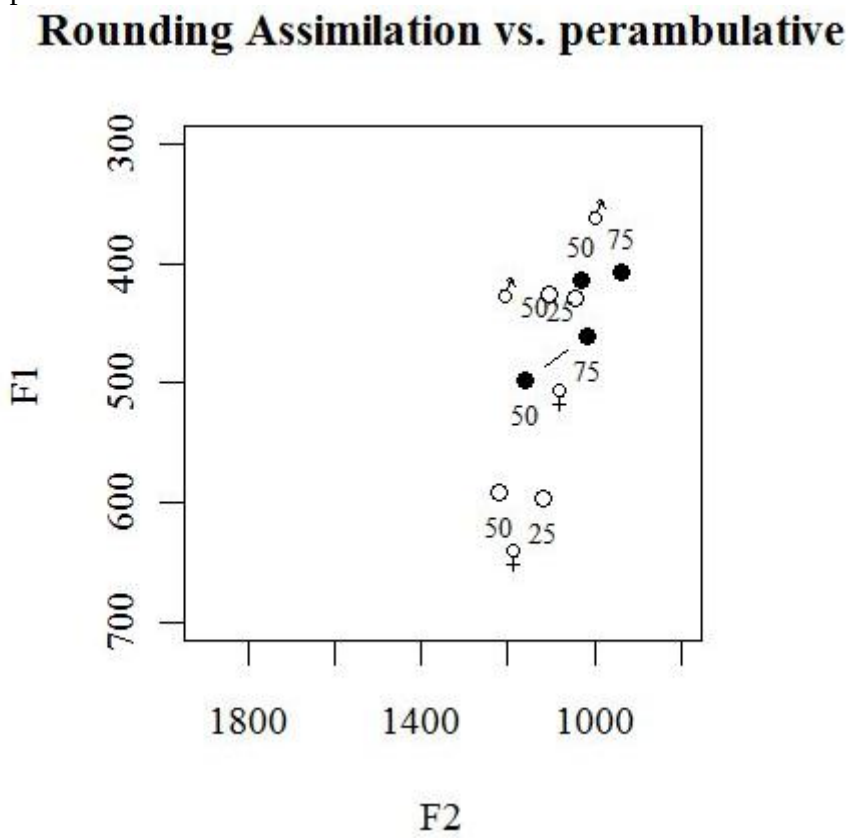
In the statistical tests, 25% of vowel duration following the perambulative prefix was compared with 75% of vowel duration before a uvular. The place of articulation of the consonant following the perambulative prefix was matched with the place of articulation of the consonant preceding the target of Rounding Assimilation (alveolar, for the tokens in (20)), so that comparisons could be made with balanced numbers of places of articulation.

The average duration of the vowels measured were .083 sec. for the vowel of the perambulative prefix vs. .075 sec. for a reduced vowel before uvular consonant.[12]

A graph of F1 x F2 is shown in (21). Notice that F2 of the vowel of the perambulative prefix is lower at 25% than at 50%—when closer to the uvular, just as for RA tokens. Round vowels which result from Rounding Assimilation had significantly lower F2 than the vowel of the perambulative prefix at 25/75% of vowel duration ($F[1,4] = 17.292$, $p = .0142$). There were no significant differences in F2 at 50%, nor in F1 or F3 at either measurement point.

[12]The two types of measured vowels were not in the same position in the word. The perambulative prefix was always word-initial, but this was only sometimes the case for RA tokens.

(21) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). The solid circles graph F1 and F2 before a uvular+rounded vowel; the open circles graph F1 and F2 after the uvular of the perambulative prefix.



At the individual level, the target of Rounding Assimilation had significantly lower F2 than that of the perambulative prefix for two speakers (one at 75% only). The discrepancy between individual and group results for F2 can be explained by the fact that RA means were lower than perambulative prefix vowel means for all speakers, even when not significant. The output of RA had significantly lower F1 for two speakers at both measurement points. The perambulative prefix had significantly lower F3 for one speaker at 75%.

2.3.4 Discussion

2.3.4.1 Support for Rounding Assimilation

The acoustic evidence, particularly the studies comparing vowel quality before round vs. unrounded vowels across uvular (2.3.3.1) and laryngeal (2.3.3.2) consonants, confirmed that Rounding Assimilation exists in Deg Xinag where suggested by auditory impressions. Both experiments confirmed significantly lower F2 before a round vowel at both the group and individual levels. There was considerable uniformity even at the individual level.

2.3.4.2 Directionality effects

As seen in 2.3.3.6, F2 was significantly lower—indicating more extreme rounding—in Rounding Assimilation contexts than with the underlying /ʊ/ of perambulative /q'ʊ/-. This difference is consistent with results of Hargus 2010, where I found significantly lower F2 and higher F1 for /ʊ/ before a uvular than after.

2.3.4.3 Consonant effects

Rounding Assimilation was confirmed to take place across a single uvular or laryngeal consonant (2.3.3.1, 2.3.3.2), and to be blocked by a cluster of alveolar+uvular (2.3.3.5) or by a velar consonant (2.3.3.4). Not as predicted, there was significantly greater F2 lowering when the consonant intervening between the round vowel and target of Rounding Assimilation was uvular as opposed to laryngeal (2.3.3.3).

F2 lowering effects of uvulars on adjacent vowels have been reported for various languages (Deg Xinag, Hargus 2010; K'ekchi, Ladefoged and Maddieson 1996; Moses-Columbian Salish and Coeur D'Alene, Bessell 1998; Ammani-Jordanian Arabic, Zawaydeh 1997). Uvulars are thus like pharyngeals, as noted by Jongman, Herd, and Al-Masri 2007:913 in a study of emphasis in Irbid Jordanian Arabic: 'a pharyngeal or uvular constriction both result in a low F2 and a high F1...' It has been observed that the 'emphatic' consonants in Arabic, which are generally articulated at the epiglottis rather than (upper) pharynx (Ladefoged and Maddieson 1996:169), often have a secondary correlate of labialization (Cairene, Lehn 1963: 30-31; Yemeni, Watson 1999). Card 1983:16 points out that 'it is interesting to note that emphasis and labialization both cause lowered second formants.' Thus it seems to be no accident that the vowel rounding which occurs before uvulars in Deg Xinag has the same acoustic effect—F2 lowering—as a uvular itself.

Although labials block roundness harmony in Nawuri (Casali 1995), Kaun 2004 does not mention other places of articulation as typically blocking or triggering rounding harmony. Perhaps the lack of phenomena parallel to Deg Xinag Rounding Assimilation in the literature on rounding harmony is an accidental gap, a consequence of the areally limited distribution of uvulars (Maddieson 2005) and the relative rarity of rounding harmony (Kaun 2004).

2.4 Summary of Deg Xinag

Rounding Assimilation appears to be a phonological process in Deg Xinag, as evidenced from restriction to certain consonantal contexts, lack of variation among speakers, effects at vowel midpoint, neutralization with underlying /ʊ/, and application in slow speech.

3 Babine-Witsuwit'en

To help solidify the case that Deg Xinag Rounding Assimilation is not simply coarticulation, it is useful to present Babine-Witsuwit'en, an Athabaskan language spoken in western central B.C., as a near-minimal pair. Subjective listening suggests that while Babine-Witsuwit'en assimilates reduced vowels to the rounding of a syllable-final labio-velar (3.1), Babine-Witsuwit'en does not have Rounding Assimilation in the contexts in which it occurs in Deg Xinag: before a single uvular or laryngeal consonant

followed by a round vowel. This was verified for the uvular context in an acoustic study (3.2).

3.1 Phonological contrasts

There are two major dialects of Babine-Witsuwit'en (B-W), Witsuwit'en (Hargus 2007) and Babine (Story 1984). Data presented here are from Witsuwit'en unless otherwise noted.

Babine-Witsuwit'en has the inventory of consonants shown in (22).

(22) B-W consonant phonemes

p p'	t t^h t'	c c^h c'	k^w k^{wh} $k^{w'}$	q q^h q'	ʔ
	ts ts^h ts'				
	tɬ $tɬ^h$ tɬ'				
	s z		x^w	χ ʁ	h
	ɬ				
m	n				
	l	j	w		

The Witsuwit'en dialect has the surface vowel contrasts shown in (23):

(23) Babine-Witsuwit'en contrastive vowels

full	*reduced*	*full*
i		u
e	ə	o
ɛ	a	

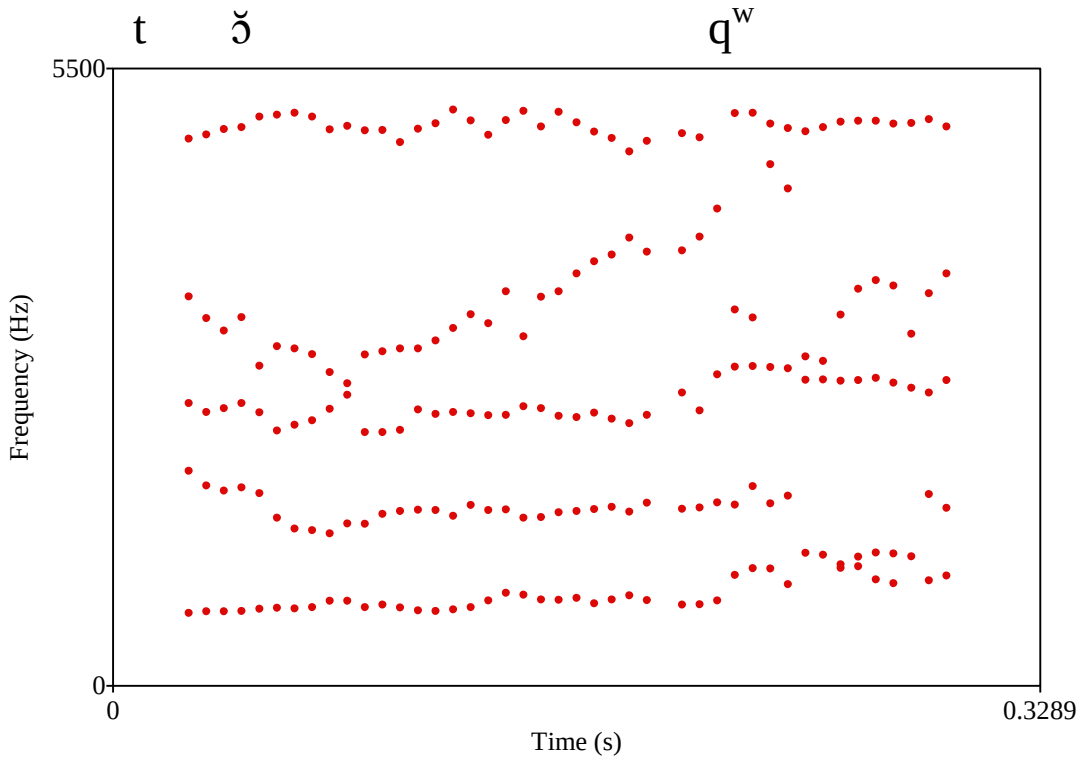
Like Deg Xinag, Babine-Witsuwit'en has stops and fricatives at the uvular place of articulation, but unlike Deg Xinag:

- B-W has palatal stops (DX has velar stops)
- B-W has a single reduced vowel /ə/ (DX has two reduced vowels, round and unround)
- B-W has a contrast in rounding among dorsal consonants, labio-velar vs. uvular; (DX does not have rounding as a secondary articulation of consonants)

While perhaps lacking Deg Xinag's Rounding Assimilation (to be investigated in 3.2), Babine-Witsuwit'en does have a phenomenon reminiscent of Rounding Assimilation. Story 1984:30-31, writing about the Babine dialect, lists [ŏ] as an allophone of /ə/ 'preceding syllable-final labialized (back) velars', with consequent retraction of the primary place of articulation of the labio-velar: /ək^w/ → [ŏq] (pre-coda rounding assimilation). Story's description of the phonetics of syllable-final labio-velars in Babine seems accurate for the Witsuwit'en dialect as well. Consider (24), a spectrogram of the final syllable of /təwenəɬtək^w/ 'it isn't boiling'. In the phonetic realization of /ək^w/, there is a fairly smooth lowering of F2 during the vowel, with the peak of rounding on the vowel not achieved until fairly close to the release of the stop. Inspection of the centers of gravity of release bursts in such tokens suggests that the stop is indeed uvular.

Although this last point deserves closer study, it is interesting to note once again a connection between rounding and uvular place of articulation.

(24) Spectrogram and formant tracks of final syllable of /təwenəɬtək^{w}/ 'it isn't boiling' (female speaker LM)



3.2 An acoustic study of effects of rounding

While subjective listening suggests that Babine-Witsuwit'en lacks the equivalent of Deg Xinag Rounding Assimilation, perhaps B-W has something like the Deg Xinag rule on a subphonemic level and fieldworkers like myself have trained themselves not to hear it because rounding is not contrastive in the reduced vowels. An acoustic study was therefore conducted to verify the (lack of) Rounding Assimilation in B-W.

3.2.1 Hypotheses

If B-W lacks Rounding Assimilation in the contexts where it occurs in Deg Xinag, then significant differences in F2 for the vowel /ə/ should not occur before round vowels when the intervening consonant is uvular ((25)a.). The B-W analog of the Deg Xinag context with intervening laryngeal was not tested, due to insufficient tokens.[13] Because of the observed rounding before syllable-final labio-velars (3.1), /ə/ before intervocalic labio-velars was also compared with /ə/ before intervocalic uvulars ((25)b.).

[13]B-W has restrictions on the distribution of vowels due to an innovative 'fortis'/'lenis' distinction in the consonants (Story 1984, Hargus 2007).

(25) Predictions concerning rounding contrasts among reduced vowels in Witsuwit'en
a. ə̲Q{u,o} vs. ə̲Qə: F2 predicted not to be significantly different
b. ə̲K^{w}ə vs. ə̲Qə: F2 before labio-velar predicted not to be significantly lower than before uvular

3.2.2 Methods

A word list was prepared and recorded with 9 speakers of the Witsuwit'en dialect, 4 male and 5 female, using the same equipment as in Deg Xinag (AT 4041 microphone in all cases). As with Deg Xinag, the target vowel was non-final, unstressed, and fairly short The consonant preceding the target vowel was always alveolar.[14]

As with Deg Xinag, the number of comparison pairs used to test each hypothesis varied from speaker to speaker (10-15 pairs per speaker), because of idiolectal differences in competence. Acoustic measurements were made using the same methodology as for Deg Xinag.

3.2.3 Results

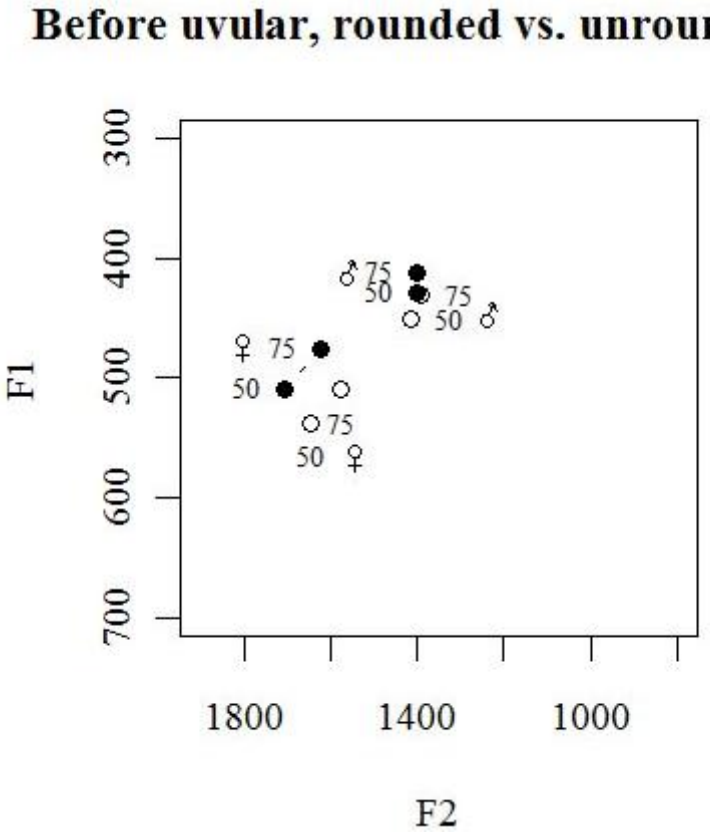
3.2.3.1 Intervocalic uvulars

F2 of vowels before uvular + rounded vowel was predicted not to be significantly different from that of uvular + unrounded vowel. The average duration of the vowels measured was .051 sec. before a rounded vowel vs. .052 sec. before an unrounded vowel, about 50% shorter than the measured Deg Xinag reduced vowels.

A graph of F1 x F2 in this context is shown in (26). There were no significant differences in F2 at either 50% or 75% of vowel duration, nor in F3 at either measurement point. Not as predicted, F1 was significantly lower before round vowels at both 50% ($F[1,8] = 12.375$, $p = .0079$) and 75% ($F[1,8] = 8.693$, $p = .0185$) of vowel duration.

[14]The target vowels on the word list were also balanced with respect to preceding 'fortis' and 'lenis' consonants, since this distinction is known to affect vowel quality in Witsuwit'en (see fn. 13).

(26) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). The solid circles graph F1 and F2 before a uvular+rounded vowel; the open circles graph F1 and F2 before uvular+/ə/.



At the individual level, only one speaker exhibited the Deg Xinag pattern, with significantly lower F2 in syllables followed by rounded vowels at 75% of vowel duration. Otherwise, there were no significant differences in F2, nor in F1.[15] For one speaker, F3 was significantly lower before rounded vowels at both measurement points, and for another speaker F3 was significantly higher before rounded vowels at vowel midpoint. Otherwise there were no significant differences in F3.

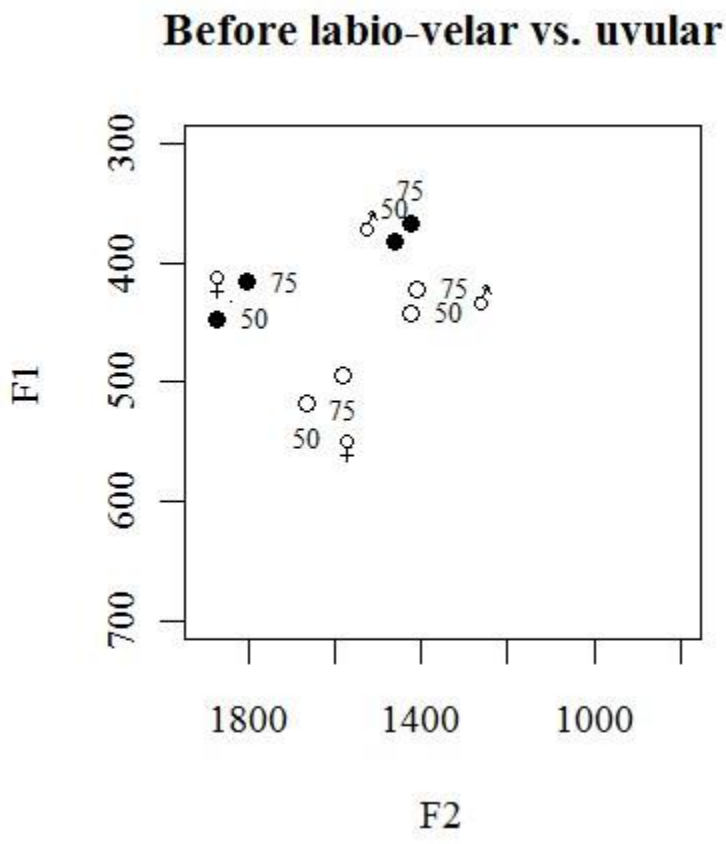
3.2.3.2 Intervocalic labio-velars

F2 of /ə/ before intervocalic labio-velar + unrounded vowel was predicted not to be significantly lower than before uvular + unrounded vowel. The average duration of the vowels measured was .053 sec. before labio-velars vs. .053 sec. before uvulars.

A graph of F1 x F2 in this context is shown in (27). F2 before /q/ was significantly lower than before /k^w/ at both 50% ($F[1,8] = 15.261$, $p = .0045$) and 75% ($F[1,8] = 8.478$, $p = .0195$) of vowel duration. F1 of /ə/ before /k^w/ was significantly higher than F1 before /q/ at both 50% ($F[1,8] = 20.712$, $p = .0019$) and 75% ($F[1,8] = 13.745$, $p = .0060$) of vowel duration. There were no significant differences in F3.

[15]The discrepancy between the group and individual F1 results is due to the fact that most individual F1 means are slightly but not significantly lower before round vowels.

(27) F1 x F2 plot for male and female speakers at two measurement points ('50'=50% of vowel duration, '75' = 75% of vowel duration). The solid circles graph F1 and F2 before a labio-velar + /ə/; the open circles graph F1 and F2 before uvular + /ə/.



At the individual level, there were either no significant differences in F2 or F2 before the labio-velar was significantly higher than before the uvular. In no case was F2 significantly lower before the uvular than before the labio-velar. With F1, there were either no significant differences or F1 before the uvular was significantly higher than before the labio-velar.

3.2.4 Discussion

The acoustic study confirmed that Babine-Witsuwit'en lacks the equivalent of Deg Xinag Rounding Assimilation, at least for intervening uvulars. However, one result common to both languages is lowering of F2 before the uvular (lower at 75% vs. 50%).[16]

[16]One unexpected result in 3.2.3.1 was the significantly lower F1 before round vowels. It seems likely that this result had nothing to due with rounding but to unbalanced numbers of high and mid round vowels on the word list (75 instances of [u] vs. 38 of [o]). A test of the effect of following vowel quality on F1 of /ə/ in the preceding syllable was significant at 50% ($F[3,24] = 6.939$, $p = .0016$) and 75% ($F[3,24] = 5.140$, $p = .0069$), with F1 significantly lower before /u/ than /o/ at both measurement points (50%, $p = .0002$; 75%, $p = .0019$).

While Babine-Witsuwit'en appears to assimilate /ə/ to the rounding of a syllable-final labio-velar, the acoustic study in 3.2.3.2 confirmed through the absence of F2 lowering that this assimilation in rounding does not occur before intervocalic labio-velars.

3.3 Summary of Babine-Witsuwit'en

The lack of effect on F2 before round vowels in Babine-Witsuwit'en helps show that Deg Xinag Rounding Assimilation is a phonological feature of that language, not simply a matter of coarticulation. Otherwise, similar anticipation of the rounding gesture would be expected to occur in all languages with similar segmental conditions, such as Babine-Witsuwit'en.

4 Evolution of Rounding Assimilation

Babine-Witsuwit'en would appear to have the phonological ingredients needed for Rounding Assimilation—uvulars, laryngeals and round vowels—but in the acoustic study presented in 3.2.3.1 only one speaker provided evidence of F2 lowering, and then only at 75% of vowel duration. The question arises as to why Deg Xinag has Rounding Assimilation whereas Babine-Witsuwit'en does not.

The answer likely involves perception. Deg Xinag has a contrast between velar and uvular stops whereas in Babine-Witsuwit'en, uvulars contrast with palatals, not velars. The common ancestor to Deg Xinag and Babine-Witsuwit'en, Proto-Athabaskan (PA), is also reconstructed with palatals (Krauss 1964), which split into palato-alveolar affricates and velar stops in Deg Xinag. F2 lowering on the vowel preceding the uvular would add an additional cue to the set which distinguishes uvulars and velars, thus enhancing that contrast.

Exactly how Rounding Assimilation evolved in Deg Xinag cannot be known with certainty, but something like the following scenario seems plausible. Proto-Athabaskan is reconstructed with four full vowels (*i: *e: *u: *a:) and three reduced vowels (*ə *ʊ *ɑ) (Krauss 1964, Leer 1979). Leer 1979:3 reconstructs 'a labialized uvular series' for Pre-Proto-Athabaskan, 'a more hypothetically reconstructed stage of the language previous to certain important phonological and structural changes' (p. 3). He further posits that PPA consonant rounding was transferred to an adjacent **ə* (PPA **q^{w}ə* > PA **qʊ*) but deleted if the vowel adjacent to the rounded consonant was not reduced (PPA **q^{w}a:* > PA **qa:*). Suppose that Pre-Proto-Athabaskan rounding was timed to coincide with the release of the dorsal articulation (like the majority of the world's languages, Ladefoged and Maddieson 1996) except in syllable-final position, as in modern Babine-Witsuwit'en: PPA */əq^{w}/ > PA *[ʊq]. Suppose further that in Proto-Athabaskan there was phonetic variation in the timing of rounding in syllable-initial position: PPA */q^{w}ə/ > PA *[q^{w}ə]~[qʊ].[17] The pattern in Deg Xinag is clearly an innovation in that language, because it is triggered in part by /o/ < **a:*. Deg Xinag could have generalized coda PPA */əq^{w}/ > PA *[ʊq] by dropping the syllable-final restriction, generalizing the context to all following round vowels.

[17]This variation would provide a better way of accounting for the labio-velar reflexes in Babine-Witsuwit'en.

5 Conclusions

In this article I have argued that Rounding Assimilation is a phonological process in Deg Xinag, not a case of VCV coarticulation. Perhaps the best evidence for this conclusion were the facts that Rounding Assimilation applies in slow speech, is present at vowel midpoint, F2 lowering occurs to an even greater extent than seen in morphemes containing underlying round vowels.

The acoustic results were corroborated by video images showing that the lip rounding begins on the vowel in Rounding Assimilation contexts. I have suggested that a gesture involving lip protrusion may be more crucial than horizontal opening in the phonetic realization of vowel rounding in Deg Xinag.

Babine-Witsuwit'en provided a set of control data showing what kinds of acoustic changes might be expected in VCV coarticulation before uvular+round vowel, lowering of F2 closer to the uvular regardless of vowel quality. However, in that language, one speaker exhibited the Deg Xinag pattern, lowering of F2 before round but not unrounded vowels, but only at the right edge of the vowel. I have suggested that Rounding Assimilation may have developed historically in Deg Xinag to enhance the innovative uvular/velar contrast in that language, and that this may have come about through extension of an anticipatory realization of rounding before labio-velars seen in modern Babine-Witsuwit'en.

Throughout this article we have seen a connection between uvulars and round vowels, presumably through their similar acoustic effect, F2 lowering. In Deg Xinag, Rounding Assimilation before uvulars resulted in more F2 lowering than before laryngeals. In Babine-Witsuwit'en, labio-velars shift to labio-uvular when pre-coda rounding assimilation takes place. F2 lowering effects adjacent to uvulars are seen in other languages as well.

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