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An acoustic analysis of vowel formants in pharyngeal and glottal contexts in Nuu-chah-nulth*

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1 Introduction

In this paper we study some of the acoustic effects the glottal stop /ʔ/ and the "pharyngealized glottal stop" /ʕ/ have on neighbouring vowels in Nuu-chah-nulth (Nootka), a Wakashan language spoken on the west coast of Vancouver Island. Previous descriptions of these two sounds reveal that they are very similar, and indeed they are often difficult for the non-native ear to distinguish. Our aims are primarily to document and describe precisely the acoustic effects these sounds have on adjacent vowels, with the assumption that such effects are a primary cue to their differentiation. As the pharyngeal is the rarer of the two sounds, our discussion focuses on its properties.

2 Background

Although written with the same symbol normally used for a pharyngeal fricative/approximant, this is not an adequate characterization of /ʕ/. This sound has been described in the past by Sapir and Swadesh (1939: 13) as "a glottal stop pronounced with the pharyngeal passage narrowed by the retraction of the tongue toward the back of the pharyngeal wall", by Swadesh (1939: 78) as a "glottal stop with pharyngeal constriction" and by Jacobsen (1969: 126) as a "pharyngealized glottal stop". Rose (1981: 15) gives a somewhat more detailed description:

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> *ʕ consists of a pharyngealized glottal closure which [...] is accompanied by a raised larynx and a retracted tongue root. ʕ is like a resonant in having no release burst (i.e. a stop release). However, associated laryngealization, perceived as a series of 'cracks', gives the impression of a series of stop bursts.*

The strong laryngeal character of /ʕ/ is manifested in various ways in the phonology. First of all, /ʕ/ patterns with the glottalized sounds phonotactically. In Nuu-chah-nulth, glottalized elements are banned from the syllable coda. This includes /ʔ/, /h/, glottalized stops (p', t', ts', tʃ', tɬ', k', k'^{w}), glottalized resonants (m', n', w', j') and /ʕ/. This is noteworthy, because the pharyngeal fricative /ħ/ is freely permitted in the coda, indicating the coda prohibition is restricted to truly glottal elements, including /ʕ/, and not more broadly to sounds which are 'guttural' (cf. McCarthy 1994).

The glottal nature of /ʕ/ is also evident in the phonological alternation called *glottalization*. Nuu-chah-nulth has a class of lexical and grammatical suffixes called glottalizing suffixes which cause glottalization of the preceding consonant, resulting in stops becoming ejectives and fricatives becoming glottalized glides. Interestingly, when the uvular stops /q/ and /q^{w}/ are glottalized, they become the pharyngeal /ʕ/. This reflects the historical evolution of /ʕ/ from /q/ and /q^{w}/ in the proto-language (Jacobsen, 1969). A few examples of the synchronic process of glottalization are given below.

(1) *Glottalization before glottalizing suffixes (a-d, Rose 1976: 58-59)*

a.	/hupt-'atɬ/	[hup.t'atɬ]	*they hid*
b.	/wik-'as/	[wi.k'as]	*not outside*
c.	/hiɬ-'atɬ/	[hi.j'atɬ]	*Inside*
d.	/ts'ax^{w}-'atɬ/	[ts'a.w'atɬ]	*speared inside*
e.	/ts'uq-'aqtɬ/	[ts'u.ʕaqtɬ]	*stabbed inside (eg. knife left in a fish)*
f.	/t'iq^{w}-'as/	[t'i.ʕas]	*sitting on the ground*

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Although in isolation both /ʔ/ and /ʕ/ have largely the same auditory profile, there is a dramatic difference in their effect on neighbouring vowels. Whereas /ʔ/ often adds creakiness, /ʕ/ adds not only creakiness, but adjacent vowels are normally somewhat pharyngealized and high vowels are regularly lowered to mid vowels. Note, however, that contrary to Rose (1981: 16), who was working on the Kyuquot dialect, we have not found that the low vowel /a/ is retracted to /ɑ/ in this environment in the Ahousaht dialect.

(2) *ʕ lowering vowels*

a.	/ʕiːtʃ.nʼuː/	[ʕɛːtʃ.nʼuː]	*bullhead fish*
b.	/ʕitʃ.ʃitɬ/	[ʕɛtʃ.ʃitɬ]	*to become rotten*
c.	/ʕu.jʼi/	[ʕo.jʼi]	*to augment, worsen*
d.	/ʕuː.kʷiɬ/	[ʕoː.kʷɪɬ]	*to augment, worsen*
e.	/ʕaː.ħuːs/	[ʕaː.ħəws]	*place name*
f.	/ʕaːtɬ.ʕaː.tɬa/	[ʕaːtɬ.ʕaː.tɬa]	*soften grass*

(3) *ʔ not affecting vowels*

a.	/ʔin.ku.wʼiɬ/	[ʔin.ku.wʼɪɬ]	*smoke house*
b.	/ʔiːts.kʷin/	[ʔiːts.kʷin]	*mouse*
c.	/ʔu.ʔaː.ɬuk/	[ʔu.ʔaː.ɬuk]	*to look after*
d.	/ʔuː.kʷiɬ/	[ʔuː.kʷɪɬ]	*to*
e.	/ʔas.xʷaː/	[ʔas.xʷaː]	*to ask for something*
f.	/ʔap.piː/	[ʔap.piː]	*back*

This study aims to capture the difference between /ʔ/ and /ʕ/ by analyzing the formant values of vowels following these consonants.

3 Acoustic Study

Formants are the resonant frequencies of one's vocal tract during speech production. They can be very informative, revealing much about such things as vowel height, lip rounding and pharyngealization. Generally, F1 corresponds to a vowel's height. The higher the vowel, the lower F1. Similarly, F2 generally corresponds to the backness of a vowel. The farther back the vowel, the lower F2 (Kent & Read, 1992: 92). Thus by constricting the

vocal tract in various places with the tongue or other muscles, one changes the formant frequencies.

In a pharyngeal environment, F1, F2 and F3 all undergo some change. Pickett (1999: 42) notes that pharyngealization can be observed as a rise in F1 and a drop in F2 on neighbouring vowels. Likewise, Ladefoged & Maddieson (1996: 307) cite a manuscript by Catford, who reports F3 is markedly lower in pharyngealized vowels. This contrasts with glottal stop, where adjacent vowels are not associated with a marked formant transition (Kent & Read, 1992: 143).

Al-Ani (1970: 59-63) studies the effect of these sounds on the formant values of adjacent vowels in Arabic. He finds that /ʔ/ has almost no effect. The pharyngeal /ʕ/, which he analyzes as a voiceless stop[1], has a much greater effect on the formants. He observes that for /i/, the pharyngeal raises F1 by 100 Hz, and lowers F2 by 500 Hz. For /u/ he finds the greatest difference being a slight rise in F2 of 150 Hz, and for /a/ a lowering of 50-100 Hz. Al-Ani concludes that these formant effects, especially F2, are the greatest distinguishing factor between /ʕ/ and /ʔ/. Similar results are reported for Arabic by Alwan (1986) and Butcher & Ahmad (1987).

Alwan (1989) studies onset F1 frequency of /a:/ in Arabic after three different articulatory gestures: uvular, pharyngeal, and glottal. He finds that F1 is higher after things perceived as pharyngeals, intermediate after things perceived as glottals and lower after things perceived as uvulars. Kent & Read (1992: 120) call for further studies to "establish the generality of this acoustic-perceptual relationship". Our paper will look for correlates to these findings in Nuu-chah-nulth, examining F1-F3.

3.1 Method

All of the data used in this paper was elicited from an adult female native speaker of the Ahousaht dialect of Nuu-chah-nulth. The data included for analysis in this paper was elicited over a four-month period during biweekly elicitation sessions. Most of the data was recorded using various analog cassette recorders such as the Marantz PMD430. Data was digitized on an iMac computer sampling at 44kHz. Then acoustic analysis was performed

[1] But cf. Laufer 1996.

using *Praat 3.8.64*, a shareware program developed by Paul Boersma and David Weenink at the Phonetic Sciences department of the University of Amsterdam.[2]

Formant averages for each of the three vowels (/a/, /i/, and /u/) were calculated in nine different contexts: a long vowel after each of C, /ʔ/, and /ʕ/; a short vowel in an open syllable after each of C, /ʔ/, and /ʕ/; and a short vowel in a closed syllable after each of C, /ʔ/, and /ʕ/. Note that in these contexts we use the symbol C to represent any non-guttural voiceless stop (i.e. not uvular, pharyngeal, laryngeal or glottalized). Although formants differ somewhat depending on the place of articulation of a particular stop, we are confident that formants for vowels after C represent an average value for non-guttural stops.

Results of the formant analysis are shown in Appendix 1. The number of tokens included in the calculation of the averages varies from 0 to 8 and this number can be seen in parentheses. The data in Appendix 1 can be read more easily as the bar graphs of Figures 1-3. Here, the values for all of the tokens from the three different syllable contexts (long vowel and 2 short vowel contexts) in Appendix 1 were averaged together. Figure 1 shows the F1 values for /i/, /u/, and /a/ for each of three different preceding consonants: C, /ʕ/ (phar) and /ʔ/ (glot). Figure 2 and Figure 3 show the corresponding values for F2 and F3 respectively.

To minimize confounding variables, the analysis was limited to vowels in word-initial syllables that were not immediately followed by a guttural consonant. Also, whenever possible, the second of three repetitions of a particular token was used for analysis. All formants were calculated at the 25% mark of the vowel.

3.2 Results

As can be seen in Figure 1, the effect of the pharyngeal on F1 is consistent across all vowels, causing an unmistakeable rise. The rising is most pronounced in the vowels /a/ and /i/, where it is 231 Hz and 206 Hz respectively, but F1 also rises 69 Hz in /u/.

[2] For information see <http://www.fon.hum.uva.nl/praat/>.

Figure 1

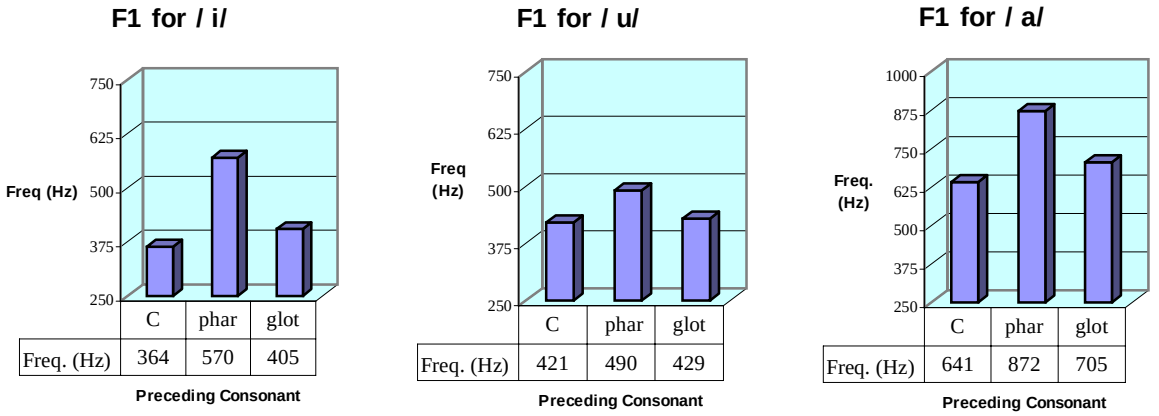


Figure 2

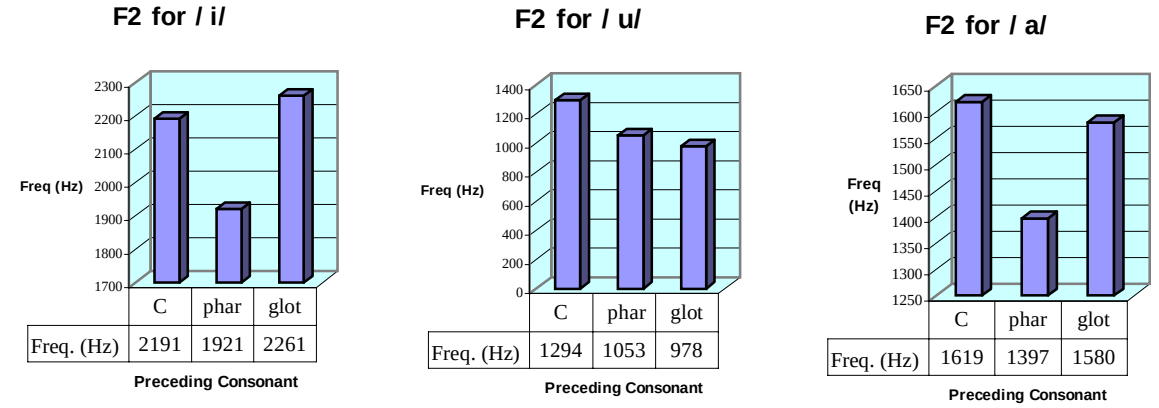
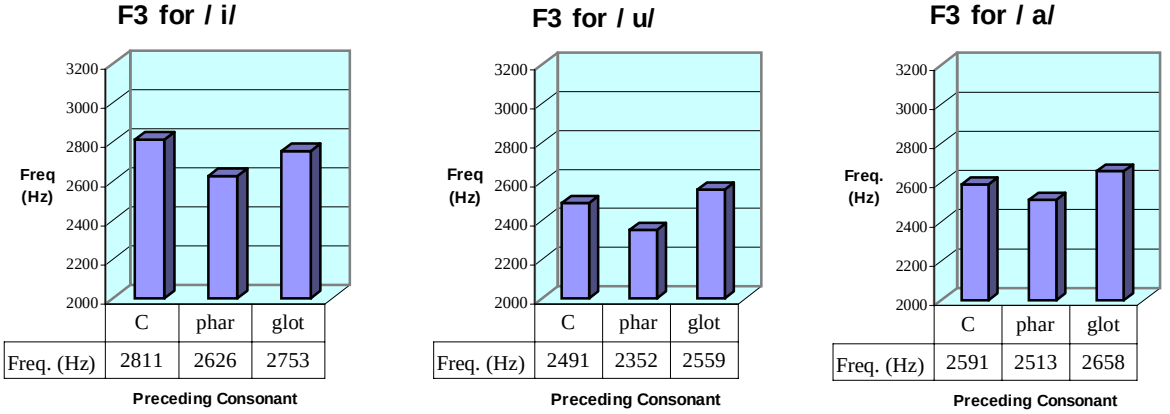


Figure 3



/ʔ/ also shows a rise in F1 across all vowels compared to the standard. However, the effect of /ʔ/ on F1 is far less salient than the effect of /ʕ/. Though much reduced, once again this rising effect is strongest in /a/ and /i/: 64 Hz and 41 Hz. The rise in F1 in /u/ is marginal, only 8 Hz.

The results for F2 are given in Figure 2. Once again, one observes quite an effect on the formant values after /ʕ/, but in this case, the formants are falling. Unlike the F1 results, the drop in F2 is relatively similar for /a/, /i/ and /u/: 222 Hz, 270 Hz, and 241 Hz respectively.

The results after /ʔ/ are somewhat more irregular. Whereas for /i/, the second formant is 70 Hz higher after the glottal stop than after the standard consonant, for /a/ F2 is 39 Hz lower than the standard. Interestingly, F2 drops for /u/ after /ʔ/ to an even greater degree (316 Hz) than after the pharyngeal (241 Hz).

In Figure 3, one finds the results for F3. For all vowels, there is a drop of the third formant after /ʕ/, most dramatically seen in /i/ (185 Hz) and least in /a/ (78 Hz). However, in the case of the glottal stop, F3 drops only 58 Hz for /i/ but rises 67 Hz for /a/ and 68 Hz for /u/ as compared to the formant values of these vowels after C.

4 Discussion

Of the results to note in the data, one interesting finding is the degree of pharyngealization on /a/ following /ʕ/. Since it is not noticeably retracted or lowered, one might expect that the effects of pharyngealization on the formants might be rather subtle. In fact, we found that the formant values of /a/ showed strong effects of pharyngealization.

One can draw a parallel between the results of our own study and Alwan's findings for /a:/. That is, pharyngeals cause the highest rise in F1, and laryngeals an intermediate rise in F1. Although uvulars are outside the scope of this paper, in Shank & Wilson (2000) support is given for the fact that uvulars cause less of a rise in F1 for /a/ than laryngeals do in Nuu-chah-nulth. Our results also establish that the same is true for /i/, and less dramatically so for /u/.

Contrary to work done on Arabic (Al-Ani 1970, Alwan 1986, Butcher & Ahmad 1987) and on Caucasian languages (Catford 1977) we did not find F2 rose for /u/ after the pharyngeal. However, Catford (294) states that a rise in F2 is difficult to explain since one might expect it to fall due to vowel retraction. In this light our results better match our theoretical expectations, but even in this case the lowering effect was much weaker on /u/ than for /i/ and /a/. Given the weaker effects found in F2 of /u/, we are inclined to say that F1 and F3 are clearer, more consistent cues to pharyngealization, contrary to the claim made by Al-Ani for Arabic.

As expected, we have not found that the glottal stop has a great effect on neighbouring vowels. Again, the one exception is F2 for /u/, where /ʔ/ appears to drop the formant to an even greater extent than the pharyngeal. At this time, an explanation is not yet forthcoming for this result.

5 Conclusion

To conclude, we have found that the formant values of vowels are significantly different adjacent to the plain glottal stop /ʔ/ as compared to the "pharyngealized glottal stop" /ʕ/ in Nuu-chah-nulth. The pharyngeal causes a greater rise in F1 and a more substantial drop in F3 than the glottal stop. This is a positive result, for the most part correlating well with the findings of researchers concentrating on Semitic and Caucausian languages.

Appendix 1: F1/F2/F3 by Syllable/Consonant Type

		F1	F2	F3
i	**Cii (5)**	360.2	2258.4	2832.6
	phar ii (1)	632.3	1835.2	2602.8
	glot ii (1)	399.6	2267.3	2789.8
u	**Cuu (4)**	401.4	1184.1	2453.3
	phar uu (2)	514.3	975.5	2120.0
	glot uu (2)	375.7	940.4	2444.4
a	**Caa (6)**	746.2	1548.1	2496.9
	phar aa (5)	898.8	1413.4	2620.9
	glot aa (2)	872.7	1586.5	3032.5
		F1	**F2**	**F3**
i	**Ci]σ (3)**	373.0	2141.2	2747.0
	phar i]σ (1)	597.1	1849.4	2618.8
	glot i]σ (1)	372.1	1790.0	2648.9
u	**Cu]σ (2)**	404.5	1608.2	2351.3
	phar u]σ (5)	480.0	1083.3	2444.3
	glot u]σ (5)	446.2	997.7	2550.6
a	**Ca]σ (3)**	614.9	1760.6	2603.5
	phar a]σ (1)	913.4	1393.2	2039.9
	glot a]σ (2)	750.5	1621.5	2637.4
		F1	**F2**	**F3**
i	**CiC]σ (1)**	353.8	2007.2	2895.4
	phar iC]σ (1)	481.6	2078.9	2657.8
	glot iC]σ (6)	411.2	2338.6	2763.7
u	**CuC]σ (4)**	449.1	1245.9	2597.4
	phar uC]σ (0)	*no examples in corpus*		
	glot uC]σ (6)	432.3	973.8	2603.9
a	**CaC]σ (8)**	572.5	1619.2	2655.9
	phar aC]σ (1)	698.3	1321.4	2446.4
	glot aC]σ (7)	643.7	1565.5	2556.8

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