The effects of post-velar consonants on vowels in Ditidaht*

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Abstract: This article examines the effects of post-velar consonants on vowels in Ditidaht using acoustic data obtained using instrumental methods from four native speakers. The results of this examination show that uvulars cause backing, pharyngeals cause centralization, and glottals cause peripheralization. A survey of phonological patterns involving post-velar consonants in Ditidaht reveals that high vowels cannot occur before coda pharyngeals. Additional phonetic investigation shows that in that same position, short /a/ and /o/ have merged, fully collapsing the vocalic height distinction among short vowels before coda /ʕ/. The results of the phonological survey show that no single pattern unifies all the post-velar consonants in Ditidaht, but that the phonological patterns that are present demonstrate phonetically-grounded phonological connections between subsets of the post-velar consonants.

Keywords: Ditidaht, post-velar consonants, phonetics, phonology, acoustic measurement, merger

1 Introduction

Ditidaht is a Southern Wakashan language spoken on Vancouver Island whose phonemic inventory includes consonants at all three post-velar places of articulation: Uvular, pharyngeal/epiglottal, and glottal. In the languages that contain similarly rich inventories of post-velar consonants (such as those in the Semitic, Cushitic, and Salish stocks), these consonants often pattern together phonologically, for example by causing effects on vowels, by being avoided in certain prosodic positions, and by systematically failing to co-occur, especially in lexical roots (Bessell 1992, 1998a,b; Hayward and Hayward 1989; McCarthy 1991, 1994). These phonological patterns have been used as evidence to support the

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claim that the post-velar consonants constitute an innate natural class, the gutturals (Hayward and Hayward 1989; McCarthy 1991, 1994). Languages like Ditidaht that contain rich inventories of post-velar consonants are important because they offer potential sources of evidence bearing on this claim. While some of the phonological patterns in Ditidaht that involve post-velar consonants have been identified in previous research (e.g. Haas 1969; Jacobsen 1969; Werle 2007, 2012), no study has investigated the phonetic effects of post-velar consonants on vowels in Ditidaht. This article presents the results of an instrumental phonetic investigation of these effects and surveys the phonological patterns in Ditidaht in which the post-velar consonants pattern together.

First, this article provides some general background on Ditidaht (Section 2), which is followed by an overview of its phonemic inventory and prosody (Section 3). The article then goes on to describe a new instrumental phonetic study of how the post-velar consonants affect the realization of vowels in Ditidaht (Section 4). After presenting the results of this study, a brief survey of the phonological patterns in Ditidaht that involve post-velar consonants is presented in Section 5. The article concludes in Section 6 with a discussion of how the phonological patterning of the post-velar consonants in Ditidaht can be interpreted.

2 General background

Ditidaht (Nitinaht; autonym *diidiitidq* 'Ditidaht language') belongs to the southern branch of the Wakashan stock and is closely related to Makah and Nuuchahnulth.[1] Within the southern branch, Jacobsen (2007:26) concludes that the closest relationship is between Ditidaht and Makah, which is reflected in the phylogenetic tree for the Wakashan stock in Figure 1.

The historical dialectal differentiation of Ditidaht is difficult to assess, but in the contemporary language, dialectal differences are minimal and often difficult to separate from individual differences among speakers. The most salient division is that between the main dialect and the dialect of Port Renfrew, which is the seat of the Pacheedaht First Nation.[2] The Ditidaht First Nation is based in Malachan (Reserve 11), which is located near the most inland point of Nitinaht Lake. The work presented here includes data that were collected with speakers in Malachan. The Ditidaht language is spoken today by fewer than ten individuals who learned it in childhood, but the language is being revitalized through language and culture classes at the Ditidaht Community School and through immersion activities at the Asaabus daycare center.

[1] The term 'Nitina(h)t' most likely comes from the rendering of the autonym *diitiidʔaaʔtx̣/* ('Ditidaht people') into Nuuchahnulth (Bouchard and Kennedy 1991:3), which would have included nasal /n/ for Ditidaht /d/ and pharyngeal /ħ/ for Ditidaht /x̣/.

[2] Mary Haas discovered an old system of counting from one to ten that was apparently borrowed from a Salish language. This language was determined to most likely be Quinault, but the exact nature and extent of the contact is unclear (Kinkade 2002).

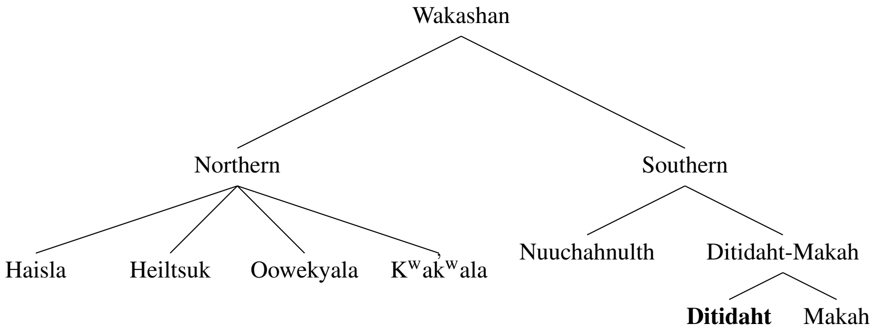

Figure 1: Phylogenetic relationships among languages of the Wakashan stock (following Jacobsen 2007)

3 Ditidaht phonemic inventory and prosody

3.1 Consonant phonemes and allophony

Ditidaht's phonemic inventory consists of 42 consonants, including sounds whose existence is marginal due to historical sound changes. Historically, /m, m̓, n, n̓/ became the voiced stops /b, b̓, d, d̓/ (Haas 1969; Kinkade 1985; Sylak-Glassman 2013; Thompson and Thompson 1972) and /q̓, q̓ʷ/ became /ʕ/ (Jacobsen 1969).[3, 4] The velars and uvulars show strong parallelism in the inventory, with both places of articulation contrasting plain versus labialized phonemes, and, like the alveolar place, contrasting plain and glottalized stops with fricatives. It is also worth noting that /h/ can only occur in the syllable onset, never in the coda.

The pharyngeal consonant and glottal stop exhibit similar patterns of allophony. Both surface as stops in onset position, with the pharyngeal surfacing as [ʡ] and the glottal surfacing as [ʔ]. However, in vowel-adjacent coda position (i.e. CV__), glottal stop is often realized as creakiness or laryngealization on the preceding vowel ([V̰]), and the pharyngeal is realized as a pharyngeal glide (symbolized [ʕ])

[3] It must be noted that some native speakers disagree with the phonemic status of the voiced glottalized plosives (/b̓, d̓/), arguing that they do not perceive these sounds to be the same as phonemes that are written the same way in Nuuchahnulth (and which often historically correspond to those in Ditidaht). Under this view, the preferred way to write these sounds is as a glottal stop followed by a plain voiced consonant, rather than a voiced consonant with an apostrophe above it. However, this study follows Werle (2007, 2012) in positing the existence of phonemic voiced glottalized consonants since this allows for a theoretically simpler explanation of Ditidaht phonotactics.

[4] The latter sound change will be discussed in more detail in Section 5. Note that in Ditidaht, /x̣, x̣ʷ/ are preserved as such. This is in contrast to Nuuchahnulth, in which both /x̣/ and /x̣ʷ/ historically merged and became /ħ/.

that strongly affects the preceding vowel.

Table 1 presents the consonant phonemes of Ditidaht. To make this work more accessible to members of the Ditidaht speech community, this article uses the current Ditidaht orthography, which is based on Wakashanist transcription. The consonant inventory is shown using Ditidaht orthography in Table 1. Table 2 shows the Ditidaht consonant inventory in IPA. The phonemes in parentheses are marginal due to sound change.[5]

	Bilab.	Alv.	Postalv.	Pal.	Vel.	Uv.	Phar.	Glot.
Plosive	p b	t d			k kʷ	q qʷ		ʔ
Glottalized Plosive	p̓ b̓	t̓ d̓			k̓ k̓ʷ	(q̓ q̓ʷ)		
Nasal	(m m̓)	(n n̓)						
Fricative		s	š		x xʷ	x̣ x̣ʷ	ʕ	h
Affricate		c c̓	č č̓					
Lateral Fricative		ł						
Lateral Affricate		ƛ ƛ̓						
Approx.	w w̓			y y̓				
Lateral Approx.		l l̓						

Table 1: The consonant phonemes of Ditidaht in the current Wakashanist orthography

[5] The phoneme /ħ/ is not listed because it occurs in far fewer words in Ditidaht than other marginal phonemes. Note that while nasals are fully marginal, and preserved only in around 30 lexical items, the glottalized uvular stops are still actively produced by the synchronic phonology through the process of hardening (Werle 2007:81–82).

	Bilab.	Alv.	Postalv.	Pal.	Vel.	Uv.	Phar.	Glot.
Plosive	p b	t d			k kʷ	q qʷ		ʔ
Glottalized Plosive	p’ ˀb	t’ ˀd			k’ k’ʷ	(q’ q’ʷ)		
Nasal	(m ˀm)	(n ˀn)						
Fricative		s	ʃ		x xʷ	χ χʷ	ʕ	h
Affricate		t͡s t͡s’	t͡ʃ t͡ʃ’					
Lateral Fricative		ɬ						
Lateral Affricate		t͡ɬ t͡ɬ’						
Approx.	w ˀw			j ˀj				
Lateral Approx.		l ˀl						

Table 2: The consonant phonemes of Ditidaht in IPA

3.2 Vowel phonemes and allophony

The vowel system of Ditidaht consists of ten phonemes, resulting from a system with five basic vowel qualities (/a, e, i, o, u/) in which length is contrastive. Although for native speakers the primary perceptual difference between long and short vowels is duration (Werle 2007:76), the long vowels are acoustically more peripheralized with less overlap in quality than the short vowels. To non-native speakers, the difference between long and short vowels is often perceived in terms of quality, with long vowels being consistently tense, and short vowels being realized as both tense and lax. Table 2 presents the Ditidaht vowel phonemes along with an impressionistic transcription of their range of variation, following Werle (2007:76) and confirmed during the course of field research. Note that in the orthography as in this chart, long vowels are indicated with double vowels rather than the length diacritic of IPA.

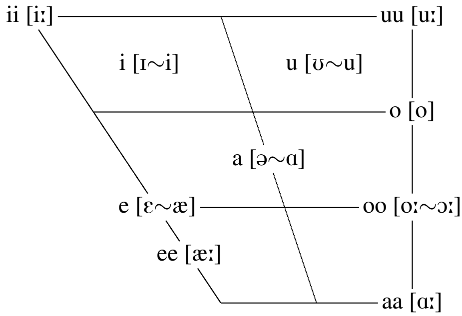

Figure 2: The vowel phonemes of Ditidaht with an impressionistic transcription of variation in IPA

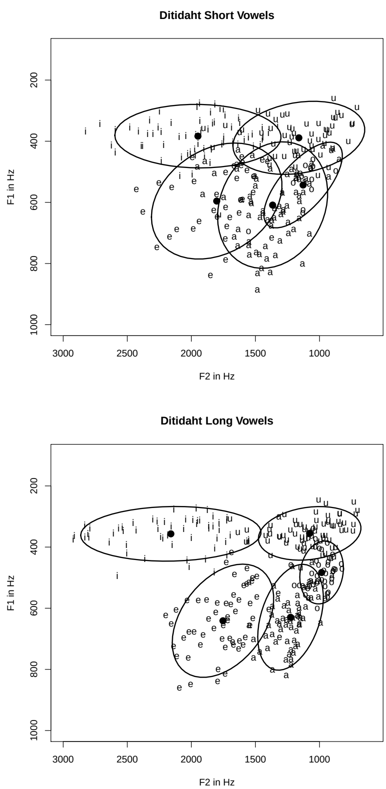

Figure 3: Vowel clouds showing the variation in the quality of short vowels (left) and long vowels (right) in Ditidaht based on 536 tokens total from four native speakers

The vowel clouds in Figure 3 show the range of variation in vowel quality for short and long vowels, respectively, based on measurements made from 536 total tokens of vowels from the speech of four Ditidaht native speakers. The ellipses in the figures encompass 80% of the tokens for each category of vowel, and the black dot in each ellipse indicates the mean realization of the vowel (which is based on all tokens, not just the 80% within the ellipse). These vowel clouds show that the short vowels occupy much of the same acoustic space as the long vowels, which establishes the fact that they are differentiated primarily by a difference in duration rather than quality. However, the short vowels extend further into the center of the space, indicating the relative prevalence of lax realizations compared to long vowels. Note that the long vowels overlap less in quality than the short vowels.

3.3 Syllable structure and stress

In Ditidaht syllables, onsets are obligatory and composed of at most one consonant (Werle 2007:76). Vowels in hiatus are not tolerated, and only a single vowel may occupy the nucleus (ibid.). Hiatus is resolved through the process of vowel fusion, which causes the combinations /a + i/ and /a + u/ (in any order) to become /e/ and /o/, respectively (ibid.). Any number of consonants in principle may appear in the coda, but clusters of more than four consonants are rare (ibid.). The distribution of consonants within a syllable is regulated by their voicing status and by their proximity to a vowel, as detailed in Table 3, which is adapted from Table 1 of Werle (2007:83).[6]

	Post-Vocalic Coda	Word-Initial Onset	Post-Consonantal Onset	Non-Vowel-Adjacent Coda
Plain Voiceless	✓	✓	✓	✓
Voiceless Glottalized	✓	✓	✓	*
Plain Voiced	✓	✓	*	*
Voiced Glottalized	✓	*	*	*

Table 3: Distribution of consonants within a syllable based on voicing and glottalization (adapted from Werle 2007:83)

Stress in Ditidaht is predictable and not phonemically contrastive (Werle 2007:91). The placement of stress is determined by the length of the vowel in the first syllable: If the vowel in the first syllable of the word is long, it is stressed, otherwise the vowel in the second syllable is stressed (regardless of length or the identity of

[6]Note that voiceless glottalized phonemes are realized phonetically as ejectives while voiced glottalized phonemes are realized with pre-glottalization, which takes the form of laryngealization or creaky voicing on the preceding vowel.

the coda consonant; ibid.). Because stress in Ditidaht is regular, it is not marked here.

4 The effects of post-velar consonants on vowels

Because Ditidaht possesses phonemic consonants at all three post-velar places of articulation, it is a strong candidate for providing surface evidence for a post-velar natural class. The effects of post-velar consonants on vowels are the type of evidence that is most frequently used to support the existence of an innate natural class, such as the guttural natural class, that consists of the post-velar consonants. Characterizing these effects in Ditidaht is therefore a crucial part of understanding their phonological patterning and evaluating how that patterning should be captured.

This section presents an instrumental acoustic study of the effects of post-velar consonants on vowels in Ditidaht. First, the methodology of the study is presented (Subsection 4.1) with a discussion of the type of data that were gathered (Subsection 4.2) and how the data were analyzed (Subsection 4.3). Next, the results of the study are presented (Subsection 4.4) and followed by discussion (Subsection 4.5). The next sections then present a broader discussion of the phonological behavior of post-velar consonants and how their patterning can be understood.

4.1 Methods

The data for this study were gathered during two trips to Malachan during May–June 2012 and May–June 2013.[7] Data were elicited through individual interviews with four Ditidaht Elders (two women, two men) who are fluent speakers and learned Ditidaht during childhood. These interviews took place in quiet environments at the Ditidaht Community School and at one of the speakers' homes. In each interview, the author elicited Ditidaht words by asking for the Ditidaht word that was represented by a given English gloss. When speakers were unsure of which word was being elicited, the author pronounced the target Ditidaht word to the best of his ability. In 2012, native speakers were asked to provide only the word being asked for. In 2013, to better control the overall rate of speech, speakers were asked to utter the target word using the carrier phrase *ƛaʔuu waa* X, 'Say X again.'[8]

[7]The recordings that were gathered during fieldwork in the summers of 2012 and 2013 will be archived with the Survey of California and Other Indian Languages at the University of California, Berkeley (http://linguistics.berkeley.edu/∼survey/) and will be digitally accessible through the California Language Archive (http://cla.berkeley.edu/).

[8]Every speaker rejected a formulation of this phrase in which the target word was in sentence-medial position. In addition, impressionistically, the speech rate of consultants

To record consultants' speech, a Zoom® Handy H4N digital recorder was used with an Audio Technica® AT803B lavalier condenser microphone in 2012 and with an AKG® C520 L head-mounted condenser microphone in 2013.

4.2 Data

For the labial, coronal, palatal, and velar places, the elicitation prompts were designed to obtain one token per speaker of each vowel quality in both long and short form in stressed position in contact with a consonant at the the place of articulation being investigated.[9] Wherever possible, given the lexicon, the elicitation prompts provided tokens in which the vowel was surrounded by consonants with the same place of articulation (e.g. both labial). The next best tokens were those in which the consonant of interest was in coda position. It was assumed, based on the effects of coda-position /ʕ/ and /ʔ/, that the effect of a consonant on a vowel would be strongest with the consonant in coda position. If neither of those two options was available, a token with the consonant of interest in onset position was chosen. Because of gaps in the lexicon, some vowel qualities were unavailable in the context of some places of articulation (e.g. short /e/ adjacent to coronals).[10]

For the post-velar places (uvular, pharyngeal, and glottal), data were elicited to obtain one token per speaker of each vowel quality in both long and short form in stressed position in contact with each post-velar consonant itself, not just any consonant at a particular post-velar place of articulation. The elicitation targets provided tokens in which the vowel was in coda position or in onset position, as well as tokens in which the vowel was surrounded. The total distribution of tokens by their position with respect to both stress and the syllable is given in Table 4.

The larger number of uvular and glottal tokens biases the mean formant measurements over the data as a whole to more closely resemble those of vowels adjacent to uvulars and glottals. This likely causes the effects of other consonantal places of articulation to appear stronger and decreases the chance that effects will be observed in vowels next to uvulars and glottals. Although the strength of consonants' effects on vowels is important here for judging whether the effect may be perceptible, the strength of the effect is otherwise less important than demonstrating which types of effects occur. Finally, despite the possible bias in the overall mean toward uvulars and glottals, the formant measurements in vowels next to these consonants still diverge from the mean in perceptible ways.

[9] For the purposes of this study, both the post-alveolar consonants and the palatal consonants are included under the umbrella term 'palatal.'

[10] These gaps occur only with the mid vowels, which are rare and appear to be derived from /i, a, u/, which function as the core vowels in the language. The mid vowels most likely arose through processes like fusion, which resolves hiatus by causing the combinations /ai/ and /ia/ to be realized as /e/ and the combinations /au/ and /ua/ to be realized as /o/ (Werle 2007:77). Surface phonotactic constraints determine the length of the fused vowel (ibid.).

	Labial						Coronal						Palatal					
Total	62						50						57					
σ Pos.	Surr		Coda		Ons		Surr		Coda		Ons		Surr		Coda		Ons	
	22		20		20		36		0		14		31		4		22	
Stress	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v
	18	4	14	6	12	8	34	2	—	—	14	0	20	11	0	4	22	0

	Velar					
Total	51					
σ Pos.	Surr		Coda		Ons	
	27		16		8	
Stress	v́	v	v́	v	v́	v
	16	11	10	6	5	3

	Uvular						Pharyngeal						Glottal					
Total	145						55						116					
σ Pos.	Surr		Coda		Ons		Surr		Coda		Ons		Surr		Coda		Ons	
	15		49		81		8		21		26		26		37		53	
Stress	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v	v́	v
	12	3	48	1	68	13	0	8	11	10	22	4	12	14	30	7	48	5

Table 4: Distribution of elicited tokens with respect to place of articulation, stress, and position in the syllable

4.3 Analysis

The original recordings were annotated using Praat (Boersma and Weenink 2001), and formants were automatically detected and extracted using a Praat script. The script took the measurements of F1, F2, and F3 for each target vowel (which constituted one token) at 33%, 50%, and 66% of the vowel's duration. For each formant in each token, these measurements were averaged to produce a mean measurement for each of the first three formants in each token. After hand correcting the formant measurements where necessary, it was found that F3 was generally unreliable. The F3 data were thus excluded from this study, and only measurements of the first two formants are used here.

Formant detection was done using Praat's implementation of the Burg algorithm for calculating LPC coefficients. The settings used were the default settings (0.0 second time step, a maximum of 5 formants, window length of 0.025 seconds, and pre-emphasis from 50 Hz), except for the maximum formant frequency, which was specified to be 5500 Hz for female speakers and 5000 Hz for male speakers.

4.4 Results

The results of the study come in the form of mean F1 and F2 measurements for each vowel phoneme in the context of each consonantal place of articulation. To interpret these measurements, a mean for all tokens, regardless of place of articulation, stress, or position in the syllable, was calculated. The mean formant measurements for vowels adjacent to consonants at each individual place of articulation were then compared to the overall mean for vowels adjacent to every place of articulation. This method of comparison departs from much previous research on the effects of post-velar consonants on vowels, which uses the vowel formant measurements adjacent to glottal consonants rather than an overall mean as a basis of comparison.[11]

To determine whether the effects of consonants on vowel quality is significant, the effects, in the form of differences from the overall mean, are compared to the just-noticeable-differences from the overall mean. The just-noticeable-difference (JND) represents the threshold past which a change in formant measurements will cause a listener to detect a difference in vowel quality. Flanagan (1955:616) determined the JNDs for F1 and F2 that caused a majority (>50%) of listeners to perceive a difference in vowel quality, and found that the JND varied depending on the initial value of the formant and whether the change was in a positive or negative direction. The maximum change necessary to cause a perceptible difference in vowel quality is given in the first row of Table 5. This table then shows the JNDs in Hz that correspond to positive and negative changes in both F1 and

[11] Other research, including Bessell (1992), interprets the formant values of vowels adjacent to glottals as being the default value.

F2 given the mean F1 and F2 values found for each vowel quality. Divergences from the overall mean that exceed these JNDs are likely to be perceptually significant, and are highlighted with shading in Table 6. This table shows the mean differences in vowel quality that occurred adjacent to each consonantal place of articulation.

V	*n*	MEAN		JNDS			
		F1	F2	+F1 5.7%	–F1 5.4%	+F2 4.5%	–F2 5.0%
a	163	609	1366	35	33	61	68
aa	67	630	1226	36	34	55	61
e	35	596	1802	34	32	81	90
ee	56	641	1753	37	35	79	88
i	76	383	1949	22	21	88	97
ii	58	357	2160	20	19	97	108
o	34	543	1128	31	29	51	56
oo	38	483	984	28	26	44	49
u	68	389	1161	22	21	52	58
uu	75	355	1077	20	19	48	54

Table 5: Mean formant measurements for vowels next to all consonants along with the just-noticeable-difference (JND)

	Labial		Coronal		Palatal		Velar		Uvular		Pharyngeal		Glottal	
	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2	F1	F2
a	-103	-372	-82	173	-109	199	-62	-302	45	-58	111	9	88	50
aa	-67	-162	46	104	-129	218	28	127	25	-20	18	91	19	-47
e	-102	18	—	—	-91	58	-10	195	-39	-129	111	-145	6	-9
ee	-32	57	-57	132	-82	41	-102	219	14	-61	74	-163	9	20
i	-2	-171	-8	92	-53	90	19	-215	31	-150	31	35	-42	310
ii	-15	172	-33	11	-38	5	-5	-44	49	-150	-24	-23	13	412
o	—	—	—	—	-55	-33	—	—	—	—	44	136	2	-53
oo	-38	-40	34	92	-50	45	28	-47	3	-68	—	—	27	1
u	-44	-203	-10	443	-5	215	28	-72	9	-197	-9	-96	-3	-42
uu	-18	-80	-7	257	-24	101	8	62	43	-77	6	195	-5	-70

Table 6: The difference from the mean for vowels in contact with consonants at each place of articulation, with differences that exceed the JND indicated by shading

4.5 Discussion

Before discussing the effects of the post-velar consonants in detail, some general remarks will be made about the effects of consonants at the labial, coronal, palatal, and velar places. To interpret the differences in formant measurements between the overall mean and specific places of articulation in Table 6, recall that F1 is inversely correlated with vowel height and that F2 is inversely correlated with vowel backness. Table 7 summarizes how the divergence of formant measurements from the overall mean can be interpreted.

Formant Shift	Effect on Vowels
F1 ↑	lowering
F1 ↓	raising
F2 ↑	fronting
F2 ↓	backing

Table 7: The interpretation of formant shifts

The labial, coronal, and palatal consonants cause effects that are well-attested in other languages. The labial consonants cause simultaneous backing and raising such that vowels become more like round /u/. However, the front vowels /e/, /ee/, and especially /ii/ seem to show fronting effects. The coronal consonants cause fronting and raising toward /i/, although fronting seems to be the primary effect.

Palatal consonants also cause fronting and raising toward /i/, but raising seems to be the primary effect. The effects of consonants at these places of articulation is summarized in the diagrams in Figure 4, which show the vowels of Ditidaht at their mean realizations within the acoustic space used in Figure 3 and use arrows to show the effects that are likely to be perceptually significant. Note that the extent of the effects is not reflected in the size of the arrows.

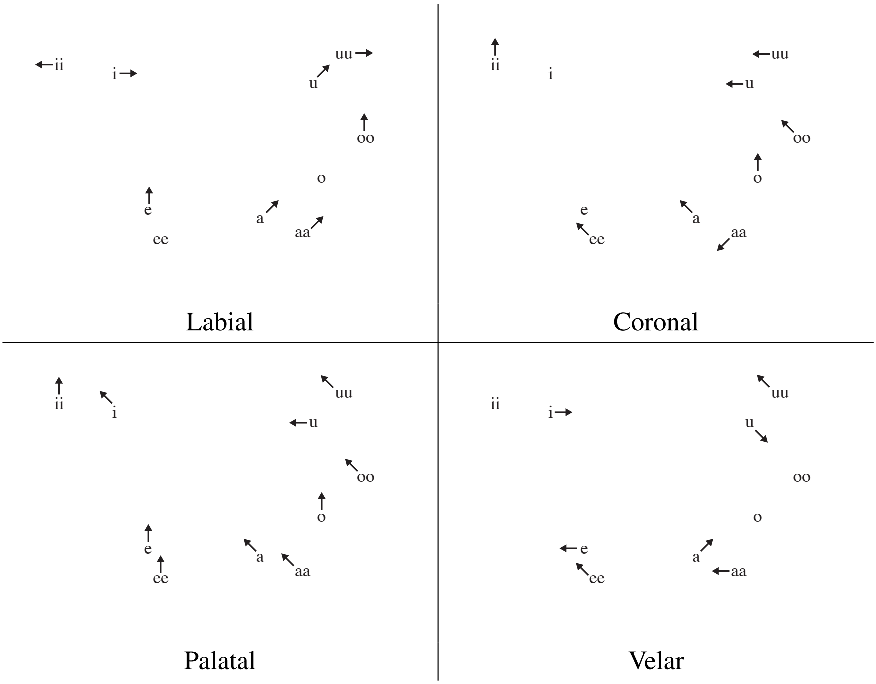

Figure 4: The effects of labial, coronal, palatal, and velar consonants on vowels

Although the pre-velar consonants cause the expected effects, the effect of the velar consonants varies across vowel qualities. There is generally little effect on F1, except in the case of the low vowels /a/ and /ee/ ([æː]). The effect of F2 appears to differ depending on height. Low vowels generally show strong fronting (except for /a/, which shows strong backing), and the high vowels generally show backing with a particularly strong effect on /i/. A diagram showing the effects of velars is included in Figure 4.

The effects of the post-velar consonants are first summarized according to each place of articulation, and then pairwise comparisons are made to highlight how the effects of post-velar consonants on vowels help to distinguish the consonants from each other. The uvulars show backing effects across all vowel qualities and lengths, even when the effects may not reach a perceptible level (as for /ii/ and /oo/). F1 is generally also higher in uvulars, indicating slight vowel lowering. These results are consistent with the cross-linguistic effects of uvulars, which are strongly associated with backing. The effect of the pharyngeal consonant on high vowels is inconsistent, but the pharyngeal consonant seems to centralize non-high vowels, lowering most vowels, backing front vowels, and fronting back vowels. The most common cross-linguistic effect of pharyngeals is to lower vowels, but centralization is attested as the correlate to vowel pharyngealization in the Nakh-Daghestanian (Northeast Caucasian) languages Tsakhur and Udi (Catford 1983:347). The glottal consonants appear to cause the vowels to more widely disperse (i.e. peripheralize). Thus, /ii/ is fronted, /uu/ is backed, and /a/ is lowered. The effects of the post-velar consonants are shown in the diagrams in Figure 5.

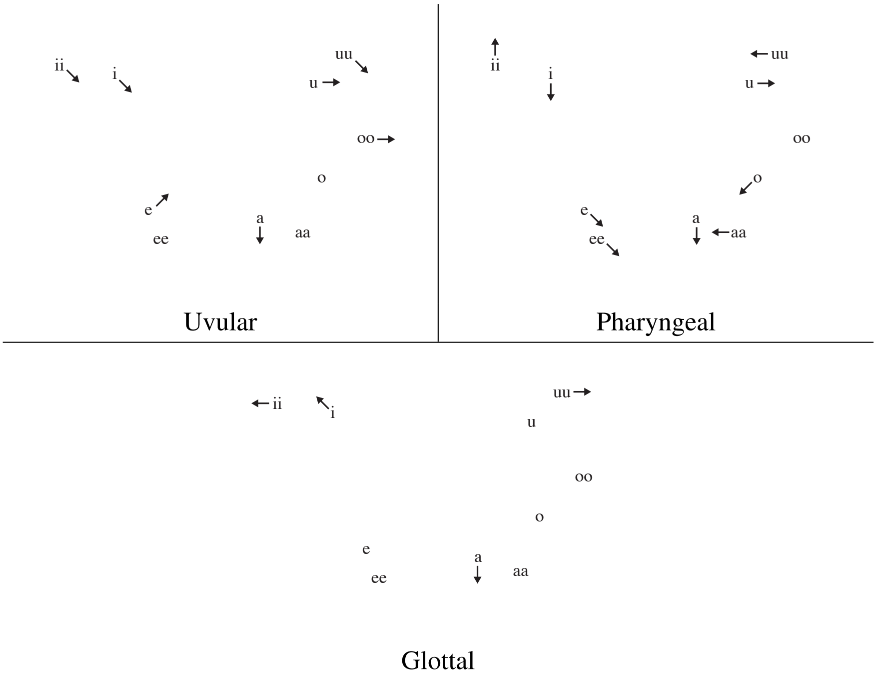

Figure 5: The effects of uvular, pharyngeal, and glottal consonants on vowels

In comparison with the velar consonants, the uvulars cause all vowels except short /a/ and /i/ to be more strongly backed. Articulatorily, the uvulars in Ditidaht are sometimes termed “back velars” since their articulation is not always strongly uvular. The acoustic effects found here point to a possible explanation for why this is possible even though the velar vs. uvular place contrast is maintained. The uvulars cause strong backing effects on vowels, and these acoustic effects can be used to accurately perceive the difference between velars and uvulars.

Table 8 shows the effects of uvulars in comparison to velars, with differences that exceed the just-noticeable-differences indicated by shading. The JNDs were calculated using the same percentages as in Table 5, but applied to the mean formant measurements found adjacent to velar consonants.

	Velar		Uvular	
	F1	F2	F1	F2
a	547	1064	106	245
aa	658	1353	-3	-147
e	586	1997	-29	-324
ee	539	1973	116	-280
i	402	1734	12	65
ii	352	2116	54	-107
o	—	—	—	—
oo	511	937	-25	-21
u	417	1090	-20	-126
uu	363	1138	35	-139

Table 8: Formant measurements for vowels in contact with uvulars relative to the mean formant measurements for vowels in contact with velars

The backing effects of uvulars distinguish them not only from velars, but from pharyngeals, which lower vowels to a greater extent than do uvulars. Table 9 shows that most vowels are considerably more front, with higher F2, when they are adjacent to pharyngeals than when they are adjacent to uvulars. In addition, the pharyngeals cause the low vowels /a/, /e/, and /ee/ to lower even further than with uvulars.

In comparison with vowels adjacent to glottals, vowels adjacent to pharyngeals are lowered and centralized. That is, back vowels are fronted and front vowels are backed. This is consistent with the effects of pharyngeals in comparison with the overall mean. Table 10 shows this and uses shading to indicate any changes that may be perceptible (i.e. which exceed the JND when the mean formant measurements adjacent to glottal consonants function as the initial values).

	Uvular		Pharyngeal	
	F1	F2	F1	F2
a	653	1308	66	67
aa	655	1206	-7	111
e	557	1673	150	-16
ee	655	1693	60	-103
i	414	1799	0	185
ii	406	2010	-73	127
o	—	—	—	—
oo	486	916	—	—
u	398	964	-18	101
uu	398	999	-37	273

Table 9: Formant measurements for vowels in contact with pharyngeals relative to the mean formant measurements for vowels in contact with uvulars

	Glottal		Pharyngeal	
	F1	F2	F1	F2
a	697	1417	23	-41
aa	648	1179	0	138
e	602	1793	105	-136
ee	661	1784	54	-194
i	338	2292	76	-307
ii	370	2572	-37	-435
o	546	1075	42	189
oo	510	985		
u	390	1139	-10	-74
uu	359	1074	2	198

Table 10: Formant measurements for vowels in contact with pharyngeals relative to the mean formant measurements for vowels in contact with glottals

In summary, uvular consonants cause vowel backing while pharyngeals appear to cause lowering and centralization. These effects hold true in comparison with the overall mean as well as when the uvulars are compared to velars and the pharyngeals are compared to glottals. Glottal consonants cause peripheralization of the three core vowel qualities /i/, /u/, and /a/.

5 Survey of phonological patterns involving post-velar consonants in Ditidaht

Several phonological patterns involve post-velar consonants, relate to their effects on vowel quality, and highlight the connections between post-velar places of articulation. Two phonological facts demonstrate that the effects of coda /ʕ/ severely limit the vowel quality contrasts that can occur with a vowel before coda /ʕ/. High vowels may not occur before a coda pharyngeal, and this is apparent through doublets with related roots. For example, the root *ciq-* appears as such in *ciciqt* 'talk to someone,' but appears with /i/ lowered to /e/ before the coda pharyngeal in *ceʕqaƛ* '(public) speaker.' The restriction holds true of high vowels generally, and applies not only to front /i/, but to back /u/. The root *duu-* appears as such in the word *duduuk* 'to sing,' but its /u/ vowel is lowered to /o/ before the coda pharyngeal in *doʕqaƛ* 'singer, person entrusted with remembering the songs of many families.'

In addition to this phonological constraint against high vowels before a coda pharyngeal, the available vowel quality contrasts are further limited by the fact that /a/ and /o/ have merged in that same position. Using the same methods as the main study presented here, 99 total tokens of /a/ and /o/ before coda /ʕ/ were obtained (77 /aʕ/, 22 /oʕ/). Figure 6 shows vowel clouds of /a/ and /o/ in this context.

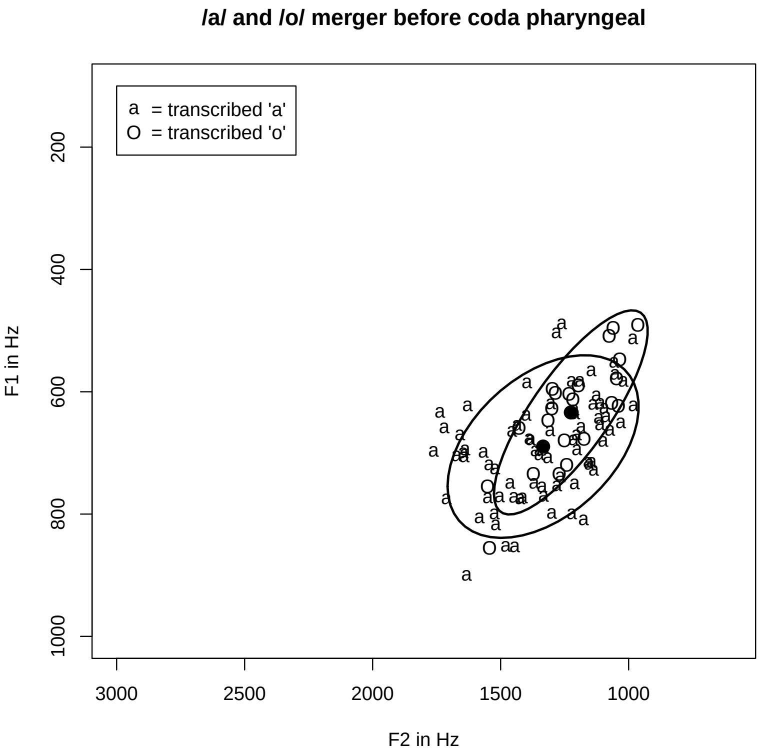

Figure 6: Overlap in /a/ and /o/ before coda /ʕ/, with ellipses encompassing 80% of tokens in each category

The two ellipses, which each encompass 80% of the tokens obtained for each category, overlap substantially although not completely. This suggests either a complete merger, in which there is no distinction between /a/ and /o/ before coda /ʕ/, or a near-merger in which the vowels are still articulatorily distinct, but are not perceived to be distinct by speakers. This merger (or near-merger) has collapsed the vocalic height distinction before coda pharyngeals such that only a front-back contrast in the form of /e/ vs. /a∼o/ now exists in that position.

Another phonological pattern that involves the post-velar consonants in Ditidaht has its roots in a well-known sound change in the language. Historically, *q̓ and *q̓ʷ merged and gave rise to modern /ʕ/ in both Ditidaht and Nuuchahnulth (Jacobsen 1969). This process is still synchronically active as part of a larger process known in the Wakashanist literature as 'hardening.' Hardening usually results in the glottalization of a phoneme preceding a hardening suffix or clitic.

The phonemes /q/ and /q^w/ harden to /q̓/ and /q̓^w/ when they follow a consonant (e.g. /bucibuχ̣^wq+ʔaq/ → [bucibuχ̣^wq̓aq] 'the black bear'), but to /ʕ/ following a vowel (e.g. /ʔiniiq+ʔa/ → [ʔineeʕa] 'there are few'; Werle 2007:81-82).

Note that in the latter example, *ʔineeʕa* 'there are few,' vowel fusion causes underlying /ii/ to surface as [ee] and does so across /ʕ/. Werle (2007:77) notes that "most cases of vowel fusion in Ditidaht involve vowel metathesis across the non-oral stops /ʔ ʕ/." Thus, the process of hardening shows a phonological connection between the uvular stops and /ʕ/ and the process of vowel fusion shows a phonological connection between /ʕ/ and /ʔ/, which both function as transparent phonemes.

6 Conclusion

This article has presented new findings on the acoustic effects of consonants, especially post-velars, on vowels in Ditidaht. It was shown that uvulars cause strong backing effects, that pharyngeals cause vowels, particularly non-high vowels, to centralize, and that glottals cause vowels to be more dispersed and peripheral. A phonological constraint against high vowels occurring before a coda pharyngeal combined with a merger (or near-merger) of short /a/ and /o/ in that same position has neutralized the phonemic height distinction in short vowels which occur before /ʕ/ in coda position. The normal five-quality distinction is collapsed to a two-quality backness distinction (/e/ vs. /a∼o/), with height distinctions eliminated.

While no single phonetic effect or phonological pattern unifies all the post-velar consonants in Ditidaht, there is phonological evidence for connections between subsets of its post-velar consonants. The hardening process provides evidence for a connection between uvulars and the pharyngeal, and the ability of vowel fusion to apply across both the pharyngeal /ʕ/ and the glottal stop /ʔ/ shows a connection between those consonants. These phonological groupings of post-velar consonants have phonetic connections, as shown by Moisik (2013). The uvular and pharyngeal consonants are articulatorily connected by the fact that tongue retraction is synergistic with the epilaryngeal constriction that is obligatory for pharyngeals, and this tongue retraction affects the position of the tongue body, which is used to articulate uvulars (74–75, 373–373). The epilaryngeal constriction involved in the articulation of pharyngeal consonants is synergistic not only with tongue retraction, but with larynx raising. This causes the glottis, in some cases, to make contact with the epilarynx, causing ventricular incursion, and this establishes an articulatory connection between pharyngeals and glottal stop (77–79). Using the theoretical framework proposed in Sylak-Glassman (2014), the phonetic connection between the pharyngeal /ʕ/ and uvular stops as well as the connection between the pharyngeal /ʕ/ and glottal stop can be used to derive the phonological natural classhood of these subsets of post-velar consonants.

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