PHONETICS AND PHONOTACTICS OF VOWEL LARYNGEALIZATION IN UPPER NECAXA TOTONAC

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ABSTRACT

The present paper reports on an investigation of the phonetics and phonotactics of vowel laryngealization in Upper Necaxa Totonac. Using analysis techniques inspired by corpus linguistics, an analysis of transcribed dictionary forms revealed a highly significant relationship between vowel laryngealization and the consonant that followed immediately after the vowel. Specifically, laryngealized vowels were far more likely to occur before glottal stops than non-laryngealized vowels were. Further to these findings, an acoustic measure of voice quality (H1-H2) was extracted from multiple time points of laryngealized and non-laryngealized vowels before and after glottal stops and other consonants. A statistical comparison of H1-H2 values between vowels in various contexts revealed that vowels followed by glottal stops had stronger indications of non-modal phonation regardless of their own laryngealization category, while vowel laryngealization itself did not affect H1-H2. In light of these findings, the the laryngealized vowels may be interpreted as resulting from collocation with glottal stops instead of bearing contrastive larygnealization themselves.

Keywords: Meso-America, documentation, laryngealized vowels, phonotactics, phonation

1. INTRODUCTION

Upper Necaxa Totonac (ISO [tku], hereafter UNT) is a Totonacan language spoken by approximately 3400 people in four communities situated along the Upper Necaxa River in the Sierra Norte of Puebla, Mexico. Like other languages of the Totonacan family, UNT is supposed to maintain a phonation contrast between laryngealized and non-laryngealized vowels [4]. This contrast may occur with any of UNT's contrastive vowel qualities, as well as either of two contrastive lengths (short and long). Vowel laryngealization may also indicate phonological phrase boundaries, as is the case in other related language varieties, such as Coatepec Totonac [21, 24, 25], Filomeno Mata Totonac [23], and Tlachichilco Tepehua [33]. As a result, word final vowels frequently are devoiced, laryngealized, or dropped entirely.

Little is known about the phonetics of laryngealized vowels into Totonacan, but some preliminary acoustic analyses have been performed. In Papantla Totonac, non-modal vowels were found to have overall lower intensity than modal vowels, and tokens produced with stiff voice appeared to be associated with the spread of voicing onto preceding stops [16]. In Misantla Totonac, Trechsel & Faber [31] measured the F1-F2 vowel space and the difference in amplitude between F0 and F1 (a measure they refer to as VQI, for Voice Quality Index). The analysis revealed a high degree of interspeaker variability in the F1-F2 space, but a more stable outcome with respect to VQI: laryngealized vowels had lower VQI scores than non-laryngealized vowels for both speakers. A recent study of duration and vowel space in UNT found that laryngealized vowels tended to have lower F0 than non-laryngealized vowels [11].

Phonation types have highly variable acoustic profiles across langauges, with differences depending in part on whether the phonation is contrastive or allophonic, breathy, creaky, or otherwise modified. Spectral and acoustic measures have been found to differentiate between modal and non-modal phonation types in several languages including English, Korean, and Hmong [12], Mazatec, Mpi, and Chong [6], Zapotec [10], and Gujarati [9, 17], among others. The difference in amplitude between the first and second harmonics, often reported as H1-H2, or H1*-H2* when adjusted for first and second formant values, appears to be the most reliable measure for differentiating phonation types across languages [19, 29], though unadjusted H1-H2 may also be used [18]. In addition to spectral differences, the timing of vowel phonation is affected by contrastiveness: non-modal phonation lasts longer and is more highly differentiated from modal phonation when the phonation differences are contrastive than when they are non-contrastive [6, 12]. In Hupa, allophonic laryngealization spreads from following consonants onto a portion of preceding vowels, but never laryngealizes the entire length of the vowel [13]. Acoustic analysis may therefore reveal evidence for interpreting laryngealization as either allophonic or contrastive in UNT.

In the present paper, the relationship between glottal stops and laryngealized vowels in UNT is explored from two perspectives. First, a collocational analysis of vowels and stops demonstrates that glottal stops are highly likely to be preceded by laryngealized vowels. Second, H1-H2 values from vowels in a variety of segmental contexts are analyzed, revealing that the presence of a glottal stop has a greater effect on laryngealization than does the vowel laryngealization category itself.

2. SEGMENTAL COLLOCATES OF VOWEL LARYNGEALIZATION IN TRANSCRIPTION

2.1. Methods

The materials for the present analysis were extracted from the digital version of the *Upper Necaxa Totonac Dictionary* [5]. All forms were included in the analysis, including head words, inflected forms, and affixes that received their own entries.

The data required little pre-processing before inclusion in the analysis because the orthography of UNT is transparent at the phonemic level. Dictionary forms were copied into a plaintext file format, then transliterated into IPA using grep and regex (regular expressions) find-and-replace methods. Following a method similar to [3], transcriptions were accepted as given in the published dictionary. Because some segments were encoded by complex character sequences (i.e affricate digraphs, ejective fricatives, vowels with length, stress and larygnealization diacritics), phonemic symbols were delimited by inserted spaces on either side. Word boundary markers (#) were inserted at the end of each word to ensure that segments were not interpreted as adjacent across word boundaries.

The resulting list of prepared segment data was then converted into a single text string from which immediately preceding and following segments were identified for all segments using the *shift* function from the data.table package [8] in R [27]. Segmental collocates of stops and vowels only are analyzed here. Vowels were divided into laryngealized and non-laryngealized, while stops were divided into oral and glottal subsets.

The results of the collocation analysis revealed a strong relationship between glottal stops and the laryngealization of vowel that precede them. These data were further subdivided and cross-tabulated according to the laryngealization of the relevant context. Chi-squared tests were performed on these count data in order to determine whether laryngealization of context segments was related to laryngealization of target segments.

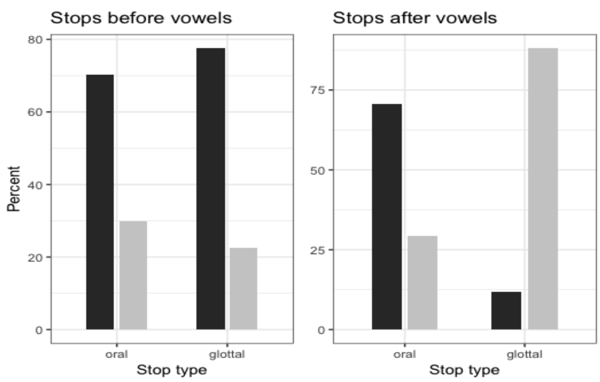
2.2. Results

Count data for stops and vowels are reported in Table 1. Non-laryngealized vowels occurred in higher proportions across both oral and glottal stops, as would be expected given the higher proportion of non-laryngealized vowels in the dictionary overall. Figure 1 illustrates the distributions of stops. Both oral and glottal stops appeared in comparable proportions before laryngealized and non-laryngealized vowels. After vowels, over 88% of glottal stops occurred after laryngealized vowels, and more than 70% of oral stops occurred after non-laryngealized vowels. A complementary pattern was apparent in vowels (Figure 2): 65% of laryngealized vowels occurred before glottal stops, and more than 90% of non-laryngealized vowels occurred before oral stops.

Table 1: Count data of stops and vowels in their preceding and following environments.

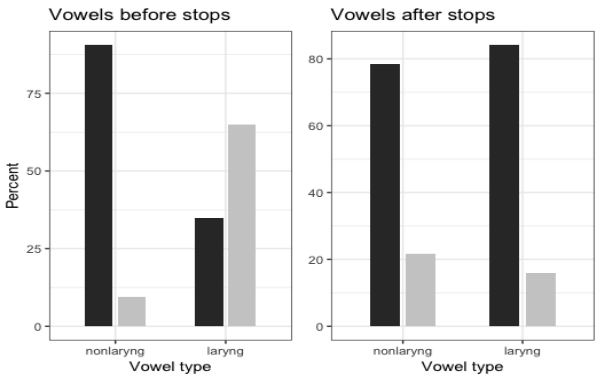
	Before vowels	After vowels
Oral	9676	5494
Glottal	2419	3400
	Before stops	After stops
Laryng V	4603	3425
Non-laryng V	4295	8676

Figure 1: Stops before and after vowels, divided by laryngeal type. Black bars represent non-laryngealized vowels; gray bars represent laryngealized vowels.



The tabulated data was analyzed using a Chi-squared test that revealed a highly significant relationship between stop type and vowel laryngealiza-

Figure 2: Vowels before and after stops, divided by stop type (oral/glottal). Black bars represent oral stops; gray bars represent glottal stops.



tion in both preceding and following environments. Oral stops were more likely to precede laryngealized vowels than would be expected given the overall proportion of laryngealized to non-laryngealized vowels (χ^2 = 51.1, df = 1, p <0.0001). Glottal stops were more likely to follow laryngealized vowels than expected (χ^2 = 2908.3, df = 1, p <0.0001).

Given the strong correlation between transcribed stop type and vowel laryngealization category, it stands to reason that some transcribed instances of vowel laryngealization are in fact the result of proximity to a following glottal stop. The next section considers the effect of glottal stops on the acoustic characteristics of vowels.

3. SPECTRAL ANALYSIS OF LARYNGEALIZATION IN VOWELS

3.1. Methods

Four speakers of Upper Necaxa Totonac (two women, two men) provided the audio data included in the acoustic analyses. Speakers ranged in age from early 30s to about 60 years old. The speakers were all native to the same village of Patla, Puebla, and were bilingual in Spanish. All speakers had grown up speaking UNT, with younger speakers being exposed to more Spanish earlier in life. All of the speakers still speak UNT in the community on a daily basis, though Spanish is also very frequently used. Interactions with the author were undertaken in Spanish. Recordings were made in speakers' homes using a Marantz portable digital audio recorder (PMD 660) and a head-mounted ear set microphone.

The word list, made up of 130 word forms, was not intentionally arranged in any particular order, and all speakers were presented with words in the same list order. The procedure for recording the word list was explained to speakers prior to beginning the recording. Speakers were asked to repeat each word three times within the frame sentence in *ixla wanli' ... chuwa* [ʃla wanlḭ ... tʃuwa] 'he said ... now'. During recording, speakers had access to written forms and translations, as well as discussion with the author.

Audio data were segmented and transcribed in Praat [7] according to the dictionary form of word items, rather than a close transcription of the phonetic signal. Boundaries were placed between vowels and adjacent glottal stops based on the regularity of oscillation period. H1-H2 measures were extracted from vowel tokens using a Praat script designed to imitate the measures taken by the VoiceSauce software developed at UCLA [32, 28]. Vowel quality was included in the linear models as a random intercept, allowing for the model to adjust the estimate for each vowel category. Since vowel quality is largely determined by the first formant [26, 30], including vowel quality in the random structure of the model in this is intended to account for formant effects that are accounted for in H1*-H2* measures reported in other voice quality literature. Measures were extracted from two time points within the vowel, at one third and two thirds of vowel duration. The data were subdivided into two conditions based on the laryngealization of either the preceding (CV) or following (VC) stop.

Separate models were fit to data according to whether the vowels were preceded or followed by oral or glottal stops, as well as by time point. Models were fitted using the *lme4* package [2] in R through stepwise model comparisons [1, 14, 15, 22]. The lmerTest package [20] was used to calculate p-values based on Satterthwaite's approximation of degrees of freedom. Initial models included fixed effects of vowel laryngealization (yes, no), stop type (oral, glottal), and time point (1, 3), with interactions, as well as control variables stress (stressed, unstressed), vowel length (short, long), and speaker sex (male, female).

3.2. Results

In vowels preceded by stops (Figure 3), those that appeared after glottal stops had higher H1-H2 values than those that followed oral stops at time 1 (est = 2.6175, SE = 0.5556, df = 4.928, t = 4.711, $p < 0.01$). The main effect of sex was also significant, with male speakers having higher H1-H2 values than female speakers. At two-thirds of vowel duration, laryngealized vowels had significantly lower H1-H2 values than non-laryngealized vowels (est = -1.5934, SE = 0.3205, df = 1073.7 t = -4.971, p $<$ 0.001). The effect of stop type also remained (est = 1.8857, SE = 0.5194, df = 13.0000, t = 3.630, p $<$ 0.005).

Figure 3: H1-H2 values for vowels after stops (CV), divided by speaker sex, consonant laryngealization, vowel laryngealization, and time point.

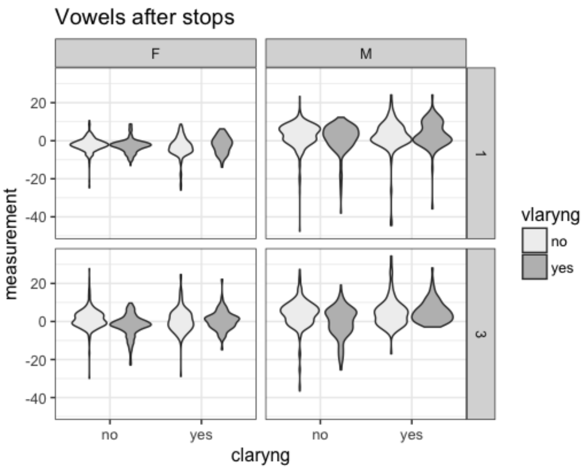
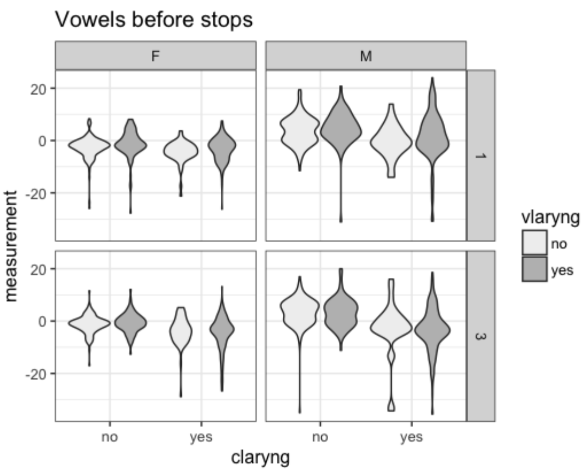


Figure 4: H1-H2 values for vowels before stops (CV), divided by speaker sex, consonant laryngealization, vowel laryngealization, and time point.



In vowels followed by stops (Figure 4), the model of data at one-third of vowel duration showed significant main effects of vowel laryngealization (est = 1.6251, SE = 0.3738, df = 446.7, t = 4.348, p $<$ 0.001), stress (est = 1.4315, SE = 0.3723, df = 361.2, t = 3.845, p $<$ 0.001), and speaker sex (est = 6.4485, SE = 0.8054, df = 14.6, t = 8.006, p $<$ 0.001). At two-thirds of vowel duration, none of the predictors in the model showed significant effects.

The above analysis revealed significant effects of vowel larygnealization on H1-H2 late in the vowel in the CV condition, and early in the vowel in VC condition. This is contrary to findings that contrastive phonation differences tend to occur early in vowel duration. Despite finding effects of vowel laryngealization in each condition, the direction of the effects varied, with higher H1-H2 in laryngealized vowels in the CV condition, and lower H1-H2 in laryngealized vowels in the VC condition. Since the typical pattern for H1-H2 values is for non-modal phonation types to have lower H1-H2 values, this oppositional pattern is not neatly explained as a cue to vowel laryngealization category in UNT. A further complication here is that stop type also had significant effects on H1-H2, with vowels that appeared after glottal stops having higher H1-H2 at both time points in the CV condition. This effect was not influenced by vowel laryngealization category. Strong effects of speaker sex were also found and warrant further investigation.

4. CONCLUSION

The analyses presented in this paper have demonstrated that there are is a relationship between transcribed vowel laryngealization and stop type; this relationship has not previously been reported in descriptions of Upper Necaxa Totonaca phonology. The strong correlation between vowels and glottal stops suggests that at least some vowel laryngealization may be the result of synchronic allophonic variation, or a diachronic source of laryngealization in allophony. As a first exploration of the relationship between laryngealized vowels and glottal stops in UNT, H1-H2 was analyzed in vowels occurring before and after oral and glottal stops. This measure was chosen because it is known to robustly differentiate between phonation categories in other languages. Both vowel laryngealization and stop type were found to influence H1-H2 values, sometimes in unexpected ways. One possible avenue for future study would be to repeat the analysis on data that has been annotated based more closely on the phonetic signal and compare the outcome to the present findings. Another approach might be to extract many voice quality measures across the entire duration of vowels in search of a cue speakers might use to maintain a heretofore poorly understood linguistic contrast.

5. REFERENCES

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