Laboratory Phonology
Journal of the Association for Laboratory Phonology

Garellek, M., López-Francisco, O., & Amith, J. D. (2025). At the margins: phonology and phonetics of Zongozotla Totonac glottalization. *Laboratory Phonology: Journal of the Association for Laboratory Phonology*, 16(1), pp. 1–35. DOI: https://doi.org/10.16995/labphon.10925

Open Library of Humanities

At the margins: phonology and phonetics of Zongozotla Totonac glottalization

Marc Garellek*, Department of Linguistics, University of California San Diego, La Jolla CA, USA, mgarellek@ucsd.edu

Osbel López-Francisco, Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México, Tlalnepantla MX, Mexico, osbel9@gmail.com

Jonathan D. Amith, Department of Anthropology, Gettysburg College, Gettysburg PA, USA, jonamith@gmail.com

*Corresponding author.

Glottal stops and glottalized ("laryngealized") vowels in Totonac and Tepehua languages are crucial for historical reconstructions, but their phonological and phonetic properties have often posed analytic problems for synchronic descriptions. In this paper, we provide in-depth phonological and phonetic analyses of glottal stops and glottalized vowels in the variety of Totonac spoken in Zongozotla, Puebla State, Mexico. We argue that glottal stops and glottalized vowels are marginal in this language: glottal stops only appear phrase-finally, and the vocalic phonation contrast has a low functional load in addition to being phonetically weak. And though glottal stops and glottalized vowels are in complementary distribution, we argue that they should be treated as distinctive sounds in the language. We provide possible diachronic explanations for many of the attested patterns, and highlight the implications for diachronic and synchronic studies of Totonacan glottalization. Overall, our paper provides a detailed, unified analysis of glottal stops and glottalized vowels in Totonac, as well as evidence for the role of postlexical structure in creating "intermediate phonological relationships" at the lexical level.

[Totonac translation of abstract:] Lu:xlakaskinka n pi tanksi natsuqa:wi kintachiwi:nkani n tu li:laqapaskani n tatanakuh, akxní la:xaqatli:yá:'w, xli:xlitá lantla ma:tsawaji:ya:'wi n kinkilhpi:nkani n chu: n kiaqapixnikani akxní n chiwi:naná:'w, akxní wana:'wi qalhtám tachiwi:ni wa ni:má n pala ka a:wán li:ma:qalhsputananá:'w, chu: wa ni:má ka kilhpu:laktanu:namah. Chaná n chu: na:má nali:aqataqsa:wi la:ntla n talaqpaliti:lhiyi n kintachiwi:kán, n chu: la:ntla n kilhtsukiní:'t. Wa:mpí lu:qalhí xlaqasi lantla n tatsawaji:yi iyma: n kiaqapixnikani akxní n chiwi:naná:'w, n pi na: chaná n chu: n ta'wa laqtsuqki:kán. Kli:qalhtawaqama:'wi kini la:ntla tlaq tla:ni nalaqtsuqki:ya:'wi n kintachiwi:kani u:má kZongozotla, Puebla, México. Tla:ni kini nakwana:'wi n pi nilakxtami wanqo:'ya:'wi qalhtanu tachiwi:ni akxní n pala ka li:ma:qasputanana:'wi jkintaqalhchiwi:kani n chu wa ni:má n ka xlakyita:'ti n kilhpu:laktanu:namah, n pi na: chaná n chu: lu:ta'wa n

qaxmatkán, xpa:lakata n pi ka ni:ni:má lantla n talaqpalí:qo:'y. Tanksi kini klaqxkutni:'ta:'wi n chu: na: tanksi kma:aqataqsni:nana:'wi xkilhtsúkuti n kintachiwi:kani iyma: n tatanaku n chu: la:ntla n talaqpali:tílhalhi wa lantla ma:tsawajiya:'wi n kinkilhpi:nkani n chu: n kiaqapixnikani akxní n chiwi:naná:'w. Kli:qalhtawaqani:'ta'wi kini lantla n tlawaqo:'ya:'wi n qalhtanu tachiwí:n, n chu: kma:siyiya:'wi lantla talaqpali:qo:'yi wa:ntú wampatana:'wi maski lu:ká ni:ni:má wa lantla n talaqpali:qó:'y.

[Spanish translation of abstract:] Cómo representar apropiadamente los cierres glotales y las vocales glotalizadas (o "laringizadas") en la familia totonaco-tepehua es esencial para la reconstrucción del protosistema de esta lengua. Sin embargo, las propiedades fonológicas de la glotalización y su realización fonética representan un desafío en las descripciones sincrónicas. En este artículo analizamos los patrones fonológicos y fonéticos de los cierres glotales y las vocales glotalizadas en el totonaco de Zongozotla, Puebla, México. Proponemos que estos sonidos son marginalmente fonémicos: los cierres glotales aparecen únicamente a final de frase, y el contraste entre vocales con voz modal y voz glotalizada tiene una carga funcional baja, además que su realización fonética es muy débil. Aunque los cierres glotales y las vocales glotalizadas están en distribución complementaria, argumentamos que deben ser tratados como sonidos contrastivos en esta lengua. Proporcionamos explicaciones diacrónicas para muchos de los patrones atestiguados y destacamos las implicaciones para los estudios diacrónicos y sincrónicos de la glotalización en el totonaco. En general, nuestro artículo proporciona un análisis detallado y unificado de los cierres glotales y las vocales glotalizadas en el totonaco, y a su vez, provee evidencias del papel que juega la estructura postléxica en la creación de "relaciones fonológicas intermedias" a nivel léxico.

1. Introduction

Contrast and allophony are at the core of phonological analysis, yet the relationship between pairs of sounds can sometimes be difficult to ascertain. Hall (2013) provides an overview of "intermediate relationships" that lead to many types of contrasts being described as "marginal." She highlights how contrasts may be marginal and ambiguously contrastive in a language for a variety of reasons. For example, the mid-vowel /e~ɛ/ and /o~ɔ/ contrasts of Standard Italian can be considered marginal because there are few minimal pairs, and because they are lexically variable and may to some degree be phonologically conditioned (Renwick & Ladd, 2016). And in Zongozotla Totonac, the language we analyze here, [e] and [o] generally only occur predictably, as allophones of /i/ and /u/ adjacent to uvular /q/ or (more variably) glottal /h/ and /ʔ/. But [e] and [o] can also appear unpredictably, for example in loanwords like the frequent /peɾo/ 'but' (< Spanish *pero*). We therefore need to posit /e/ and /o/ as contrastive sounds in the language, even if their phonemic status is marginal.

Why are some phonological relationships more difficult to characterize than others? As Hall (2013) and others mention, this can result (a) because different criteria are being used by different researchers, (b) because a given criterion often does not provide straightforward evidence for or against contrast versus allophony, and (c) because different criteria can be in conflict with one another. A classic case is the English contrast between /h/ and /ŋ/: they are in complementary distribution (suggesting they are in an allophonic relationship), but are so phonetically dissimilar so as to make their belonging to the same phonemic category very unlikely. But there are other reasons why a phonological relationship can be difficult to determine. A common reason is the presence of foreign or specialized strata in the phonology, such as the case of Totonac mid vowels that we mentioned earlier. Other such reasons are high variability in how a category is realized, as reported earlier for Italian mid vowels (Renwick & Ladd, 2016), and a sound's low frequency.

Prosodic structure also plays an important role in intermediate relationships. Sounds can have limited phonotactic distributions within the word, as is the case for /h/ and /ŋ/ in English. But higher phrasal structure can also matter. In Dagbani (as well as other West African languages), final glottal stops appear only pre-pausally, as long as certain phonological, morphological, syntactic, and pragmatic conditions are met (Hyman, 1988). In this paper, we also focus on glottalization—by which we mean both glottal stops and glottalized vowels—in Zongozotla Totonac (henceforth abbreviated as ZoT), a Totonacan variety spoken in Mexico. To foreground our analysis, we will argue that glottalization displays three kinds of marginality:

1. The phonation contrast between glottalized and modal vowels is marginal because there are few minimal pairs and because the glottalized vowels are phonetically only weakly glottalized, as reported in other Totonac languages (e.g., Puderbaugh, 2019a, §6.2; Tino Antonio, 2020).

2. Glottal stops are marginal in terms of their prosodic distribution: they are almost always word-final, but word-final glottal stops only surface when the word is also phrase-final. Still, we argue that glottal stops should be posited as part of the phonemic inventory, rather than as a phrase marker, because glottal stops contrast with /h/ and word-final vowels in phrase-final position.
3. Glottal stops and glottalized vowels are in complementary distribution. Nevertheless, we argue that their phonological behavior supports an analysis whereby these sounds are distinct categories in the language.

The remainder of the paper is structured as follows: in Section 2, we provide some background on Totonac languages, particularly with respect to their sound inventories. We also include information on Zongozotla, the municipality in the state of Puebla (Mexico) where our data were collected. Then in Section 3, we describe the data collection, including details on how our materials were generated, on our speakers, and on the recording procedure. We present the results in Section 4, which is divided into four subsections: a discussion of the sound inventory for ZoT; an acoustic analysis of the phonation contrast on vowels; a phonological analysis of glottal stops; and a phonological analysis of the relationship between glottal stops and glottalized vowels. Then in Section 5, we discuss reasons why the phonation contrast is phonetically weak, why glottal stops are marginal in the language, and the importance of our findings for future comparative analyses of Totonac glottalization.

2. Background

The Totonac languages belong to the Totonacan ("Tepehua-Totonac") group of languages (Glottocode: toto1251) spoken by approximately 250,000 people in the Eastern Sierra Madre range of Mexico, centered in the state of Puebla (see map, **Figure 1**). The language family is fairly small, but there exist proposals that link it to the Mixe-Zoquean languages (Brown et al., 2011) and even to Chitimacha in the US state of Louisiana (Brown et al., 2014). The family is generally divided into Totonac and Tepehua branches, but internal divisions are still poorly understood (Beck, 2024).

The phonemic inventory differs little across Totonac varieties (Beck, 2024; Davletshin, 2019). A typical consonant inventory consists of only voiceless obstruents: four to five plosives /p t k q (ʔ)/, three affricates /t͡s t͡ɬ t͡ʃ/, and four fricatives /s ɬ ʃ h/, the latter of which is often described as velar /x/. Sonorants generally include two nasals /m n/ and three approximants /w l j/. The typical vowel inventory consists of three qualities /i u a/, contrastive length (e.g., /i/ versus /i:/), and contrastive phonation (e.g., modal /i/ versus laryngealized /ḭ/). Contrastive quality, length, and phonation are usually fully cross-classified. Non-low vowels /i u/ (regardless of length or phonation) typically lower to [e o] around uvulars and (more variably) before

glottals. As for suprasegmental phenomena across Totonac languages, lexical stress tends to be surface-contrastive while also being predictable to some degree from the morphology (Garcia-Vega, 2022; MacKay, 1994; McFarland, 2009). Pitch is not contrastive.

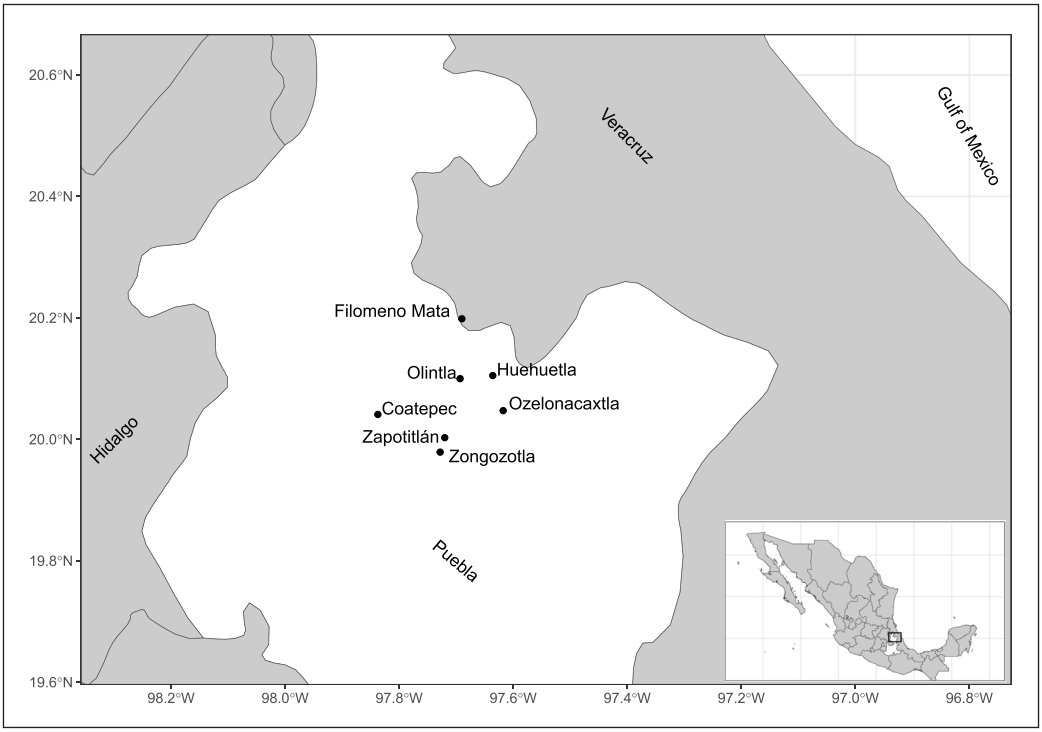

Figure 1: Map showing Zongozotla and neighboring varieties of Totonac mentioned throughout the paper. Filomeno Mata Totonac is more distantly related to the other varieties shown here, which are otherwise all members of the Highland Totonac branch.

We will henceforth refer to the phonation contrast as one between modal versus *glottalized* vowels, departing from the research tradition on Totonac which refers to the latter as "laryngealized" (in Spanish, *laringealizado/laringizado*). This is for two reasons, one language-internal and the other language-general. First, we wish to highlight the intermediate phonological relationship that exists between glottal stops and glottalized vowels, as noted in other related languages like Upper Necaxa Totonac (Puderbaugh, 2019a, §6.2). Second, when discussing glottalized vowels' phonological patterning, we wish to abstract away from details of their phonetic realization, focusing instead on the fact that they are produced with glottalization, i.e., with some degree of glottal constriction (Garellek et al., 2023). (The term "laryngealization" is even more general than glottalization, in that any sound produced with some amount of (epi-) laryngeal constriction could be considered "laryngealized.") And as we show in Section 4.2, phonetically the glottalized vowels are best described as being produced with weakly-glottalized

"tense voice" (Dawson et al., 2022), which has also been reported (in Spanish as *voz tensa*) in Olintla Totonac (Tino Antonio, 2020).

This paper focuses on the variety of Totonac spoken in Zongozotla, in the state of Puebla, Mexico. The municipality of Zongozotla has a population of approximately 10,000–12,000 individuals. The vast majority of its population speak Totonac, but most speakers are bilingual in Spanish to differing degrees of fluency. The younger generation is beginning to lose their linguistic skills in Totonac, although this is still the language that dominates communication inside and outside the household. Some inhabitants only speak Spanish while a very few are bilingual in Totonac and Nahuatl. In a wider context Zongozotla is one of many communities, with a total population of about 120,000, that speak what has been classified as "Highland Totonac" (Glottocode: high1243; ISO 639-3: tos).

To our knowledge, previous to our work the only existing literature on Zongozotla Totonac is a short unpublished wordlist by McQuown (1976). But the variety is geographically close and linguistically similar to Totonac from Zapotitlán de Méndez, described in detail by Herman Aschmann (Aschmann, 1946; Aschmann & Wonderly, 1952; Aschmann, 1983). Still, there are considerable differences between our analysis of glottalization and that of neighboring varieties of Highland Totonac, as we describe in more detail in the following sections.

3. The data collection and corpus

Our corpus is part of a broader NSF-funded project (led by third author Jonathan D. Amith), whose goals are to document the language (particularly the lexicon and morphosyntax) and culture (particularly ethnobiological knowledge) across Totonac and other Indigenous languages of Mexico.

We formulated a wordlist that was designed to illustrate the sounds of the language, and in particular to highlight contrasts between modal versus glottalized vowels. No effort was made to constrain the wordlist, for example in terms of part-of-speech, syllable count, and frequency. The first author, Marc Garellek, drafted a Totonac wordlist with Spanish glosses based on lexical items from Zapotitlán Totonac (Aschmann, 1946), given the two municipalities' geographic proximity and phonological similarities between the two varieties. The second author, Osbel López-Francisco, who is a Totonac speaker from Zongozotla, checked and revised the wordlist, the final version of which comprises 229 lexical items. The latter two authors recorded the data from eight speakers (four women and four men, including the second author) in Zongozotla in May 2022. Demographic information for the speakers can be found in **Table 1**. Recordings took place over 4 days for about 4 hours each day. Two speakers per day would alternate pronouncing about half the list (about 1 hour of recording for each half list). Speakers were compensated for their participation.

Code	Gender	Age
APG 426	Female	49
CLC 503	Female	31
ESP 427	Female	43
IPN 389	Male	51
OLF 385 (second author)	Male	31
PLC 504	Female	31
RLC 505	Male	59
SLC 388	Male	54

Table 1: Demographic information about the speakers in the corpus (see also Acknowledgements).

Audio recordings were made starting at about 10 PM each day (to avoid outside sounds) in a quiet room with acoustic foam to mitigate echo. The recorder was a Sound Devices 722 set at 48 kHz and 16 bits, with each speaker wearing a Countryman e6 ear-worn omnidirectional microphone. Speakers were instructed to read the words from the 229-word list (randomized before presentation, with the same order for all speakers). The complete wordlist is viewable as supplementary materials at https://osf.io/hkxbw/. The words appeared in Totonac and Spanish. When the speaker had difficulty, the second author would intervene and try to prompt the speaker to utter the targeted word. It was rarely necessary for him to pronounce the solicited word himself.

Each word was said in isolation three times, and then included in the carrier sentence *X iyma: n tachiwí:n* 'X is a word' (in Totonac). Thus the ZoT corpus on which subsequent analyses are based includes 229 lexical items, each recorded four times (three times in isolation, once in the carrier), for a total of about 916 tokens per speaker and over 7300 tokens in total. Some tokens were excluded due to background noise or mispronunciations, but this did not lead to the exclusion of any target lexical item in the phonetic analysis presented in Section 4.2, where we will also discuss further exclusions due to issues with the estimation of acoustic measures or statistical outliers.

4. Results

In this section, we first provide a basic description of the sound inventory of Zongozotla Totonac. We then provide an acoustic analysis of the phonation contrast, followed by more detailed phonological analyses of glottal stops and of the relationship between glottal stops and non-modal (glottalized) vowels.

4.1. Sound inventory of Zongozotla Totonac

Our analysis of the overall sound inventory of Zongozotla Totonac reveals a system that is quite similar to those described for other Totonac languages (Beck, 2024; Davletshin, 2019), particularly those belonging to the Highland group (Aschmann, 1946; Román Lobato, 2008; Troiani, 2007): as shown in **Table 2**, consonants contrast six places of articulation, voicing is not contrastive in obstruents (but stops are usually phonetically voiced word-internally after nasals), and affricates and fricatives contrast in terms of central versus lateral airflow.

	Labial	Alveolar	Postalveolar/ Palatal	Velar	Uvular	Glottal
Stop	p	t		k	q	ʔ
Affricate		t͡s	t͡ʃ			
Lateral affricate		t͡ɬ				
Fricative		s	ʃ			h
Lateral fricative		ɬ				
Nasal	m	n				
Approximant	w	l	j			

Table 2: Phonemic consonant inventory of ZoT for Totonac lexicon. The tap /ɾ/ occurs only in Spanish loanwords, but is also contrastive.

As in many Totonacan languages (Herrera Zendejas, 2023; McFarland, 2009; Román Lobato, 2008), /q/ can variably be realized as a stop, affricate [qᵡ], fricative [χ, ʁ], or as a pre-fricated affricate [ᵡqᵡ]. To our current knowledge, this variation is not predictable. Glottal stops occur phonetically before word-initial vowels, which themselves may be modal or glottalized (a point to which we return when describing vowels), but otherwise are found almost exclusively word-finally. This is a crucial point for our analysis in Section 4.4. In contrast to the cross-linguistic tendency for glottal "stops" to be mostly (creaky-)voiced, even utterance-finally (Garellek et al., 2023), in ZoT phrase-final glottal stops are almost categorically realized as "canonical" glottal stops, i.e., with a period of sustained voiceless closure followed by a release. Glottal /h/ is realized as [x] or (before /i/) [ç] in onset position, but we nonetheless consider it to be underlyingly glottal due to its phonological behavior, which we describe in Section 4.3.

All sonorants tend to be gradiently breathy-voiced or devoiced when they occur phrase-finally. For example, /aw, aj, an/ can each surface as [aw̤~aw̥, aj̤~aç, an̤~an̥] at ends of phrases. The lateral approximant /l/ only occurs prevocalically, and so this devoicing does not affect the contrast between /l/ and /ɬ/. This tendency for *phrase-final breath* (Duarte-Borquez et al., 2024) is an important fact to which we will return in Section 5.2.1.

There are three contrastive vowel qualities, each of which contrasts further in terms of length and phonation type (see also **Table 3**). Vowels /i, u/, irrespective of their length or

phonation type, lower to [e, o] categorically adjacent to a uvular, even when a nasal intervenes, and are orthographically marked with *e, o*, as in (1); before /h, ʔ/, high-vowel lowering is common but more variable in occurrence (and rarely marked orthographically), and is often gradiently realized. For example, /ih/ can surface as [ih], [eh], or [iᵉh]. In Spanish loans like /peɾo/ 'but,' mid vowels occur non-adjacent to any uvular or glottal and thus could be considered phonemic as well (but they do not contrast in terms of length or phonation). Vowel /a/ also tends to be produced further back as [ɑ] adjacent to uvulars, as found across the Totonacan family (e.g., in Mecapalapa Tepehua; Herrera Zendejas 2023). In all contexts, short /a/ is often realized as [ə].

(1) *Categorical high-vowel lowering adjacent to /q/ versus gradient lowering before /h, ʔ/:*[1]

/t͡ʃaqiːj/	[t͡ʃaˈqeːj]	*chaqé:y*	'*lo lava*, s/he washes it'
/pu̱ːqu/	[ˈpo̱ːqo]	*po:'qo*	'*sucio*, dirty'
/lunqnan/	[loɴqˈnan]	*lonqnán*	'*hace frío*, it's cold'
/kukuh/	[ˈkukuh, ˈkuku̱h, ˈkukoh]	*kukuh*	'*arena*, sand'
/pa̱ʃniʔ/	[ˈpa̱ʃniʔ, ˈpa̱ʃni̱ʔ, ˈpa̱ʃneʔ]	*pa'xni'*	'*cochino*, pig'

Of particular relevance for this paper is the limited distribution of certain vowels. In ZoT long vowels do not appear word-finally. This is in contrast to neighboring varieties from Zapotitlán and Ozelonacaxtla, where word-final long vowels are described. Cognates with word-final long vowels in neighboring varieties appear in ZoT with a final consonant, especially /j, h/. For example, /t͡ʃaqiːj/ *chaqé:y* '*lo lava*, s/he washes it' from the example in (1) is /t͡ʃiqiː/ in Ozelonacaxtla Totonac (Román Lobato, 2008, p. 34).

	Front	**Central**	**Back**
Short (long) modal	i(ː)	a(ː)	u(ː)
Short (long) glottalized	i̱(ː)	a̱(ː)	u̱(ː)

Table 3: Phonemic vowel inventory of ZoT in the native Totonac lexicon. Mid-vowels [e, o] (short and long, modal and glottalized) are allophonic in words of Totonac origin but occur contrastively (only for short, modal vowels) in Spanish loanwords.

Modal and glottalized vowels are subject to other phonological processes and have restricted distributions that differ from the patterns reported for related varieties: (1) As in other varieties

[1] Glosses will appear throughout in both Spanish (in italics) and in English to ensure that examples are accessible to Totonac speakers and Spanish-speaking Totonac-language researchers. Words will also be written in the working orthography of Zongozotla Totonac developed by the second author. In this orthography, certain allophonic processes are indicated. For example, vowel lowering adjacent to uvulars is always marked, and word-final vowels that devoice phrase-finally are not marked when the word appears in isolation, but are marked when the vowel is retained. Thus depending on its position, /pu̱ːqu/ can be written as either *po:'qo or po:'q*. But throughout the paper, we will include the orthographic variant of a word that most closely aligns with its phonemic transcription, unless otherwise indicated.

of Totonac, all vowels at the beginning of a word sound glottalized; for closely-related Zapotitlán Totonac, Aschmann (1946, 1983) analyzes immediately word-initial vowels as underlyingly glottalized ("laryngealized"). This is largely due to phonetic reasons, namely that word-initial vowels are irregular in voicing and often preceded by a glottal stop. We will return to this point in Section 4.3; (2) Unlike in neighboring varieties, in ZoT glottalized vowels also do not occur underlyingly in word-final position; and (3) modal vowels devoice phrase-finally. These facts will be crucial for our analysis of the relationship between glottal stops and glottalized vowels in Section 4.4, and for our broader discussion in Section 5.

As with other varieties of Totonac, ZoT has surface-contrastive placement of lexical stress (which is also dependent to some degree on the morphology; MacKay, 1994; McFarland, 2009), but length and phonation contrasts are found on both unstressed and stressed syllables. In our broad phonemic transcriptions then, we avoid marking stress unless its placement is non-default (e.g., if stress appears fixed within a given morph of a polymorphemic word), but narrow allophonic transcriptions will always be marked for lexical stress.[2]

4.2. The phonetics of modal and glottalized vowels

In this section, we describe the phonetic characteristics of the phonation contrast on vowels in Zongozotla Totonac. For a language with a vocalic phonation contrast, ZoT stands out for two reasons: (1) the contrast has a very low functional load, and (2) the contrast appears to be very weak, with phonologically glottalized vowels almost never showing perceptually strong glottalization.

Although many words have glottalized vowels, we were able to find only a few minimal or even near-minimal pairs between modal and glottalized vowels in ZoT. Our phonetic analysis will involve only nine (near-)minimal pairs because so far those are the only pairs we have managed to find. Our impressions listening to the recordings suggest that the contrast is more strongly realized on long vowels than on short vowels, but in general the contrast is quite subtle. This is illustrated in **Figure 2**, which shows two representative (near-)minimal pairs differing in terms of vowel phonation: /kiɬni?/ versus /kḭɬni?/ and /paska:t/ versus /kaka̰:t/. For both pairs the glottalized vowel looks remarkably similar to the modal one, with regular voicing throughout. But the glottalized vowels in both /kḭɬni?/ and /kaka̰:t/ have more energy in the higher frequencies than their modal counterparts, and the long glottalized vowel for /kaka̰:t/ shows a more pronounced drop in voicing amplitude toward its end than does its modal counterpart, /paska:t/.

[2] The working orthography for the language marks stress using acute accents: stress goes unmarked if it occurs on the penult, otherwise it is marked.

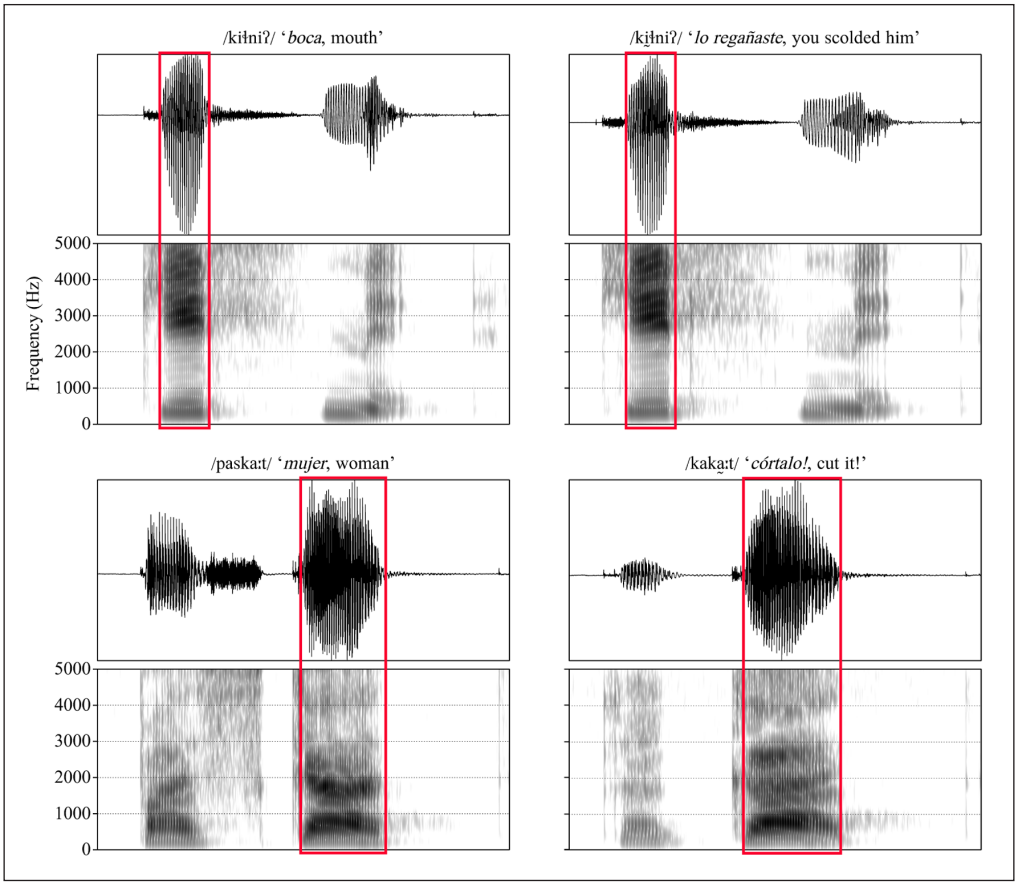

Figure 2: Minimal and near-minimal pair in terms of phonation, with the relevant vowels enclosed in red rectangles. Words with glottalized vowels appear on right. The first pair (top row) was uttered by female speaker APG 426; the second pair (bottom row) by male speaker IPN 389.

Based on our informal audiovisual investigation, we expected that glottalized vowels will be differentiated from modal ones primarily in terms of their spectral tilt and voicing intensity, though we also expected there to be an interaction with vowel length. To control as much as possible for other sources of acoustic variation, we restrict this analysis to minimal or near-minimal pairs, controlling for placement of lexical stress and the manner of articulation of surrounding consonants, as both factors may influence voice quality (Garellek, 2022). Our list of nine word pairs is shown in **Table 4**.[3]

[3] In other Totonacan languages, cognates with Zongozotla Totonac /ʃanat/ 'flower' tend to have a glottalized initial vowel (e.g., in Zapotitlán; Aschmann, 1983). But our analysis will confirm that, according to most measures except Residual H1* (see **Figure 8**), the initial vowel of this word is phonetically more similar to other glottalized vowels in this variety than to modal vowels.

Modal		**Glottalized**	
/ʃanat/	*xanat*	/ʃa̰nat/	*xa'nat*
'*flor*'	'flower'	'*sudor*'	'sweat'
/paskaːt/	*paská:t*	/kakaːt/	*kaká:'t!*
'*mujer*'	'woman'	'*córtalo!*'	'cut it!'
/ʃkut/	*xkut*	/ʃkṵta/	*xku'ta*
'*tejón*'	'coati'	'*agrio*'	'sour'
/paqɬ/	*paqlh*	/pa̰qɬ/	*pa'qlh*
'*floreció*'	'it blossomed'	'*lo quebró*'	's/he broke it'
/t͡ʃaːn/	*cha:n*	/t͡ʃa̰ːn/	*cha:'n*
'*cocido*'	'cooked'	'*hormiga*'	'ant'
/puːqu/	*po:qo*	/pṵːqu/	*po:'qo*
'*espeso*'	'thick'	'*sucio*'	'dirty'
/aːmaːt͡ʃaʔ/	*a:ma:chá'*	/ama̰ːt͡ʃaʔ/	*ama:'chá'*
'*allá está acostado*'	's/he's lying there'	'*va por allá*'	's/he's going there'
/kiɬniʔ/	*kilhni'*	/kḭɬniʔ/	*ki'lhni'*
'*boca*'	'mouth'	'*lo regañaste*'	'you scolded him'
/paqʃa/	*paqxa*	/pa̰qʃa/	*pa'qxa*
'*ruido de un golpe*'	'hit (onomat.)'	'*lo desvaina*'	's/he shells it'

Table 4: Wordlist used for the phonation analysis.

As mentioned earlier, words were read three times in isolation, followed by once in the carrier. Across all speakers, a total of 557 tokens were analyzed. The target vowels were segmented based on the onset and offset of F1 and F2 excited by voicing. The acoustic measures were calculated using VoiceSauce (Shue et al., 2011), which outputs a value of each measure every millisecond. We targeted the acoustic measures shown in **Table 5** (we refer the reader to Garellek, 2022 for an overview). These were selected because they capture different components of glottalized (i.e., more constricted) phonation. We avoided adding additional measures that were highly correlated with those in **Table 5**.

Residual H1* is a relatively new measure that assesses the amplitude of H1 (corrected for formant frequencies and bandwidths) but also factors out the RMS energy. It is calculated by modeling H1* as a function of RMS energy, and then subtracting the product of the modeled RMS energy's beta value and the particular token's RMS energy from that token's H1* level; see Chai & Garellek (2022) for more details. The more constricted the phonation, the lower the

value of Residual H1*. Chai and Garellek found that this measure was better correlated with glottal constriction and less susceptible to error than the better-known spectral tilt measure, H1*–H2*.

Harmonic spectral levels	Inharmonic spectral levels	Other
Residual H1*	HNR < 500 Hz	Root-mean-squared (RMS) energy
	Subharmonics-to-harmonics ratio	Strength of Excitation (SoE)
		F0

Table 5: The acoustic measures of voice quality used in the analysis of phonation.

We selected HNR < 500 Hz (harmonics-to-noise ratio below 500 Hz) as a noise measure, because it focuses on noise specifically in the lowest frequencies and thus captures F0 irregularity well. We also included subharmonics-to-harmonics ratio, because constricted voice qualities can be characterized by more prominent subharmonics in the spectrum.

Other measures included in the model were root-mean-squared (RMS) energy (the overall energy in the signal from both noise and signal), which can be lower due to increased constriction; strength of excitation (SoE), a measure of voicing intensity specifically (also expected to be lower due to increased constriction); and F0 (fundamental frequency), which is usually lower in constricted voice qualities, but can be higher for certain types of tense voice (Gordon & Ladefoged, 2001; Keating et al., 2015). VoiceSauce's default settings were used to calculate these parameters. The F0 was calculated using STRAIGHT (Kawahara et al., 1998) and the formants via Snack (Sjölander, 2004).

F0 values greater than 3 standard deviations from each speaker's mean were considered outliers and removed. Within each vowel category, we calculated the Mahalanobis distance on the F1–F2 space between each individual token relative to the mean of the category; the larger the Mahalanobis distance is, the more deviant the token is from the center of the category and the more likely there is a tracking error for that vowel. We also considered tokens with a Mahalanobis distance larger than 6 as outliers. We then removed all timepoints with F0 and formant outliers, and averaged each measure over the entire vowel. The outlier removal led to the exclusion of 14 out of the 557 tokens. Duration was log-transformed due to its being log-normally distributed.

To determine which acoustic measures, when taken together, predict glottalized versus modal vowels, we fitted a Bayesian logistic regression model using *brms* (Bürkner, 2018) in R. We predicted vowel phonation (dummy coded with "modal" as baseline) by the scaled mean acoustic

measures and their interaction with vowel length and with random intercepts by speaker and word pair. The model was specified with weakly informative priors as Normal(0,1.5) in log-odds space for both the intercept and the fixed effects, and was fitted to draw 5000 samples in each of four Markov chains, with a burn-in period of 1000 iterations per chain.[4]

We find compelling evidence for the following parameters as predictors of the phonation contrast: SoE ($\beta = -0.94$, 95% CrI $= [-1.33, -0.59]$), Residual H1* ($\beta = -0.83$, 95% CrI $= [-1.21, -0.45]$), RMS energy ($\beta = -0.67$, 95% CrI $= [0.34, 1.02]$), duration ($\beta = 1.01$, 95% CrI $= [0.60, 1.44]$), and the interaction between RMS energy and vowel length ($\beta = -0.57$, 95% CrI $= [-0.91, -0.25]$). Compared to modal vowels, glottalized vowels are longer and have lower SoE and Residual H1*, suggesting weaker voicing due to greater glottal constriction. Glottalized vowels also have more RMS energy overall, but this effect is largely driven by long vowels (**Figure 3**).

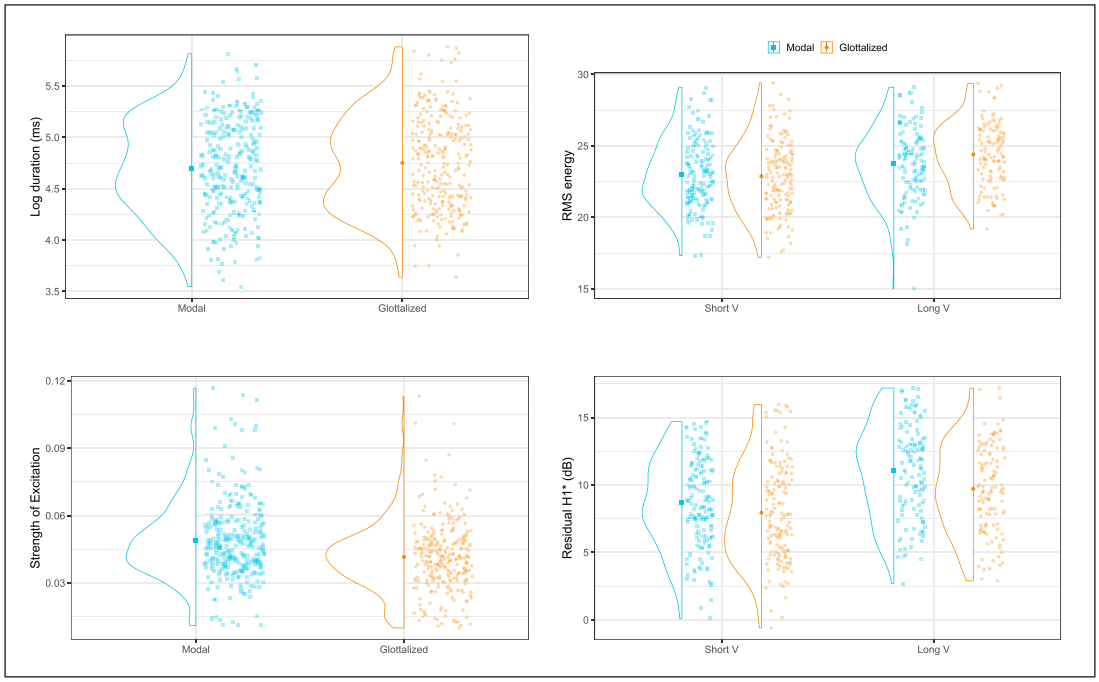

Figure 3: Credible acoustic predictors of the phonation contrast. Violin plots show the distribution and points show each observation. The larger point indicates the mean value.

[4] The model's syntax was: *Phonation* = *'Glottalized'* ~ *scale*(*ResidualH1**) + [...] + *scale*(*F0*) + *scale*(*ResidualH1**) : *Vowel.Length* + [...] + *scale*(*F0*) : *Vowel.Length* + (1|*Speaker*) + (1|*Pair*), *family* = *bernoulli*(*link* = *'logit'*), *prior* = *c*(*prior*(*normal*(0, 1.5), *class* = *Intercept*), *prior*(*normal*(0, 1.5), *class* = *b*)), *iter* = 5000, *warmup* = 1000, *chains* = 4, *cores* = 4).

Therefore, glottalized vowels differ from their modal counterparts in ways that are expected for creaky versus modal contrasts. However, the differences in mean are very small and there is a large overlap in distributions. According to our perceptual impressions, vowel glottalization is also markedly weaker than expected, given the first and third authors' extensive experience with various kinds of glottalized or creaky vowels in other languages such as Hmong, Mazatec, Mixtec, !Xóõ, and Zapotec (DiCanio et al., 2015; Keating et al., 2023). Therefore, we can conclude that the phonation contrast in ZoT is not only marginal (in terms of the rarity of minimal pairs), but also that it is only weakly realized phonetically.

To explore further the phonation contrast and its phonetic realization, in **Figure 4** we plot time course data for the four acoustic measures (aside from duration) that emerged as credible predictors. (The top facet showing RMS energy is further subdivided by vowel length, given the interaction that emerged in the regression model.) For SoE and Residual H1*, the distinction between modal versus glottalized vowels is realized throughout most of the vowel's duration. For RMS Energy, the increase in overall energy associated with glottalized long vowels is also found throughout the vowel.

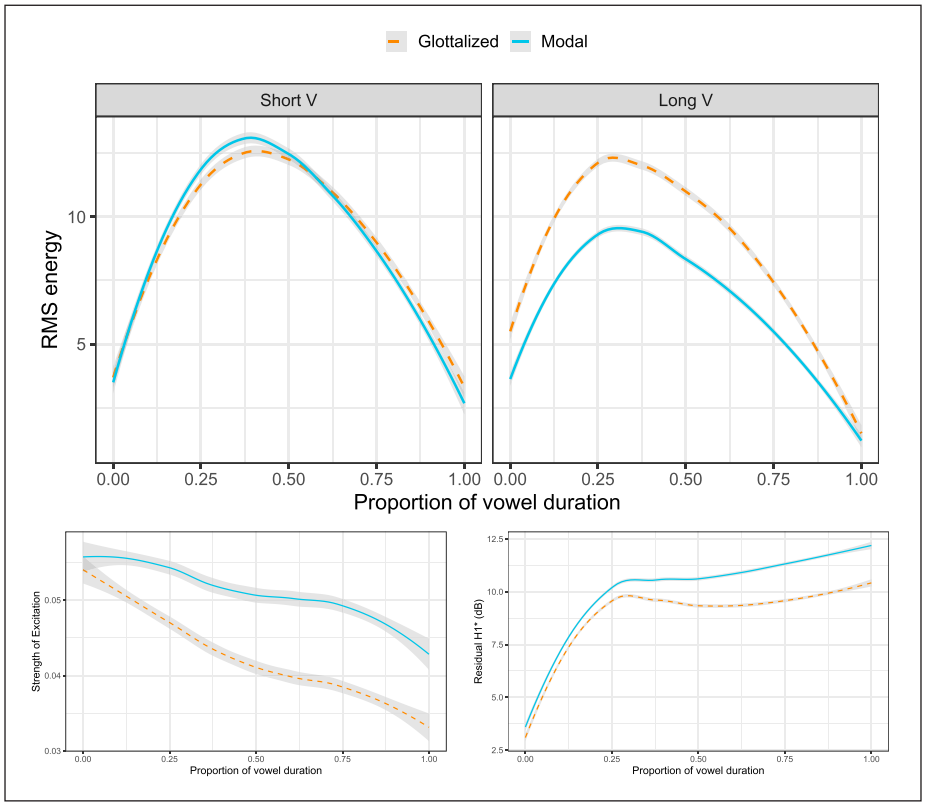

Figure 4: Time course plots for the three acoustic measures (excluding duration) that emerged as predictors of the contrast. Shaded areas indicate Loess smoothing about the mean value.

Next we explore the variation across word pairs. **Figure 8** in the Appendix shows, for each acoustic measure, the difference between the modal versus glottalized vowel in each word pair. We can see that some measures are more robust across word pairs: strength of excitation is higher for modal vowels across all pairs except for *xkut-xku'ta* and *paqxa-pa'qxa*, which show no difference along this measure; duration is lower for modal vowels across all pairs of words except for *xkut-xku'ta* (no difference) and *paqlh-pa'qlh* (effect in the opposite direction). The other acoustic measures show either more pairs that overlap with 0, or more pairs whose differences are in the opposite direction from the main effect for that measure. There is also no single pair of words for which a main effect (in the expected direction) is not found for at least one acoustic measure. This confirms that the phonation contrast is indeed found for all pairs, even if it is weak in its phonetic realization.

Finally, we explore cross-speaker variation. **Figure 9** in the Appendix shows the difference between the modal versus glottalized vowels, here averaged across all word pairs, for each acoustic measure. We see that some speakers more reliably produce a difference in phonation than others. For example, RLC 505 produces the contrast mainly in terms of Residual H1*. Of all measures, SoE shows the more robust pattern across speakers. This is similar to what was found across word pairs.

In sum, the acoustic differentiation between modal and glottalized vowels is very weak, and the main acoustic measures that emerged as predictors of this contrast (vowel duration, RMS energy, Residual H1*, and SoE) vary both across speakers and word pairs in terms of whether and to what extent they reliably differentiate the phonation types.

4.3. The distribution of glottal stops

In this section, we provide an analysis of the distribution of glottal stops in Zongozotla Totonac. Based on their limited word-internal and phrasal distributions, we will argue that glottal stops should be considered marginally contrastive sounds in the language.

Evidence for the phonemic status of glottal stop comes from word-final position, where /ʔ/, /h/, and ∅ contrast, as in (2).

(2) *Word-final glottal contrasts:*

/jaːstaʔ/	[ˈjaːstaʔ]	*ya:'sta'*	'*cuñado de mujer*, woman's brother-in-law'
/taːtah/	[ˈtaːtah]	*ta:tah*	'*abuelo*, grandfather'
/ʃkuta/	[ˈʃkutaˀ]	*xku'ta*	'*agrio*, sour'

Although words ending in an underlying glottal consonant appear to be common in the lexicon, the glottal consonants (as well as final vowels) only surface as in (2) when they occur phrase-finally. Elsewhere, word-final /ʔ/ and /h/ delete and word-final vowels retain their voicing, as shown in **Figure 5**. This is presumably due to a constraint, common across Totonac languages, against C#C sequences across phrase-medial word boundaries (Román Lobato, 2008; McFarland,

2009, §2.6.5.1; Garcia-Vega, 2022, §2.3.1; Quintana Godoy, 2022). When a word ends in a consonant, the constraint is satisfied via deletion (of the glottal consonant) or /-i/ epenthesis (if the first word ends in a non-glottal consonant, as in /paskaːt/ *paská:t* '*mujer*, woman'). Examples of these alternations are seen in (3).

(3) *Constraint against /C#C/ sequences across phrase-medial word boundaries:*

		Phrase-final	*Phrase-medial*
/-ʔ/	/jaːstaʔ/	[ˈjaːstaʔ]	[ˈjaːsta]
/-h/	/taːtah/	[ˈtaːtah]	[ˈtaːta]
/-V/	/ʃkʊ̯ta/	[ˈʃkʊ̯taˌ]	[ˈʃkʊ̯ta]
Non-glottal /-C/	/paskaːt/	[paˈskaːt]	[paˈskaːt-i]

Thus glottal stops, though contrastive word-finally, rarely surface within a phrase. This is common across Totonac languages, and has led some researchers to posit that phrase-final glottal stops are either inserted phrasal markers (Ozelonacaxtla Totonac; Román Lobato, 2008), or that there is a change in progress whereby lexical glottal stops are being reanalyzed as postlexical, i.e., phrasal, markers (Filomeno Mata Totonac; McFarland, 2009). We will return to this point in Section 5.

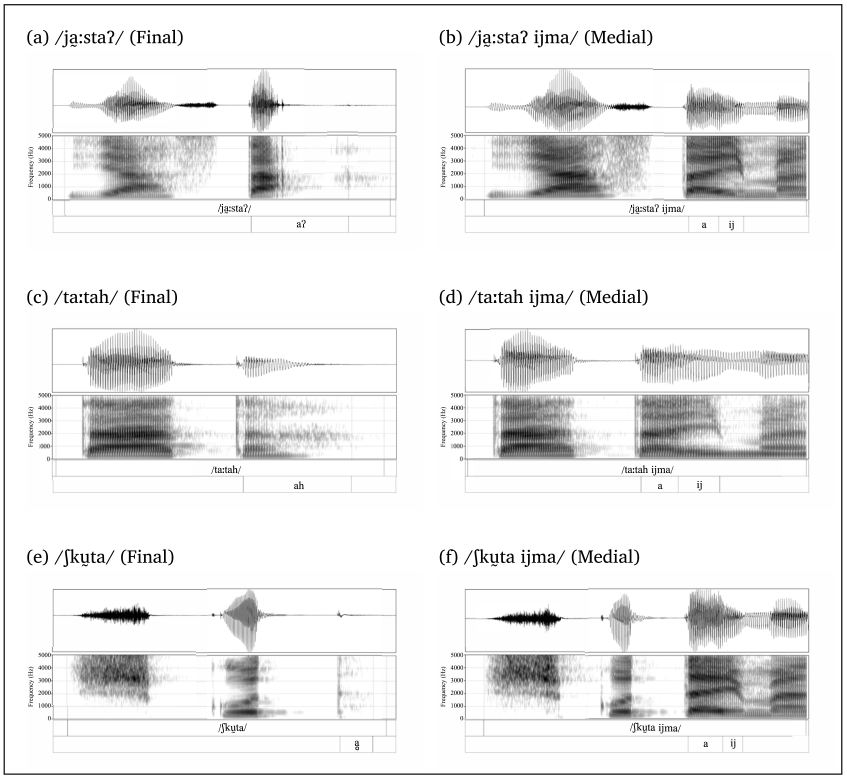

Figure 5: Comparisons between /ʔ, h, a/ in phrase-final (left) versus phrase-medial (right) positions. All tokens were produced by speaker APG 426. Note the absence of glottal consonants phrase-medially.

In contrast to /h/, glottal stops cannot appear in coda position in the middle of the word. Indeed, morphological derivation that should in theory lead to a word-medial coda /ʔ/ instead results in deletion of the glottal stop. For instance, ZoT has a first-person plural possessive nominal construction *ki(n)-X-kán* 'our X.' When the nominal root ends in /-h/, that glottal is retained even though it occurs word-medially; in contrast, a root ending in /ʔ/ loses its glottal in comparable derived forms, as in (4).

(4) *Loss of coda /ʔ/ but retention of /h/ with suffixation:*
/kin-t͡ʃit͡ʃiʔ-ˈkan/ [kint͡ʃit͡ʃiˈkan] *kinchichikán* '*nuestro perro*, our dog'
/kin-ta:tah-ˈkan/ [kinta:tahˈkan] *kinta:tahkán* '*nuestro abuelo*, our grandfather'

In sum, underlying word-final glottal consonants do not surface except when the word is phrase-final. Glottal fricatives have a less restricted distribution, as they can appear in word-medial codas (as well as in onset position, where they surface as [x] or [ç]; see Section 4.1).

Now we turn to glottal stops that appear in non-final position within the word. Vowel-initial words are often preglottalized; that is, they begin with a glottal stop. **Figure 6** shows a token of [ʔuˈkʃiɬa̰] *ukxilha* '*lo ve*, s/he sees it/him,' where the word-initial vowel is preceded by a glottal stop and some irregular voicing at the beginning of the vowel.

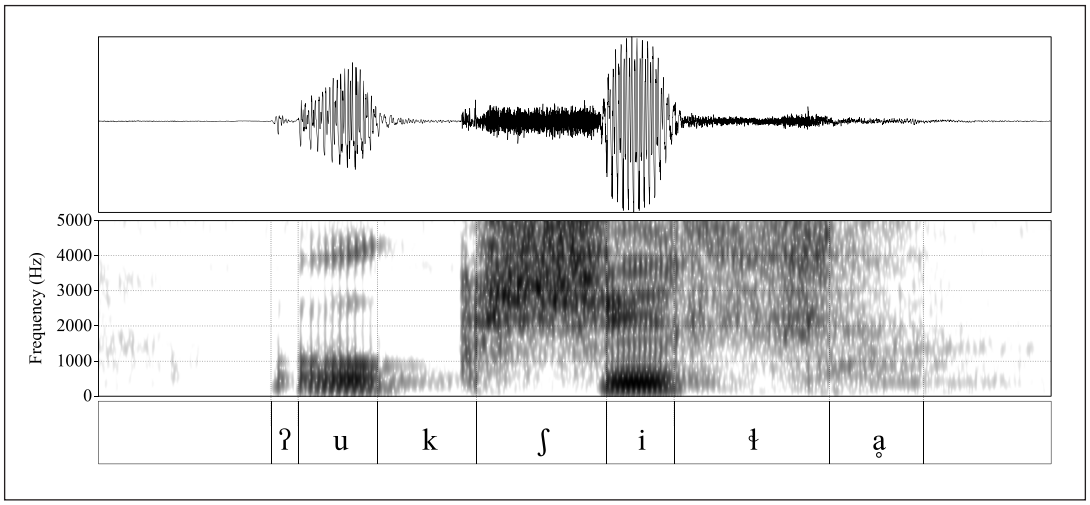

Figure 6: Vowel-initial [ʔuˈkʃiɬa̰] *ukxilha* '*lo ve*, s/he sees it/him,' with a preceding glottal stop. Token uttered by speaker RLC 505.

Immediately word-initial vowels (i.e., those not preceded by an onset consonant) also do not appear to contrast on the surface in terms of phonation. These facts have led some researchers (e.g., Aschmann (1946) for Zapotitlán Totonac) to treat word-initial vowels in Totonac as underlyingly glottalized rather than modal. In that case, the glottal stop would be part of the

phonetic implementation of a glottalized vowel in word-initial position. Thus if true for ZoT, the word illustrated in **Figure 6** could be transcribed phonemically as /u̯kʃiɬa/ instead of as /ukʃiɬa/. But contemporary understanding of the sources of irregular voicing (Garellek, 2022) suggests that irregular voicing on the initial vowel should not be used to motivate its underlying status as glottalized. Glottal stops usually lead to creaky voice on an adjacent vowel (Garellek, 2014; Garellek et al., 2023), so word-initial vowels in ZoT (as well as in Zapotitlán Totonac) can "appear" glottalized by virtue of an inserted glottal stop that is motivated by phrasal position rather than by lexically-specified phonation.

We also note that a third alternative exists, namely that all syllables must have an onset, such that so-called "word-initial" vowels are in fact preceded by a phonemic glottal stop (e.g., /ʔukʃiɬa/). But we believe such word-initial glottal stops are best analyzed as postlexical glottalization of initial vowels, rather than as phonemic /ʔ/, because they occur phrase-initially, where domain-initial strengthening in many languages leads to glottalization (Cho, 2016; Garellek, 2014, 2022). If the glottal stop were underlying, we would need some explanation for why it almost invariably does not surface in phrase-medial position. For example, when a vowel-final word like /ʃku̯ta/ occurs in our carrier sentence before vowel-initial /ijmah/, hiatus is never repaired: [ˈʃku̯t**a** ˈ**i**jma-n ta̯t͡ʃiˈwi̯ːn]; see also the lack of glottalization in hiatus for the phrase-medial tokens in **Figure 5**. Moreover, if word-initial glottal stops were underlying, we would need to explain why intervocalic glottal stops are so rare, especially given that word-*final* /ʔ/ is always realized strongly as a "canonical" glottal stop. But if instead we assume that the glottal stop is a result of prosodic strengthening of a word-initial vowel, that would make ZoT similar to the many languages with variable word-initial glottalization.

Ultimately, we assume that the phonation contrast does exist underlyingly in word-initial position, and that (verbal) morphophonological alternations provide evidence of the contrast. The form [ʔuˈkʃiɬa̰] *ukxilha* '*lo ve*, s/he sees it/him/her' alternates with first-person [kuˈkʃiɬa̰] *kukxilha* '*lo/la veo*, I see it/him/her,' where the verbal root begins with a modal vowel. In contrast, the verb root for 'go' is /a̰n/, with a glottalized vowel. We know this because that vowel is predictably glottalized, even word-medially; e.g., [hka̰n] *jka'n* '*voy*, I go.' Therefore, we posit that /ukʃiɬa/ begins with a modal vowel underlyingly, and undergoes word-initial glottalization. Unfortunately, we did not elicit forms to test whether the word-initial phonation contrast is maintained or neutralized on the surface after word-initial glottalization occurs, but this should be tested in future work.

In word-medial position, glottal stops are extremely rare and variable across speakers. To our knowledge, these can occur only in hiatus between two glottalized vowels, as in (5). The comitative prefix is /ta̰ː-/, which we know contains a glottalized vowel because the glottalization predictably surfaces with this prefix, as in [ta̰ːtɬaˈwaj] *ta:'tlawáy* '*lo hace con él*, s/he does it with him.' The verb root for 'go' is /a̰n/, with a glottalized vowel that is predictably glottalized. When /a̰n/ is preceded by the comitative prefix, the verb can surface as [ta̰ːˈʔa̰n] *ta:'án* '*se va con él*,

s/he leaves with him,' with a glottal stop between the two glottalized vowels, or as [tą̰:ˈą̰n], without the glottal stop. In our data set, instances of phonetic glottal stop [ʔ] in this word are speaker-specific: half of the eight speakers consistently say [tą̰:ˈʔą̰n], whereas the other half consistently say [tą̰:ˈą̰n], as illustrated in **Figure 7**. These groups do not appear to be structured according to age or gender. Therefore, we analyze word-medial glottal stops as a speaker-dependent form of prosodic strengthening of glottalized vowels under hiatus.

(5) *Variable word-medial glottal stops at hiatus between glottalized vowels*

	With comitative /tą̰:-/	*With 1SG. /(h)k-/*
/tɬawaj/ '*hacer*, do'	[tą̰:t͡ɬaˈwaj] ta:'tlawáy	[kt͡ɬaˈwaj] ktlawáy
	'*lo hace con él*, s/he does it with him'	'*hago*, I do'
/ą̰n/ '*ir*, go'	[tą̰:ˈʔą̰n, tą̰:ˈą̰n] *ta:'án*	[ˈhką̰n] *jka'n*
	'*se va con él*, s/he leaves with him'	'*voy*, I go'

In sum, in this section we showed that, while some glottal stops can be considered contrastive in Zongozotla Totonac, the distribution of those phonemic glottal stops is limited. They contrast only in coda position; onset glottal stops, which are found before word-initial vowels and between glottalized vowels at a morphological juncture, are analyzed as derived from prosodic strengthening of a word-initial vowel or from hiatus involving two glottalized vowels. Thus in terms of their lexical phonotactics, glottal stops appear to have a limited distribution similar to that found in other unrelated languages, including Chinese varieties with coda /ʔ/ (Chai, 2022) as well as Western Muskogean (Ulrich, 1993).

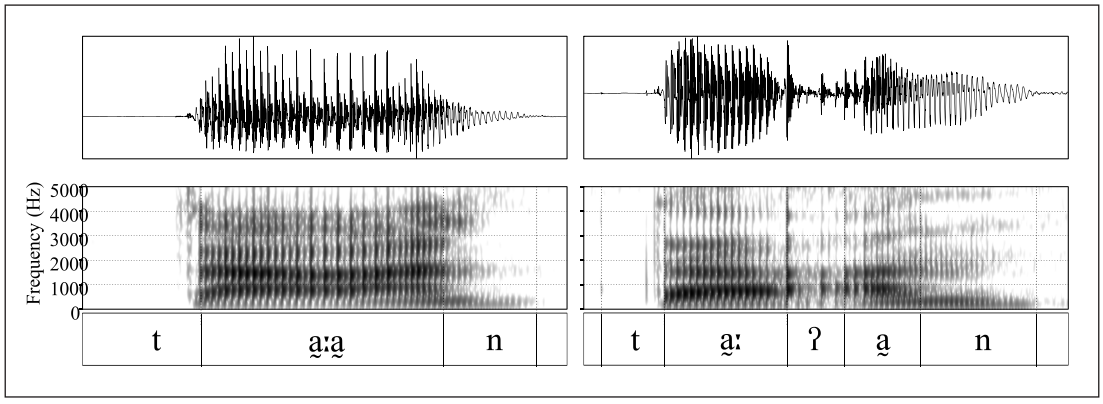

Figure 7: Cross-speaker variation in the realization of /tą̰:ˈą̰n/ *ta:'án* '*se va con él*, s/he leaves with him' without an intervocalic glottal stop (left) versus with a glottal stop (right). The token on the left is from speaker SLC 388, whereas the one of the right is from RLC 505.

But the distribution of phonemic glottal stops is especially limited, because they cannot appear in word-medial coda position; they are only found word-finally, and morphophonological alternations that involve suffixation to a root ending in a glottal stop results in the loss of this

sound. Therefore, there must be an active constraint in the language against word-*non*final (phonemic) glottal stops. And postlexical phrasing also matters, as ZoT further restricts surface glottal stops to phrase-final position.

4.4. The phonological relationship between glottalized vowels and glottal stops

Is there a phonological relationship between glottalized vowels and glottal stops in Zongozotla Totonac? While we have been treating them as distinctive sounds in the language, in fact [V̰] and [Vʔ] sequences are in complementary distribution: glottalized vowels generally do not occur word-finally, whereas [Vʔ] sequences *only* occur word-finally (and recall that the [ʔ] only surfaces at the end of a phrase). Instances of derived word-final glottalized vowels provide the sole exception to this distribution: if a word ends in /V̰h/, the /h/ is not realized phrase-medially (recall (3)). Thus /skuhmạ̰h/ *skujma'h* '*está trabajando*, s/he is working' is realized as [ˈskuhmạ̰] in phrase-medial position—without the word-final /h/ but retaining a glottalized vowel that appears word-finally in the derived phrase-medial form. In the same environment, a word ending in a glottal stop would be realized with a word-final modal vowel. A summary of these distributions by phrasal position is shown in (6). Note that glottalized vowels are never followed by a coda glottal stop, and in word-final position long vowels are not found in open syllables or in those closed by a glottal consonant.

(6) *Distributions of word-final rhymes ending in a vowel or in a glottal consonant:*

	Phrase-final	*Phrase-medial*
/-V/	[-V̰]	[-V]
/-Vh, -V̰h, -Vʔ/	[-Vh, -V̰h, -Vʔ]	[-V, -V̰, -V]
/-V̰ʔ, -Vː, -V̰ː, -Vːʔ, -Vːh/	(unattested)	(unattested)

The complementary distribution of [V̰] versus [Vʔ] sequences at the very least suggests that [Vʔ] sequences are allophonic realizations of underlying word-final /V̰/. Nonetheless, we argue that they should be treated as contrastive sounds. One reason is that glottalized vowels and glottal stops are perceptually quite distinct, in a way that would render them, at the very least, "quasi-phonemes" (Kiparsky, 2014). Another reason is that, as we have argued in Section 4.2, the contrast between modal versus glottalized vowels is marginal, with the latter being only weakly differentiated from the former. Yet the realization of glottal stops is phonetically robust, so much so that they are typically realized as canonical voiceless glottal stops.

But morphophonological alternations provide probably the strongest evidence that [V̰] and [Vʔ] represent distinctive entities in synchronic ZoT. Recall in (4) that, in the first-person plural possessive *ki(n)-X-kán* construction, if the nominal root ends in an /h/, the fricative is retained; in contrast, root-final /ʔ/ disappears, regardless of whether the root-final glottal stop is in a stressed

(as in [t͡ʃiˈt͡ʃiʔ] '*perro*, dog') or unstressed syllable (as in [ˈpa̱ʃniʔ] '*cochino*, pig'), as shown in (7). If [Vʔ] were the word-final allophone of underlying /V̰/, then we would expect it to surface as [V̰] when it appears in this construction. Instead, the root-final /ʔ/ disappears and the preceding vowel remains modal: /kin-t͡ʃit͡ʃiʔ-ˈkan/ '*nuestro perro*, our dog' surfaces as [kint͡ʃit͡ʃiˈkan], not as *[kint͡ʃit͡ʃḭˈkan, kint͡ʃit͡ʃiʔˈkan]. This cannot be explained by a constraint against glottalized vowels in this construction: with /liːwa̱j/ *liːwa'y* '*carne*, meat,' the glottalized vowel remains after suffixation.

(7) *Loss of coda /ʔ/ but retention of glottalized vowels with suffixation:*

/kin-pa̱ʃniʔ-ˈkan/	[kimpa̱ʃniˈkan]	*kimpa'xnikán*	'*nuestro cochino*, our pig'
/kin-t͡ʃit͡ʃiʔ-ˈkan/	[kint͡ʃit͡ʃiˈkan]	*kinchichikán*	'*nuestro perro*, our dog'
/kin-taːtah-ˈkan/	[kintaːtahˈkan]	*kinta:tahkán*	'*nuestro abuelo*, our grandfather'
/kin-liːwa̱j-ˈkan/	[kiliːwa̱jˈkan]	*kili:wa'ykán*	'*nuestra carne*, our meat'

Therefore, the phonological relationship between glottalized vowels and glottal stops can also be considered what Hall (2013) calls "intermediate." On the one hand, they are in complementary distribution, suggesting an allophonic relationship. On the other hand, glottalized vowels are phonetically very distinct from glottal stops, and the sounds' divergent behavior in alternations provides evidence that /ʔ/ should be considered synchronically contrastive with glottalized vowels.

5. General discussion

In the previous section, we found that the phonation contrast in Zongozotla Totonac is phonetically weak and that glottal stops are marginal phonemes that are in complementary distribution with glottalized vowels. In this section, we provide possible explanations for these findings and discuss their implications for future linguistic research on Totonacan, and, more broadly, on Mesoamerican languages.

5.1. Implications of the phonetically-weak phonation contrast

Glottalization plays an outsize role in both diachronic and synchronic phonological analyses across the Totonacan family. In terms of historical analyses, MacKay & Trechsel (2018, p. 55) state: "The key question that must be addressed in any reconstruction of [Proto-Totonac-Tepehua] concerns the status of laryngealized vowels and glottalized consonants in the protolanguage." That is because scholars disagree on whether the protolanguage should be hypothesized as having glottalized vowels (Arana Osnaya, 1953; Brown et al., 2011; Levy, 1987) or (different sets of) glottalized consonants, including clusters with glottal stops (Davletshin, 2019; MacKay & Trechsel, 2018).

But the analysis of glottalization in present-day Totonac and Tepehua languages is also contentious. As McFarland (2009, p. 13) writes in her dissertation on Filomeno Mata Totonac: "The writers of published grammars of all varieties [of Totonac-Tepehua languages] have struggled with the analysis of glottal features, which are variously accounted for as the phoneme /ʔ/, ejection on stops, laryngealization of vowels, and/or part of the vocalic nuclei, (either Vʔ, ʔV or ʔVʔ)." Part of the reason for the analytic struggles is that, across Totonac varieties, the historical contrast between modal versus glottalized vowels shows a continuum between full maintenance and complete loss, with many varieties having lost the contrast (in favor of modal vowels) in all, or nearly all, contexts. For instance, in his dictionary of Zapotitlán Totonac (which is part of the Highland group of Totonac languages), Aschmann (1983, p. 141) writes: *"En varios pueblos se utiliza [una contracción o un cierre en la laringe] sólo al final de la palabra u oración."* ("In several towns [laryngeal constriction or closure] is used only at the end of the word or utterance.") Further, the phonetic differentiation between modal versus glottalized vowels can be very weak. We have shown this to be true in ZoT, where the glottalized vowels can be described phonetically as at most "slightly constricted," that is to say "tense." The same has been argued for Olintla Totonac, though with more limited phonetic analysis (Tino Antonio, 2020). Huehuetla Totonac, another Highland variety, is reported to have only modal vowels; it further allows vowel-final words to variably end in a glottal stop (Troiani, 2007), which suggests that the presence of glottal stops is unrelated to the lexical phonology.

Why would some varieties of Totonac, including ZoT, have a weak phonation contrast, and why do others appear to have no contrast in phonation at all? We suggest that the relatively small number of contrasts (Davletshin, 2019) contribute to the phonetic weakening and eventual loss of the phonation contrast. As we discussed in Section 4.2, the functional load of the phonation contrast is low, both in ZoT and across the family. When there is competition in the lexicon, such as when a word has at least one minimal pair competitor, we can expect a tendency toward hyperarticulation of the phonetic attributes that helps differentiate competitors (Nelson & Wedel, 2017; Wedel et al., 2018). Conversely, a relative dearth of competition is associated with phonetic hypoarticulation. Moreover, a higher functional load of a contrast can inhibit diachronic loss of that contrast (Wedel et al., 2013). Therefore, diachronic phonation weakening and loss across Highland Totonac varieties can have had their origins in functional considerations of the contrast, namely the lack of competition between lexical items differing in terms of phonation type. This may also help explain why glottalized vowels are phonetically so weakly differentiated from modal ones in ZoT. Are glottalized vowels realized as only weakly non-modal (1) because of the lack of competition in the lexicon, (2) because the contrast is undergoing diachronic loss, (3) for both these interrelated reasons, or (4) for independent reasons? We don't know the answer, but we suspect an ongoing change toward phonation loss (possibly due to its low functional load) is at play. If phonation is indeed being lost in ZoT via

gradual weakening of the phonetic characteristics of glottalization, then this would likely be a case of "merger by approximation" (Labov, 1994, p. 321), involving the gradual coalescence of two categories. Mergers by approximation can sometimes result in a single category bearing the same mean value as one of the original categories. This seems to be at work here: glottalized and modal phonation appear to be coalescing, with the remaining category being phonetically modal.

The phonetically weak realization of the phonation contrast also has important implications for comparative studies of Totonac glottalization. If modal versus glottalized vowels are only weakly differentiated in some varieties, then glottalized vowels are likely to go underdescribed. In fact, this appears to be true for previous work on ZoT. In his field notes transcribing words across several Highland Totonac varieties, McQuown (1976) transcribed ZoT words with word-final glottal stops, but did not transcribe non-final vowels as glottalized, even where we do. Thus for the word '*árbol*, tree' in ZoT, McQuown transcribed *kíwi*ˀ, i.e. /kiwiʔ/. In contrast, our own orthographic rendition and phonemic transcription are *ki'wi'* /kiwiʔ/, indicating a word-medial glottalized vowel. It is not the case that McQuown *heard* but neglected to *transcribe* non-final glottalization; in his transcription of Zapotitlán Totonac, McQuown transcribes the same word with glottalization on both vowels (cf. Aschmann (1983)'s dictionary spelling as *qui'hui'*, i.e., /kiwi/). Thus McQuown did hear and transcribe non-final glottalized vowels in Zapotitlán Totonac, but in ZoT he probably did not hear non-final glottalized vowels, and thus did not transcribe them.

This has important implications for comparative and diachronic work on Totonac. For example, McQuown (1990) variably transcribed word-medial glottalized vowels in Coatepec Totonac, another Highland variety: for instance, '*árbol*, tree' is listed as both /kiwiʔ/ (p. 493) and as /kiwiʔ/ (p. 44), and word-medial glottalized vowels do not appear to be transcribed in other texts by McQuown (Levy, 2020). Were glottalized vowels variably transcribed in Coatepec because, as in ZoT, they were too weak to be detected? This is an important question to answer for comparative work, because Coatepec is cited in comparative studies as an example of a Totonac variety that lacks the phonation contrast (Davletshin, 2018; MacKay & Trechsel, 2018). In sum, impressionistic transcriptions for Coatepec Totonac and other varieties of Totonac should be revisited using detailed field research and phonetic analysis like the kind we have employed here. We hope to do this in the near future, using the elicitation list and strategy that we employed for Zongozotla. While it is likely that some varieties have indeed lost the phonation contrast, it seems equally likely that others retain the contrast in the way that Zongozotla does—with a very weak phonetic implementation of the glottalization. Extensive careful and comparative elicitation and analysis will be needed to resolve this question.

5.2. Explaining the complementary distribution between glottalized vowels and glottal stops

Another problem for synchronic analyses concerns word-final glottal stops, especially in varieties such as Zongozotla Totonac, where glottal stops only surface phrase-finally. Recent hypotheses of Proto-Tepehua-Totonac (Brown et al., 2011; Davletshin, 2018; MacKay & Trechsel, 2018) reconstruct the proto language, if tentatively, as having glottal stops in word-final position. This has implications for how we analyze the complementary distribution in ZoT between glottalized vowels and glottal stops, which we argue below can either be inherited or innovated.

In ZoT, word-final glottal stops are always realized as "canonical" glottal stops, i.e., with mostly voiceless constriction (see panel (a) of **Figure 5**). But in perhaps most languages, glottal stops are realized with voiced glottalization throughout the constriction (Garellek et al., 2023). This means that the distinction between creaky vowels [V̰] and vowel-glottal stop sequences [Vʔ] should not be posited mainly in terms of some kind of assumed "typical" phonetic realization, because in fact creaky vowels and modal vowels followed by glottal stops typically look and sound the same. For this reason, Garellek et al. (2023) argue that the choice of analyzing glottalization as [V̰] versus [Vʔ] should be based primarily on its phonological patterning rather than on its phonetic properties. Indeed, in Section 4.4 we argued that the strongest evidence for treating final [ʔ] as underlying /ʔ/ (rather than as a phrase-final realization of /V̰/) is due to the glottal stop's phonological behavior, not its phonetic realization.

Why might the phonetic similarities between glottalized vowels and glottal stops matter for Totonac more broadly? First, the fact that [V̰] and [Vʔ] can be realized in the same way provides a potential explanation for the complementary distribution found in ZoT between glottalized vowels (which do not occur word-finally) and glottal stops (which mainly occur word-finally). That is, it is possible to posit a change such as *V̰# > Vʔ#, as language users reinterpreted a word-final glottalized vowel as a modal one followed by a glottal stop. Indeed, Davletshin (2018) has already posited this as a sound change for some Totonac varieties.

Second, the fact that /V̰/ and /Vʔ/ can be phonetically identical provides another reason to reexamine previous analyses of glottalization in Totonac. For instance, where Zapotitlán Totonac has word-final glottalized short vowels /V̰/, ZoT only has /Vʔ/; thus, '*árbol*, tree' is /kin̰wḭ/ in Zapotitlán Totonac but /kin̰wiʔ/ in ZoT. (Interestingly, there are very few[5] words with word-final /V:/ or /V̰:/ in Aschmann (1983)'s dictionary, and their cognates in ZoT lack a final long vowel. For example, the dictionary entry *lāntlā'* (/la:ntɬa̰:/) '*cómo*, how,' with a final long glottalized vowel, corresponds to ZoT /la:ntah/.) In this paper, we argue that there is phonological evidence

[5] In Aschmann (1983)'s dictionary, we found only one word ending in /V̰:/ (described in the main text) and two word/roots ending in /V:/. There are additional examples of long vowels appearing word-finally but before another word within a phrase; length here might reflect compounding. In ZoT, compounds often induce lengthening of the compound's initial word's final vowel.

for positing word-final /ʔ/ instead of /V̰/ in ZoT. Is there comparable *phonological* evidence in Zapotitlán Totonac for word-final /V̰/? We don't yet know, but the answer would bear on crucial questions related to the reconstruction of Proto-Tepehua-Totonac. Clearly then, the study of Totonac sounds could benefit from more, and deeper, phonological and phonetic analyses.

5.2.1. The possible role of "phrase-final breath"

If we assume that a phonological change like *V̰# > Vʔ# did in fact occur, then we should seek independently-motivated explanations for this change. We argue below for one possible explanation, which benefits from being able to further account for why phrase-final glottal stops are voiceless and so strongly realized in ZoT, in contrast to the typological tendency for glottal stops to be mostly voiced (Garellek et al., 2023).

We propose that both facts can be accounted for by the occurrence in Totonac of *phrase-final breath*, the increased vocal fold spreading (i.e., "breath") at the ends of phrases, resulting in voiced sounds becoming breathy-voiced or even fully devoiced (Duarte-Borquez et al., 2024). Phrase-final breath is phonetically motivated in utterance-final position because ends of utterances are associated with low subglottal pressure, more vocal fold spreading, and higher transglottal flow (Slifka, 2006). Together these favor breathiness and devoicing, as well as irregular voicing, in the form of unconstricted spread-glottis creak (Garellek, 2019; Keating et al., 2015). Given that phrase-final breath is also found at ends of phrases in utterance-medial position, we assume that *utterance*-final breath must have eventually generalized to *phrase*-final breath, just as researchers have posited for obstruent devoicing (Blevins, 2006; Myers & Padgett, 2015; Westbury & Keating, 1986).

Across Totonacan languages, researchers report that phrase-final vowels devoice, and that sonorants devoice or are weakly voiced (Aschmann, 1946; Davletshin, 2018; Garcia-Vega, 2022; McFarland, 2009; Puderbaugh, 2019b; Román Lobato, 2008; Tino Antonio, 2020; Troiani, 2007). As we described in Section 4.1, this is also the case for Zongozotla Totonac. These facts are consistent with ends of phrases in Totonac being produced with phrase-final breath. And though it is widely found across Totonac languages, phrase-final breath appears to be an areal, i.e., Mesoamerican (DiCanio & Bennett, 2020), phenomenon: similar patterns are found across Mayan languages (Bennett, 2016), in Chicontepec Nahuatl (Aguilar, 2020), and in Mexico City and Salvadoran Spanish (Avelino, 2018; Dabkowski, 2018; Salgado, 2023). The term "phrase-final breath" was recently coined by Duarte-Borquez et al. (2024) to refer to the phenomenon as it occurs in bilingual speakers of American English and Mexican Spanish.

How might the presence of phrase-final breath in Totonac influence the distribution and realization of glottalization? Assuming that phrase-final breath has long been present in the language family, it may also account for the posited sound change whereby *V̰# > Vʔ#. That

rule was posited for word-final position, but its source may in fact be specifically phrase-final. If ends of phrases are marked with breath, we would expect phrase-final vowels to devoice. This is clearly what happens to *modal* vowels in ZoT and many other Totonac varieties. But if a *glottalized* vowel occurs in phrase-final position, the presence of breath could weaken its glottalization, because vocal fold spreading (for breath) and constriction (for glottalization) are antagonistic gestures.

Glottal stops are produced with stronger glottalization than voiced glottalization (Garellek et al., 2023). So if [V?] is the reflex of word-final *V̰, then this change could be considered a form of prosodic strengthening of glottalization (Garellek, 2014). Thus, it is plausible for glottal stops to have emerged in ZoT from strengthening of /V̰/ in phrase-final position, as a means of strengthening the phonation contrast when it occurs in phrase-final breath. Glottal stops could subsequently have been reanalyzed by language users as lexically-contrastive sounds. Although prosodic strengthening is more common in domain-initial rather than domain-final positions, it is nonetheless attested across languages of the world (Cho, 2005; Tabain, 2003). In Mesoamerica specifically, it has been documented for two Otomanguean languages, Itunyoso Trique (DiCanio, 2010) and Yoloxóchitl Mixtec (DiCanio et al., 2015), though in the latter case it is unclear whether the prosodic strengthening is due to prominence or domain-finality (or both of these factors).

If glottal stops developed from historically glottalized vowels in phrase-final position, what happened to word-final glottalized vowels in phrase-medial positions? Our assumption is that the glottal stop realization would then have generalized from phrase-final to word-final position, such that all glottalized vowels would have been realized as [V?] word-finally at some intermediate stage of the language. We note here that Salgado & Pinta (2024) posit a similar account of Nawat (Uto-Aztecan; Guatemala) word-final /h/ in loanwords originating from vowel-final Spanish words, also as a result of (what we call) phrase-final breath that generalized to word-final position from phrase-final position.

Recall that word-final /ʔ/ does not surface unless it is also phrase-final. So if it is true that word-final glottal stops in ZoT are a result of *V̰# > Vʔ# which later generalized from phrase-final to word-final position, then we also have to account for the absence of word-final glottal stops on the surface in phrase-medial position. But recall that word-final /h/ is also prohibited from surfacing in phrase-medial position (7). Thus, we can assume that the absence of both /h/ and /ʔ/ reflects a shared ban against word-final, phrase-medial, glottal consonants, possibly due to the constraint against C#C within a phrase. The upshot is that phrase-final breath may have led to the development of glottal stops from historically glottalized vowels, but a synchronic ban against word-final glottal consonants in phrase-medial position is what has led to glottal stops' frequent alternation with zero in the current state of the language, as shown in (8).

(8) *Possible diachronic changes, as well as synchronic processes, involving glottalization:*

Proposed sound changes	*Phrase-final*	*Phrase-medial*
Phrase-final strengthening of /V̰/	*V̰ > [V?]	
Generalization to word-final position		*V̰ > /V?/
Synchronic rule	*Phrase-final*	*Phrase-medial*
No word-final glottal consonants phrase-medially		/V?/ → [V]
		/Vh/ → [V]

This possible diachronic account of ZoT glottalization makes certain predictions that should be tested across the Totonac family. One prediction is that phrase-final breath should lead to instances of glottal stops after word-final glottalized vowels in varieties that retain /V̰#/. That is, there may well be varieties of Totonac that retain word-final /V̰ V̰:/, but in which these sounds are realized as [V̰? V̰:?] in phrase-final position. Because we hypothesize that phrase-final glottal stops could have emerged in response to phrase-final breath, we also predict that, if there exist varieties without phrase-final breath, those varieties should *not* show correspondences between historical *V̰ and any glottal stops that might occur. But if glottal stops are inherited, perhaps in part from a nominalizer *-ʔ suffix (Davletshin, 2018), then there may be current varieties that retain glottal stops in nominals after both modal and glottalized vowels.

Regardless of their historical origin, it is surprising that glottal stops would be so strongly realized phonetically in synchronic ZoT: our data suggest they are so typically realized as complete stops [ʔ], even though glottal stops are generally produced with incomplete constriction across languages (Garellek et al., 2023). We argue that this too might reflect the language's response to the antagonistic relationship between phrase-final breath and glottalization. If the tendency is to spread the glottis at ends of phrases, then doing just that would result in weakening and even loss of glottal stops. But if glottal stops are produced with full constriction, then phrase-final breath is suppressed for phrases ending in /ʔ/. Thus, phrase-final breath provides a motivation for the canonical realization of glottal stops as phonetic voiceless stops.

6. Conclusion

In this paper, we provide the first in-depth description and analysis of the sounds of Zongozotla Totonac. We have paid particular attention to the behavior and realization of glottalization, by which we mean both glottal stops and glottalized ("laryngealized") vowels. Our study also presents the most in-depth phonetic and phonological analysis of glottalization in a Highland Totonac variety to date.

We have argued that contrasts involving glottalization are marginal in ZoT across the board. Glottal stops have a limited phonotactic distribution within the word, and word-final glottal stops only surface when the word occurs phrase-finally. Glottalized vowels are phonetically weak: they

are produced with only slight increased constriction that is variably realized phonetically both across minimal pairs and speakers. As in all Totonac varieties, the contrast between glottalized and modal vowels has a low functional load (Davletshin, 2019). Our phonetic analysis suggests that the phonation contrast is so weak and variable so as to be undergoing loss, as already suggested for other Highland Totonac varieties. Future research should also investigate whether listeners reliably distinguish modal versus glottalized vowels, in ZoT as well as across the family.

Another interesting finding is that the contrast between glottalized vowels and glottal stops is itself only marginally contrastive, with the two categories occurring in complementary distribution except in derived cases of word-final glottalized vowels (where final /V̰h/ surfaces as [V̰] in phrase-medial position). In Section 5.2, we posited that this apparent complementary distribution could reflect a sound change whereby historically glottalized vowels became /V?/ word-finally, a process previously argued by Davletshin (2018) for Coatepec Totonac. We further hypothesize that such a sound change may have emerged in response to phrase-final breath, a widespread phenomenon across Totonac and other Mesoamerican languages. Even if phrase-final breath was not ultimately responsible for such a sound change, it may still serve as a synchronic pressure for realizing /?/ with strong glottalization.

The field of comparative Totonac studies would greatly benefit from more studies which rely on both detailed phonetic analysis of the phonation contrast as well as phonological evidence to motivate glottalization as being either vocalic or consonantal. The field currently relies on transcriptions which, as a result of the absence of phonetic analyses, might underdescribe the presence of a phonation contrast; it also relies on transcriptions of glottalization which, as a result of incomplete phonological analyses, might better be analyzed as glottal stops instead of as glottalized vowels (or vice versa). A complete analysis of glottalization clearly requires both phonetic and phonological evidence in order to be convincing. A final important message to be gleaned from Zongozotla Totonac is that the intermediate phonological relationships that lead to marginal contrasts (Hall, 2013) can arise from high up the prosodic hierarchy as a result of the influence from utterance edge effects. It is only by analyzing sounds according to both their phonetic characteristics and their phonological patterning—and at different prosodic levels—that we can approach a complete picture of their behavior.

Appendix

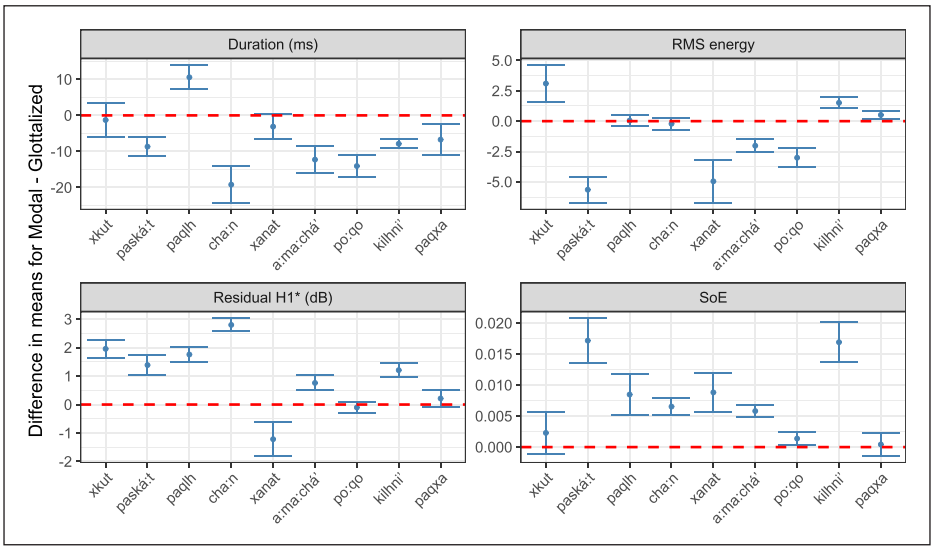

Figure 8: Differences between modal and glottalized vowels for the acoustic measures that emerged as predictors, separated according to word pair. The x-axis label shows only the modal word in its orthographic representation. The dot shows the mean difference, and error bars indicate standard error about the mean. When error bars overlap with 0, one can infer that there is no difference between modal and glottalized vowels.

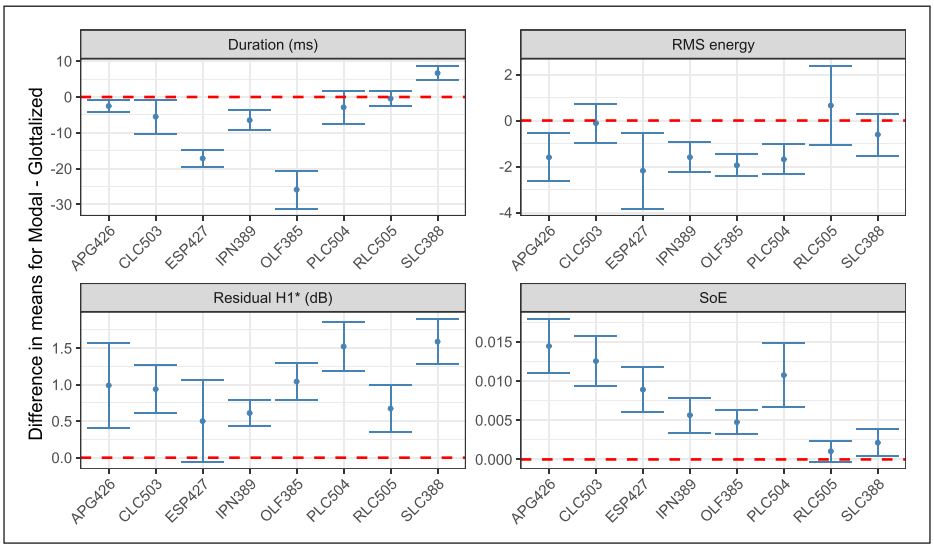

Figure 9: Differences between modal and glottalized vowels for the acoustic measures that emerged as predictors, according to each speaker. The dot is the mean difference, and error bars indicate standard error about the mean. When error bars overlap with 0, one can infer that there is no difference between modal and glottalized vowels.

Acknowledgments

We would like to thank the speakers who recorded with us and shared their knowledge of Zongozotla Totonac: Areli Ponce García (APG 426), Clemencia López Cruz (CLC 503), Epifania Sahinos Pérez (ESP 427), Isac Pérez Núñez (IPN 389), Priscilia López Cano (PLC 504), Rosendo López Cano (RLC 505), and Sebastián López Cano (SLC 388). Osbel López-Francisco (OLF 385) is the second author.

We also thank Ashlinn Barber-Woeltjen, Hayley Dawson, and Lexi Ricasata for discussion and assistance with data organization and audio segmentation, as well as Eric Baković, Sharon Rose, and other members of the Phonetics-Phonology meeting group at UCSD for helpful discussion. An earlier version of this study is reported in Dawson et al. (2022). We also thank Claudia Duarte-Borquez and Gabriela Caballero for proofreading the Spanish translation of the abstract, and the LabPhon editorial team (Alan C. L. Yu, Bettina Braun, and Bernardo Rechea) for their careful review and copy-editing of the paper.

Research was supported by NSF CISE-RI award #2211952 "From Acoustic Signal to Morphosyntactic Analysis in One End-to-End Neural System" and NSF DLI award #2109821 "A comparative database for biologists, botanists, and linguists," Jonathan D. Amith, PI on both projects.

Competing interests

The authors have no competing interests to declare.

Authors' contributions

All authors contributed to the conceptualization of the study. All authors contributed to the experiment design. Osbel López-Francisco and Jonathan D. Amith made and processed the audio recordings. Marc Garellek led the analysis and drafted the manuscript, with input from the other authors. All authors contributed to manuscript revision. All authors read and approved the submitted version.

References

Aguilar, A. E. (2020). *Phonology and phonetics of laryngeal sounds in Chicontepec Nahuatl* [Unpublished doctoral dissertation]. University of California, San Diego.

Arana Osnaya, E. (1953). Reconstrucción del prototototonaco [Reconstruction of Proto-Totonacan]. *Revista Mexicana de Estudios Antropológicos [Mexican Journal of Anthropological Studies]*, *23*, 123–130.

Aschmann, H. (1946). Totonaco phonemes. *International Journal of American Linguistics*, *12*, 34–43. https://doi.org/10.1086/463885

Aschmann, H., & Wonderly, W. L. (1952). Affixes and implicit categories in Totonac verb inflection. *International Journal of American Linguistics*, *18*, 130–145. https://doi.org/10.1086/464163

Aschmann, H. P. (1983). *Vocabulario totonaco de la Sierra* (2nd ed.) [Highland Totonac lexicon]. SIL International.

Avelino, H. (2018). Mexico City Spanish. *Journal of the International Phonetic Association*, *48*, 223–230. https://doi.org/10.1017/S0025100316000232

Beck, D. (2024). Totonacan languages. In S. Wichmann (Ed.), *The languages and linguistics of Mexico and Northern Central america: A comprehensive guide* (pp. 555–598). Mouton de Gruyter. https://doi.org/10.1515/9783110421705-012

Bennett, R. (2016). Mayan phonology. *Language and Linguistics Compass*, *10*, 469–514. https://doi.org/10.1111/lnc3.12148

Blevins, J. (2006). A theoretical synopsis of Evolutionary Phonology. *Theoretical Linguistics*, *32*, 117–166. https://doi.org/10.1515/TL.2006.009

Brown, C. H., Beck, D., Kondrak, G., Watters, J. K., & Wichmann, S. (2011). Totozoquean. *International Journal of American Linguistics*, *77*, 323–372. https://doi.org/10.1086/660972

Brown, C. H., Wichmann, S., & Beck, D. (2014). Chitimacha: A Mesoamerican language in the Lower Mississippi Valley. *International Journal of American Linguistics*, *80*, 425–474. https://doi.org/10.1086/677911

Bürkner, P.-C. (2018). Advanced Bayesian multilevel modeling with the R package brms. *The R journal*, *10*, 395–411. https://doi.org/10.32614/RJ-2018-017

Chai, Y. (2022). *Phonetics and phonology of checked phonation, syllables, and tones* [Unpublished doctoral dissertation]. University of California San Diego.

Chai, Y., & Garellek, M. (2022). On H1–H2 as an acoustic measure of linguistic phonation type. *Journal of the Acoustical Society of America*, *152*, 1856–1870. https://doi.org/10.1121/10.0014175

Cho, T. (2005). Prosodic strengthening and featural enhancement: Evidence from acoustic and articulatory realizations of /ɑ,i/ in English. *Journal of the Acoustical Society of America*, *117*, 3867–3878. https://doi.org/10.1121/1.1861893

Cho, T. (2016). Prosodic boundary strengthening in the phonetics–prosody interface. *Language and Linguistics Compass*, *10*, 120–141. https://doi.org/10.1111/lnc3.12178

Dabkowski, M. F. (2018). *Variable vowel reduction in Mexico City Spanish* [Unpublished doctoral dissertation]. The Ohio State University.

Davletshin, A. (2018). Las vocales finales, los procesos fonéticos finales y mediales en el protototonaco-tepehua: Un primer acercamiento [Final vowels, final and medial phonetic processes in Proto-Totonac-Tepehua: An initial approach]. In E. C. Buenrostro Díaz, L. Meléndez Guadarrama, & M. San Giacomo Trinidad (Eds.), *Lingüística histórica de lenguas indomexicanas: Hallazgos y discusiones recientes* [Historical linguistics of Indo-Mexican languages: Recent findings and discussions] (pp. 139–186). Universidad Nacional Autónoma de México.

Davletshin, A. (2019). Laryngealized vowels and laryngealized consonants in the history of the Totonacan languages of Mexico. *Journal of Language Relationship*, *17*, 177–196. https://doi.org/10.31826/jlr-2019-173-404

Dawson, H., Garellek, M., López-Francisco, O., & Amith, J. D. (2022). *Tense voice without the high f0: The case of glottalized vowels in Zongozotla Totonac* [Poster presented at the Fall 2022 meeting of the Acoustical Society of America]. https://doi.org/10.1121/10.0016292

DiCanio, C., & Bennett, R. (2020). Mesoamerica. In C. Gussenhoven & A. Chen (Eds.), *The Oxford Handbook of Language Prosody* (pp. 408–427). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198832232.013.25

DiCanio, C., Nam, H., Amith, J. D., García, R. C., & Whalen, D. H. (2015). Vowel variability in elicited versus spontaneous speech: Evidence from Mixtec. *Journal of Phonetics*, *48*, 45–59. https://doi.org/10.1016/j.wocn.2014.10.003

DiCanio, C. T. (2010). Itunyoso Trique. *Journal of the International Phonetic Association*, *40*, 227–238. https://doi.org/10.1017/s0025100310000034

Duarte-Borquez, C., Van Doren, M., & Garellek, M. (2024). Utterance-final voice quality in American English and Mexican Spanish bilinguals. *Languages*, *9*, 70. https://doi.org/10.3390/languages9030070

Garcia-Vega, M. (2022). *Morphology of Zihuateutla Totonac* [Unpublished doctoral dissertation]. University of Alberta.

Garellek, M. (2014). Voice quality strengthening and glottalization. *Journal of Phonetics*, *45*, 106–113. https://doi.org/10.1016/j.wocn.2014.04.001

Garellek, M. (2019). The phonetics of voice. In W. Katz & P. Assmann (Eds.), *Routledge handbook of phonetics* (pp. 75–106). Routledge. https://doi.org/10.4324/9780429056253-5

Garellek, M. (2022). Theoretical achievements of phonetics in the 21st century: Phonetics of voice quality. *Journal of Phonetics*, *94*(101155), 1–22. https://doi.org/10.1016/j.wocn.2022.101155

Garellek, M., Chai, Y., Huang, Y., & Van Doren, M. (2023). Voicing of glottal consonants and non-modal vowels. *Journal of the International Phonetic Association*, *53*, 305–332. https://doi.org/10.1017/s0025100321000116

Gordon, M., & Ladefoged, P. (2001). Phonation types: A cross-linguistic overview. *Journal of Phonetics*, *29*, 383–406. https://doi.org/10.1006/jpho.2001.0147

Hall, K. C. (2013). A typology of intermediate phonological relationships. *The Linguistic Review*, *30*, 215–275. https://doi.org/10.1515/tlr-2013-0008

Herrera Zendejas, E. (2023). Mecapalapa Tepehua. *Journal of the International Phonetic Association*, *53*, 287–303. https://doi.org/10.1017/S0025100321000098

Hyman, L. M. (1988). The phonology of final glottal stops. In *Proceedings of the 1st Western Conference on Linguistics (WECOL1)* (pp. 113–130). California State University.

Kawahara, H., de Cheveigné, A., & Patterson, R. D. (1998). An instantaneous-frequency-based pitch extraction method for high-quality speech transformation: Revised TEMPO in the STRAIGHT-suite. *5th International Conference on Spoken Language Processing (ICSLP-1998)*, 0659. https://doi.org/10.21437/icslp.1998-555

Keating, P., Garellek, M., & Kreiman, J. (2015). Acoustic properties of different kinds of creaky voice. In The Scottish Consortium for ICPhS 2015 (Ed.), *Proceedings of the 18th International Congress of Phonetic Sciences* (Paper 0821). International Phonetic Association.

Keating, P., Kuang, J., Garellek, M., Esposito, C. M., & Khan, S. (2023). A cross-language acoustic space for phonation distinctions. *Language*, *99*, 351–389. https://doi.org/10.1353/lan.2023.a900090

Kiparsky, P. (2014). New perspectives in historical linguistics. In C. Bowern & B. Evans (Eds.), *The Routledge handbook of historical linguistics* (pp. 64–102). Routledge.

Labov, W. (1994). *Principles of linguistic change* (Volume I: Internal factors). Blackwell.

Levy, P. (1987). *Fonología del totonaco de Papantla, Veracruz* [Phonology of Papantla (Veracruz) Totonac]. Universidad Nacional Autónoma de México.

Levy, P. (2020). Norman A. McQuown's Coatepec Totonac texts. *IJAL Texts Online*, *3*(1). https://www.americanlinguistics.org/?page_id=2658

MacKay, C. J. (1994). A sketch of Misantla Totonac phonology. *International Journal of American Linguistics*, *60*, 369–419. https://doi.org/10.1086/466242

MacKay, C. J., & Trechsel, F. R. (2018). An alternative reconstruction of Proto-Totonac-Tepehua. *International Journal of American Linguistics*, *84*, 51–92. https://doi.org/10.1086/694609

McFarland, T. A. (2009). *The phonology and morphology of Filomeno Mata Totonac* [Unpublished doctoral dissertation]. University of California, Berkeley.

McQuown, N. A. (1976). Vocabularios totonacos: Hueytlalpan, Olintla, Ozomatlán, Papantla, Tajín, Tepanco, Zapotitlán, Zongozotla (recopilados en el invierno de 1940 por Norman A. McQuown) [Totonac lexicon: Hueytlalpan, Olintla, Ozomatlán, Papantla, Tajín, Tepanco, Zapotitlán, Zongozotla (compiled in winter 1940 by Norman A. McQuown)]. In *Microfilm collection of manuscripts on cultural anthropology*. University of Chicago.

McQuown, N. A. (1990). *Gramática de la lengua totonaca. Coatepec, Sierra Norte de Puebla* (Vol. 4) [Totonac grammar. Coatepec, Northern Highlands of Puebla]. Instituto de Investigaciones Filológicas, Universidad Nacional Autónoma de México [Institute of Philological Research, National Autonomous University of Mexico].

Myers, S., & Padgett, J. (2015). Domain generalisation in artificial language learning. *Phonology*, *31*, 399–433. https://doi.org/10.1017/S0952675714000207

Nelson, N. R., & Wedel, A. (2017). The phonetic specificity of competition: Contrastive hyperarticulation of voice onset time in conversational English. *Journal of Phonetics*, *64*, 51–70. https://doi.org/10.1016/j.wocn.2017.01.008

Puderbaugh, R. (2019a). *Laryngealization in Upper Necaxa Totonac* [Unpublished doctoral dissertation]. University of Alberta.

Puderbaugh, R. (2019b). Phonetics and phonotactics of vowel laryngealization in Upper Necaxa Totonac. In S. Calhoun, P. Escudero, M. Tabain, & P. Warren (Eds.), *Proceedings of the 19th International Congress Of Phonetic Sciences* (pp. 2085–2089).

Quintana Godoy, M. (2022). *Juncture epenthesis in Filomeno Mata Totonac: Prosodic constraints and syntactic conditions* [Unpublished master's thesis]. University of Alberta.

Renwick, M. E. L., & Ladd, D. R. (2016). Phonetic distinctiveness vs. lexical contrastiveness in non-robust phonemic contrasts. *Laboratory Phonology*, *7*(19), 1–29. https://doi.org/10.5334/labphon.17

Román Lobato, G. (2008). *La juntura fonológica en el totonaco de Ozelonacaxtla, Huehuetla, Puebla* [Phonological juncture in the Totonac spoken in Ozelonacaxtla, Huehuetla, Puebla] [Unpublished master's thesis]. CIESAS.

Salgado, H. (2023). *New voices for ancestral sounds: The acquisition of Nawat phonology by speakers of Salvadoran Spanish* [Unpublished doctoral dissertation]. The Ohio State University.

Salgado, H., & Pinta, J. (2024). The perceptual origin of added glottals in Spanish loans in Modern Nahuan. *International Journal of American Linguistics*, *90*, 83–123. https://doi.org/10.1086/727524

Shue, Y.-L., Keating, P. A., Vicenik, C., & Yu, K. (2011). VoiceSauce: A program for voice analysis. *Proceedings of the International Congress of Phonetic Sciences*, 1846–1849.

Sjölander, K. (2004). *Snack sound toolkit*. Stockholm KTH. http://www.speech.kth.se/snack

Slifka, J. (2006). Some physiological correlates to regular and irregular phonation at the end of an utterance. *Journal of Voice*, *20*, 171–186. https://doi.org/10.1016/j.jvoice.2005.04.002

Tabain, M. (2003). Effects of prosodic boundary on/aC/ sequences: Articulatory results. *Journal of the Acoustical Society of America*, *113*, 2834–2849. https://doi.org/10.1121/1.1564013

Tino Antonio, J. (2020). Las vocales laringizadas y su manifestación fonética en el totonaco de Olintla [Laryngealized vowels and their phonetic realization in Olintla Totonac]. *Lingüística Mexicana. Nueva Época [Mexican Linguistics: New era]*, *2*, 7–30. https://doi.org/10.62190/amla.lmne.2020.2.1.1

Troiani, D. (2007). *Fonología y morfosintaxis de la lengua totonaca. Municipio de Huehuetla, Sierra Norte de Puebla* [Phonology and morphosyntax of Totonac spoken in Huehuetla, Northern Highlands of Puebla] [Instituto Nacional de Antropología e Historia. Colección científica 515 [National Institute of Anthropology and History, Scientific Collection 515]. Mexico City].

Ulrich, C. H. (1993). The glottal stop in Western Muskogean. *International Journal of American Linguistics*, *59*, 430–441. https://doi.org/10.1086/466212

Wedel, A., Kaplan, A., & Jackson, S. (2013). High functional load inhibits phonological contrast loss: A corpus study. *Cognition, 128*, 179–186. https://doi.org/10.1016/j.cognition.2013.03.002

Wedel, A., Nelson, N., & Sharp, R. (2018). The phonetic specificity of contrastive hyperarticulation in natural speech. *Journal of Memory and Language*, *100*, 61–88. https://doi.org/10.1016/j.jml.2018.01.001

Westbury, J. R., & Keating, P. A. (1986). On the naturalness of stop consonant voicing. *Journal of Linguistics*, *22*, 145–166. https://doi.org/10.1017/S0022226700010598