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*Local and non-local consonant–vowel interaction in Interior Salish**

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1 Introduction

Local consonant–vowel (C–V) interaction is attested in many languages, both as a phonetic and as a phonological process. There can be a clear developmental relationship between the two, with phonologisation of phonetic interaction occurring quite commonly (Hyman 1976, Ohala 1981). Thus, a common (historical) context for nasal vowels is an adjacent nasal consonant. When consonants trigger non-local effects (i.e. when the domain of the consonantal feature extends beyond adjacent segments), typically both vowels and consonants are targeted. For example, in consonant-induced nasal or emphasis harmony all segments in the harmony domain usually take the consonantal feature. If some segments are neutral, targets still include both consonants and vowels.

(1) *Consonant-induced harmonies*
  a. *Warao nasality* (data from Piggott 1992)
    rightward spread blocked by oral obstruents
      mõỹõ ‘cormorant’   mõãũpu ‘give them to him’
  b. *Palestinian emphasis* (data from Davis 1995)
    rightward spread blocked by /i j ʃ ʤ/
      ṭụụḅ-ạḳ ‘your blocks’   ṭiin-ak   ‘your mud’

In contrast, Interior Salish faucal harmony presents a typologically unusual case of non-local C–V interaction with no apparent effect on segments between the C trigger and the non-adjacent V target. Faucal

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harmony is triggered by faucal consonants (uvulars and pharyngeals) and targets preceding vowels, up to six segments away from the faucal. An example is *y'ál-stq* 'summer', where vowel quality is determined by the uvular /q/ and intervening consonants are unaffected (data from Reichard 1938). This kind of non-local C–V interaction is (i) very rare and (ii) not transparently related to either C-induced harmonies or purely local C–V interactions of the kind that give rise to nasal vowels.[1]

The Salish data, then, raise questions about the properties and origins of non-local as opposed to local C–V interaction. Since Salish harmony involves action-at-a-distance, one might not expect the same kind of causal relationship between phonetic and phonological events as is found in local C–V structure. Let us phrase this as the null hypothesis. Applied to faucal harmony, the null hypothesis says that non-local faucal harmony bears no necessary or principled relationship to phonetic faucal–vowel interaction. Alternately, one might expect a principled and causal relationship between phonetic faucal interaction and its non-local, phonological counterpart. Interior Salish data are particularly suited to examining these hypotheses since the modern language family splits into two types with respect to faucal–vowel interaction. One class of languages has purely local, phonetic interaction between faucals and immediately preceding vowels, while another class has faucal harmony on any preceding vowel, whether it is adjacent to the trigger or not. Given these two classes, data from local, phonetic faucal–vowel interaction can be compared with the local and non-local interaction of the harmony languages.

Two immediately observable similarities between local and non-local faucal–vowel interaction suggest a causal relationship: the direction of interaction is regressive, and a faucal consonant must be present. This paper presents evidence for additional similarities between local and non-local faucal–vowel interaction and defends the origin of faucal harmony in local, anticipatory C–V coarticulation. We argue that both phonetic and phonological faucal–vowel interactions are actively constrained by physiological and acoustic factors. Specifically, this paper presents the results of an acoustic examination of local faucal–vowel coarticulation in Nxaʔamxcin (Nx; also known as Moses-Columbia Salish, spoken in Washington State) and faucal harmony in Snchitsuʔumshtsn (Sn; also known as Coeur d'Alene Salish, spoken on the Washington–Idaho border). Several phonetic details found in local C–V interaction are echoed in the phonological data in a non-arbitrary way. First, acoustic data show that both types of interaction condition similar frequency values at some point in the formant trajectory, and second, several phonetic constraints on /i/–faucal interaction play a role in the harmony. These findings suggest a close relation between phonetic and phonological interaction, despite the typological peculiarity of Salish faucal harmony.

More generally, the acoustic data analysed here contribute to several

[1] Vowel harmonies are different again. Vowel harmonies skip consonants, as does Interior Salish faucal harmony, but are not triggered by consonants.

domains. First, within Salish studies, little instrumental phonetic work exists, despite an impressionistic record of extensive phonetic interaction within a large inventory. Also, the question of intervening segment transparency in faucal harmony has not been examined phonetically, despite the contribution of such description to our understanding of this unusual aspect of faucal harmony. Second, we examine an unusual phonological process from the perspective of phonetics and gain some insight into the relationship between the two. As such, the issue of phonetic *vs*. phonological realisation is raised. The present data indicate that temporal distribution and stability of formant cues are crucial factors differentiating phonetic from phonological processes. The formant properties of coarticulated and harmonised vowels can overlap in terms of absolute frequency values and placement in vowel space, but frequency values are distributed differently in the temporal domain (Keating 1990b, Cohn 1993, Zsiga 1995). Third, the absence of extended coarticulation in faucal harmony provokes consideration of perceptual factors in phonology which may dictate preferred segmental loci for particular features. Accommodating this requires attention to perceptual factors in phonological analysis (Bladon 1986, Ladefoged 1989, Keating 1990a). Finally, faucal harmony is typically analysed as [RTR] spread from the class of faucals (Bessell & Czaykowska-Higgins 1991, Bessell 1992, Czaykowska-Higgins 1992, Doak 1992, Elorrieta 1996; but see Cole 1987 for a different analysis). However, faucal harmony differs from other post-velar harmonies where a similar feature has been invoked, such as [RTR] or [Pharyngeal]. Thus, Semitic emphasis differs with respect to targets (all segments, as opposed to V only) as well as triggers (emphatic consonants as opposed to faucals). Faucal harmony also differs from Semitic guttural lowering, which includes faucals (as well as laryngeals) as triggers, but requires melodic adjacency. If this typological variation in post-velar harmonies has any basis in phonetic differences in consonant articulation (hence feature composition) and C–V interaction, studies of the sort presented here can provide valuable information for comparison and clarification.

The remainder of this paper is organised as follows. §2 introduces Salish and presents data illustrating local and non-local faucal effects. §3 reports on an acoustic investigation of vowels in the faucal and non-faucal context and discusses the relationship between local coarticulation and local harmony. §4 extends the discussion to non-local harmony and concludes the paper.

2 Interior Salish

The Interior Salish languages are spoken in present-day British Columbia, Washington, Idaho and the western edge of Montana. The generalised Interior Salish consonant inventory, as represented by the reconstructed Proto-Salish inventory in (2), contains ten faucal consonants, the uvulars and pharyngeals.[2] These ten faucals are found in all of the present-day Interior Salish languages. Nxaʔamxcin has two additional pharyngeals, /ħ $ħ^{w}$/.

(2) *Proto-Salish consonant inventory* (Kinkade 1990, translated into IPA)

labial	p	p’		m	m’
coronal	t	t’		n	n’
	t^{s}	t^{s}’	s	r	r’
		$t^{ɬ}$’	ɬ	l	l’
palatal				j	j’
velar	k	k	x	ɣ	ɣ’
	k^{w}	k’^{w}	x^{w}	w	w’
uvular	q	q’	χ		
	q^{w}	q’^{w}	$χ^{w}$		
pharyngeal				ʕ	ʕ’
				$ʕ^{w}$	ʕ’^{w}
glottal	ʔ		h		

All Interior Salish languages show noticeable local interaction between faucals and preceding vowels. A subset of languages have non-local interaction, with anywhere from one to six segments intervening between the faucal and a vowel. Despite these domain differences, transcriptional notation by different Salish scholars is noticeably consistent across languages.

2.1 Coarticulation: local faucal effects

The most common Interior Salish vowel system is /i a u/ and sometimes /ə/, with the /a/-vowel varying in phonetic quality through [e ɛ æ a], depending on the language.[3] In non-faucal environments all vowels have their most high and front qualities; in faucal environments they have more back and/or low qualities. The distinction is often referred to as ‘non-retracted’ *vs.* ‘retracted’. The phonetic quality of stressed /i a u/ in Nxaʔamxcin in non-faucal and faucal contexts illustrates this trend:[4]

[2] The term faucal is borrowed from Reichard (1938), who describes the faucal region as being ‘trilled’ in the production of the Sn pharyngeals. Here the term is extended to designate the entire class of segments which trigger faucal harmony. In Sn the faucal class includes two coronals /r r’/, which are assumed to have a faucal articulation in addition to their coronal place of articulation.

[3] Most of the Interior languages have a small class of roots with a retracted vowel that is not predictable from context. These roots initiate their own RTR harmony domain and may provide evidence for additional vowels. However, it is possible to analyse this subset of the vocabulary with a lexically unassociated [RTR] specification. In either case, this feature does not interfere with the faucal harmony that is discussed here.

[4] The Nx /$t^{ʃ}$/ affricate is usually transcribed ‘c’. Phonetically, however, it tends towards an alveopalatal offglide. Coronal stop–fricative sequences in Salish data are affricates unless otherwise noted.

(3) *Nxaʔamxcin* (fieldnotes, Bessell)

Non-faucal context			*Faucal context*		
tᶴílkʃt	[i]	'five'	tᶴíqn	[ɪ, ɪe, e]	'digging'
stᶴúɬm	[u]	'bull'	tᶴnúχʷtaʔ	[o, ɔ]	'Come!'
tᶴákaʔ	[æ, a]	'older sister of a man	ɬáqlxtaʔ	[a, ɑ]	'Get up!'

In those languages where C–V effects are purely local, the interaction appears to be phonetic. There are several strands of evidence for this. Vowel quality is variable across and within languages with local C–V interaction and the extent of retraction can vary within individual speakers. Before faucals an offglide is sometimes transcribed, especially on the high front vowel, /i/. Retracted allophones of /a/ vary in backness and height, while retracted /u/ varies between [o] and a more open quality, [ɔ]. Pharyngeals, the other member of the faucal class, also condition retracted vowels of similar value. However, vowels before pharyngeals are often heard with a general 'pharyngeal' quality that uvulars do not condition (van Eijk 1985 for St'at'imcets, Czaykowska-Higgins (fieldnotes) for Nxaʔamxcin). The basic variation for /i a u/ and /ə/ (if present) across languages is given in Table I (Kinkade 1967, Gibson 1973, Mattina 1973, Kuipers 1974, 1989, van Eijk 1985, Thompson & Thompson 1992).[5]

Similar local coarticulatory effects from faucals are found in other languages. Egyptian Arabic (Harrell 1957) shows lowering and slight backing of vowels in the context of uvulars, and offglides in the context of

	non-faucal vowels				*faucal vowels*			
	/i/	/u/	/a/	/ə/	/i/	/u/	/a/	/ə/
Nxaʔmxcin	i	u	a	ə	e	o	ɑ	ʌ
	e	ʊ	æ	ʊ	ɛ	ɔ		
		o		ɨ				
Colville	i	u	a	ə	iᵊ	ʊᵊ	ɑ	ə
	e	o	æ	ʊ	ɪ	o		
				ɨ				
Nɬeʔkepmxcin	i	u	ɛ	ə	e	o	æ	ʌ
(Thompson River	i̞	u̞		ʊ	e̞			
Salish)				ɨ				
				ɪ				
St'at'imcets	i	u	æ	ə	ɛ	ɔ	a	ʌ
(Lillooet)	e	o						
Sxwepmxcin	i	u	ɛ		ɪ	ɔ	æ	
(Shuswap)			æ		ɛ		a	

[Table I. Languages with local effects]

[5] It is possible that some of the recorded variation is transcriber-dependent, but the basic differences recorded in (4) are acknowledged by researchers who have heard several, if not all, of the individual languages.

pharyngeals. Lowering and/or backing from adjacent uvulars is also reported in Quechua dialects (Elorrieta 1996), Tungusic languages (Li 1996) and other languages of the Pacific North-west (Bessell 1992). Clearly, vowel retraction is a common phonetic phenomenon based on articulatory interactions between the gestures required for faucal articulation and the basic vowel qualities.

2.2 Faucal harmony languages

The most eastern Interior Salish languages have phonological vowel retraction in the context of both local and non-local faucals. These languages are SnchitsuʔumshtsnandSnchitsuʔumshtsn and the dialect continuum referred to as Spokane-Kalispel-Flathead (Sp-Ka-Fl).[6] In these languages a root or suffix vowel followed by a faucal anywhere in the word surfaces with vowel qualities similar to those discussed above. Prefix vowels, with the exception of a small class, do not retract. The examples below are taken from Snchitsuʔumshtsn. Vowels in the context of both local and non-local faucals are transcribed as retracted for their entire duration (Reichard 1938, Doak 1992). No offglides are transcribed, and no instances of variation between a relatively unretracted and a retracted version of a vowel are noted. In fact, vowel quality is so consistent that Doak (1992) formulates morpheme structure constraints in the language which prohibit the occurrence of the unretracted vowels /i u/ in the context of faucals.

(4) *Sn local faucal context* (Reichard 1938): [ɛ ɑ ɔ] *only*

u-tsɛ́qʷ	'it's bright red'
tɑ́q-ntˢ	'he touched it'
ʔɛtˢʔɔ́qʷs	'he's drinking'

(5) *Sn non-local harmony* (Reichard 1938): i_2 ~ ɛ, i_1 ~ ɑ, ɛ ~ ɑ, u ~ ɔ

	Non-faucal context		*Non-local faucal context*	
a.	tˢíʃ-t	'it is long'	tˢɛ́ʃ-ɑlqʷ	'he is tall'
b.	dlím	'he galloped hither'	tʲ-dlɑ́m-ɑlqʷ	'train'
c.	sɛ́ttʲ-ntˢ	'he twisted it'	nɛʔ-sɑ́ttʲ-ɛʔqs-n	'crank (on a car)'
d.	ʔɛ-niʔ-kús-ɛlstʲn	'hair curls back from forehead'	ʔat-kɔ́s-qn	'his hair is curled'

The distinction between i_2 ~ ɛ and i_1 ~ ɑ in Snchitsuʔumshtsn is regular, but unique among the harmony languages. The two *i*'s are traditionally termed /i_1/ ([ɑ] in harmony context; see (5b)) and /i_2/ ([ɛ] in harmony context; see (5a)). Kinkade & Sloat (1972) propose that /i_1/ is the reflex of Proto-Salish *a, while /i_2/ is the reflex of *i.

Spokane-Kalispel-Flathead shows a slightly different pattern from Snchitsuʔumshtsn, in that /i/ is unaffected by a faucal context and

[6] The indigenous term for Spokane is Npoqinishcn, Kalispel is Qalispe and Flathead (also known as Montana Salish) is Séliš.

surfaces as [i], (6a). The other two vowels undergo harmony as in Snchitsuʔumshtsn (6b, c). Reduced vowels are not transcribed in these forms.

(6) *Kalispel faucal harmony* (Vogt 1940): i ~ i, e ~ a, u ~ o

	Non-faucal context		*Faucal context*	
a.	i-qʷín	‘it is green’	i-qʷín-lqs *i-qʷén-lqs	‘he has a green shirt’
b.	i-tᶴn-qʷétˢ	‘I am warm’	qʷátˢ-qn	‘hat’
c.	i-púm	‘it is brown’	tᶴne-s-n-póm-qn-i	‘I am smoking skins’

Harmony occurs regardless of segments between the faucal and preceding vowels. This is illustrated in (7), using data from Flathead (Egesdal 1993).

(7) *Flathead faucal harmony through several segments* (/i/ transparent)

Non-faucal context		*Faucal context*	
q’eʔʃín	‘shoe’	q’aʔʃin-sqá(χeʔ)	‘horseshoe’
ʔúpn	‘ten’	ʔɔ́-ʔ(u)pn-(e)tᶴst-q(i)n	‘thousand’

The form [q’aʔʃin-sqá(χeʔ)] shows /i/-transparency and harmony across five segments. An even more extreme example is [ʔɔ́-ʔpn-tᶴst-qn], where the surface form contains only the initial stressed vowel, six consonants removed from the faucal trigger.[7] The full range of Interior Salish harmony alternations is given in (8) (Reichard 1938, Vogt 1940, Kinkade 1967, Carlson 1972, Egesdal 1993).

(8) *Faucal harmony summarised*

	Non-faucal	*Faucal*
Snchitsuʔumshtsn	i_1 i_2 ɛ u	ɑ ɛ ɑ ɔ
Kalispel	i e u	i a o
Spokane	i e u	i a ɔ
Flathead	i e u	i ɑ ɔ

All preceding examples show uvulars as the conditioning faucal, but pharyngeals function as faucals also. Examples of local V–ʕ effects abound in all the faucal harmony languages, but since pharyngeals occur only in root morphemes and not in suffixes, non-local effects are less common. However, a good example is the Spokane repetitive construction, which in some roots is formed by prefixing Ce-, where C is a copy of the initial root consonant (9a). In the context of faucal roots, this /e/ retracts to [a], as in the regular Spokane faucal harmony (9b).

[7] Unstressed vowels are usually deleted in surface form. Egesdal (1993) gives a narrow transcription of this form: [ʔɔ́ʔpʰn̩tᶴʰs̩tʰqʰn̩].

(9) *Spokane repetitive morpheme* C_1e+ (Bates & Carlson 1997)

a. *Non-faucal roots*: [e]

tʃ’ip’ tʃ’e+tʃ’íp’-ʃ ‘scissors’

b. *Faucal roots*: [a]

naq’ n’a+n’áq’-ʃin’ ‘smelly feet’

luʕ’ʷ n-l’a+l’óʕ’ʷ-eʔ ‘wore a loose dress without a belt’

3 Acoustic investigation

As noted, the impressionistic transcription of local faucal interaction in Nx-type languages identifies it as phonetic. The Sn-type interaction, on the other hand, has the profile of a phonological interaction in both the local and the non-local forms. Based on the information presented thus far, we can identify at least four commonalities between faucal coarticulation and harmony. First, the triggers are identical (the class of faucal consonants); second, the direction of harmony and coarticulation is the same (right to left); third, vowel quality in local and non-local faucal contexts is similar (vowels are ‘retracted’); and fourth, /i/ appears to resist phonetic coarticulation with faucals (the transcription of offglides and less retracted allophones) and does not undergo faucal harmony in one of the two harmony languages. To compare faucal coarticulation (local only) and faucal harmony (local and non-local), we first identify the acoustic events that accompany faucal interaction with vowels. We do this by examining the frequency and temporal distribution of vowel formants in faucal and non-faucal contexts. Then we compare the realisation of faucal features in both languages. The comparison reveals a number of distinctions between phonetic and phonological behaviour, particularly gradience and variability on the one hand, as opposed to stable, categorical effects on the other. Finally, we investigate the relationship between local vowel–faucal (VQ) interaction (phonetic and phonological) and non-local VQ harmony. This in turn involves the question of how intervening segments are affected, so we examine consonantal production in non-local harmony data.

In this investigation, data from Nx represent the coarticulation languages, and data from Sn are used for the harmony class. Both languages fall within Thompson’s class of Southern Interior Salish (Thompson 1979). This removes, as far as possible, factors that might otherwise compromise the comparison.

3.1 Methods

Three female speakers of Nx were recorded saying lexical items with each of /i a u/ in the context of a non-faucal and an adjacent uvular.[8] The

[8] Vowel–pharyngeal sequences are not examined in this paper, primarily because it is difficult to elicit forms controlled in the same way as the database of uvulars (see §2.2). A further problem is that Salish pharyngeals are glides, rendering Vʕ sequences difficult to segment. This complicates the comparison undertaken in this

words examined here are taken from a longer list that was elicited in units of five to ten forms at a time. /ə/ is not included since Sn, the comparison language, does not have it. Where possible, two words for each context were recorded, with two repetitions of each form. In all cases the preceding context is restricted to a coronal consonant or in one case, a glottal that is preceded by a coronal.[9] All measured vowels are stressed vowels. Recordings were made with a Marantz PMD 430, an AKG D320B unidirectional microphone and metal tapes. In the following, 'Q' represents the faucal context, 'nonQ' the non-faucal context. Analysed vowels are underlined. Faucal triggers are in bold.

non-faucal	*adjacent faucal*	*speaker*
i/nonQ	i/Q	
tᶴi̲lkʃt 'five'	tᶴí̲**q**n 'digging'	AB, ED, MM
	kn kaʃ tᶴí̲**q**uxᵂ 'I am going to dig'	
a/nonQ	a/Q	
tᶴá̲kaʔ 'older sister of a man'	ɬá̲**q**lx taʔ 'Sit down!'	AB, ED, MM
(t-)ʔa̲tᶴ (ASPECT)	na̲**q**s 'one'	
u/nonQ	u/Q	
stᶴú̲ɬm 'bull'	tᶴnú̲**qχ**ᵂtaʔ 'Come!'	AB, ED, MM
ūtᶴ ú̲t (REFL)		AB

[Table II. Nxaʔmxcin database]

Two speakers of Sn were recorded (one male, one female).[10] In Sn it is possible to match exactly the environment for non-faucal and non-local faucal contexts since the same root appears in both contexts (see (5)). Roots with an initial coronal were chosen where possible, so as to match the Nx data.[11] For the adjacent faucal context, different roots had to be used, but the preceding environment is restricted to a coronal except for the /u/ vowel, where [tˢʔ] precedes. Unfortunately, I was unable to elicit exactly the same pair for the {a/nonQ, a/…Q} condition, so different

study, since the temporal location and extent of coarticulation is a primary focus. However, it is quite clear from other acoustic work that Salish pharyngeals condition a raised F1 and lowered F2, just as uvulars do (see Bessell 1992, Flemming *et al.* 1994).

9 Coronals are the most common segments in the Salish inventory, so they offer the best chance of controlling place of articulation in the preceding context across both languages. Even so there is one case in the Nx data of a preceding glottal stop, though it in turn is preceded by a coronal. Glottals do not have an oral constriction location and contribute little to the formant structure of vowels, particularly F2. As such this departure from the data structure should not have much effect.

10 See note 14 for discussion of speaker sex and dialect issues.

11 The Sn root /kus-/ does not begin with a coronal, but a velar-initial root is a better choice than a labial-initial root because the F2 effects of velars and coronals are more similar than labials and coronals.

roots are used for each speaker. Two or three repetitions of each token were recorded. In figures, the low vowel in both languages is symbolised as ‘a’, although its non-faucal value is phonetically [a] in Nx and [ɛ] in Sn. This distinction is indicated in the transcription of forms in each language.

non-faucal	*adjacent faucal*	*non-adjacent faucal*	*speaker*
i_2/nonQ	i_2/Q	i_2/…Q	
t^{s}í̱ʃt ‘long’	ut^{s}ɛ̱**q**^{w} ‘bright red’[12]	tt^{s}ɛ̱́ʃt^{s}ɛʃ**q**n ‘he has long hair’ t^{s}ɛ̱́ʃɑl**q**^{w} ‘he is tall’	LN, BL
i_1/nonQ		i_1/…Q	
dlí̱m ‘he galloped hither’		t^{ʃ}dlɑ̱́mɑl**q**^{w} ‘train’	LN, BL
a/nonQ	a/Q	a/…Q	
sɛ̱́tt^{ʃ}nt^{s} ‘he twisted it’	tɑ̱́**q**nt^{s} ‘he touched it’	nɛʔsɑ̱́tt^{ʃ}ɛʔ**q**s-n ‘crank (on a car)’	LN
g^{w}ɛ̱́pt ‘fuzzy’		tgw ɑ̱́pɑl**q**ʃn ‘one fuzzy leg’	BL
u/nonQ	u/Q	u/…Q	
ʔɛniʔ kú̱sɛlst^{ʃ}n ‘hair curls back from forehead’	ʔɛt^{S} ʔƛ̱**q**^{w}s	ʔat kɔ̱́s**q**n ‘his hair is curled’	LN, BL

[Table III. Snchitsuʔumshtsn database]

Recorded data were digitised at 12,500 Hz and 16 bits using CSL, the Kay Elemetrics acoustic analysis package. The duration of each stressed vowel was measured, and first and second formant readings taken at onset, one-third duration, two-thirds duration and offset. The four time points are referred to as T1–T4. In Fig. 1 (a spectrogram of the Nx form [t^{ʃ}íqən]) these time points are indicated on the horizontal axis with small squares. At vowel onset (T1) and vowel offset (T4) direct cursor readings from the screen were taken by placing the mouse arrow on the centre of the formant at the first and last glottal pulses of the vowel, respectively. These points are indicated in the figure with arrows. At T2 and T3, readings from linear predictive coding (LPC) spectra and fast Fourier transform (FFT) narrow-band displays were averaged. At such points, cursor readings from the spectrogram itself were included only if there were inconsistencies between the FFT and LPC analyses. Stops in these data are released, whether prevocalic or postvocalic.

[12] This form is transcribed with a rounded uvular by Reichard (1938), and is rounded in other Interior Salish cognate forms. However, both Sn speakers in the present database have almost no rounding in this form.

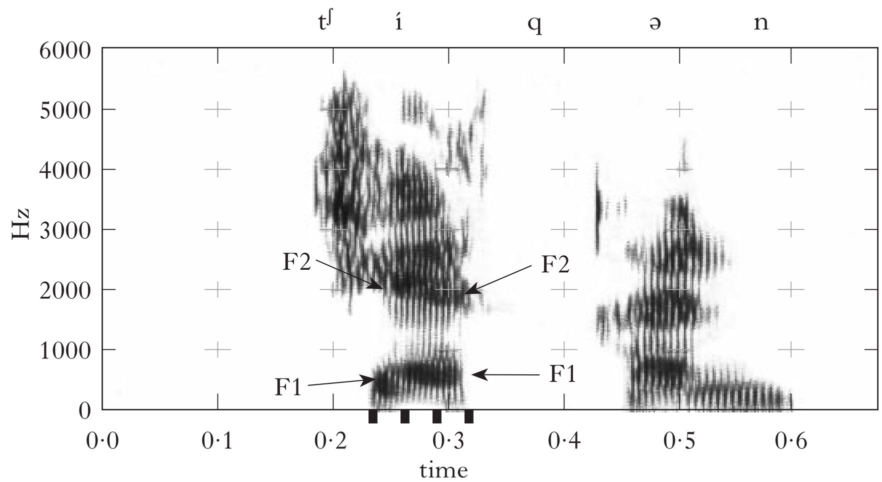

Figure 1
Nx [tʃíqən]

Before proceeding to a full-scale comparison of the two languages, a single factor analysis of variance (ANOVA) was undertaken to see if Nx and Sn vowels are distinct beyond the range of their inherent variability. The data in (10) show that they are: Nx and Sn have greater between-group than within-group differences, in both contexts (faucal and non-faucal) for both formants ($p \leq \cdot 05$).

(10) *ANOVA* ($p \leq \cdot 05$)

source of variation	*degrees of freedom*	*mean squares s2 between/s2 within*	
V/nonQ, F1	155	6·49	(Fcrit 3·9)
V/nonQ, F2	155	15·97	(Fcrit 3·9)
V/Q, F1	265	17·52	(Fcrit 3·87)
V/Q, F2	265	34·06	(Fcrit 3·87)

3.2 Vowels in the context of faucals: formant movement

Based on our understanding of acoustic theory and general articulation, we can predict the direction of formant movement in VQ sequences. We know that both uvulars and pharyngeals involve constriction in the pharynx. Uvulars involve backing of the rear tongue dorsum into the uvular region, just at the top of the pharynx. Pharyngeals involve a constriction lower in the pharynx than uvulars, accomplished by tongue root and/or epiglottal activity (Ladefoged & Maddieson 1996). Given this constriction location, acoustic theory predicts that faucals will condition

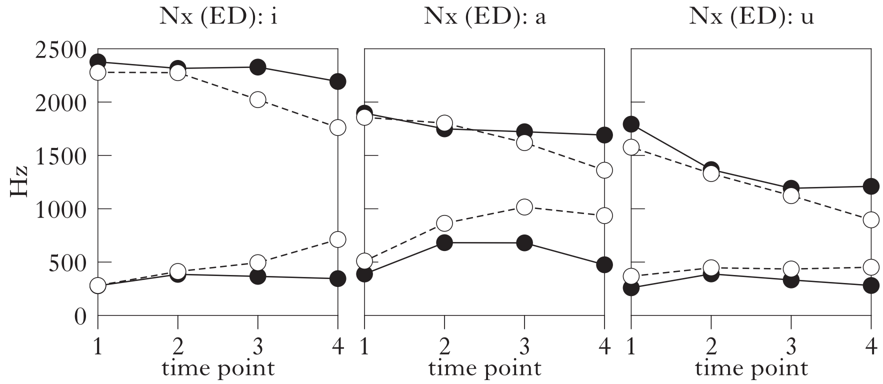

Figure 2
Nx (ED) formant tracks

transitions with a high F1 and a low F2 (Klatt & Stevens 1969, Alwan 1986). The comparison of physiological and acoustic data from Arabic faucals confirms the association between constriction in the upper and/or lower pharynx with high F1 and low F2 (Klatt & Stevens 1969, Ghazeli 1977, Alwan 1986). We can also predict where, in the course of a preceding vowel, consonant-induced formant transitions should occur. Anticipatory coarticulation in a VQ sequence predicts that F1 raising and F2 lowering will be most apparent as the vowel approaches the faucal.

In the next sections we examine displays of frequency and temporal information from each language, contrasting the non-faucal with the faucal context. First, and closest to the raw data, are four-point tracks of the first and second formants, reflecting the averaged readings for tokens from T1 to T4. This shows the overall formant trajectory within each condition so that we can evaluate the direction of formant movement. Second, we graph the difference in formant frequency values between /i a u/ in the two contexts, at each time point. This quantifies the absolute differences between contexts and indicates where retraction is greatest.

3.2.1 *Four-point formant tracks: Nx.* Figure 2 presents formant data from Nx speaker ED. Black circles connected by a solid line represent the nonQ condition; white circles connected by a dashed line represent the Q condition. Data from two other speakers are given in Fig. 8 (App. A).

From Fig. 2 we see that faucals condition exactly the formant movement that acoustic theory predicts, namely an increase in F1 and a decrease in F2 as the faucal is approached. This is true for all three speakers, although there is some speaker-specific and vowel-specific variation in details of the formant transitions. For example, speakers vary in how early the faucal context is evident and in the magnitude of formant movement. This is discussed further below. In the non-faucal condition the consonant

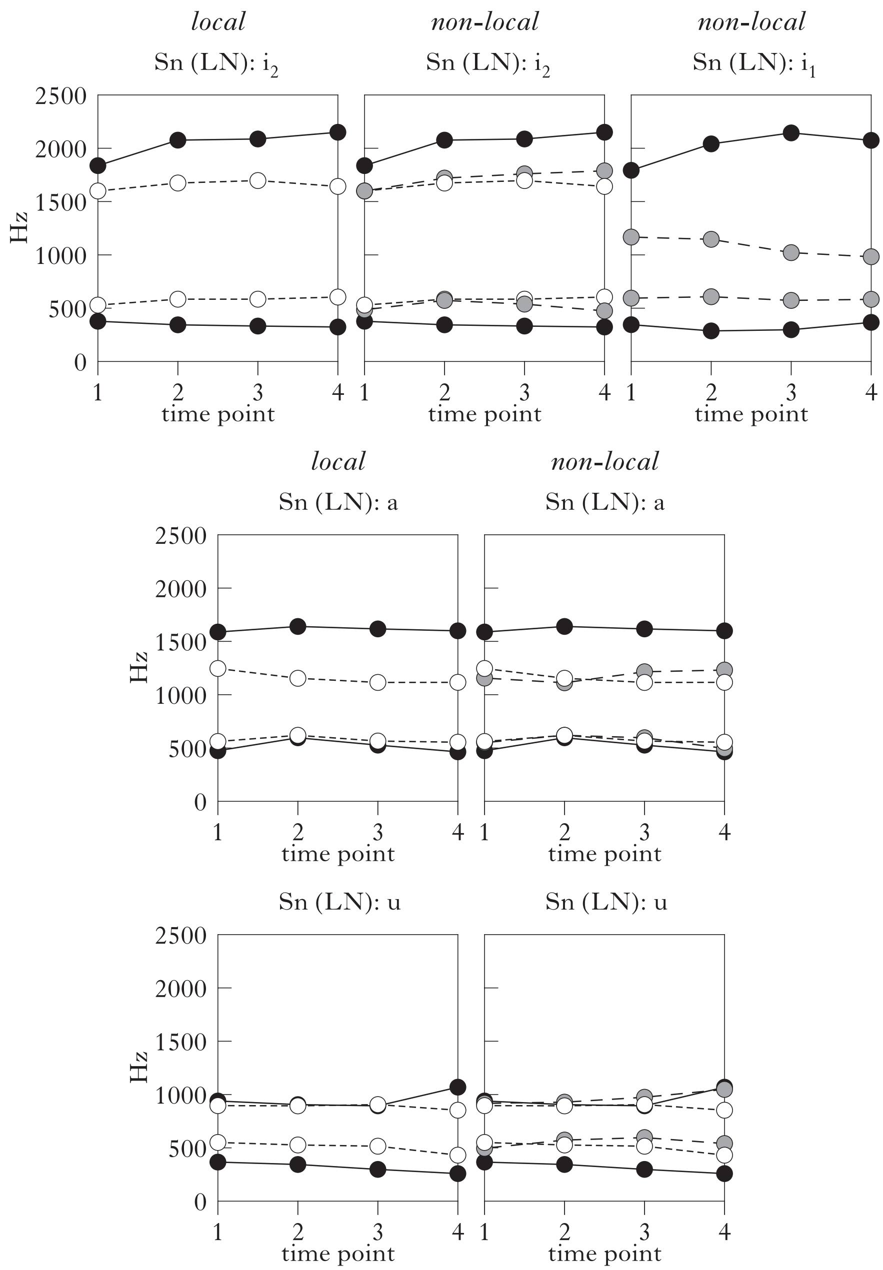

Figure 3
Sn (LN) formant tracks

following V is a coronal in all cases but one, and the expected high F2, relatively low F1 is present.

3.2.2 *Four-point formant tracks : Sn.* Recall that the data for Sn include local (V/Q) and non-local (V/…Q) harmony triggers. For clarity we graph these conditions separately. Figure 3 contains a single speaker's data (LN), with V/nonQ and the local V/Q condition graphed on the left. As in Fig. 2, black circles and solid lines represent the nonQ condition, white circles and dashed lines represent the Q condition. Fig. 12 (App. B) presents corresponding data from the second speaker (BL).

Consider first the V/nonQ and V/Q condition, in the 'local' graphs. Here we see F1 raising and F2 lowering in V/Q, as predicted by acoustic theory. However, F1 raising and F2 lowering do not apply to each vowel in the same way. With /i/, we have both F1 and F2 movement. With /a/, F2 lowers but F1 raises only marginally. With /u/, F1 raising is present throughout the vowel and F2 separates only at the end. Speaker BL has similar tracks, except F2 lowering on /u/ comes earlier in the vowel. Also, Sn vowels in the two conditions are distinct early in their production and for the duration of the vowel.

The non-local Q condition is added in the graphs on the right, using grey circles and heavy dashed lines. The V/Q and V/…Q formant trajectories are virtually identical, but with some differences towards the end of the vowel. The V/…Q condition shows the effect of the coronal following the vowel, so we get some F1 lowering and F2 raising. In contrast, the V/Q condition shows additional F1 raising and F2 lowering in the final portion as the faucal is approached.

In sum, Sn vowels in the two faucal conditions show several things. First they show overall retraction in the form of F1 raising and/or F2 lowering, regardless of whether the faucal is adjacent to the vowel or not. Second, they show some local effect from whatever consonant is adjacent to the vowel. This effect is most evident in the last third of the vowel.

3.3 Difference between F-values

We have established that faucals condition compact formant structure on preceding vowels. However, the formant trajectories also indicate several language-specific differences in response to a faucal. Here we investigate the magnitude of formant difference between the faucal and non-faucal conditions. The data allow us to evaluate the second prediction, that coarticulatory retraction is greatest as the faucal is approached.

3.3.1 *Nx formant differences.* In order to gain a numerical measure of the formant distance between faucal and non-faucal vowels, the frequency values of F1 and F2 for the faucal environment were subtracted from F1 and F2 in the non-faucal context, at each time point. This method measures retraction on V/Q *relative* to V/nonQ, i.e. it takes into account the effect of both contexts. In Fig. 4 we present data from Nx. Delta F2 (i.e. the difference between non-faucal and faucal F2) is the first value to

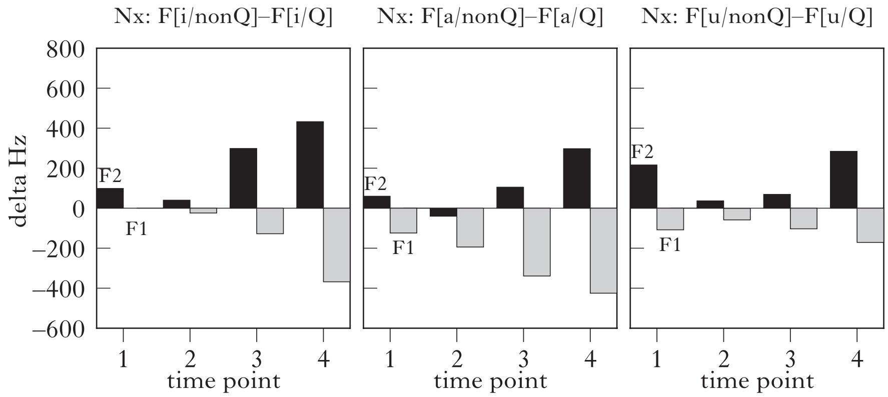

Figure 4
Nx (ED) formant differences

appear, followed by delta F1 for the same vowel at the same time point. The third and fourth bars represent delta F2 and F1 at T2, and so on. Differences in F2 tend to be positive, confirming F2 lowering in the faucal context, while differences in F1 tend to be negative, since F1 raises in a faucal context. See Fig. 9 (App. A) for additional speakers, and Table VII (App. A) for values plotted here.

These results confirm the trend noted in the formant trajectories: all three speakers of Nx show increasing distance between retracted and unretracted vowels. Overall, maximal differentiation between the two contexts, measured on both F1 and F2, occurs in the final one-third of the vowel. More specifically, maximal formant differentiation between V/Q and V/nonQ is at T4 in 14 out of 18 possible cases (three vowels × three speakers × two formants). Of the four exceptions, in three the greatest formant difference is found at T3 rather than T4. It is useful to reverse the comparison, considering where the two contexts produce most similar vowels, since this is not necessarily the direct inverse of where differences are greatest. Vowels are most similar in the first third (T1 10/18; T2 6/18). At T3, 2/18 retain the closest match. There are no close matches at T4. These findings are consistent with the prediction that phonetically coarticulated V/Qs will be maximally retracted as they approach the flanking faucal. The earlier observation that Nx retraction is gradient is also confirmed: the distance between V/nonQ and V/Q increases steadily throughout the vowel.

3.3.2 *Formant differences: Sn.* The 'local' graphs in Fig. 5 plot formant differences between Sn V and V/Q. The 'non-local' graphs show differences between V and V/…Q. Data from speaker BL is graphed in Fig. 13 (App. B). Table IX (App. B) presents the raw frequency differences on which this figure is based.

Sn vowels show large, stable differences for most of their duration. Data from both speakers show that the location of greatest formant differences

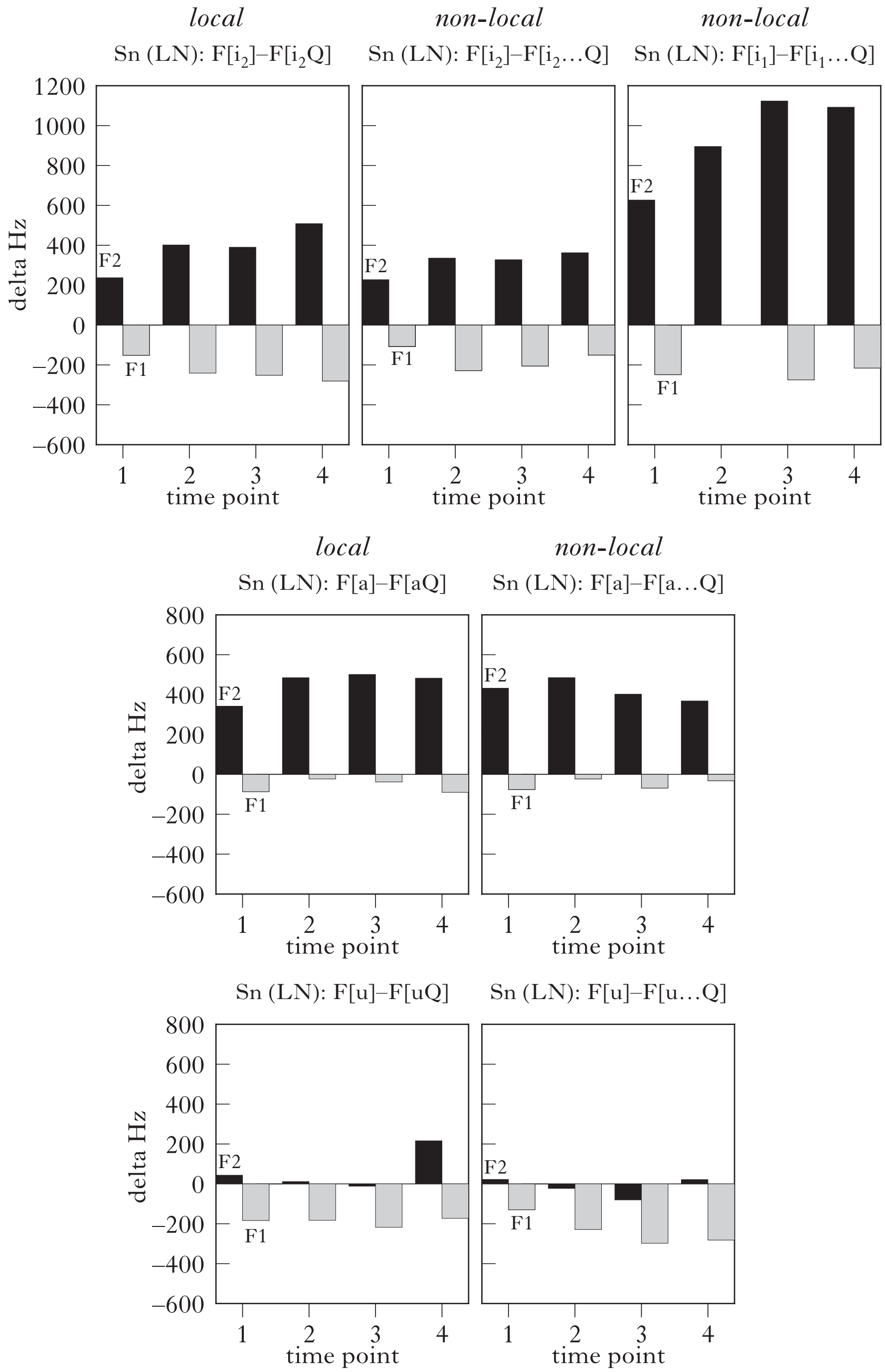

Figure 5
Sn (LN) formant differences

between V/nonQ and V/…Q contexts occurs from T2–T4. The breakdown is as follows: 1/16 at T1, 4/16 at T2, 7/16 at T3 and 4/16 at T4 (four vowels × two speakers × two formants). Thus, the maximally distinct portions of the vowels are in the middle, rather than at the absolute beginning or end. Sn V/nonQ and V/…Q are most similar to one another at T1 (8/16) and T4 (6/16), and least similar at T2 (1/16) and T3 (1/16). This distribution reveals coarticulation with the initial consonant, which was held constant across conditions, and an effect from the final consonant, which is identical in V/nonQ and V/…Q conditions because the root is the same. In the local V/Q context the adjacent uvular further differentiates the vowels as they approach the faucal, as noted from the formant trajectories. Thus, maximal differentiation between V/nonQ and V/Q occurs at T4 in 6/12 cases, at T3 in 3/12 and at T1 in 3/12.[13] These ratios reflect local coarticulation in addition to phonological retraction. V/nonQ and V/Q are most similar to one another where the flanking consonant is comparable, at T1 (6/12). The mid portion of the vowel is least similar: 2/12 at T2, 0/12 at T3.

In Sn, then, the prediction that retraction will be greatest towards the end is not met in a straightforward way. Rather, Sn V/…Q show most retraction in the middle, and the V/Q condition shows large retraction in the centre as well as additional retraction at the end. Nx vowels, on the other hand, simply have maximal retraction at the end. In the next section we quantify this difference, at each time point. This reveals cases where formant differences alone do not distinguish Nx coarticulation from Sn harmony.

3.4 Nx and Sn compared: from phonetics to phonology

We compare the location and degree of retraction in Nx and Sn by scoring for each time point at which formant frequency differences between non-faucal and faucal contexts are greater in one language.[14] Table IV uses the

[13] The total number of comparisons is 12 rather than 16 because of the loss of /i_1 ~ ɑ/ comparisons, which exist only in the V/nonQ *vs.* V/…Q condition.

[14] In comparing Nx with Sn, it must be remembered that Sn speakers are not matched for sex, there being one female (BL) and one male (LN) speaker. Since the male vowel space is more compact than the female vowel space, formant differences between V/nonQ and V/Q are predicted to be smaller for LN's data than BL's. This in turn could raise problems for a comparison of LN formant differences with the three female Nx speakers, since we expect the distance between LN's vowels to be less, regardless of contextual conditioning. However, it transpires that the distinction between LN's faucal and non-faucal vowels is consistently larger than that found in Nx, regardless of the reduced vowel space. This simply confirms the categorical distinction between the two languages, despite conditions that would encourage the opposite finding. A reviewer reminds me that the normalisation issues for the present data are more complex than a mismatch for speaker sex. This is certainly true. Dialectal variation may be playing a role within both sets (even coming from a different family can be relevant), not to mention the fact that we are comparing two different languages. My point here is simply that mismatch in speaker sex does not itself compromise the finding that Nx and Sn vowels are different.

Sn delta Hz	*Nx* delta Hz	F		T1	T2	T3	T4
i_2–i_2/…Q	i–i/Q	F1		6	6	6	2
		F2		5	5	2	0
			total	11/12	11/12	8/12	2/12
i_2–i_2/Q	i–i/Q	F1		6	6	6	5
		F2		6	6	5	5
			total	12/12	12/12	11/12	10/12
i_1–i_1/…Q	i–i/Q	F1		6	6	6	4
		F2		6	6	6	5
			total	12/12	12/12	12/12	9/12
a–a/…Q	a–a/Q	F1		1	0	0	0
		F2		6	6	6	5
			total	7/12	6/12	6/12	5/12
a–a/Q	a–a/Q	F1		3	0	0	0
		F2		3	5	5	3
			total	6/12	5/12	5/12	3/12
u–u/…Q	u–u/Q	F1		2	2	3	2
		F2		0	4	2	2
			total	2/12	6/12	5/12	4/12
u–u/Q	u–u/Q	F1		2	2	3	1
		F2		0	4	4	4
			total	2/12	6/12	7/12	5/12

[Table IV. Cases where {V/nonQ–V/Q} and {V/nonQ–V/…Q} in Sn is greater than or equal to {V/nonQ–V/Q} in Nx]

delta Hz data discussed above and compares Sn with Nx at each of the four time points. Formant frequency differences from each Sn speaker (two) are compared with formant frequency differences from each Nx speaker (three), giving rise to six comparisons for each formant of each vowel, and a total of twelve comparisons for each vowel. Table IV charts those differences which are *greater* in Sn compared with Nx (i.e. where Sn vowels are more differentiated). As an example, consider F1 differences for the /i/ vowel. At T1, Sn i_2–i_2/…Q results in a bigger difference (delta Hz value) than Nx i–i/Q for all six combinations. As a result, a score of 6 is entered in Table IV. For F2, only 5 combinations result in a higher value for Sn, so 5 is entered. Trends in the data are discussed vowel by vowel, starting with /i_2/. The local and non-local contexts are discussed separately.

/i_2/. In Sn the difference between i_2/nonQ as opposed to i_2/…Q is greater than the difference between i/nonQ and i/Q in Nx. This difference is greatest for both formants at T1 and T2, but reduces somewhat at T3. Sn i_2/nonQ *vs*. i_2/Q is consistently more distinct than Nx i/nonQ *vs*. i/Q, at all time points.

/i_1/. Sn i_1 *vs.* i_1/…Q is more distinct from Nx i *vs.* i/Q in all cases from T1 to T3, but diminishes a little at T4.

/a/. Sn a/…Q and a/Q are consistently more distinct from a/nonQ, but on F2 measures only. F1 does not differentiate Sn and Nx vowels in the two classes except marginally at T1 only.

/u/. The difference between u/nonQ and u/Q in the two languages does not bear out greater formant distinctiveness in Sn. At T1 and T4, Nx vowels in the two contexts are actually more different from one another than the Sn vowels. At T2 and T3, the difference is about even on both formants. This is the opposite of the trends noted for /i a/.

3.4.1 *Summary and discussion of findings.* These two sections have presented information on the cues to retraction and their location in each language. In both languages faucals condition some degree of F1 raising and F2 lowering, albeit with differences. Nx retraction is largely a gradient, right-edge effect. The VQ formants show a gradient transition with considerable change in frequency over time. Moreover, there is variation in the extent of retraction among speakers. Gradience of this sort is attested in other examples of phonetic coarticulation. Cohn's investigation of phonetic nasalisation in English VN sequences shows a similar edge effect, with increasing nasal airflow as the nasal consonant is approached (Cohn 1993). Zsiga (1995) looks at frequency cues in the spectrum of phonetically palatalised alveolar obstruents in English. Such segments show a gradient change from initial alveolar to offset values in the palatal range (with some speaker variation), a large change over time and variation in timing of the change.

Sn {V/Q, V/…Q}, on the other hand, do not show primarily edge effects for either speaker, despite attested local effects in the V/Q context. Retracted vowels are distinct early in production and {V/Q, V/…Q} have a formant plateau lacking in Nx data. Similarly, Zsiga (1995) shows that palatoalveolar obstruents are distinct from phonetically palatalised alveolars in frequency value and distribution of those values. In French, phonemic nasalised vowels show rapid transitions from a preceding oral consonant and 'nasal airflow…for most or all of their duration' (Cohn 1993: 52). This profile is consistent with the categorical, phonological realisation of a feature, where extended duration of cues and possibly a plateau phase are relevant (see also Pierrehumbert 1980, Keating 1990b).

Formant differences reveal additional information. Early in production Sn non-faucal and faucal vowels are more different from each other than their Nx counterparts, but become increasingly similar to Nx vowels as they reach their final third. This is an important point, since it pinpoints a similarity in terms of vowel contrast but a constraint on where that similarity is realised: Nx and Sn vowels are similar, but only briefly, and only towards vowel offset.[15] Moreover, Sn V/Q and V/…Q both show

[15] In fact, there are some points where Nx retracted vowels are more distinct from their non-retracted counterparts than in Sn. For example, for /i_2/, Nx F2 distinctions exceed those found in Sn $i_2 - i_2$/…Q vowels at T1 and T2 in 1/6 cases, and at T3 in 4/6 cases. At T4, both F1 (4/6) and F2 (6/6) distinctions exceed those

evidence of local coarticulation with their final consonant. This phonetic edge effect is overlaid on overall retraction. This is exactly as we predict if harmony is phonological.

We also see variation in how individual Sn V/Q can differ from Nx V/Q. Sn /a/ (which is phonetically [ɛ]) shows retraction mostly via backing, whereas Nx /a/ lowers as well as backs. Nx is truer to the prediction that F1 will rise in the context of a faucal. This difference raises an interesting point about the phonologisation of retraction. Phonetically, faucals affect both F1 and F2 and reduce the distance between these two formants. Phonologisation, however, may limit itself to a subset of these details. In the case of Sn a/(...)Q, formant compactness is achieved by F2 lowering and minimal amounts of F1 raising, less than we expect given the phonetic evidence of Nx a/Q. Finally, neither F1 nor F2 values differentiate Sn /u/ and Nx /u/ in the faucal context. On this measure Nx u/Q is actually a bit more retracted than Sn u/Q and u/...Q. Either Nx u/Q is as harmonised as Sn u/Q, or else we have missed something.

In the next section we examine a feature of Sn vowels that does differentiate Nx u/Q from its Sn counterparts. That feature is stability of formant structure.

3.5 Coarticulation and harmony: variability and change

We know from formant trajectories that Sn retracted vowels have a steady-state portion, whereas Nx vowels are more transitional. The plateau phase in the graphs of Sn formant differences supports this observation. In this section we examine this aspect of formant structure by calculating the standard deviation of each formant over its entire trajectory. This gives us a measure of variability in vowels, over time, which differentiates Nx from Sn.

3.5.1 *Standard deviations: Nx and Sn.* A measure of variability within the trajectory of each vowel was calculated by averaging the F1 and F2 values across its four time points, and calculating the standard deviation for each formant. Recall that the place of articulation of the initial consonant is held constant, thus minimising the contribution of C1 to the variability examined here.

Within Nx, V/Q have higher standard deviations from the mean than V/nonQ in 16/18 cases (three speakers × three vowels × two formants). How is this to be interpreted? We know from the formant trajectories (Fig. 2) that V/Q formant movement is fairly consistent in a given direction (rising for F1, lowering for F2). As a result, the high standard deviation in V/Q cannot be attributed to variation around a relatively constant frequency. Rather, the high standard deviation in V/Q is consistent with greater overall formant movement in a single direction. The data are given in Table VIII (App. A).

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from Sn. However, the time points at which Nx distinctions exceed those found in Sn are at the end of the vowel and are in the minority, except for /u/.

In Sn, on the other hand, retracted vowels, whether in the local or non-local faucal condition, do not have greater standard deviation than V/nonQ. Standard deviations for both speakers show non-faucal vowels with the same or slightly more variation as faucal vowels: 7/14 for LN, 8/14 for BL. See Table X (App. B) for data. These findings are consistent with formant trajectory data (Fig. 3), where Sn vowels are relatively stable throughout their duration, regardless of context.

3.5.2 *Vowel variability : Nx and Sn compared.* Table V compares standard deviations for Nx and Sn, using the same method as in Table IV. One score is given for each case out of a possible 12 where Sn has *less* standard deviation in a vowel than Nx.

Sn	*Nx*	F1(sd)	F2(sd)	*total*
i_2/nonQ	i/nonQ	4	2	6/12
i_2/…Q	i/Q	6	6	12/12
i_2/Q	i/Q	6	6	12/12
i_1/nonQ	i/nonQ	6	0	6/12
i_1/…Q	i/Q	5	6	11/12
a/nonQ	a/nonQ	4	3	7/12
a/…Q	a/Q	4	6	10/12
a/Q	a/Q	6	6	12/12
u/nonQ	u/nonQ	6	5	11/12
u/…Q	u/Q	4	6	10/12
u/Q	u/Q	5	4	9/12

[Table V. Standard deviations compared]

Vowels in the non-faucal context show comparable standard deviation in each language, except for /u/, which is more stable in Sn. However, all Sn vowels in the faucal context, local or non-local, show less standard deviation than Nx V/Q. In fact, the stability of Sn vowels may be a crucial indication of harmony. Recall that in terms of raw frequency differences, Sn u/(…)Q is not more distinct from plain /u/ than in Nx (§3.1). Nonetheless the existing contrast, though relatively small, is more stable in Sn.

The /a/ vowel presents a similar case, but only for F1. Sn /a/ is relatively front and shows large F2 movement in harmony context, but little F1 movement. Nx a/Q raises F1 throughout the vowel, but does not shift F2 very much. As a result, Table V shows larger Nx distinctions on F1, but larger Sn distinctions on F2. But again, the difference between nonQ and Q contexts is more stable in Sn than in Nx for F1 and F2. Clearly, then, the evaluation of harmony as opposed to coarticulation is not based solely on momentary formant differences, or even the magnitude of those differences, but on a more global assessment over the time course of the vowel. This is consistent with earlier work (Keating 1990b, Cohn

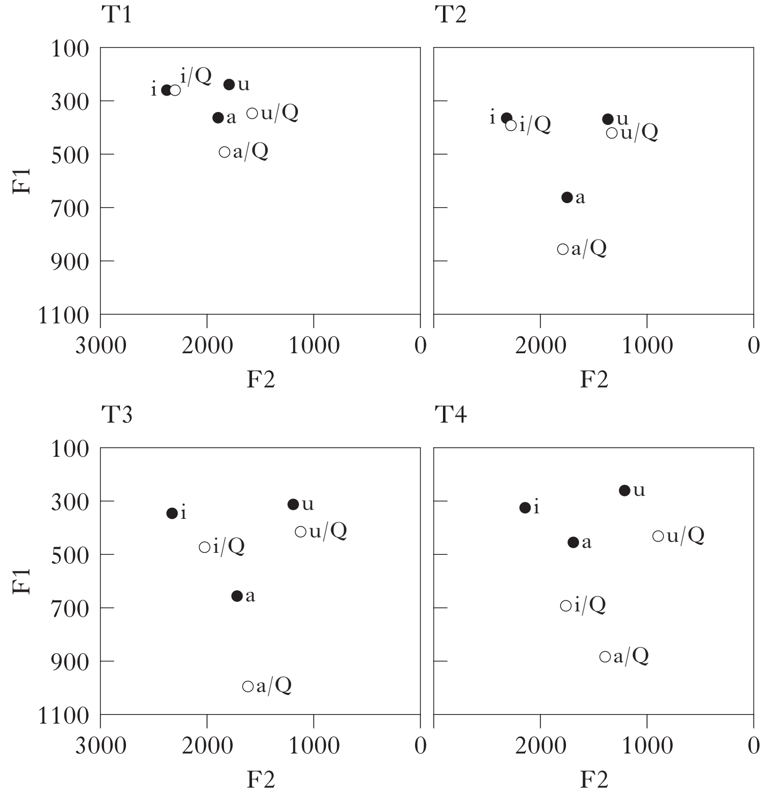

Figure 6
Nx (ED) vowel plots, T1–T4

1993, Zsiga 1995) that relates longer cue duration with phonological realisation.

3.6 Standard vowel plots Nx: T1–T4

We turn now to view the entire vowel system, using standard (F2, F1) vowel plots for each time point. This display clarifies some of the trends noted from the formant tracks and allows us to evaluate how retraction affects contrast in the overall vowel system. The vowel plots also reveal vowel-specific responses to the faucal context in terms of magnitude and timing of retraction. As in previous displays, black circles represent V/nonQ and white circles represent V/Q.

3.6.1 *Nxaʔamxcin.* First, the Nx vowel plots clearly reveal an increasing separation between the class of retracted and unretracted vowels over time. This separation is most extreme towards the end of the vowel. By T4, the vowel space can be divided into an unretracted (high, front) and a retracted (low, back) portion.

Second, individual vowels show slightly varying responses to the faucal context. Both /u/ and /a/ show both F1 and F2 effects, but with considerable speaker-dependent variation. a/Q shows F2 lowering (backing) for all speakers, but with variation at what time point in the vowel. ED and MM do not begin to lower F2 in a/Q until T3, whereas AB backs the vowel earlier. a/Q is overall the lowest vowel in the system, unapproached by any other V/Q, with the single exception of u/Q for AB (Figs. 10 and 11 in App. A). Variation in the height of u/Q is confirmed by F1 values. AB lowers u/Q to a/Q space right from T1, whereas ED and MM show more modest lowering. /i/ is unique among the vowels. For all speakers, i/Q shows relatively little early movement compared to u/Q and a/Q. This is clear in Fig. 6 at T1 and T2, and in Figs. 10 and 11. In support of this observation, 75 % of the formant differences between i/nonQ and i/Q at T1 and T2 (three speakers) are *smaller* than any other {V/nonQ, V/Q} difference. But at T3 this difference disappears, and at T4 i/Q shows more movement than the other vowels. Thus, despite evidence for /i/ initially resisting faucal coarticulation, it is not true that i/Q does not shift, or that it does not shift as much as the other vowels. It is the timing of the shift which is delayed relative to other vowels, with the result that the first third of i/Q is minimally differentiated from i/nonQ. While perceptual tests are required to establish that i/Q is less distinct from i/nonQ in early time points than other {V/nonQ, V/Q} pairings, the impressionistic transcription of offglides for i/Q suggests that this is so.

Finally, the extent to which both i/Q and u/Q approach the value of the underlying low vowel of the system, /a/, varies across speakers. For speakers ED and MM i/Q at T4 is actually lower and almost as back as a/nonQ. This T4 effect is more dramatic for ED than MM. For AB, however, i/Q does not approach /a/-space. This variation is consistent with the varied phonetic transcription of i/Q, as noted in (3). In terms of achieved vowel quality, both an i ~ ε and an i ~ a alternation are present in the data. u/Q also varies in height. For AB, u/Q is consistently lower than unretracted /a/. MM has an u/Q as low as unretracted /a/. ED, however, has very modest lowering.

3.6.2 *Standard vowel plots: Snchitsuʔumshtsn.* At T1, the vowel plot for LN shows clustering consistent with five vowel classes: {i_2, i_1}, {a, i_2/ … Q, i_2/Q}, {a / … Q, a/Q, i_1 / … Q}, {u / … Q, u/Q}, {u}. These classes correspond exactly to the five surface vowel qualities of stressed vowels that are transcribed in Sn: [i ε ɑ ɔ u]. Here we see evidence for these classes of vowels at T1, just as indicated by the formant tracts in Fig. 3.

The two faucal contexts (local and non-local) show little difference early in the vowel (vowel classes are circled). This remains true throughout the vowel, with some disintegration late in the vowel where local coarticulatory effects from the final C may be quite strong. For example, u/Q shows the effect of rounding on the uvular, hence the lowering of both formants visible at T3 and T4.

Speaker BL (Fig. 14 in App. B) shows coarticulatory effects at T1 and

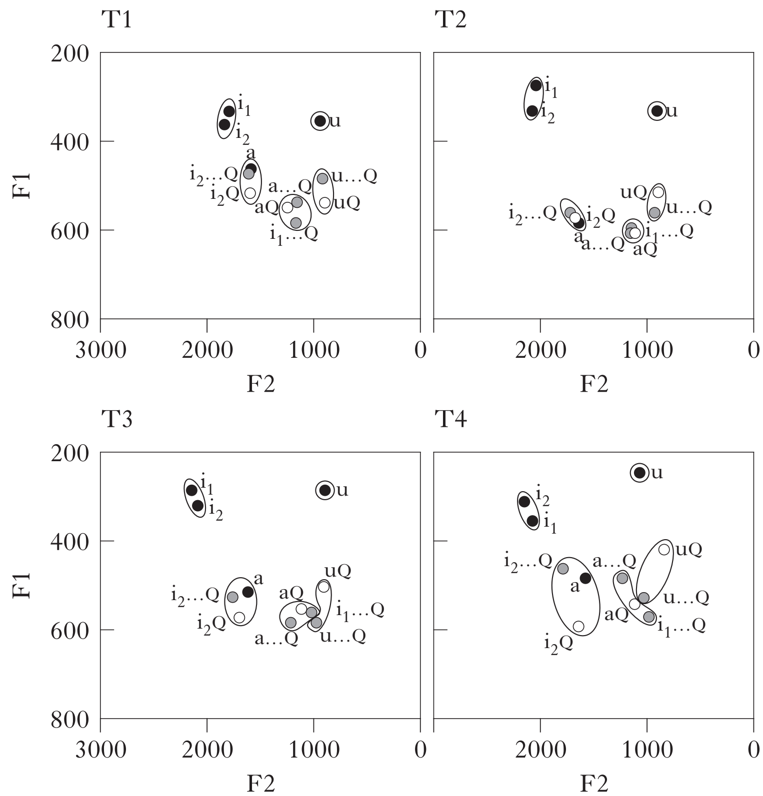

Figure 7
Sn (LN) vowel plots, T1–T4

T4. As a result, vowel distribution at T1 is noticeably skewed by coarticulation with the initial consonant, and at T4 the final consonant has an effect. In the case of V/Q, T4 shows additional F1 raising and F2 lowering not found in the V/nonQ condition. Both speakers retract /i/, either to /ɛ/ or /ɑ/. This is the surface evidence for i_2/ɛ and i_1/ɑ pairings. There is no /i/-resistance of the sort found in Nx.

3.7 From local articulation to local harmony: summary and discussion

We return now to the question posed at the beginning of this paper: how, if at all, is Interior Salish faucal harmony related to local C–V events? To simplify matters, we deal first with the emergence of local harmony.

Let us begin by summarising the similarities between coarticulation and harmony. First, vowels in the faucal context have a compact formant structure, with F1 and F2 relatively close to one another. A retracted vowel quality is achieved, at some time point, in both languages. Second, Nx /i/ has a minimal response to faucals for the first third of its duration and then shows retraction to [ɛ] and/or [a]. In Sn, [ɛ] results from harmony on /i_2/, [ɑ] results from harmony on /i_1/. Faucal harmony in Sp-Ka-Fl does not target /i/ at all. Third, retraction has a systemic effect in the sense that retracted vowels, as a class, occupy a distinct portion of the vowel space (low, back space).

What differentiates Sn from Nx is the way these similarities are realised. Nx V/Q are in transition. The formant trajectories show gradient change over a large range of values, differences between retracted and non-retracted vowels increase over time and the vowel system migrates towards retracted space. Sn V/(…)Q, on the other hand, show less transitional formant structure, with formant compactness established early and remaining stable for the duration of the vowel. As a result, V/(…)Q occupy retracted space from the beginning rather than migrating towards it. This stability of formant structure is so important that it even serves to distinguish Sn vowels from Nx vowels in cases where raw formant values alone do not.

The similarities between coarticulation and harmony are encouraging for the hypothesis that harmony developed from coarticulation. But how might the transition from local coarticulation to local harmony take place? This question has been asked of other phonologised CV interactions. Traditionally, a production explanation is advanced, proposing increasing change in the direction of the final outcome. For example, Hyman (1976) proposes six stages for the development of contrastively nasalised vowels from VN contexts. Each stage involves, among other things, increasing nasalisation of the vowel. Similarly, extending the temporal domain of Nx coarticulation within a vowel would result in a V/Q profile very close to Sn V/Q. Moreover, we know from individual speaker variation that Nx V/Q effects can appear quite early in the vowel. This indicates that the transition from Nx-type V/Q to Sn-type V/Q is potentially a matter of extension and regularisation of properties already present in synchronic, phonetic data. Presumably, however, there is a perceptual threshold beyond which coarticulated vowels are likely to be heard (and then reinterpreted) as fully retracted, so it may not be necessary for retraction to exceed the Nx paradigm by much (cf. Ohala 1981).

However, the behaviour of /i/ in harmony languages requires additional explanation since it has two harmony patterns, neutrality or retraction. Again, let us restrict ourselves to local iQ sequences for now, since additional questions are raised by non-local neutrality. The behaviour of /i/ is predicted if we consider phonetic coarticulation from the perspective of constraints on articulator activity. The raised and fronted tongue blade of /i/ is directly antagonistic to the low, back gesture required for faucals (Stewart 1971, Recasens 1991, Archangeli & Pulleyblank 1994). Likewise, the acoustic requirements for /i/ (low F1, high F2) conflict with the acoustic qualities that define faucals (high F1, low F2). In Nx this phonetic conflict manifests itself as delayed retraction, simply because it takes time for the tongue to shift from the /i/ target to the faucal target.

Phonetic coarticulation does take place, however, and since the distance between the high front /i/ position and the faucal position is considerable, the effect on the vowel can be large. Acoustic data suggests that both [ɛ] and a low back vowel, here transcribed as [a], can be achieved in Nx iQ sequences. How does this translate to the local harmony context? In Sn, no surface i/Q or i/...Q condition exists: we have either ɛ/(...)Q or ɑ/(...)Q. We note here that the seeds of both harmony vowels exist in the phonetic variation of Nx i/Q coarticulation. Even if the $i_1 \sim$ ɑ alternation is historically conditioned (thus marked on lexical entries) the $i_2 \sim$ ɛ alternation has a clear phonetic basis. As with the other vowel alternations, what is present in phonetic form is regularised and made categorical in phonological form. A second variation in the treatment of i/Q occurs in Sp-Ka-Fl, where i/(...)Q does not harmonise at all. Here the gestural and acoustic antagonism between faucals and /i/ (realised as a delay in retraction) is made categorical as the absence of harmony.

Recasens (1984, 1989, 1991) provides some experimental evidence for this kind of reasoning. Recasens hypothesises that articulatory regions not involved in vocalic constriction are relatively free to coarticulate with adjacent segments. Thus, a low vowel, particularly one lacking a front/back contrast as in Salish, would be free to coarticulate with a faucal gesture. The lip rounding of /u/ is quite independent from faucal gestures and while the rear dorsal gesture for /u/ is not as independent, it is not antagonistic to faucal articulation. As a result we predict u/Q and a/Q effects. i/Q interaction is delayed since the tongue is subject to contradictory requirements, and so is not free to coarticulate with the faucal in the same way as /a u/. Acoustic and electropalatographic data support the basic premises of Recasens' work.

We conclude that the relationship between VQ coarticulation and VQ harmony is not arbitrary, but supports the development of local VQ harmony from local VQ coarticulation. This still leaves us with non-local harmony. But we know that the basic cues for local and non-local harmony are the same; only phonetic edge effects differentiate the two. The obvious question is whether non-local harmony could have arisen by the same coarticulatory mechanisms as local harmony, only over a larger domain. §3.8 looks at the properties of consonants between the trigger and target in an attempt to address this question.

3.8 Intervening consonants

Can we extend a strictly local model such as the one proposed for the development of local VQ harmony and use it to account for the development of non-local V/...Q harmony? One possibility is successive iterations of local phonetic coarticulation. For example, to arrive at a form like [y'ɑ́l-stq] 'summer', the uvular coarticulates with the preceding /t/. Then this newly retracted /t/ coarticulates with /s/, and so on, until all segments between the vowel and the uvular are retracted, much like Semitic emphasis. The problem with this model is that no transcription of

Salish faucal harmony shows intervening consonants affected (11a). The most obvious expectation, that velars become uvulars in harmony context, is not supported (11b).[16]

(11) *Sn consonant transparency*

a.	y’ɑ́l-stq	‘summer’	b.	tɛ́k’ʷ-nc	‘he laid one down’
	kʷɛ́nʃ-qit	‘how many days’		ɑn-t’ɑ́kʷ-qn	‘it lies on top’

A weaker version of this model requires some undefined amount of retraction on intervening segments, without it being contrastive, categorical or even audible. However, this weak retraction must still be sufficient to permit successive coarticulation. The weaker the intervening retraction, the more difficult it is to link audible and contrastive retraction on a distant vowel with coarticulation.

In the absence of direct articulatory data, here we examine the acoustic properties of some harmony forms to see if there is any acoustic evidence for retraction on consonants. The data provide several cases of coronal fricatives and affricates in a position to retract. Such consonants are particularly important since there is independent evidence that Interior Salish coronals can be retracted. Czaykowska-Higgins (1990) isolates a small class of Nx roots that do not contain a faucal, but nonetheless have a retracted vowel which conditions an [RTR] domain.[17] Vowels and coronal consonants within this domain are transcribed as retracted.

(12) *Nx retracted coronals* (Czaykowska-Higgins 1990)

l̤i̤y	‘come loose’
k̇-l̤i̤y’-ạ́nk	‘cinch came loose’

Prior acoustic examination of Nx retracting roots confirms a contrast between plain and retracted /s l ɬ/ (Bessell 1997).[18] The following cues to retraction were found. Retracted laterals have a lowered F2, similar to the cue to Arabic emphatic consonants (al-Ani 1970). For example, retracted /ɬ/ has a clear effect on a following /i/ vowel, with F2 increasing rapidly upon consonantal release. The Nx sibilant contrast seems best reflected in peak frequency values. Retracted /s/ (which is heard as [s]-like) has higher frequency peaks in the mid 50 ms portion of the fricative than unretracted /s/ (which has an alveopalatal, [ʃ]-like quality). These findings parallel the /s/ ~ /ʃ/ contrast in English, where /s/ likewise has higher frequency peaks than /ʃ/ (Hughes & Halle 1956, Behrens & Blumstein 1988).

[16] There is one exception to this that I know about, in Flathead data, but the alternation between velar and uvular is not consistent (S. Thomason, personal communication).

[17] All of the Interior languages have some roots which trigger a progressive RTR harmony. Such roots are usually analysed with a floating [RTR] specification, with subsequent realisation on vowels, or in some cases, coronal consonants. Progressive harmony is a completely separate process from faucal harmony in Sn. See Doak (1992) for a demonstration of this in Sn.

[18] Other coronals may be retracted, but confirmation of this awaits further acoustic work.

form	*fricative duration* (sec)	*LAS peak* (Hz)	*peak of first 50 ms* (Hz)	*fricative duration* (sec)	*LAS peak* (Hz)	*peak of first 50 ms* (Hz)
	speaker BL			*speaker* LN		
tˢíʃt	0·162 (·025)	3359·5 (48·79)	3371 (195·1)	0·2075 (·013)	2706 (32·52)	2809 (80·61)
tˢέʃɑlqʷ tˢέʃ(tˢɛʃ)qin	0·114 (·015)	3359·5 (85·027)	3325 (141·781)	0·171 (·005)	2901 (334·048)	2912.25 (332·404)
kús	0·107 (·001)	3692·5 (226·98)	3841·5 (113·84)	0·146 (·010)	4024·5 (113·844)	2798 (584·07)
kɔ́sqn	0·098 (·028)	4242·5 (64·35)	4288·5 (357·08)	0·495 (·515)	4220 (65·05)	3015·5 (1021·76)
sέttʃ				0·0505 (·0007)	2970 (210·71)	
sɑ́ttʃɛʔqsn				0·069 (·014)	3623·5 (161·92)	

[Table VI. Peak frequencies in Sn /ʃ s tʃ/ in harmony context]

Given that Nx coronals can bear the retraction feature, if Sn harmony is born of coarticulation over intervening segments, we might expect Sn coronals in harmony spans to exhibit retraction cues. Bearing in mind the earlier findings from Nx, the long-term average spectrum (LAS) of the frication present in Sn /ʃ s tʃ/ in faucal and non-faucal contexts was determined. A second measure, peak of the first 50 ms of frication, was taken to minimise any coarticulatory interaction with the following consonant context.

Results in Table VI indicate that there is little difference in the spectral frequency of Sn /ʃ s tʃ/ in harmony and non-harmony contexts. This is clearest in the /ʃ/ of /tˢíʃt/ *vs.* /tˢέʃɑlqw, tˢέʃ(tˢɛʃ)qin/, where the difference is marginal. The /s/ of harmonised /kɔ́sqn/ shows higher LAS peak spectral frequencies than non-harmonised /kús/ for both speakers. This is likely due to the strict adjacency of the uvular, since speakers vary in how temporally intrusive the peak raising is. For example, the high standard deviation (1021·76 Hz) of the first 50 ms in LN's production of /kɔ́sqn/ is caused by token-to-token variation, with one token showing little early peak raising. Since the other token has raised peaks, it appears that local retraction is variable in extent, as we would predict for a purely local phonetic effect. Local retraction from strictly adjacent faucals, then, seems to be confirmed. Finally, the affricate /tʃ/ also shows higher peak values in the faucal condition, /sɑ́ttʃɛʔqsn/. There is data from only one speaker, and this too may be an adjacency effect, in that no consonant with an oral place of articulation intervenes between /q/ and /tʃ/. The current findings are consistent then with local consonantal retraction, but not non-local retraction over oral consonants.

4 Discussion and conclusion

At present then, we have no phonetic evidence for a relationship between faucal harmony and iterative coarticulatory retraction. While it is possible that Sn went through iterative retraction in the historical development of non-local harmony, with subsequent loss of retraction on all segments except vowels, this hypothesis is unfalsifiable. So we ask if there is another route whereby coarticulation may still underlie non-local harmony without intervening segments being affected. What about long-distance rather than iterative coarticulation?

The hypothesis of articulatory independence discussed in §3.7 can be applied to long-distance interaction. The theory predicts that when gestural requirements on C and V are maximally independent, articulator-specific, gradient coarticulation can operate over a multi-segment domain. Such coarticulation is attested in French data, where lip protrusion on rounded vowels is anticipated well in advance. Benguerel & Cowan (1974) document anticipatory lip protrusion in the sequence /istrstry/ (in e.g. *une sinistre structure*) on all six consonants before the round vowel /y/. Moreover, there is some evidence that faucals can condition long-distance gradient effects. Gradient faucal interaction is attested in Papantla Totanac, where a progressive uvular harmony prohibits /i u/ in the context of uvulars. In Totanac uvular lowering propagates long-distance through sonorant laterals, but decreases in effect the further the vowel is from the uvular (Elorrieta 1996, based on Levy 1987).

Considering articulatory relationships over multi-segment domains, we predict complete independence between faucals and labial consonants. Coarticulation should proceed over a VpQ span, for instance. Faucal harmony in Interior Salish meets this prediction. Coronal consonants should oppose faucal gestures, especially those coronals with very precise production constraints (such as fricatives, due to channelling requirements). This phonetic antagonism between high, front articulations and faucals is confirmed in the Nx i/Q interaction. However, coronal consonants do not block long-distance faucal harmony. This, combined with evidence that coronals are not themselves retracted, suggests that synchronic Sn harmony is *not* a direct translation of long-distance coarticulation into phonology. The same conclusion must be drawn from /i/-transparency in the non-local harmony of Sp-Ka-Fl. A direct coarticulation explanation for non-local harmony predicts that the unretracted left edge of iQ sequences should *block* the spread of coarticulated retraction. The transparency of /i/ requires some re-interpretation, at which point we can no longer appeal to a direct coarticulatory basis for non-local retraction. The fact remains that in synchronic data, all consonants are transparent and apparently unaffected, while vowels regularly bear the retraction feature. If we take this distribution seriously we must ask why vowels are the only targets.

The most direct explanation of the development of non-local faucal harmony departs from the purely articulatory accounts explored above and appeals to perceptual factors and feature salience. Consider first the fact that faucal consonants are relatively rare in languages of the world. Uvulars occur in 14·8% of the languages in Maddieson's sample, pharyngeals in 4% (Maddieson 1984). Labial, coronal and velar consonants, on the other hand, appear in the vast majority of the world's languages. The explanation for this distribution likely involves ease of production and perceptual contrast (Lindblom & Maddieson 1988). On the other hand, what we have called retracted vowels occur very commonly in vowel systems of five and more members, which form the vast majority of the world's vowel systems (Crothers 1978, Maddieson 1984).

This distribution suggests that faucal features are maximally compatible with vocalic rather than consonantal structure.[19] This may form part of the motivation for the association of faucal features with vowels, regardless of the lexical location of the feature.[20] In Nx the association of faucal features with vowels takes a phonetic form, with coarticulation from faucal consonants onto immediately preceding vowels. In Sn the phonologisation of local coarticulation lays the ground for a more general assignment of faucal features to vocalic structure, so that faucal features appear on any preceding vowel. This establishes a non-local harmony span in which consonants are simply irrelevant. Crucially, however, the thoroughly phonetic substrate of V/Q interaction is still apparent: non-local V/Q interaction is still conditioned by the phonetically motivated factors familiar to us from Nx coarticulation. Namely, the direction of the harmony is regressive, vowels alternate with exactly the qualities that are found in local coarticulation and /i/'s antagonism to retraction has phonological expression as neutrality.

This view of faucal feature interaction permits a simple account of /i/ variability that proved elusive under a direct coarticulation account. We know that the gestural and acoustic antagonism between /i/ and faucals can be phonologised as neutrality on /i/ – this has already been established as a phonetically motivated possibility. For argument's sake we can state this antagonism as a feature cooccurrence restriction *[RTR, high, front] (cf. Archangeli & Pulleyblank 1994). The separate, but nonetheless phonetically based requirement that faucal features be realised on vocalic structure continues to respect this feature cooccurrence restriction. When /i/ alternates with [ɛ] or [ɑ], as in Sn, the vowel [ɪ], with its prohibited feature configuration [RTR, high, front], is avoided. When /i/ is transparent, as in Sp-Ka-Fl, [RTR, high, front] is likewise avoided. Even the opacity of coronal articulations in Semitic emphasis respects *[RTR, high, front], but at the expense of propagating the harmony itself. Precisely these variations are predicted once non-local faucal harmony is

[19] There is a burgeoning literature exploring the phonetic bases for facts of this sort that may subsequently play a role in phonological systems. See Bladon (1986), Lindblom & Maddieson (1988), Steriade (1996), among others.

[20] A preference for vocalic structure may also explain why it is RTR, and not some other feature, which provides this rare instance of non-local C–V interaction. I leave exploration of this for future research.

uncoupled from direct dependency on coarticulatory patterns alone. Instead it becomes important to view the harmony in a larger phonetic context. Whether a language expresses phonetic antagonism as transparency (Salish) or opacity (Arabic) reflects interaction with additional factors, such as the production, parsing and perception benefits derived from an extended featural domain. Such benefits may be pursued at the expense of costs incurred by other phonetic factors, but the importance of phonetic constraints is maintained.

We conclude then, that the data are consistent with a phonetic basis for Sn harmony, rendering it non-arbitrary in the sense that it is constrained by phonetic factors. On the other hand, the null hypothesis regards any continuing similarity between coarticulation and harmony as historical detritus. In the extreme case, the null hypothesis predicts that vowel advancing, or rounding, is possible in the context of (non-local) faucals. As far as we know, this does not occur.

Appendix A: Nxaʔamxcin (speakers AB and MM)

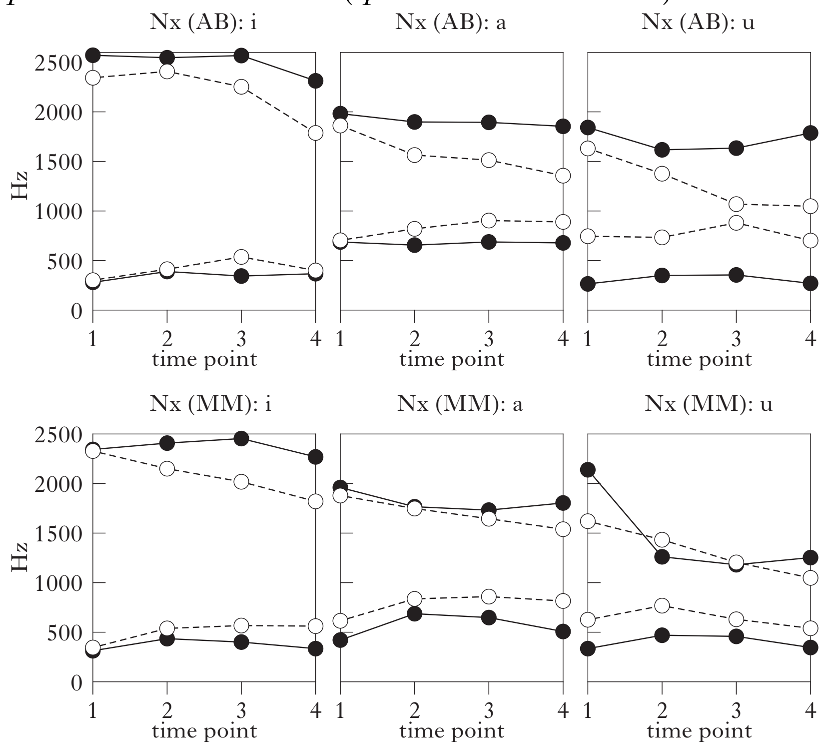

Figure 8
Nx (AB, MM) formant tracks

	T1			T2			T3			T4		
	AB	ED	MM	AB	ED	MM	AB	ED	MM	AB	ED	MM
i–i/Q												
F1	−21·5	−·25	[illegible]	−23·5	−27	−103·5	−193	−127	[illegible]	−32	−367	[illegible]
F2	227	97	16	137·5	40	258	316	304·5	436	551	432	448
a–a/Q												
F1	−20	−124	[illegible]	−204	−194	−149	−275	−339	[illegible]	−305	−427	−308
F2	120	60	[illegible]	219	−40	17·5	289	105	[illegible]	422	297	265
u–u/Q												
F1	−480	−108	[illegible]	−384	−58	−299	−526	−103	[illegible]	−432	−171	−194
F2	211	216	[illegible]	241	37	−172	565	69	[illegible]	740	314	206

[Table VII. Nx formant differences (Hz)]

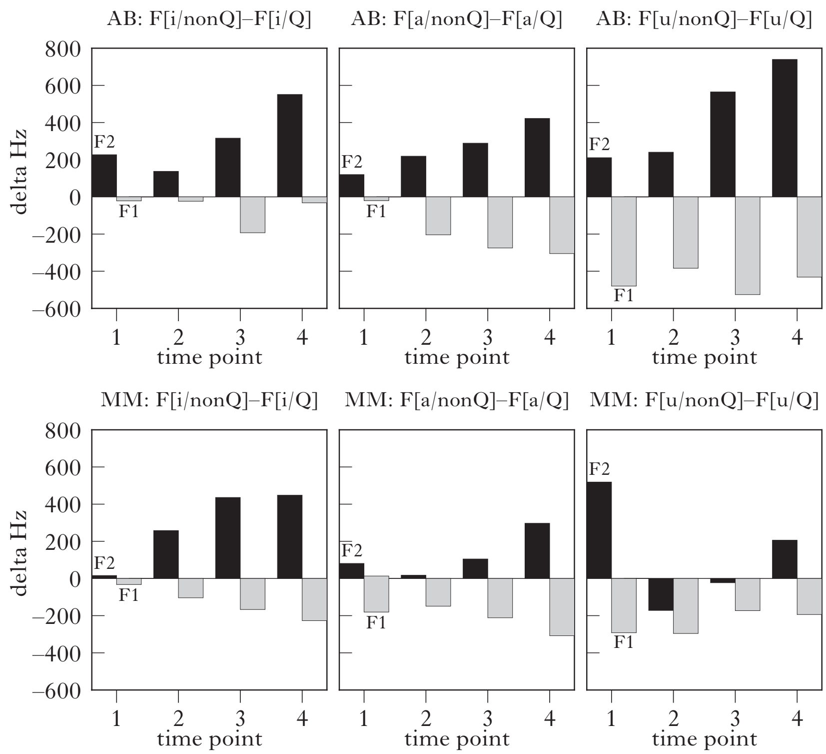

Figure 9
Nx (AB, MM) formant differences

	AB		ED		MM	
	F1	F2	F1	F2	F1	F2
i/nonQ	47	125	45	78	56	80
i/Q	96	294	181	247	105	214
a/nonQ	15	54	147	90	123	101
a/Q	91	211	217	200·5	112	145
u/nonQ	49	111	58	279	71	454
u/Q	72	262	39	290	95	252

[Table VIII. Standard deviation (Hz) in Nx (AB, ED, MM)]

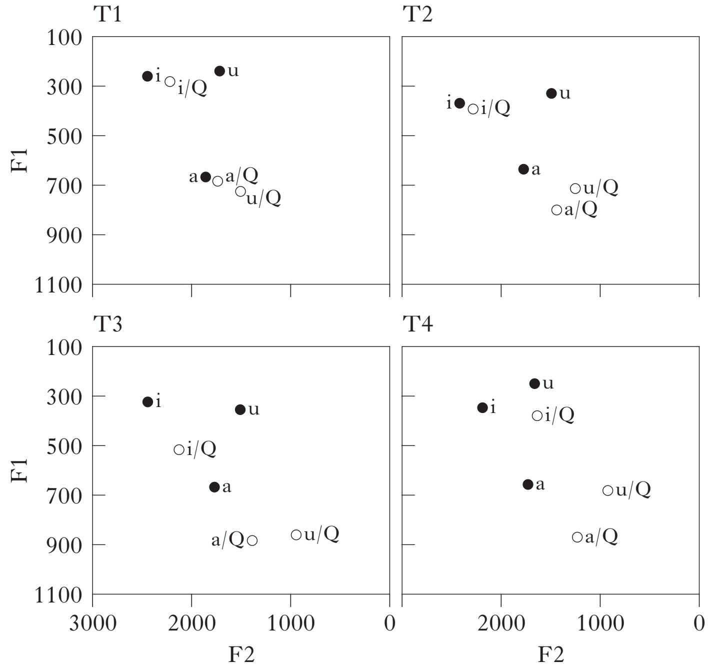

Figure 10
Nx (AB) vowel plots, T1–T4

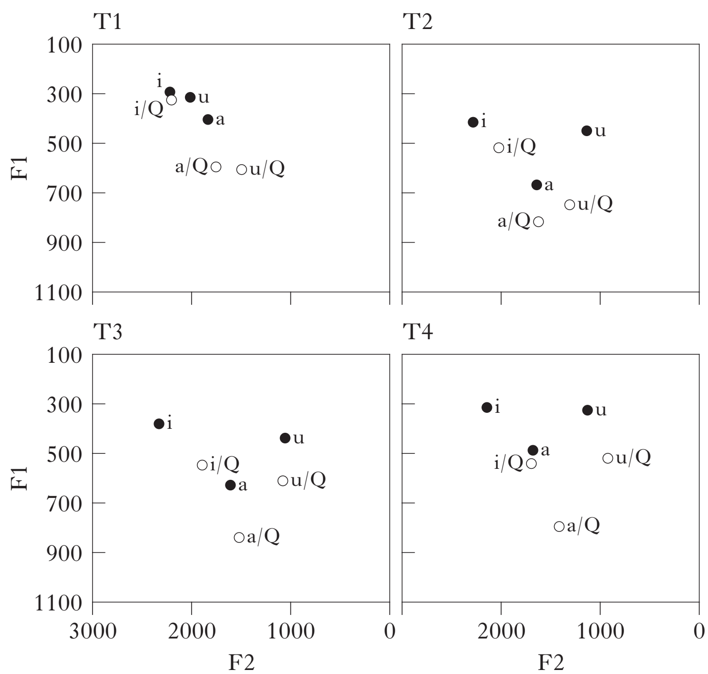

Figure 11
Nx (MM) vowel plots, T1–T4

Appendix B: Snchitsuʔumshtsn (speaker BL)

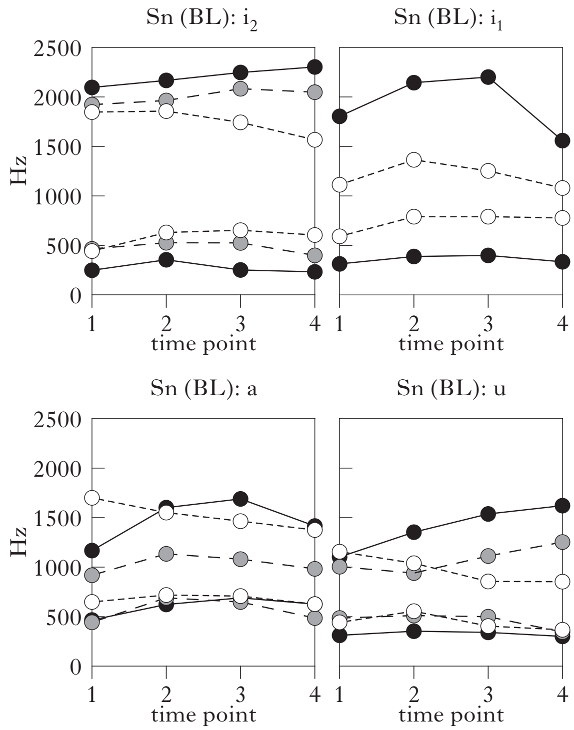

Figure 12
Sn (BL) formant tracks

		T1		T2		T3		T4	
		LN	BL	LN	BL	LN	BL	LN	BL
i_2–i_2/…Q	F1	−108	−217	−229	−172	−206	−273	−151	−166
	F2	227	173	355	202	327	164	362	255
i_2–i_2/Q	F1	−151·5	−194·5	−240·5	−275·5	−252	−401·5	−281	−372
	F2	237·5	248	401·5	309·5	390	504·5	508	736
i_1–i_1/…Q	F1	−248·5	−268	−321	−402·5	−275	−391·5	−216	−443
	F2	626·5	691·5	895	779·5	1123	948	1092	475·5
a–a/…Q	F1	−76	23	−23	−67	−69	42	−32	140·5
	F2	432	248·5	528	466·5	401·5	609	367·5	432·5
a–a/Q	F1	−87	−182	−23	−95·5	−38	−18	−90	0
	F2	342	−553	485	49	501	226	482·5	39·6
u–u/…Q	F1	−130	−131	−229	−202	−298	−123·	−281·5	−67
	F2	22	97·5	−23	413	80·5	425	21·5	367·5
u–u/Q	F1	−184	−174·5	−183	−.58	−217·5	−158·5	−173	−45
	F2	43·5	−54·5	11·5	309	−11·5	681·5	216	767·5

[Table IX. Sn formant differences (Hz)]

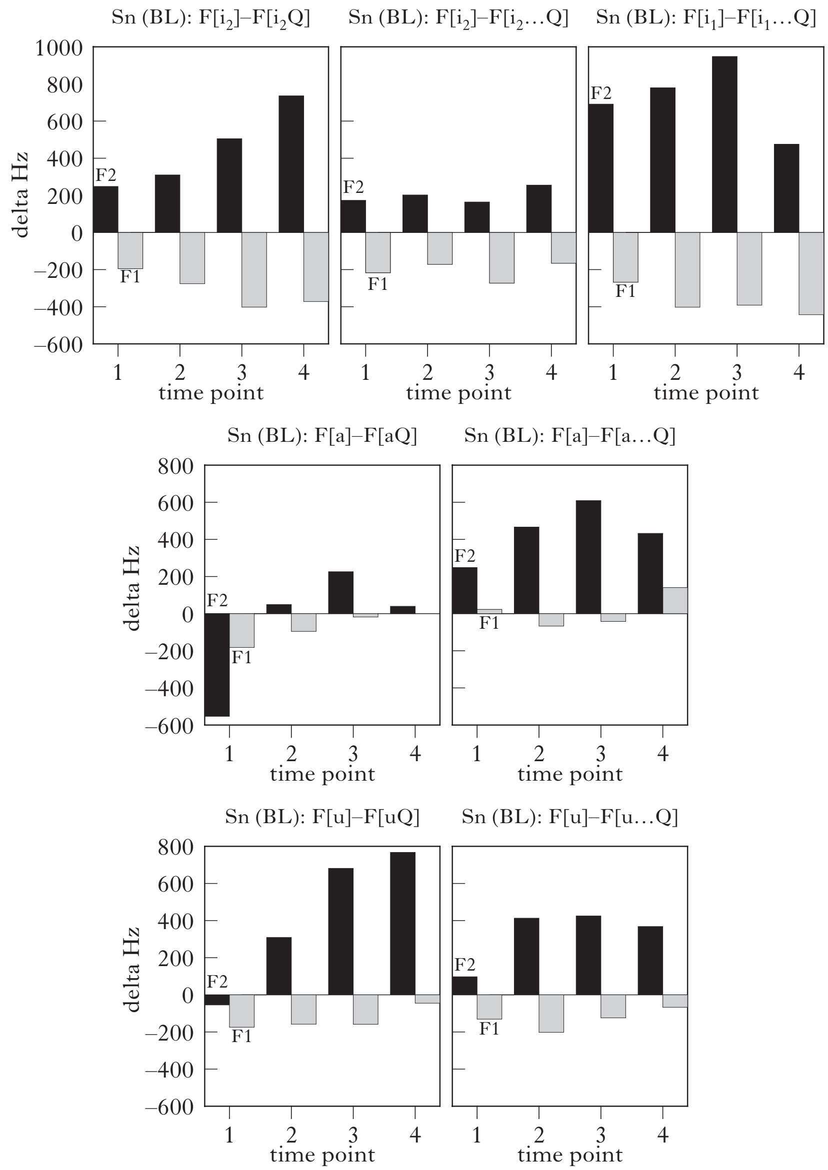

Figure 13
Sn (BL) formant differences

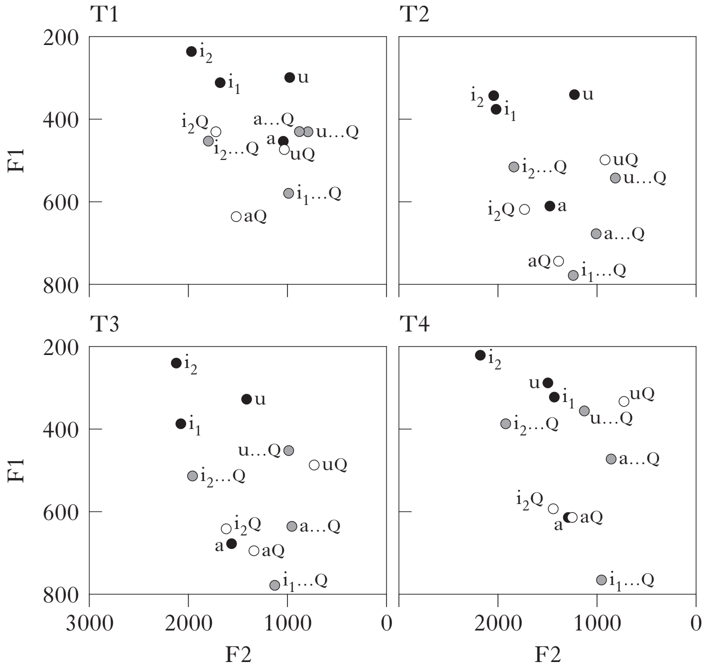

Figure 14
Sn (BL) vowel plots, T1–T4

	LN		BL	
	F1	F2	F1	F2
i/nonQ	24	138	55	90
i/…Q	46	78	60	73
i/Q	32	42	95	134
i_1/nonQ	38	152	37	302
i_1/…Q	14	91	97	131
a/nonQ	60	22	95	231
a/…Q	54	55	120	96
a/Q	29	61	44	138
u/nonQ	48	80	24	229
u/…Q	43	59	77	236
u/Q	51	23	77	149

[Table X. Standard deviation (Hz) in SN (LN, BL)]

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