Canadian Journal of Linguistics/Revue canadienne de linguistique 52(1/2): 43–70, 2007

The Effects of Post-Velar Consonants on Vowels in Nuu-chah-nulth: Auditory, Acoustic, and Articulatory Evidence

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1. Introduction

The phonetic and phonological interaction of post-velar consonants with vowels has been well documented in a variety of languages. Acoustic analyses of these effects have been done for languages such as Interior Salish (Bessell 1998a, 1998b) and many dialects of Arabic, including Palestinian Arabic (Shahin 2002), Egyptian Arabic (Elgendy 2001), Jordanian Arabic (Zawaydeh 1998), and Iraqi Arabic (Al-Ani 1970; Butcher and Ahmad 1987). The direction (i.e., leftward versus rightward) and precise effect (i.e., retraction, lowering, and/or schwa-colouring) of the consonant on the vowel seem to differ language to language (see Gick and Wilson 2006 for cross-linguistic examples).

Nuu-chah-nulth,[1] a Southern Wakashan language spoken on the west coast of Vancouver Island, is a language rich with post-velar consonants. However, the phonetic documentation that has been done on consonant-vowel interactions in the language either has solely relied on transcription and not been backed up with acoustic and/or articulatory analysis (Sapir and Swadesh 1939; Stonham 1999),

I am very grateful to my Nuu-chah-nulth consultants for sharing their language and time. I am also very grateful to Bryan Gick, Joe Stemberger, Henry Davis, Eric Vatikiotis-Bateson, and Pat Shaw for their helpful critiques and discussions. Thanks to Rose-Marie Déchaine and the Ling 518 graduate students for comments on various drafts, and to Laura Downing and Scott Shank for helpful discussions in the earliest stages. This work was supported by a SSHRC grant to Henry Davis and an NSERC grant to Bryan Gick. Ultrasound and other laboratory equipment used for this article were supplied through a CFI grant to Bryan Gick.

[1] Nuu-chah-nulth (known by some as *Nootka*) is an endangered language that, according to the 2001 census conducted by Statistics Canada, has about 410 mother-tongue speakers, 320 of whom are at least 50 years old.

or has not distinguished between leftward and rightward effects (Rose 1981), or has focused on only rightward effects (Shank and Wilson 2000a, 2000b; Wilson 2000), or has not included all post-velar consonants in its description (Carlson et al. 2001). The purpose of the present article is to fill this gap by meticulously documenting the leftward and rightward effects of all post-velar consonants on all vowels in Nuu-chah-nulth and to support this documentation with auditory (Study 1), acoustic (Study 2), and articulatory (Study 3) evidence. Given the cross-linguistic rarity of languages containing sounds that have pharyngeal as the primary place of articulation (Maddieson 1984), and given the endangered status of Nuu-chah-nulth, accurate documentation of the language is imperative.

The article is primarily descriptive, but it does have theoretical implications such as the issue of whether the lowering and retracting effects of the consonants on the acoustic output of the vowels is phonological or a phonetic by-product of conflicting tongue gestures, or a combination of the two.

In section 2 of this article, the Nuu-chah-nulth sound system is described, and the full phonemic inventory is given. Also, other researchers' findings on Nuu-chah-nulth vowel lowering/retraction and schwa offglides and onglides are reviewed. In section 3, the results and discussion of Study 1, an auditory study, are presented, showing the extensive variability in the perceived output of Nuu-chah-nulth vowels in post-velar consonant environments. Study 2, an acoustic study of the formants of vowels that follow post-velar consonants, is presented in section 4. Then in section 5, the results and discussion are presented of Study 3, an articulatory study using ultrasound, designed to determine the articulatory nature and cause of the excrescent schwa that appears between high front vowels and retracted consonants. Finally, in section 6 conclusions are given and topics for future research are suggested.

2. The Nuu-chah-nulth Sound System and a Brief Literature Review

The vowel and consonant inventories of the Ahousaht dialect of Nuu-chah-nulth are given and then a brief review is made of studies of consonant-vowel effects in Nuu-chah-nulth.

2.1. The sound system of Nuu-chah-nulth

The sound system of Nuu-chah-nulth is "among the world's most complex" (Carlson et al. 2001:275). There are six contrastive vowels, /i, iː, u, uː, a, aː/, and these can be realized in a number of ways, even when they occur in words without post-velar consonants (see Table 1, which is a summary adapted from the phonetic realizations given in Stonham 1999).[2] Note that in non post-velar contexts,

[2]Stonham is describing the Tseshaht dialect of Nuu-chah-nulth. Also, Stonham does not explicitly state the variability of these phonetic realizations, and since the present study concentrates mainly on post-velar consonant contexts, no statement can be made regarding the consistency of the realizations in this table.

Table 1: Phonetic realizations of Nuu-chah-nulth vowels when *not* adjacent to post-velar consonants

	/i/	/iː/	/u/	/uː/	/a/	/aː/
open syllables	[i]	[iː]	[ʊ]	[uː]	[a]	[aː]
closed, stressed syllables	[i]	[iː]	[ɔ]	[uː]	[a]	[aː]
closed, unstressed syllables	[ɪ]	[iː]	[ɔ]	[uː]	[ʌ]	[aː]

Table 2: Ahousaht Nuu-chah-nulth consonant inventory

	Bilabial	Alveolar	Lateral	Post-alveolar	Palatal	Velar	Labio-velar	Uvular	Labio-uvular	Pharyngeal	Laryngeal
Voiceless stops	p	t				k	kʷ	q	qʷ		ʔ
Ejective stops	p̓	t̓				k̓	k̓ʷ				
Voiceless affricates		ts	tɬ	tʃ							
Ejective affricates		ts̓	tɬ̓	tʃ̓							
Fricatives		s	ɬ	ʃ		x	xʷ	χ	χʷ	ħ	h
Nasals	m	n									
Glottalized nasals	m̓	n̓									
Glides					j		w				
Glottalized glides[3]					j̓		w̓			ʕ	

long vowels are always phonetically realized with the same quality, whereas short vowels are often somewhat centralized.

There is also a wide range of plain and glottalized consonants, as listed in Table 2. There are eight post-velar sounds in the language: /q/, /qʷ/, /χ/, /χʷ/, /ʕ/, /ħ/, /ʔ/, and /h/. Both /χ/ and /χʷ/, especially the latter, are fairly rare in Nuu-chah-nulth. Although the two laryngeals (/ʔ/ and /h/) do affect vowels by making them creaky (i.e., laryngealized), they have no measured lowering/retracting effect on the place of articulation of the vowels (Shank and Wilson 2000b), and thus they will not be analyzed in this article.[4]

[3]Carlson et al. (2001:276) list /ʕ/ as a plain approximant or glide, (i.e., not a glottalized glide), and based on laryngoscopic observation, they state that its phonetic realization is [ʡˤ], an epiglottal stop with concomitant pharyngealization (Esling and Harris 2005). However, due to its phonological patterning (i.e., like all laryngeal and glottalized consonants in Nuu-chah-nulth, but unlike the pharyngeal fricative, it never appears in the syllable coda) and due to various glide-like acoustic properties (Wilson 2000), it is listed here as a glottalized glide.

[4]They are, however, discussed in section 3.3.

Pharyngeals (/ʕ/ and /ħ/) are cross-linguistically rare (Maddieson 1984), appearing in some indigenous North American languages (i.e., Nuu-chah-nulth and Interior Salish), as well as a handful of other languages. Jacobsen (1969) gives a good description of the evolution of pharyngeals from glottalized uvular stops in the Nootka proto-language, and Carlson and Esling (2003) give a detailed phonetic account of how this may have happened. This historical shift is still reflected in the modern language in the process of glottalization, whereby consonants become glottalized before glottalizing suffixes (Kim 2000, 2003). In this context, where stops (other than uvulars) surface as ejectives, and fricatives surface as glottalized glides, /q/ and /qʷ/ regularly surface as /ʕ/.

2.2. Past studies describing the effects of post-velar consonants on vowels

Vowel lowering/retraction and an excrescent-schwa effect adjacent to post-velar consonants occur in a variety of different languages, with the direction and precise effect on the vowel differing from language to language.[5] A full review of these cross-linguistic cases is beyond the scope of this article, but a brief review of four studies on Nuu-chah-nulth is given.

Sapir and Swadesh (1939:13), in what is the standard reference on Nuu-chah-nulth, state that “there are various timbre changes of vowels induced by particular consonants, also pseudo-diphthongs due to glides (particularly *e*-glides due to *q* and *a*-glides due to *ħ* and *ʕ*)”. However, they are not specific about the direction of the effects.

Rose (1981:16, Table 2) lists the allophonic variants of short vowels in the Kyuquot dialect of Nuu-chah-nulth, when those vowels are adjacent to various consonants. However, Rose does not separate leftward from rightward effects, but groups them all together under the label *adjacent to*. Also, she does not include /ħ/ or /h/ in her list of consonants, although she says that /ħ/ is “like a resonant in having large formant transitions which are perceived as offglides and onglides in adjacent vowels” (1981:15).[6] Rose includes the following post-velar consonants in her table: /q/, /qʷ/, /ʕ/, and /ʔ/. The allophones of the short vowels adjacent to these four post-velar consonants are as follows (adapted from Rose 1981:16, Table 2):

(1)	adjacent to /q/:	/i/>[ɛ],	/u/>[ɔ̞],	/a/>[ɑ]
	adjacent to /qʷ/:	/i/>[ɛ],	/u/>[ɔ̞],	/a/>[ʌ̠]
	adjacent to /ʕ/:	/i/>[ɛ̝],	/u/>[ɔ̠],	/a/>[ɑ̠]
	adjacent to /ʔ/:	/i/>[ɪ̞],	/u/>[ʊ̞],	/a/>[ɑ]

[5]In many languages, vowel lowering/retraction occurs in vowels that are not adjacent to post-velar consonants (i.e., cases of harmony; see Bessell 1998b for examples). Those cases involving harmony are not discussed here.

[6]Rose does not specify which vowels, but implies that all have off/onglides. In the results in section 3 of the present article, it can be seen that in the Ahousaht dialect, no off/onglides are perceived on the low vowel when it is adjacent to /ħ/.

It is difficult to compare this data to the results in section 3 because those results differ according to whether the consonant precedes or follows the vowel, and because Rose only lists the effects on short vowels.

In his study of the phonetics and phonology of the Tseshaht dialect of Nuu-chah-nulth, Stonham (1999) describes the effects of uvulars and pharyngeals on vowels. It should be noted, however, that his description of the sound system of Nuu-chah-nulth is based on the field notes of Edward Sapir (n.d.), who most certainly did not have the benefit of being able to undertake acoustic/articulatory analyses of his data. Also, because Stonham's (1999) description does not specifically separate rightward from leftward effects,[7] and because these have been found to differ (Gick and Wilson 2006), a more complete analysis is necessary.

Stonham (1999:21) states that in Tseshaht Nuu-chah-nulth, "diphthongs only occur phonetically, but. . . are never found phonemically in the language". One of the examples he gives of an environment that triggers diphthongization is /i/ next to a uvular consonant, "which produces a broken vowel with the offglide of a lower articulation". He gives an inventory of the phonetic realizations of all vowels. These realizations generally agree with the results of my study. However, Stonham (1999:18) gives [ɑi] and [ai] as the phonetic realizations of /i/ after /ħ/, while my results indicate that /i/ is realized as [e] or [eɪ] in this context.[8]

In a recent description of the Ahousaht dialect of Nuu-chah-nulth, Carlson et al. (2001:277) state that "for many speakers, there can be a pharyngealized schwa transition between close [high] vowels and a pharyngeal". The two examples they give are with the high vowel /i/, first preceding /ħ/ and then following /ʕ/. The latter example shows the /i/ in /ʕi/ being produced with a schwa offglide (not onglide). This does not seem likely, phonetically, as the tongue body is low and retracted for the pharyngeal, then rises (with tongue root advancement) for the /i/ and should not have to lower again following the /i/. Carlson et al. (2001:278) also state that a schwa transition occurs between the /i/ and /q/ in /iq/, something that the data in section 3 confirms. Unfortunately, Carlson et al. do not mention anything about the rightward effects of uvulars on vowels, nor do they specifically list the effects, other than the schwa transition, of pharyngeals on vowels.

3. Study 1: An Auditory Evaluation

A first study was conducted to determine the precise nature of the consonant effects on vowel quality, and to determine whether or not the effects appear to be

[7] Stonham (1999: Chapter 2) describes the environment in which each particular phonetic instantiation of a given phoneme is found. However, he uses the words "adjacent to uvular and pharyngeal consonants" (p. 15) and "in the environment of uvulars and pharyngeals" (p. 17) without stating which side of the vowels the consonants are on.

[8] It is not impossible that this is a typographical error in Stonham's work, as other errors do occur (e.g., in 2.2.1.13 and 2.2.2.8, the offglide probably should be [ə] instead of [e], and the word "front" should replace "back" in both examples).

categorical or gradient. In this first study, a detailed auditory evaluation was made of the effects of post-velar consonants on neighbouring vowels in the speech of one Ahousaht Nuu-chah-nulth speaker. Data collected by the author was transcribed and analyzed, and generalizations were made about the effects of each of the six non-laryngeal, post-velar consonants (/q/, /qʷ/, /χ/, /χʷ/, /ʕ/, and /ħ/) on each of the three vowels of Nuu-chah-nulth, both long and short (/i/, /iː/, /u/, /uː/, /a/, and /aː/), preceding and following the consonants. Some example data is presented in section 3.2.

3.1. Method

One native speaker of Nuu-chah-nulth, MJD, was recorded saying a number of words in a carrier phrase. MJD grew up speaking Nuu-chah-nulth in the 1940s and 1950s at home and in the community on Flores Island. She is a bilingual speaker of Nuu-chah-nulth and English. Admittedly, having only one speaker makes for a very small sample, but unfortunately this limitation is often the norm for studies of endangered languages. It is possible that some of the speech observed may be idiosyncratic of this speaker rather than being characteristic of the community in general.

The words used in Study 1 were recorded over a period of about three years (January 2000–January 2003).[9] Words for this study were chosen so that each vowel under investigation had one and only one post-velar consonant adjacent to it. This limited the number of different words available for analysis to 145, but it was deemed a necessary action to give a clearer picture of the consonant effects on the vowels. Each word was usually spoken in the carrier sentence shown in (2) three times, but because the recordings were made within different research projects over a period of three years, the carrier sentence was not necessarily always used.

(2) waːmitsiʃ __________________ wa
waː-mit-sii-ˀʃ __________________ wa
say-PAST-1SG.IND __________________ confirmation
'I said ______________, right?'[10]

It is conceivable that the word-final /ʃ/ immediately preceding the stimulus could have an effect on the articulation of a word-initial pharyngeal or uvular in the stimulus. However, at least 50% of the stimulus types did not have the post-velar consonant under investigation as their initial consonant.

[9]Thanks to Scott Shank, who helped to elicit words from MJD during many of the earlier recording sessions.

[10]The following abbreviations are used:

SG	singular
IND	indicative
IMP	imperative

Words were recorded using one of two recording media: (i) a Marantz PMD430 analog cassette recorder in a quiet room, or (ii) a Sony mini-disc MZ-R37 digital recorder in a soundproof booth. Data were digitized on an iMac computer, sampling at 44 kHz. All tokens were transcribed into Nuu-chah-nulth orthography, which was then checked by the speaker, MJD. Vowel lowering/retraction around post-velar consonants was analyzed for all vowels that were bordered by exactly one post-velar consonant. This resulted in a total of 185 vowels being analyzed in the 145 available words. Two or three tokens of each word were available to check whether token-to-token variability existed. Auditory analysis was completed using SoundEdit 16 Version 2 to vary the tempo of the utterances, thus making it easier to hear vowel quality. Each vowel in question was listened to at a variety of rates, including the normal rate and at very slow speed, sometimes at more than four times its original duration, using a tempo-altering feature (Tempo) of SoundEdit. It should be noted that the Tempo feature did not alter the pitch (f0) and did not appear to alter the location of formants of the signal, thus making it less likely that this researcher's perception was impaired.

Morphology was not taken into consideration for the purposes of this study. In future studies, this is obviously something to address. However, although phonologically based effects are often influenced by the morphology, it is expected that purely phonetic effects (i.e., ones that are due to the biomechanical speech production system) would not be influenced by morphology.[11]

3.2. Results

A summary of the perceived effects of post-velar consonants on vowels can be seen in Table 3. Each of the 36 cells in the left half of the table shows the phonetic realization(s) of a different vowel-consonant combination — the vowel at the top of the given cell's column followed by the consonant in the middle column of the given cell's row. Each of the 36 cells in the right half of the table shows the same thing, but with a consonant-vowel combination (i.e., the vowel follows, rather than precedes, the consonant). Where there are no symbols in a particular cell of the table, it means that in over three years of elicitation sessions, there were no words found with that vowel-consonant or consonant-vowel combination (and with no post-velar consonant on the other side of the vowel). If there is more than one symbol in a given cell, it means that the phonetic realization of that particular vowel-consonant or consonant-vowel combination was variable. In these cases, the symbols are listed in descending order of frequency of occurrence in this data set. The subscript beside each symbol is the number of types (not tokens) in which

[11] Joe Stemberger (p.c.) points out that phonetic effects might be influenced by lexical frequency. I know of no word frequency list for Nuu-chah-nulth, so this proves difficult to test. An anonymous reviewer points out that estimated frequency and usage frequency are highly correlated, so with a large enough sample of speech, the effects of lexical frequency may be testable.

Table 3: Summary of phonetic realizations of vowels, preceding and following post-velar consonants

Vowel precedes post-velar consonant						*Post-velar*	*Vowel follows post-velar consonant*					
/aː/	/a/	/uː/	/u/	/iː/	/i/	↓	/i/	/iː/	/u/	/uː/	/a/	/aː/
aː$_{5}$	ʌ$_{4}$ a$_{2+1}$ a̝$_{0+1}$	uː$_{2}$	ʊ$_{1}$	eː$^{ə}_{4}$ iː$^{ə}_{2}$	ɪ$^{ə}_{3+2}$ e$^{ə}_{2}$ ə$_{0+2}$	/q/	e$_{3+1}$ ɪ$_{2+1}$ ɛ$_{1}$ ə$_{1}$	eː$_{4}$ eɪ$_{2}$	ʊ$_{2}$ u$_{1}$	uː$_{4}$	ʌ$_{4+2}$ a̝$_{4+2}$ a$_{3}$	aː$_{3}$ a̝ː$_{1}$ ɑː$_{1}$
ʌ$_{1}$	—	uː$_{1}$	u$_{1}$	—	ɪ$^{ə}_{1}$	/qʷ/	ɪ$_{2+2}$ ɛ$_{0+2}$ ə$_{0+1}$	iː$_{1}$	—	—	ʌ$_{2}$	aː$_{2}$
aː$_{2}$	ʌ$_{2}$	—	u$_{1}$	—	ɪ̙	/χ/	e$_{1+1}$ eɪ$_{0+1}$	—	u$_{1}$	uː$_{2}$	a$_{2}$ ʌ$_{1}$	—
—	—	—	—	—	—	/χʷ/	—	—	—	—	—	aː$_{2}$
aː$_{1}$	ʌ$_{2}$ a$_{1}$	—	—	iː$^{ə}_{1}$	i$^{ə}_{4}$ e$^{ə}_{1}$	/ʕ/	e$_{3}$ ɛ$_{1}$ ɛ$^{ə}_{1}$ ɛ$^{e}_{1}$	eː$_{2}$ eɪ$_{1}$	aʊ$_{3+1}$ o$_{0+2}$ ə$_{0+1}$	oʊ$_{2}$	a$_{2+2}$ ʌ$_{1+2}$	aː$_{6}$
aː$_{1}$	a$_{4}$	uː$_{1}$	ɔ$_{5}$ o$_{1}$	iː$^{ə}_{2}$ ɪː$^{ə}_{2}$ eː$_{2}$ iː$_{1}$	e$_{3}$ i$^{ə}_{1}$ i$_{1}$	/ħ/	e$_{5+1}$ e̝$_{1}$ eɪ$_{0+1}$	eɪ$_{2+1}$ eː$_{1+1}$	aʊ$_{3+1}$ ʊ$_{0+1}$	oʊ$_{2}$ aʊ$_{1}$	a$_{5}$	aː$_{5}$

that phonetic realization occurred. A notation such as *2+1* means that the given phonetic realization occurred in a total of three types (i.e., three different words), but one of those types was perceived to have tokens with variable pronunciations. As an example of how to read Table 3, an interpretation of the cell where /i/ follows /q/ (i.e., the upper left cell of the right half of the table) is now given. In that cell, there are four phonetic symbols, each with a subscript: e$_{3+1}$, ɪ$_{2+1}$, ɛ$_{1}$, and ə$_{1}$. What this means is that out of the eight different words analyzed that contained /qi/, three words had /i/ consistently (i.e., in every token of that word) realized as [e], two words had /i/ consistently realized as [ɪ], one word had /i/ consistently realized as [ɛ], and one word had /i/ consistently realized as [ə]. The eighth word had some tokens where /i/ was realized as [e] and some tokens where it was realized as [ɪ] — the "+1" part of each subscript.

3.2.1. Uvular consonant effects

Although the uvular fricatives (both plain and rounded) are quite rare in Nuu-chah-nulth, from the available data in Table 3 it can be seen that they behave similarly to the uvular stops in their effects on adjacent vowels. The only notable difference is that while the uvular stop causes a preceding high front vowel to have a schwa offglide, the uvular fricative does not. Example data for the stops can be seen in (3) and (4), and for the fricatives in (5).

The plain /q/ usually lowers a following /i/ and /iː/ to a mid vowel (3a, b, c) and often lowers a preceding /i/ and /iː/ to a mid vowel as well (3e, g). However, the labio-velarized /qʷ/ has no lowering effect on a following /i/ or /iː/ (3e, f).[12] As seen in (3b, d, e, g, h, i), there is a schwa offglide from /i/ and /iː/ to /q/ as well as from /i/ to /qʷ/.

(3)	a.	/qitʃin/	[qetʃɪn]	‘louse’
	b.	/siqiːɬ/	[sɪᵊqeːɬ]	‘to cook’ (/i/ sometimes realized as [ə] here)
	c.	/qiːʃqiːʃa/	[qeɪʃqeɪʃa]	‘limping’
	d.	/siqmis/	[sɪᵊqmɪs]	‘pus’ (first /i/ sometimes realized as [ə] here)
	e.	/qʷiːʔiqsu/	[qʷiːʔeᵊqsu]	‘parent-in-law’
	f.	/qʷiniː/	[qʷɪniː]	‘seagull’
	g.	/ʔumʔiːqsu/	[ʔumʔeᵊqsu]	‘mother’
	h.	/qatstsʼiːq/	[qatstsʼiᵊq]	‘sixty’ (the /a/ sometimes sounds raised to /ʌ/)
	i.	/tʼiqʷaːsitɬ/	[tʼɪᵊqʷaːsɪtɬ]	‘to sit down’

As can be seen in (4), /q/ and /qʷ/ have no lowering effect on neighbouring /u/ or /uː/, and no effect on /a/ or /aː/.[13]

(4)	a.	/maquːɬ/	[maquːɬ]	‘blind’
	b.	/ʔuːqmis/	[ʔuːqmɪs]	‘have fun; enjoy’
	c.	/kʼuːqʷaː/	[kʼuːqʷaː]	‘moving quietly or cautiously’

The uvular fricative, /χ/, always lowers a following /i/ (5a, b), but (based on only one type) it does not seem to lower a preceding /i/ or cause a schwa offglide (5c). /χ/ does not affect neighbouring /u/ or a following /uː/, /a/, or /aː/. The labio-velarized uvular fricative, /χʷ/, is quite rare — the only data available show that it does not affect a following /aː/ (5e), an expected result based on the fact that neither /χ/ nor /q/ affect /aː/ or /a/.

(5)	a.	/haːχits/	[haːχets]	‘bee’
	b.	/tsiːʃχik/	[tsiːʃχek]	‘dirty hair’ (variable between [e] and [eɪ])
	c.	/kʼʷikʼʷiχasitɬ/	[kʼʷikʼʷɪχasɪtɬ]	‘to kiss someone on the cheek’
	d.	/puχʃitɬ/	[puχʃɪtɬ]	‘to rise (e.g., bread)’
	e.	/tsapχʷaː/	[tsapχʷaː]	‘boiling’

[12]Table 3 shows an apparent contradiction to this statement, but it should be noted that there were only two tokens (not types) where /i/ was realized as [ɛ] or [ə]. In both of these tokens, the nasal /n/ followed the /i/ in question, so the vowel may be perceived as being lower than it really is.

[13]Table 3 shows a single case of /aː/ being lowered to /ɑː/ following /q/. This happens in the word /ʕuːpqaː/ ‘whistling’ and it is believed to be an anomaly in the data.

3.2.2. Pharyngeal consonant effects

Both pharyngeal consonants, /ʕ/ and /ħ/, lower high vowels that follow them. There are also cases where they both lower high vowels that precede them, but this is variable and it occurs more frequently before /ħ/ than before /ʕ/. When a high front vowel precedes the pharyngeal consonants, there is usually a schwa offglide on the vowel. This offglide is always present before /ʕ/ but not always present before /ħ/. Example data for /ʕ/ can be seen in (6), (7), and (8), and data for /ħ/ in (9) and (10).

The glottalized pharyngeal glide, /ʕ/, always lowers a following /i/ and /iː/ (6a, b, c, d), but does not lower a preceding /iː/ (6b). It sometimes lowers a preceding /i/ (6e), but usually it does not (6c). There is always a schwa offglide from a preceding /i/ or /iː/ (6b, c, e).

(6)	a.	/ʕiʃiː/	[ʕeʃiː]	‘ankle bone’
	b.	/tsiːʕitɬ/	[tsiːᵊʕetɬ]	‘to ask permission’
	c.	/t̓iʕiːtɬ/	[t̓iᵊʕeɪtɬ]	‘to sit down on the ground’
	d.	/ʕiːtʃn̓uː/	[ʕeetʃn̓uː]	‘bullhead fish’
	e.	/miʕaːt/	[meᵊʕaːt]	‘river sockeye salmon’

/ʕ/ lowers a following /u/ and /uː/ (7; 8a). Interestingly, no examples could be found of /u/ or /uː/ occurring before /ʕ/, even though /u/ and /uː/ can appear before glottalized resonants (7a).

(7)	a.	/ʕuj̓i/	[ʕoj̓i]	‘medicine’
	b.	/ʕumaː/	[ʕaʊmaː]	‘running/streaming water’
	c.	/ʕuːpqaː/	[ʕoʊpqɑː]	‘whistling’

As can be seen in (8), /ʕ/ has no effect on neighbouring /a/ or /aː/. These vowels do not retract to [ɑ] or [ɑː].

(8)	a.	/p̓aʕum/	[p̓aʕom]	‘giant chiton (type of mollusk)’
	b.	/miʕaːt/	[meᵊʕaːt]	‘river sockeye salmon’
	c.	/ʕaːmiq/	[ʕaːmeᵊq]	‘horse clams’

The pharyngeal fricative, /ħ/, always lowers a following /i/ and /iː/ (9a, b, c) and sometimes a preceding /i/ and /iː/ too, although what happens to /i/ before /ħ/ is extremely variable (see 9d, e, f).

(9)	a.	/ħijiːħi/	[ħejiːᵊħe]	‘these ones’ (ə-offglide not always there; [e] or [eɪ])
	b.	/ʔatħiː/	[ʔatħeː]	‘night’ (variable between [eː] and [eɪ])
	c.	/ħiːx/	[ħeɪx]	‘a type of small purple sea urchin’
	d.	/ʔiːħ/	[ʔɪːᵊħ]	‘big’ (ə-offglide very slight)
	e.	/ɬiħiːpitap/	[ɬeħpitap]	‘cover something’ (/iː/ is not pronounced here)
	f.	/tɬiːħaː/	[tɬiːħaː]	‘travelling’

/ħ/ lowers a following /u/ and /uː/ (10a, b, c) but not a preceding /u/ or /uː/ (10d, e).[14] As can be seen in (10b) and (10d), /ħ/ has no lowering effect on neighbouring /aː/, and the same is true of neighbouring /a/.

(10)	a.	/ħumiːs/	[ħaʊmiːs]	‘cedar’
	b.	/ʕaːħuːs/	[ʕaːħaʊs]	‘a land base name (from which came *Ahousaht*)’
	c.	/ħuːjiɬ/	[ħoʊjiɬ]	‘over there on the floor’
	d.	/suːħaː/	[suːħaː]	‘spring salmon’
	e.	/kuħsaːp/	[kɔħsaːp]	‘open something’

3.3. Discussion

The results in section 3.2 indicate that vowel lowering and/or retraction does take place, although it is not triggered by every post-velar consonant and does not affect every vowel in the same way. As seen in Table 3, there is considerable variability in the interactions. Taking /i/ as an example, there are at least four different degrees of vowel lowering/retraction: [ɪ], [e], [ɛ], and [ə]. Bessell (1998b) uses variability in the phonetic output as an argument to separate phonetic from phonological vowel lowering effects in Salish languages. However, Rose (1996:90) explains that variable vowel realizations are due to the feature [RTR] imposing “the articulatory function of retracting the tongue root, which, while phonologically relevant in harmony, may have different phonetic effects from one language to another”.

If Nuu-chah-nulth vowel lowering is phonetic, it should be explainable in terms of biomechanical side effects due to the hydrostatic nature of the tongue (Kier and Smith 1985), cases of gestural conflict resolution (Gick and Wilson 2006), or cases of language-specific phonetic control (Kingston and Diehl 1994). The fact that /q/ does not lower /u/ makes sense given the articulation of the two sounds. Both /q/ and /u/ are articulated at the top/back of the oral cavity, and so the tongue body gestures used to articulate the two do not conflict. Thus, there is no biomechanical need for the vowel to lower. However, /i/ is articulated with the tongue body high and forward and the tongue root advanced, whereas /q/ has the tongue body high and back and the tongue root retracted. Thus, in the case of /i/, there is a gestural conflict and when /i/ follows /q/, it is produced as [e]. Because of the degree of tongue root retraction in pharyngeal consonants, a gestural conflict also exists between pharyngeals and high vowels. This alleged tongue root retraction in Nuu-chah-nulth uvulars and pharyngeals will be demonstrated clearly with ultrasound data in Study 3.

It is hypothesized that the schwa offglide from /i/ to a following /q/, /ʕ/, or /ħ/ is similar to the excrescent schwa that shows up in faucal contexts in English *fire* and *feel* (Gick and Wilson 2001), in Mandarin *jir* (Gick and Wilson 2006), in Afar (Bliese 1981), in Somali (Armstrong 1964), in Inuktitut (sound files down-

[14]In (10e), the /u/ is realized as a lower vowel [ɔ], but since this is a natural realization in a non post-velar context, it does not necessarily imply vowel lowering.

loaded on March 7, 2003, from `www.shindale.com/inuktitut/index.shtml`), and in Chilcotin *s̃id* [ˌsᵊit] 'kingfisher' (Cook 1983, 1993). In these kinds of cases, Gick and Wilson (2006) show that the tongue travels through schwa-space, a schwa-like configuration, on its way from a high front vowel to a faucal consonant or vice versa. Note that in Nuu-chah-nulth the schwa glide occurs on the vowel that precedes the post-velar consonant, while the opposite is true in Chilcotin.

In Nuu-chah-nulth, before consonants that involve some sort of closure (i.e., /q/, /qʷ/, and /ʕ/), the schwa offglide always occurs. However, the results are much more variable before the fricative, /ħ/. The reason for this variability could be due to different relative contributions of tongue root retraction and pharyngeal constrictor muscle contraction in creating the constriction required for /ħ/. If the tongue root has a relatively high contribution to the pharyngeal constriction, then that retracted gesture will conflict with any neighbouring advanced tongue root gesture such as in the production of /i/.

When comparing the data on /ħ/ in (9) to the data on /ʕ/ in (6), note that the pharyngeals, /ʕ/ and /ħ/, have different effects on preceding /iː/. While both pharyngeals can lower a preceding /i/, it is more common that /ħ/ does so. Also, /iː/ is sometimes realized as /eː/ before /ħ/, but is never lowered before /ʕ/. Perhaps the pre-glottalization on /ʕ/ restricts (but does not completely eliminate) its ability to lower a preceding vowel. Since /ħ/ is purely pharyngeal with no glottalization, it is free to lower vowels on either side of it. Even though /i/ rarely lowers before /ʕ/, the appearance of a schwa offglide before /ʕ/ in (6b) and (6c) indicates that the tongue is moving before the pre-glottalization of /ʕ/. This is supported by Esling et al.'s (2002) fibreoptic nasendoscope video recordings of an Ahousaht speaker producing /ʕ/. The speaker's tongue root can be seen to retract very far back in her mouth, blocking the camera view of the larynx below. Esling et al. speculate that the tongue root helps to clamp down on the ventricular vocal folds which in turn clamp down on the vocal folds, and they hypothesize that /ʕ/ is actually an epiglottal stop, contrary to Catford (1977:163), who thought it was a "ventricular or strong glottal stop [ʕ·ʔ]".

Looking at the effects of the uvular stops /q/ and /qʷ/ on vowels, we can see that /q/ always lowers a following high front vowel, usually to [e, eː], never allowing it to be realized as /i/. The fact that /qʷ/ has no lowering effect on a following /i/ or /iː/ is probably due to the fact that the labialization on /q/ does not simply involve the lips, but is more like a /w/ (i.e., labial-velar). This is confirmed for the Kyuquot dialect by Rose (1981:14) who states that "labialized consonants are characterized by velarization as much as by rounding". Hence, tongue root conflict is resolved in the transition through /w/. If V-lowering was phonological and was triggered by [RTR] or a pharyngeal node (Rose 1996:80–81), then /qʷ/ should trigger the lowering. This claim cannot be backed up with evidence from /χʷ/ because that segment is so rare.

The results in Table 3 show only one type where /a/ is realized as [ɑ], confirming the results of Shank and Wilson (2000b), who found no significant change in F2 of /a/.[15] This result may be dialect dependent — Rose (1981:16) found that in the Kyuquot dialect, /a/ is retracted to /ɑ/ in the environment of pharyngeals. On the other hand, Stonham (1999:16) studied the Tseshaht dialect and states that the low vowel is "unaffected by surrounding uvulars or pharyngeals". But, because Stonham mixes the "a" and "ɑ" characters, using the former for text and the latter for headings, it is unclear what he means.

Although laryngeals were not investigated in this study, a brief discussion of them is warranted here. Because the tongue is not the primary articulator for a laryngeal sound, gestural conflicts between laryngeals and surrounding vowels do not exist. Thus, on purely phonetic grounds, it is expected that laryngeals would not lower/retract vowels, as Rose (1996) states is true for her *Placeless Laryngeals*. Laryngeals are even transparent to local faucal retraction in Lillooet (van Eijk 1997) and in Moses-Columbian Salish (Bessell 1992), but not in Nuu-chah-nulth (e.g., the /i/ in /ʔanaħʔis/ 'small' is realized as [ɪ], not [e]). Laryngeals could have a phonological effect on neighbouring vowels, and in some languages such as Sliammon Salish (Blake 2000), laryngeals do lower/retract vowels. Also, in the Northern Wakashan language of Oowekyala (Howe 2000:153–154), the high vowels /i, u/ are realized as [e, o] after uvulars *and laryngeals*. Howe (2000:75) cites studies showing this to be true in other Northern Wakashan languages too, namely Heiltsuk, Haisla, and Kwakw'ala. In Southern Wakashan languages, including Nuu-chah-nulth, laryngeals do not lower or retract vowels.

One never finds /i/ or /iː/ realized as [i] or [iː] respectively, following /q/, /χ/, /ʕ/, or /ħ/. At first glance, it seems that in vowel-consonant and consonant-vowel combinations, linear order is important. In many cases it is the first segment that retains its acoustic targets, while the second segment's articulatory gestures are either compromised or an excrescent schwa intervenes. It is also clear from Table 3 that schwa offglides almost always occur on high front vowels that precede uvular stops and pharyngeals. These offglides very rarely occur on vowels that follow post-velar consonants.

Upon studying the exact context of each consonant-vowel interaction, it becomes apparent that the phonetic realization could possibly reduce to a question of rightward versus leftward effects and specifically whether the post-velar consonant is tautosyllabic with the vowel. Because there are no vowel-initial syllables in Nuu-chah-nulth, for all rightward effects the consonant is always in the onset, tautosyllabic with the vowel in question, and vowel lowering generally occurs. In leftward effects, when the consonant is in the coda, again tautosyllabic with the vowel in question, vowel lowering also occurs. However, when the consonant is in the onset of the next syllable, schwa generally transitions from something higher

[15] Shank and Wilson (2000b) did find a significant drop in F3, indicating pharyngealization (but not retraction) of /a/.

([i] or [ɪ]). This is true for all consonant-vowel and vowel-consonant combinations studied here except /iħ/.

A question that arises when studying the effects of post-velar consonants on vowels is why the trend is for vowels to be affected by consonants, but not the other way around (Recasens 1999:94). After all, vowels can certainly affect consonants in many contexts in different languages (see Recasens and Espinosa 2006 for examples). One possible explanation for post-velar consonant-to-vowel rather than vowel-to-consonant effects is that the retraction/lowering effect on the vowel serves as a clear cue to the place of articulation of the consonant adjacent to it. We can speculate that, with the relatively large number of consonant places of articulation in Nuu-chah-nulth, it may be easier to perceive a change in vowel place than it is to perceive a change in the place of the post-velar consonant.

4. Study 2: Formant Measurements of Vowels Following Post-Velar Consonants

While Study 1 was a qualitative look at Nuu-chah-nulth vowels as perceived and transcribed by this researcher, Study 2 is a quantitative look at the formants of many of the same vowels. However, the measurements in this study are limited to vowels that follow the consonants in question. In other words, Study 2 deals with rightward effects of consonants on vowels. The main leftward effect shown in Study 1, that is, the schwa offglide that appears on vowels before post-velar consonants, is analyzed in more detail in Study 3 (section 5).

4.1. Method

Most of the same recordings that were used for Study 1 were also used for Study 2, thus the recording method is exactly the same as described in section 3.1. Once again, words were chosen so that the vowels being measured were not followed by post-velar consonants. The first three formants of vowels in numerous words were measured, some with an initial post-velar consonant and others with a non post-velar consonant as the initial consonant. Non post-velar consonants included only those that are non-ejective, non-glottalized, and at the velar place of articulation or farther forward.[16] All formant values were taken at the 25% duration mark of the vowel (i.e., 25% from the onset of the vowel). The 25% mark was chosen to ensure that any effects were more likely to be long-term consonantal effects rather than simply formant transitions. Since in this acoustic study only rightward effects of consonants on vowels were measured, the 25% mark also ensured that any measured effects on vowels were more likely due to the preceding, not following, consonant. To minimize confounding variables, the formant

[16]The following nine stops, fricatives, and affricates were included as non post-velar consonants: /p t k ts tɬ tʃ s ɬ ʃ/. Glides and nasals were not included because of the difficulty in determining the precise location of the onset of a following vowel.

Table 4: F1 and F3 means (in Hz) for each vowel when following a consonant of the given place

	F1			F3		
	/a/ and /aː/	/i/ and /iː/	/u/ and /uː/	/a/ and /aː/	/i/ and /iː/	/u/ and /uː/
Non post-velar	640 (N = 16, SD = 99)	371 (N = 12, SD = 26)	414 (N = 8, SD = 38)	2598 (N = 16, SD = 119)	2756 (N = 12, SD = 244)	2445 (N = 8, SD = 133)
Uvular	635 (N = 12, SD = 71)	425 (N = 8, SD = 52)	409 (N = 3, SD = 13)	2583 (N = 12, SD = 77)	2721 (N = 8, SD = 190)	2401 (N = 3, SD = 397)
Pharyngeal	845 (N = 14, SD = 109)	529 (N = 11, SD = 75)	512 (N = 11, SD = 95)	2576 (N = 14, SD = 254)	2634 (N = 11, SD = 174)	2315 (N = 11, SD = 193)

analysis was limited to vowels in word-initial syllables. Acoustic analyses were completed using Praat (v. 4.0.30)[17] to look at waveforms and spectrograms, and to calculate formants. The default formant settings for Praat were used, namely 5500 Hz maximum frequency, five formants, 25 ms window length, and 30 dB dynamic range.

4.2. Results

Table 4 contains formant measurements for vowels that follow word-initial consonants of various types. The number of vowels (N) and standard deviation (SD) are both included for every cell of the table. Measurements of the long and short versions of each vowel are not separated here. The non post-velar consonants included are described in section 4.1. As for the uvular consonants, only /q/ was included, as there were no available tokens with word-initial /χ/. Both pharyngeal consonants, /ʕ/ and /ħ/, were included. As both anterior tongue body lowering and tongue root retraction are best visible through increases in F1 (Pickett 1999), and as pharyngeal constrictions are also usually visible through decreases in F3, only results for F1 and F3 are presented in Table 4. Although Pickett (1999) states that decreases in F2 are a good indicator of pharyngealization, cross-linguistic data has shown a variety of results for F2 in the context of pharyngeals and uvulars.[18]

Figures 1 and 2 show the same results in a more easily interpretable way. T tests were done to compare the effects of types of consonants within each vowel category. Results show that the F1 of vowels following pharyngeals is significantly

[17] Praat is an acoustic analysis freeware program that can be downloaded from `www.praat.org`.

[18] Alwan (1986:75–76) shows that uvulars condition an unchanged F2 before /uː/ and /aː/. Butcher and Ahmad (1987:168) give Arabic results showing that pharyngeals condition a higher than normal F2 for /uː, u, oː/. Again for Arabic, Al-Ani (1970) also shows that pharyngeals raise F2 of /u/.

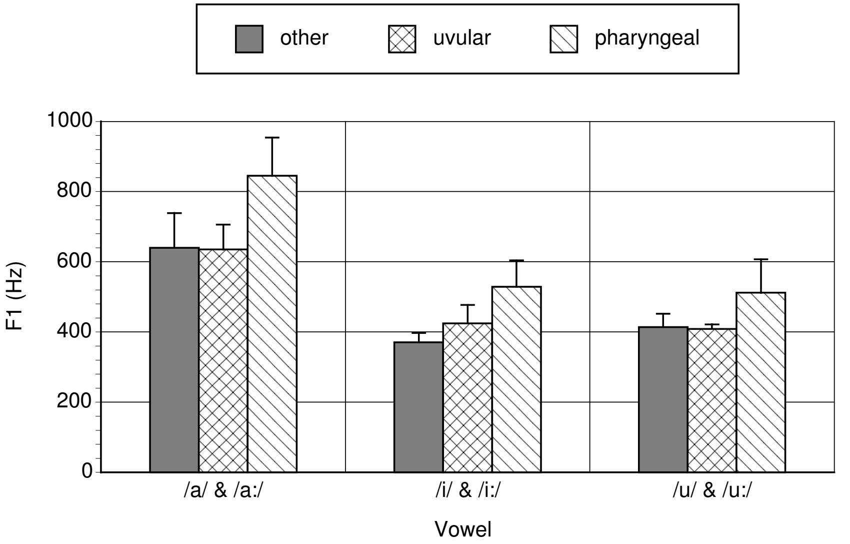


Figure 1: Effect of consonant on F1 across vowels

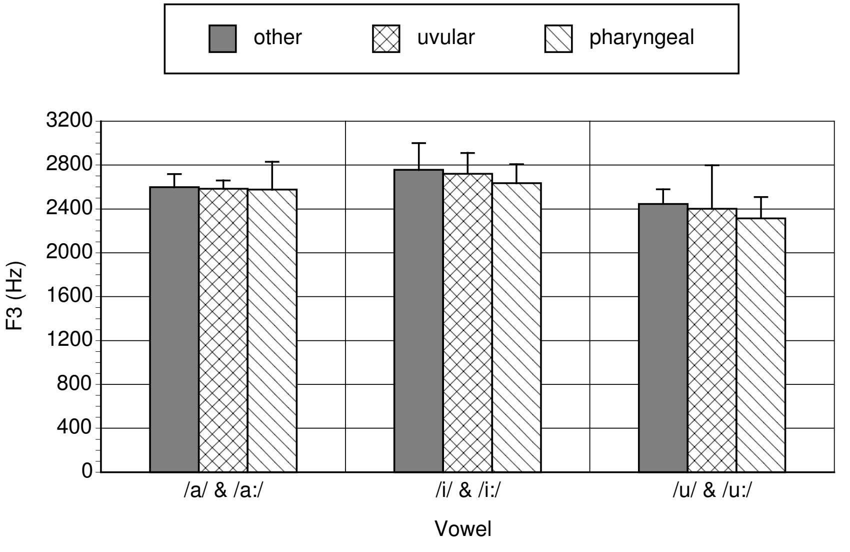


Figure 2: Effect of consonant on F3 across vowels

higher than the F1 of vowels following non post-velar (labelled *other*) consonants. This is true for all three sets of vowels [t(39) = 5.87, p <.0001 for /a/; t(28) = 6.97, p <.0001 for /i/; and t(19) = 2.92, p =.0087 for /u/]. F1 is also higher following pharyngeals than following uvulars. Again, this is true for all three sets of vowels [t(39) = 5.58, p <.0001 for /a/; t(28) = 4.14, p =.0003 for /i/; and t(19) = 2.18, p =.0417 for /u/]. However, when comparing the F1 of vowels following uvulars to that of vowels following non post-velar consonants, it is only significantly higher for /i/, but not for /a/ or /u/ [t(39) = 0.12, p =.9085 for /a/; t(28) = 2.16, p =.0395 for /i/; and t(19) = 0.09, p =.9259 for /u/].

As for F3, t tests indicate that for any given vowel category, there are no significant differences between the effects of the three different consonant groups. The closest the F3 results come to significance is when comparing high vowels following pharyngeals to the same vowels following non post-velar consonants [t(28) = 1.40, p =.1716 for /i/; and t(19) = 1.36, p =.1904 for /u/]. F3 is lower following the pharyngeals, but not significantly so.

4.3. Discussion

The vowel formant results of Study 2 clearly support the auditory results of Study 1. If one looks at F1, an indicator of tongue body height, we see that uvulars have a negligible effect on /u/ and /a/, similar to the results in Table 3 of Study 1. In the case of /u/, F1 = 414 Hz when it follows non post-velar consonants, whereas F1 = 409 Hz when it follows uvulars (if anything, making the vowel higher). For /a/, F1 = 640 Hz when it follows non post-velar consonants, whereas F1 = 635 Hz when it follows uvulars — again, making the vowel higher, if anything. When /i/ follows a uvular consonant, F1 is significantly higher (425 Hz) than when it follows a non post-velar consonant (371 Hz). This fits well with the perception from Study 1 of /i/ as [e] following /q/.

As for the F1 results for vowels that follow pharyngeal consonants, it was found that F1 is significantly higher for all vowels when they follow pharyngeals than when they follow non post-velar consonants. This almost certainly indicates that the tongue body has been lowered in vowels that follow pharyngeals. If tongue root retraction is occurring during the pharyngeal consonants, it follows that, in addition, the tongue body should probably be lower due to the hydrostatic nature of the tongue. These F1 results for vowels following pharyngeals support the transcriptions in Table 3, where /i/ is most often lowered to [e], and /u/ to [aʊ] or [oʊ].

The fact that there were no significant differences in F3 across consonants is slightly puzzling and no explanation is forthcoming at this time. A constriction in the pharyngeal region should be indicated by a lowered F3, but this does not seem to be the case here.

5. Study 3: An Ultrasound Investigation

Study 3 briefly investigates the role of the tongue root in the articulation of post-velar consonants. The purpose of Study 3 is to confirm that it is indeed tongue root retraction and not simply a constriction formed by the pharyngeal constrictor muscles that is active in the production of the Nuu-chah-nulth pharyngeal consonants. Study 3 is also motivated by a need to determine the reason for the excrescent schwa described above, and to confirm that the tongue does indeed have conflicting gestures that it must produce. The only way to tell for certain whether the vowel-lowering effect is a by-product of the biomechanical speech system is to look directly at the movement of the articulators.

More motivation for Study 3 includes the fact that, to my knowledge, there exist no articulatory phonetic data for any Wakashan language other than two laryngoscopic studies, one by Carlson et al. (2001) and the other by Esling et al. (2002).[19] This is certainly the first study ever to collect real-time ultrasound speech data from speakers of Nuu-chah-nulth,[20] and it is one of a small but growing number of ultrasound studies of North American indigenous languages (Gick et al. 2006; McDowell 2004; Namdaran 2006).

5.1. Method

Ultrasound data were collected from one native speaker of Nuu-chah-nulth, KF.[21] Like the subject in Studies 1 and 2, KF grew up speaking Nuu-chah-nulth in the 1940s and 1950s at home and in the community on Flores Island. She is a bilingual speaker of Nuu-chah-nulth and English.

Real-time, 2D, mid-sagittal ultrasound data of the movements of the tongue during speech were collected in a number of sessions during a one-year period. The subject was recorded saying a number of words embedded in a carrier sentence.

The equipment used was an Aloka SSD-900 portable ultrasound machine using a 3.5 MHz electronic convex intercostal probe UST-9102 with a 90-degree field of view. The method of data collection was the same as that described in Gick (2002). KF held the probe against her own neck, just above the larynx, so that a mid-sagittal section of the tongue was visible from the tongue root to the tongue tip. A constant probe position was maintained using a laser pointer attached to the probe. KF was seated facing a wall a distance of 2 m away. The laser

[19]Direct comparisons cannot be made between the present study and the studies by Carlson et al. (2001) and Esling et al. (2002). Their data showed the adduction/abduction of the vocal folds as well as relative degree of retraction of the tongue root. The articulatory data in the present study are focused on the relative timing of the tongue root gesture compared to the tongue body gesture.

[20]The Nuu-chah-nulth ultrasound data that appear in Gick and Wilson (2006) are part of the data collected for this study.

[21]Ultrasound data were also collected from MJD, the subject of Studies 1 and 2, but the image quality was not high enough to be useful. This is a common occurrence and it may be related to tongue muscle density or tongue size (Bryan Gick, p.c.) or it simply may be caused by not maintaining enough upward pressure on the ultrasound probe during data collection.

pointer projected an image of crosshairs onto the wall, where a 10 cm square was drawn. KF was instructed to keep the crosshairs upright and within the square; the investigator monitored her accuracy during the study.

The ultrasound video signal was recorded on VHS cassettes. The acoustic signal was simultaneously recorded to VHS to ensure synchronization with the video signal, using a Pro-Sound YU-34 unidirectional dynamic microphone amplified through a built-in amplifier in a Tascam cassette recorder.

After collection, videos were digitized to a Macintosh G4 from the VHS tape using an XLR8 video card with Adobe Premiere (v. 6.0) video editing software. This software was used to edit and analyze the images. Tongue root, tongue body, and tongue tip gestures were analyzed, as was their relative timing.

As with Studies 1 and 2, words for this study were chosen so that the vowel under investigation had only one post-velar consonant adjacent to it. Each word was spoken in a carrier sentence. The carrier sentence used by KF is shown in (11). The subject alternated between using either Cory or Randi, the names of her grandchildren, at the start of the sentence. Both names end with a high front vowel, ensuring that the tongue root is advanced before saying the stimuli words. This makes it easier to see tongue root retraction, especially when the stimuli are post-velar initial words. This also provides a test of whether there are vowel-lowering effects across word boundaries, that is, from the [i] of "Cory" and "Randi" to a following post-velar consonant.

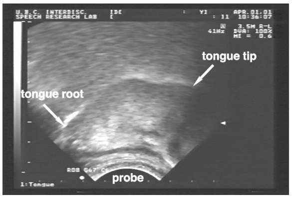
(11) Cory/Randi, ______________ wa:ʔi:
Cory/Randi, ______________ wa:-ʔiˑ
Cory/Randi, ______________ say-2SG.IMP
Cory/Randi, say ______________ .

5.2. Results

Figure 3 shows a sequence of ultrasound images for the first syllable of the word *ci:kci:ka* 'listing', as when travelling in a canoe going 90 degrees to the wind, on the left and *ci:qci:qa* 'talking' on the right. The difference in tongue root retraction and tongue dorsum backing between /k/ and /q/ can be seen clearly, as can the excrescent schwa configuration ("schwa-space", Gick and Wilson 2006) in *ciiqciiqa*.

The ultrasound images in this section are all mid-sagittal cross-sections of the tongue. The longest curved line going across the middle of each image is the upper surface of the tongue, with the tongue root on the left and the tongue tip on the right. Because of the position of the probe on the subject's neck, the images turn out to be rotated so that true vertical is actually about 45 degrees off what it appears to be in the images. If one rotates a given image counter-clockwise about 45 degrees, the image is then in the intuitively correct orientation. Thus, pure tongue root retraction will show the surface of the tongue moving not only to the left, but also up.

[t] Alveolar stop closure part of affricate *c* ([ts]) in *ciːk*. (Practically identical to realization in Fig. 3b.)



[s] Release of alveolar stop closure into alveolar fricative [s]. (Practically identical to realization in Fig. 3b.)

[iː] Peak of vowel /iː/. (Practically identical to realization in Fig. 3b.)

No excrescent schwa (as in Fig. 3b).

[k] Stop closure for /k/ in *ciːk*.

[k] Stop release for /k/. The tongue anterior raising is the anticipation of the /t͜s/ onset to the next syllable.

Figure 3a: Ultrasound image sequence for /tsiːk/.

Alveolar stop closure part of affricate *c* ([ts]) in *ci:q*. (Practically identical to realization in Fig. 3a.) [t]

Release of alveolar stop closure into alveolar fricative [s]. (Practically identical to realization in Fig. 3a.) [s]

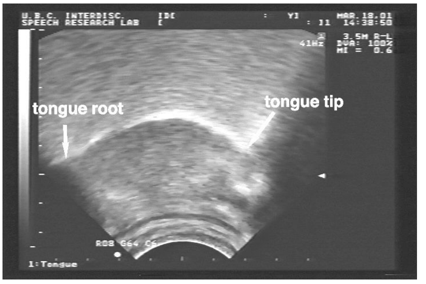
Peak of vowel /iː/. (Practically identical to realization in Fig. 3a.) [iː]

Excrescent schwa in *ci:q*, as tongue root retracts, anticipating the uvular stop. [ᵊ]

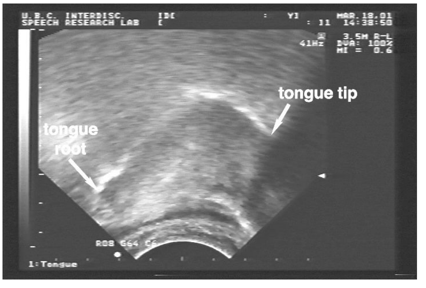
Stop closure for /k/ in *ci:q*. Note the extreme tongue root retraction for /q/. [q]

Stop release for /q/. The tongue anterior raising is the anticipation of the /t͜s/ onset to the next syllable. [q]

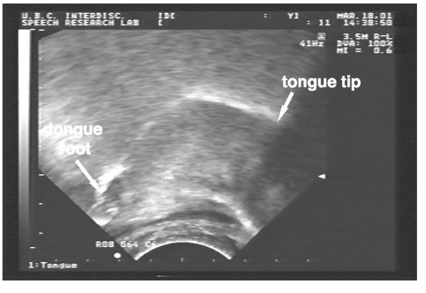
Figure 3b: Ultrasound image sequence for /tsiːq/.



[ʕ]



[e]

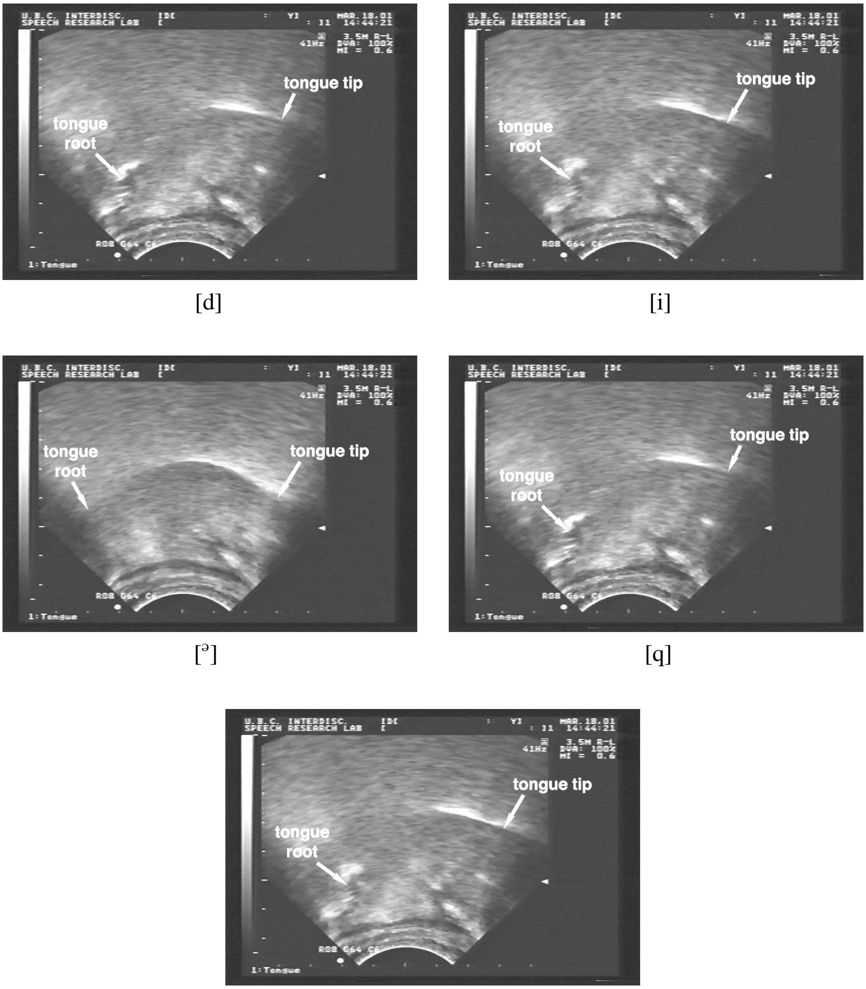


[ɪ]

Figure 4: Ultrasound image sequence of the /ʕiː/ part of /k̓ʷaʕiːts/

In Figure 4, observe the very retracted tongue root for [ʕ], along with a lowered tongue body. As the tongue moves toward /i/, the tongue root advances and this movement is concurrent with the tongue body rising. The resultant sound is [e]. Then, after the tongue root has stopped, the tongue body continues to rise, giving the effect of a diphthong.

In Figure 5, the tongue root is fairly far advanced for [d] and [i], but it starts to retract soon thereafter on its way to articulate [q]. Also, the tongue body lowers as the tongue root is retracting. The tongue is in a schwa-like configuration



[d] [i]

[ᵊ] [q]

[e]

Figure 5: Ultrasound image sequence of [diᵊqe] in *Randi qitʃin*

between the [i] and [q]. For [q], the tongue root is retracted and the tongue body is lowered. The vowel following /q/ is /i/, and that requires an advanced tongue root. As the tongue root is advancing, the tongue body rises automatically due to the hydrostatic nature of the tongue, and the two parts of the tongue reach their target configuration at the same time. The tongue body does not continue rising, so no diphthong is perceived.

5.3. Discussion

Figures 3, 4, and 5 are typical of the motions of the articulators in cases of V-lowering and excrescent schwa. Figures 3 and 5 are clear examples of the excrescent schwa that arises between the high front vowel /i/ and a following /q/. This schwa arises because the tongue root is going from one extreme to another, and (as argued in Gick and Wilson 2006) neither /i/ nor /q/ is willing to compromise its tongue root target. In this case, /i/ is the only segment that could compromise its tongue root target. However, because it comes before /q/ here (in the linear sense), the tongue root target is usually fully realized. This issue of linearity was discussed briefly in section 3.3.

The presence of the excrescent schwa in Figure 5 shows that the word boundary does not affect the schwa off/onglide. This is consistent with the excrescent schwa being a phonetic effect, where word boundaries should not make a difference (unless there is a pause between words). Although there are phonological effects that cross word boundaries, in many cases word boundaries block phonological effects. In V-harmony in Turkish, for example, word boundaries block the spread of harmony (Lewis 2001).

Figure 4 is an example of the diphthong that often results when /iː/ follows /ʕ/. In this case, the tongue body raising for /iː/ is clearly driven by the tongue root advancement. The two gestures are concurrent and relatively similar in magnitude. The /iː/ is at first realized as [e] because the tongue root is so far retracted from /ʕ/ that the tongue body is still low. Because the tongue body/tongue tip are still moving for one frame (33 ms) after the tongue root reaches its target, it appears that there is still motivation for /i/ to be realized as close as possible to [i]. This is a potentially important point that distinguishes whether or not the vowel lowering is simply biomechanical or a case of Kingston and Diehl's (1994) phonetic control. Discussion of this point is beyond the scope of this article.

Diphthongs are also found to replace /u/ and /uː/ when these vowels follow pharyngeals. In these cases, exactly the same thing is happening: the tongue root is reaching its target for the lower half of the diphthong, and then the tongue body keeps rising to attain its target for the upper half.

6. Conclusions and Directions for Future Research

This article provides one of the most detailed descriptions of the effects of post-velar consonants on vowels in Nuu-chah-nulth. An auditory evaluation (Study 1) revealed that high front vowels often get lowered when they precede a uvular or pharyngeal consonant. They also almost always have a schwa offglide before uvulars and pharyngeals. This schwa offglide does not always occur before the fricatives, though. The ultrasound investigation (Study 3) confirmed that this schwa offglide occurs because the tongue is moving through a schwa-like configuration on its way from the high front vowel to the retracted consonant. It was also shown that high front vowels that follow pharyngeals and uvulars (with the exception of the labialized uvular) are usually lowered (Study 1). As for high back vowels, it was shown that they are lowered and/or diphthongized following (but not preceding) pharyngeals, and that they are unaffected by uvulars. It was further confirmed that the tongue root is very active in the articulation of uvular and pharyngeal consonants (Study 3). It was also found that the F1 of vowels that follow pharyngeal consonants is significantly higher than that of vowels that follow non post-velar consonants (Study 2). In addition, the F1 of /i/ when it follows uvular consonants is significantly higher than when it follows non post-velar consonants. For each vowel group, there was no significant F3 difference across the three consonant groups.

Some things that have not been factored into the analysis here are morphology, stress, and syllable type (open versus closed). However, as lowering occurs only in adjacent segments, it is unnecessary to consider morphology (boundaries of roots/suffixes) as providing the boundary or context for lowering.[22] It is clear that for the phonetic by-product cases, even word boundary does not change the fact that a schwa off-glide is heard (e.g., "Randi [ə] /qitʃin/"). On the other hand, morphology may play a part in determining whether lowering is phonologically or phonetically controlled. For example, the type of lowering that occurs with true pharyngeals may be different from that which occurs with pharyngeals that are synchronically derived from uvulars followed by a glottalizing suffix. This is an area left for future research. Whether a syllable is stressed or not makes a difference to the quality of the vowel in that syllable. Waldie (2003) gives the most recent analysis of Nuu-chah-nulth stress, and in future work stress could be controlled for based on the rules given there. The relevance of the position (onset or coda) of the post-velar consonant was discussed in sections 3.3 and 5.3, but it needs to be investigated further with more words. The syllable type in which the vowel appears is directly related to this and should also be taken into account. It was also proposed that linear order determines the precise effect of vowel lowering, but this is an area for future research. Other points not considered in this article, but ones that affect coarticulation (Recasens 1999:102–103) are prosodic factors such as segmental duration and speech rate.

The results discussed here have potential implications for phonology. The lowering/retracting effects on the vowels could be due to phonological reasons — for example the spread of a certain feature. These effects could also be due to phonetic reasons such as simple biomechanical effects like the resolution of conflicting tongue gestures (Gick and Wilson 2006), as well as phonetic control (Kingston and Diehl 1994). A plethora of phonological feature trees have been proposed — even just for segments produced in the post-velar section of the vocal

[22] In Moses-Columbia Salish, root retraction and suffix retraction are distinct processes, but these are cases relating to vowel harmony (long-distance) not local coarticulatory effects (Bessell 1998b).

tract (Czaykowska-Higgins 1987; Davis 1995; Elorrieta 1991; Goad 1991; Halle 1995; Hayward and Hayward 1989; McCarthy 1991, 1994; Remnant 1990; Shahin 2002) — and many of these proposals are at least partly based on evidence from vowel lowering and retraction. It is important to separate phonetic from phonological effects; arguably only the latter should be considered when constructing feature trees.

Going beyond the scope of this article, a question to ask is why local phonetic vowel lowering has developed into long-distance vowel harmony in Interior Salish and many other languages, while in Nuu-chah-nulth there is no vowel harmony.

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