Glottalized stops and affricates in Eastern Mayan languages[1]

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X.1 Eastern Mayan languages

The Eastern Mayan languages consist of the K'ichean and Mamean sub-branches of the family, and are primarily spoken in the Guatemalan highlands (on Mayan languages belonging to other branches, see Avelino this volume). Eastern Mayan includes several widely-spoken languages, most notably Kaqchikel, K'iche', Q'eqchi' (all K'ichean), and Mam (Mamean), which have (roughly) between 750,000 and 1.5 million speakers each. Other Eastern Mayan languages have comparatively few speakers, e.g. under 150,000 for Tz'utujil and Ixil, under 15,000 for Sakapulteko and Awakateko, and under 7500 for Uspanteko and Teko.[2]

The Guatemalan government officially recognizes 15 languages in the Eastern Mayan branch: alphabetically, these are Achi, Awakateko, Chalchiteko, Ixil, Kaqchikel, K'iche', Mam, Poqomam, Poqomchi', Q'eqchi', Sakapulteko, Sipakapense, Tektiteko (Teko), Tz'utujil, and Uspanteko. The issue of what constitutes a distinct 'language' vs. 'dialect' is politically fraught in Guatemala, beyond the scientific issues involved. Two languages with official recognition, Achi and Chalchiteko, are arguably dialects of K'iche' and Awakateko, respectively. For a general overview of the Mayan languages, see Aissen et al. (2017) and references there.

Language contact between members of the Mayan family has played a significant role in the linguistic development of Eastern Mayan languages. See e.g. Barrett (1996, 2003), Law (2014, 2017), Tandy (2023), and references there for details.

X.2 Glottalized stops and affricates in Eastern Mayan

Detailed descriptions of the phonetics and phonology of glottalized stops in Mayan languages can be found in Bennett (2016), England & Baird (2017), Bennett et al. (2022b, 2023a), and Sobrino Gómez & Bennett (submitted). Our discussion here focuses on the phonetic properties of these sounds. Important precursors to this chapter include Campbell (1973), Pinkerton (1986), and Russell (1997); for additional references, see the bibliographies of the works cited above.

[1] Thanks to Noah Elkins, Robert Henderson, Igor Vinogradov, Maya Wax Cavallaro, and Elizabeth Wood for their advice and feedback on this article, and for sharing materials with us.

[2] Estimates of speakers per language are from the 2018 Guatemalan census; see https://censo2018.ine.gob.gt/explorador. Speakers of Eastern Mayan languages are also present in Mexico (primarily Teko and Mam), Belize (primarily Q'eqchi'), and diaspora communities in the U.S. and Canada.

Table 1 provides a list of phonemic stops and affricates which are typically found in Eastern Mayan languages. Retroflex consonants occur in Mamean languages, but not K'ichean languages. Some Eastern Mayan languages have also innovated stops at other places of articulation, such as palatalized velar /kʲ kʲˀ/ or lamino-alveolar /t͡s̻ t͡s̻ˀ/ (see also Adell 2019, Bennett et al. 2022b).

	Bilabial	**Alveolar**	**Post-alveolar**	**Retroflex**	**Velar**	**Uvular**	**Glottal**
Plain plosives	p	t t͡s	t͡ʃ	t͡s̻	k	q	
Glottalized plosives	ɓ ∼ ɓ̥ ∼ pˀ	tˀ t͡sˀ	t͡ʃˀ	t͡s̻ˀ	kˀ	ɢ̥ˀ ∼ qˀ	ʔ

Table 1 – Phonemic stops and affricates commonly found in Eastern Mayan languages.

The transcriptions in Table 1 underscore an important point about glottalized sounds in Eastern Mayan: the glottalized bilabial and uvular stops show extensive variation between implosive, ejective, and other realizations. We return to this point below.

In the following sections we provide a phonetic description of glottalized stops in Eastern Mayan languages, based on previous literature as well as our own fieldwork with K'ichean languages (particularly Kaqchikel and Uspanteko). It bears mentioning that almost all phonetic studies of glottalized stops in Mayan have been limited in scope. There is a need for more studies which do (at least) the following: (i) provide a quantitative, instrumental analysis, (ii) based on many tokens, (iii) of both stops and affricates, at several different places of articulation, (iv) produced in a range of phonetic contexts, (v) recorded with a reasonably large number of speakers, (vi) carefully controlling for the language and dialect of the speakers, (vii) taking into account the speech genre of the recording, (viii) and exploring a range of different phonetic parameters. Most prior studies satisfy only a few of these desiderata at a time. We hope that future work addresses these lacunae.

X.2.1 Ejectives

At most places of articulation, glottalized stops are typically realized as ejectives. An example is provided in Fig. 1, which shows a waveform, spectrogram (0-7500 Hz), and pitch track (75-200 Hz) for Uspanteko *tk'isk* [ˈtkˀiskʰ]. Recordings used for illustration are taken from spontaneous narratives unless otherwise noted; similarly, recordings were made by co-author Bennett unless

otherwise noted. Where needed, we make distinction between phonemic forms and phonetic forms by means of / / vs. [ ] brackets.

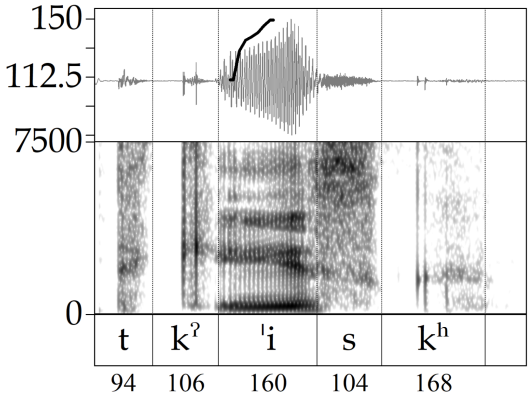


Figure 1 – Ejective [kʔ], Uspanteko *tk'isk* /t-kʔis-k/ → [ˈtkʔiskʰ] 'he finishes' (recorded 2021)

In Fig. 1, ejective [kʔ] is distinguished from plain [t] by (i) the intensity of the release burst, and (ii) the quality of the release phase. In ejectives, there is often a period of relatively low amplitude – and sometimes silence – between the release of the stop and the onset of the following segment (see also Figs. 2, 3). Presumably, this gap reflects the persistence of glottal closure beyond the release of the oral constriction. Additionally, the onset of the following vowel may show coarticulatory effects with glottal constriction: in this example, the amplitude of the vowel is relatively low at vowel onset, likely due to laryngeal coarticulation with constricted [kʔ] (Russell 1997). Notably, there is no clear difference in the duration of the release phase (≈ 'VOT') for [kʔ] vs. [t] here (see e.g. Russell 1997, Adell 2019; cf. Wagner & Baker-Smemoe. 2013).

Ejectives may also be produced with relatively weak release bursts in Eastern Mayan languages (see also Percival 2024). This is illustrated in Fig. 2, which shows two renditions of the same word, produced utterance-initially at the beginning of a narrative, by two different speakers. The top left panel shows a [kʔ] with a relatively strong burst, and the top right panel a [kʔ] with a relatively weak burst (where 'strong' and 'weak' refer to e.g. burst intensity relative to following vowel amplitude). The bottom panel shows the same strong vs. weak comparison for two tokens of ejective [tʃʔ] within a single word (here, utterance-finally).

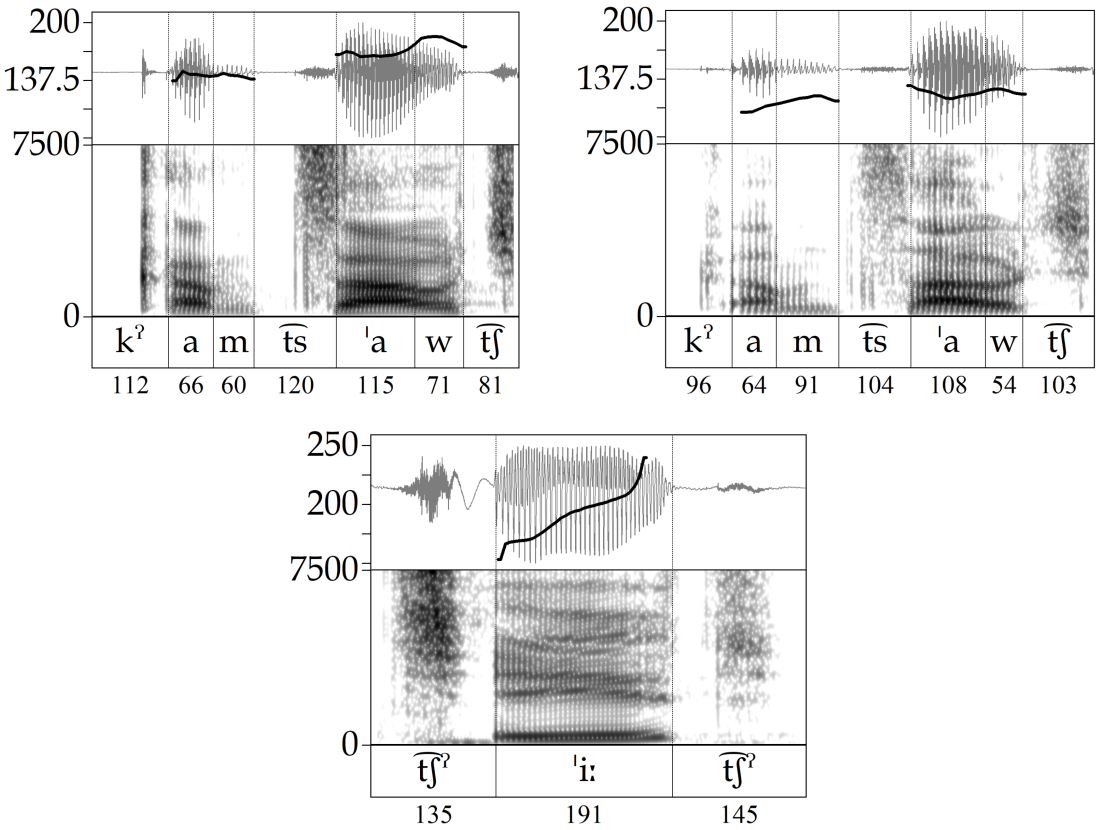


Figure 2 – 'Strong' vs. 'weak' [kʔ] in Uspanteko *k'amtzawch* [kʔamˈt͡sawt͡ʃ] 'hello' (top, recorded 2021) and *ch'iich'* [t͡ʃʔiːt͡ʃʔ] 'metal, machine, car' (bottom, recorded 2018)

In the top right panel, the onset of the vowel following [kʔ] is also produced with creaky or laryngealized voice, as a result of coarticulation with the glottal closure for [kʔ]: this is evident from the relatively wide, and somewhat irregular spacing of glottal pulses (= low, quasi-periodic f0), and the reduced amplitude of the vowel (compare left vs. right panels). Glottalized stops very commonly cause adjacent vowels and sonorants to become creaky in Eastern Mayan languages.

Figs. 3 and 4 provide some additional examples from Kaqchikel and Mam illustrating these basic observations.

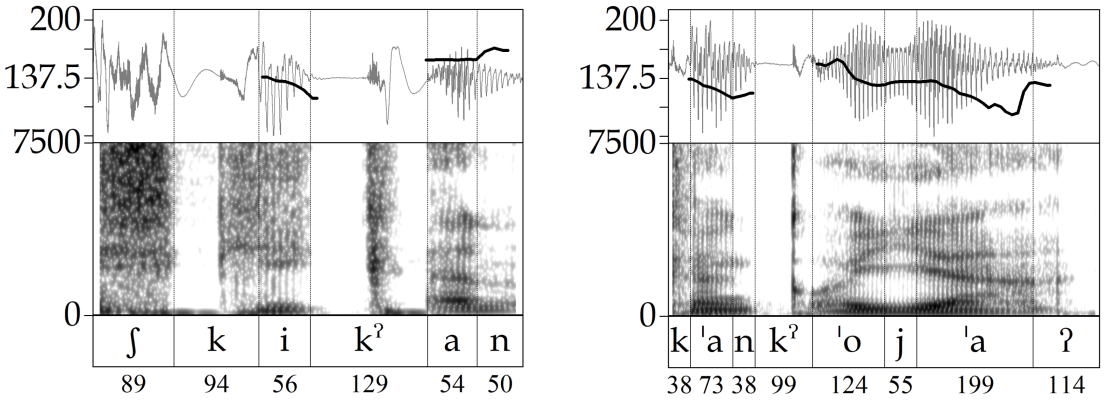


Figure 3 – Kaqchikel *xkik'an* [ʃkiˈkʔan] 'they brought it' and *kan k'o ya'* [ˈkan ˈkʔo ˈjaʔ] 'there's (still) water' (Sololá variety, recorded 2013)

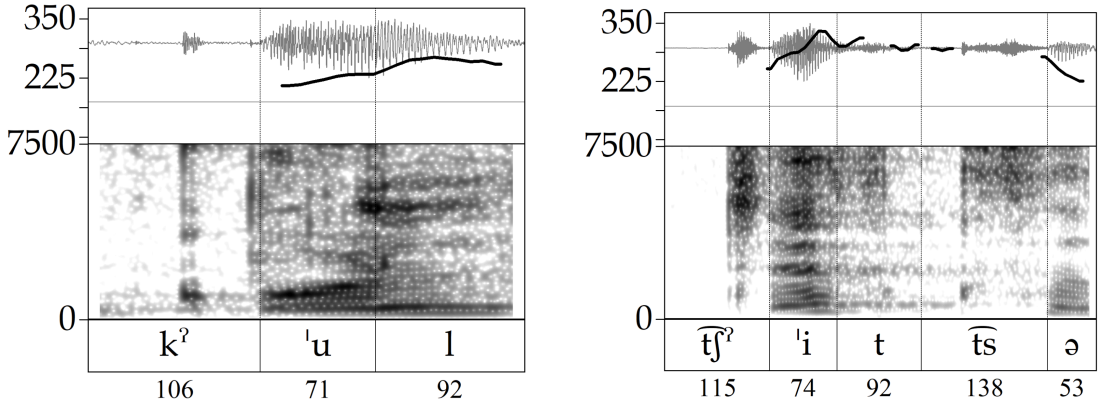


Figure 4 – Mam *k'ul* [ˈkʔul] 'bush' and *ch'it tza* [ˈt͡ʃʔit=t͡sə] 'almost=well' (Todos Santos variety, Elkins 2023, Speaker ZC)

Poqomam, and some varieties of Poqomchi', have a phonemic labial ejective /pʔ/, yielding a three-way /p ɓ pʔ/ contrast not found elsewhere in Eastern Mayan. The emergence of a phonemic ejective /pʔ/ owes to contact with lowland Mayan languages outside of the Eastern branch; see Law (2014), Sobrino Gómez & Bennett (submitted), and Avelino (this volume). See below on the phonetics of historical /ɓ/ in Poqomam; Fig. 7 below illustrates some purely allophonic cases of ejective [pʔ] in other Eastern Mayan languages.

Bennett et al. (2022b) observe that the release of ejective stops may be followed by a brief period of audible schwa-like voicing, particularly in word- and phrase-final position (Fig. 5). They speculate that these releases may have an aerodynamic source. After the oral constriction for the ejective is released, if the glottis remains sealed, sub-glottal air pressure may

be significantly higher than oral air pressure. This pressure differential would then facilitate rapid transglottal airflow at the point the vocal folds separate, leading to brief, passive voicing.

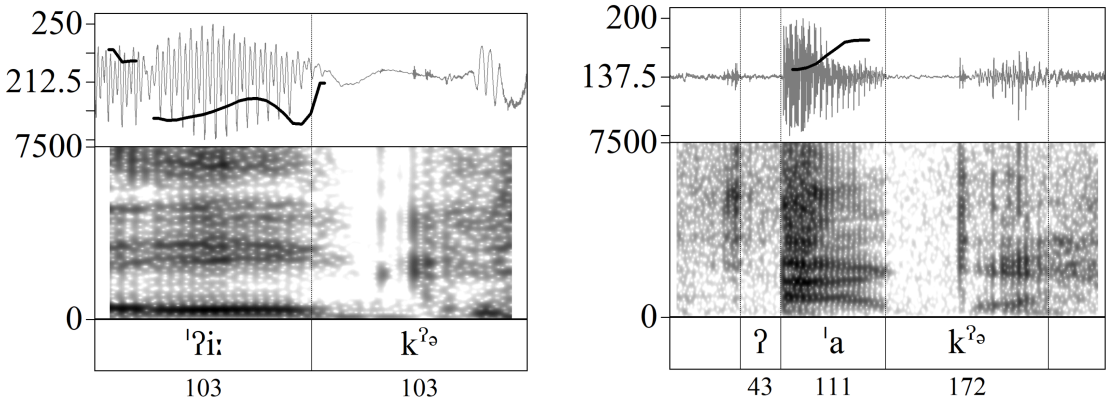


Figure 5 – Uspanteko *iik'* [ʔiːkˀ] ‘month’ (sentence translation task, recorded 2017) and Poqomchi’ *ak'* [ʔakˀ] ‘new’ with brief voiced releases (wordlist data, Bin 1998)

If correct, this aerodynamic perspective on voiced releases could provide a synchronic explanation for their occurrence; it could also be understood as the diachronic source for a phonetic pattern which has now become grammaticized, in the sense of being intentionally implemented by speakers, rather than passively emerging from aerodynamic factors.

Impressionistically, the same voiced releases may also occur for implosives (section X.2.2). This occurs in some dialects of Kaqchikel, e.g. Santiago Sacatepéquez Kaqchikel *jöb'* [χɔɓ̥ˀ] ‘rain’. A similar aerodynamic mechanism could be at play here, provided that (i) voiceless implosives are produced with a sealed glottis, such that (ii) glottal lowering also leads to increased sub-glottal air pressure relative to oral air pressure (e.g. Ladefoged & Maddieson 1996:87-90).

Voiced releases are not often reported for glottalized consonants in the Mayan family, or any other language, as far as we are aware. Further study seems merited.

X.2.2 Implosives

Bilabials

The glottalized bilabial shows a fair amount of phonetic variability in Eastern Mayan languages. It is most frequently realized as an implosive [ɓ] or [ɓ̥] (Fig. 6). The distribution of voiced [ɓ] vs.

voiceless [ɓ̥] is somewhat unclear: voicing appears to vary between languages, dialects, and possibly speakers, as well as phonetic context.

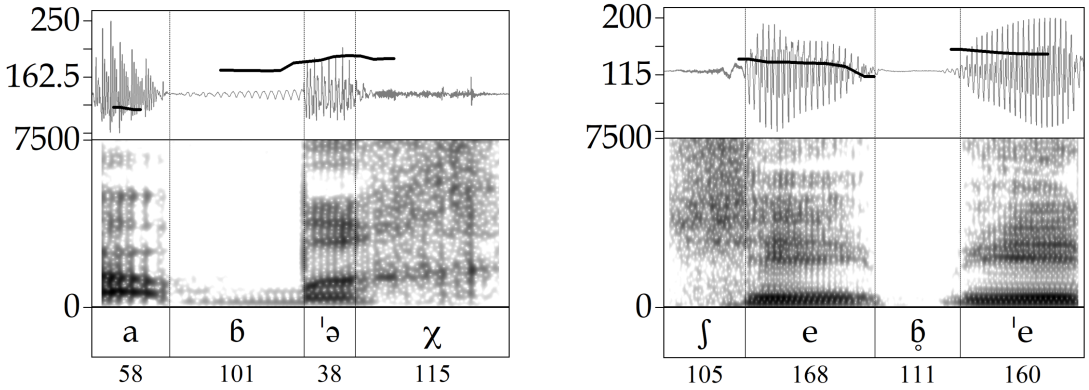


Figure 6 – Voiced [ɓ] in K'iche' *ab'äj* [aˈɓəχ] 'stone' (Chichicastenango variety, Wood & Chicoj Xirum 2019) vs. voiceless [ɓ̥] in Kaqchikel *xeb'e* [ʃeˈɓ̥e] 'they went' (Comalapa variety, recorded 2013)

Implosive [ɓ]/[ɓ̥] are acoustically characterized by the lack of a clear, strong release burst (Fig. 6). Closure voicing for voiced [ɓ] may be irregular (i.e. creaky). The amplitude of closure voicing in [ɓ] may be relatively stable, or may increase over time. Even in voiceless [ɓ̥], there may be brief periods of voicing immediately prior to release (Ladefoged & Maddieson 1996:87-90, Bennett et al. 2022b; also Fig. 6 right panel). As with ejectives, implosives often induce creaky voice on neighbouring vowels and sonorants (Fig. 6, left panel).

The glottalized bilabial is frequently realized as an ejective [pˀ] or unreleased implosive [ɓ̚]/[ɓ̥̚] in word-final position. However, ejective realizations do occur with some frequency even in prevocalic position (Fig. 7). Apart from the tendency toward more [pˀ] allophones in word-final position, the factors which determine ejective vs. implosive realizations of the glottalized bilabial in Eastern Mayan languages are not well understood.

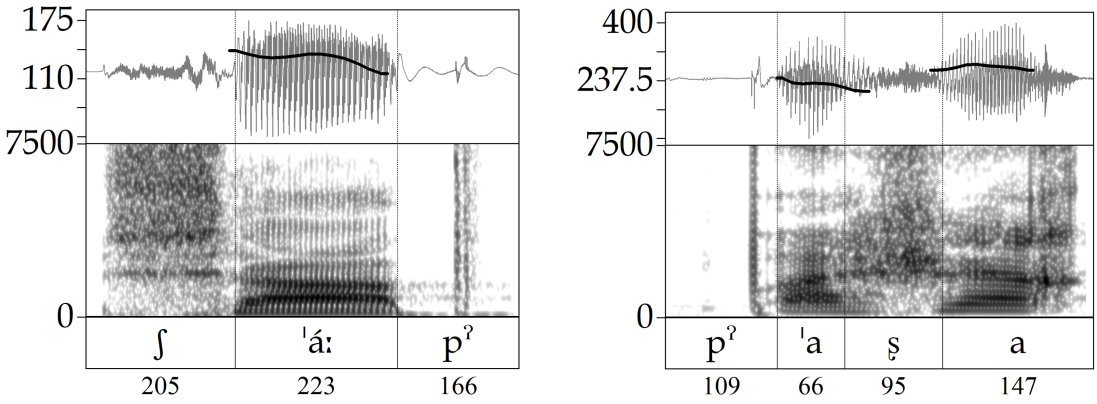


Figure 7 – Ejective [pˀ] realizations of the glottalized bilabial in Uspanteko *xáab'* /ʃáːɓ̰/ → [ˈʃáːpˀ] 'vomit' (wordlist data, recorded 2016) and Ixil *b'axa* /ɓaʂa/ → [ˈpˀaʂa] 'first' (Cotzal variety, Sánchez Toma et al. 2016)

In Poqomam and Poqomchi', historical */ɓ/ may be realized as glottalized [wˀ], or as glottalized [mˀ] or [m̰ˀ] word-finally or before a consonant (Fig. 8; see e.g. Brown 1979, Smith-Stark 1983, Santos Nicolás and Benito Pérez 1998, among others). In recordings that we've consulted on the Archive of the Indigenous Languages of Latin America (https://ailla.lib.utexas.edu/), glottalization is quite audible on [mˀ], but more subtle on [wˀ].

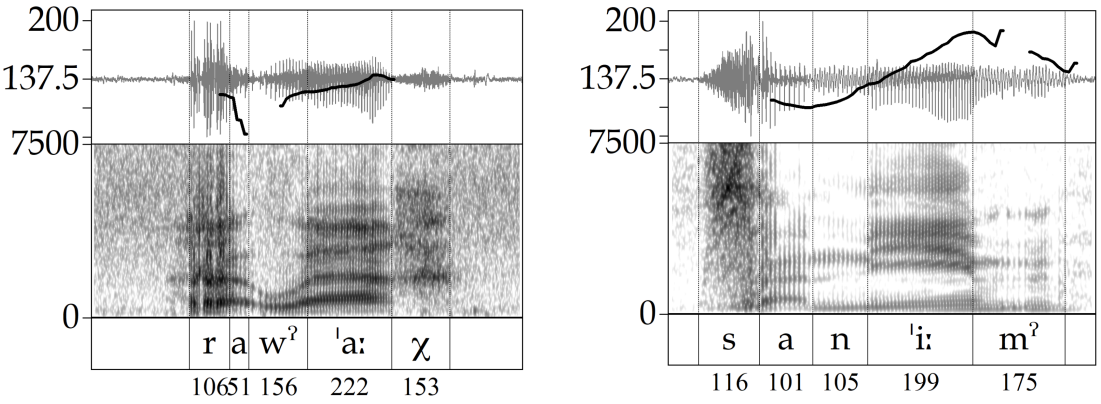


Figure 8 – Historically glottalized bilabial **b'* > [wˀ, mˀ] in Poqomchi' *rab'aaj* [raˈwˀaːχ] 'his stone' and *saniib'* [saˈniːmˀ] 'sand' (wordlist data, Belejú variety, Caal Morán 1998 (left), Bin 1998 (right); see also Fig. 5 above)

Indeed, glottalization is not always phonetically evident on [wˀ] allophones of historical **b'*, even for speakers who do clearly glottalize [wˀ] in some tokens (Fig. 9). In the materials we've examined, glottalization of [wˀ] seems more common word-internally than word-initially (or at

least, it is more *obvious* word-internally). Some speakers always produce **b'* > [w] as plain, without any indication of glottalization. Additionally, many speakers have unreleased [b̰̄] in word-final position rather than glottalized [mˀ]/[m̰ˀ] (Fig. 9). Dialect variation likely plays a role in these patterns of allophony (e.g. Brown 1979:29, Pinkerton 1986, Malchic Nicolás et al. 2000).

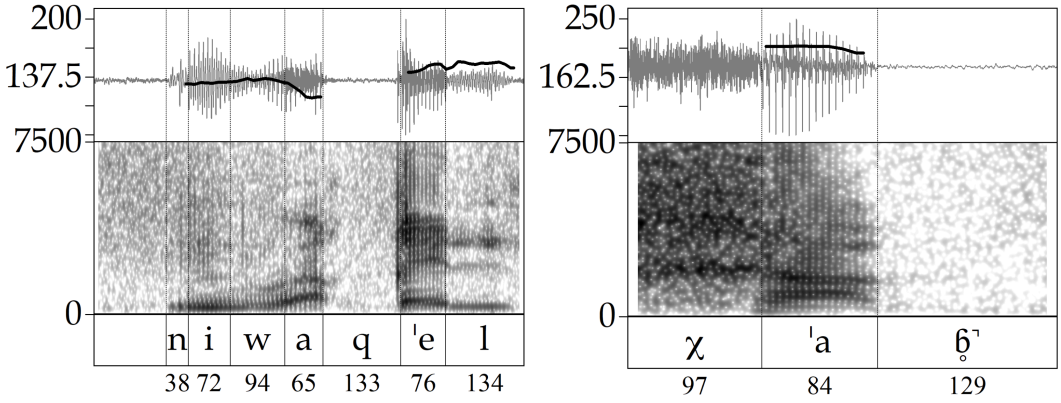


Figure 9 – Apparent plain [w] realization of historical **b'* in Poqomchi' *nib'aqel* [niw$^{(ʔ)}$aˈqel] 'my bone' (wordlist data, Belejú variety, Caal Morán 1998; compare with Fig. 8, left), and final [b̰̄] realization in Poqomam *jab'* [ˈχab̰̄] 'rain' (wordlist data, variety unknown, López & Malchic Nicolás 1998)

To our knowledge, there are no dedicated studies of glottalized [wˀ] or [mˀ]/[m̰ˀ] realizations of historical */ɓ/ in Poqomam or Poqomchi', or in other Mayan languages where allophones of this type are reported (e.g. Q'eqchi and Ixil; Stewart 1980, Adell 2019). More detailed phonetic investigation is called for.

Uvulars

Glottalized uvular stops also vary between ejective and implosive realizations in Eastern Mayan languages (Fig. 10). Just as with glottalized bilabial stops, the factors conditioning this variation are poorly understood, though word-final position does seem to favor ejective [qˀ] as well. Unlike glottalized bilabial stops, implosive [ɠ̊] realizations of the glottalized uvular stop are most commonly voiceless (Fig. 8; see e.g. Adell 2019:83 on voiced realizations).

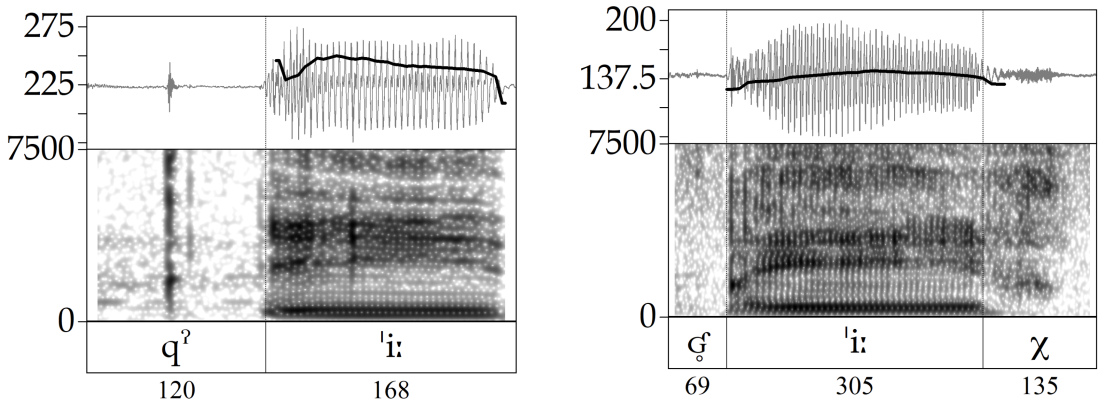


Figure 10 – Realizations of the glottalized uvular stop in Ixil *q'ii* [ˈqʔiː] 'day' (Cotzal variety, Sánchez Toma et al. 2016) and Mam *q'iij* [ɢ̥ˤiːχ] 'day' (Todos Santos variety, Elkins 2023, speaker FPM)

Other places of articulation

Glottalized /kʔ/ and the affricates /t͡sʔ t͡ʃʔ t͡ʂʔ/ are almost always ejective in Eastern Mayan, though various lenited forms occur in connected speech (the same is true of less common phonemes like /kʲʔ t͡ɕʔ/). Alveolar /tʔ/ – a sound which tends to occur in relatively few words in Mayan languages – can be realized as implosive in at least Mam (England 1983:26) and Tz'utujil (Dayley 1985:15). This is illustrated for Tz'utujil in Fig. 11. Both [ɗ] and [ɢ̥ˤ] may occur as allophones of /tʔ/ in this language (Maya Wax Cavallaro, p.c.).

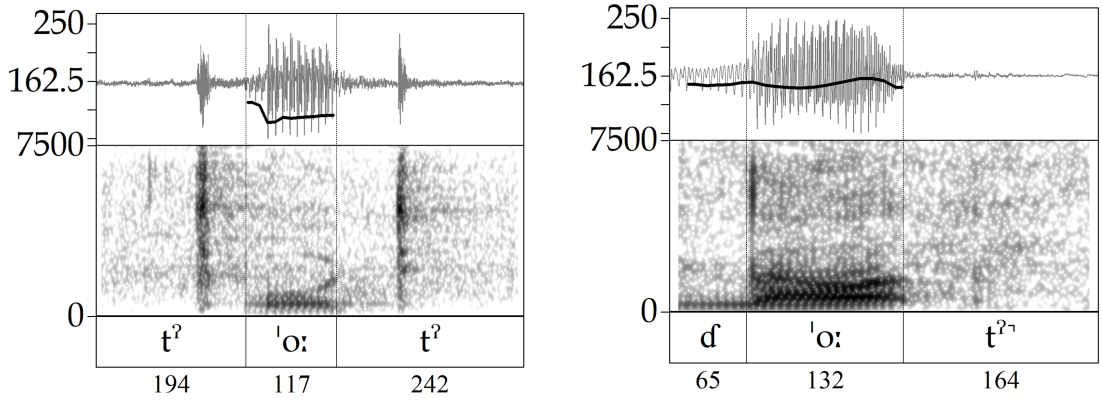
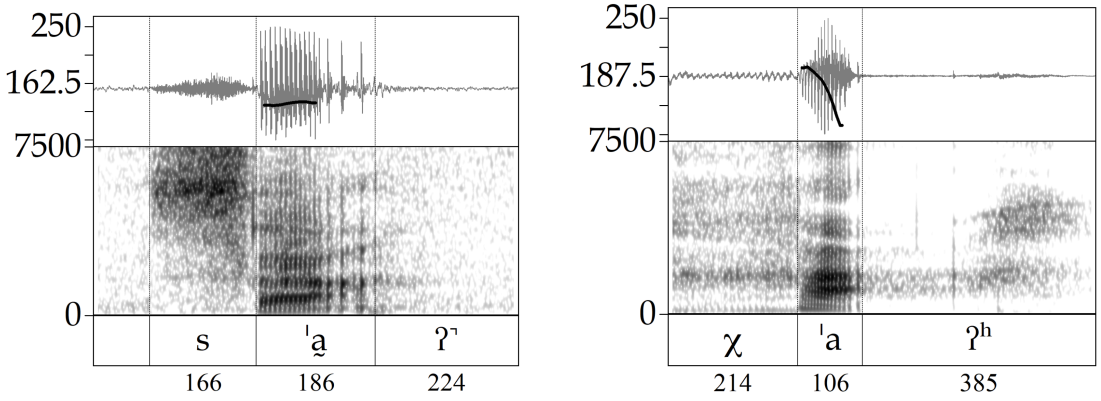


Figure 11 – Ejective and implosive realizations of glottalized alveolar stop in Tz'utujil *t'oot'* /tʔoːtʔ/ → [ˈtʔoːtʔ] ~ [ˈɗoːt̚ʔ] 'snail' (wordlist data; San Pablo La Laguna variety, Culum 1998; San Pedro La Laguna variety, Sequec 1998)

Implosive realizations of /tˀ qˀ/ are not just ‘lenited’ realizations of ejectives. Bennett et al. (2023a) point out that ejectives and implosives require the contraction of different muscle groups for raising vs. lowering the larynx. This implies that variation between ejectives and implosives in Eastern Mayan reflects variation between discretely different allophones, rather than a continuum of productions between ejective and implosive endpoints. The same point applies equally to ejective realizations [pˀ] of implosive /ɓ/ or /ɓ̥/.

X.2.3 Glottal stop

As in many languages, glottal stop has a range of phonetic realizations in Eastern Mayan (see also Bennett et al. 2022b, Garellek et al. 2023, and references there). It is frequently realized as creaky voice, without any period of full glottal closure, particularly between vowels or sonorant consonants. However, true stop-like realizations also occur, especially in word-final position and after obstruent consonants. In final position, glottal stop may be audibly released, and sometimes even aspirated. Lastly, vowel+[ʔ] sequences may also be realized as ‘rearticulated’ vowels: these are vowels which give the auditory impression of being temporarily interrupted by glottal constriction, before returning to a more modal articulation. Examples of these different outcomes are provided in Fig. 12.



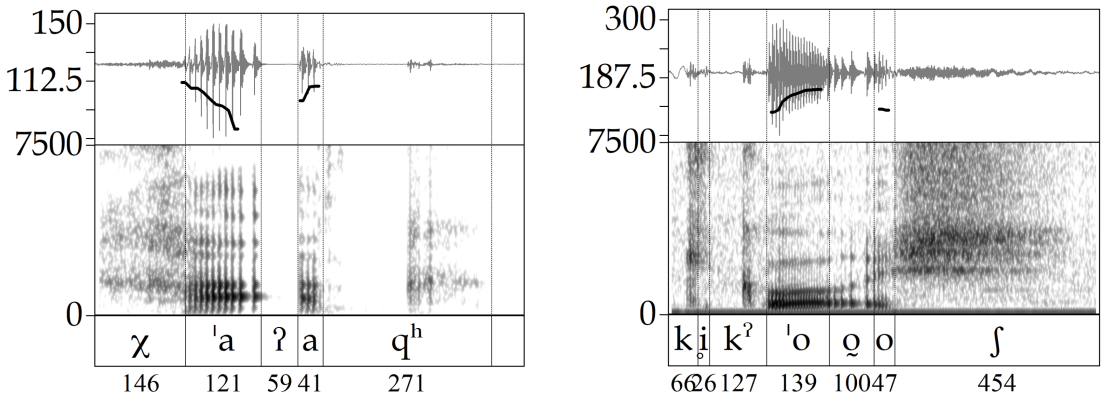


Figure 12 – Clockwise from upper-left: some phonetic realizations of glottal stop in Q'eqchi' *sa'* /saʔ/ → [ˈsãʔ̃] 'stomach, inside' (creak; wordlist data, Livingstón variety, Chub 1998), Uspanteko *ja'* /χaʔ/ → [ˈχaʔʰ] 'water' (closure with aspiration; recorded 2019), Sakapulteko *kik'o'x* /ki-kˀoʔʃ/ → [kiˌˈkˀo͡oʃ] 'their stomachs' (vowel rearticulation; Uluán Espinoza & Vásquez Aceytuno 2004), and Uspanteko *jja'aq* /χ-χaʔ=aq/ → [ˈχaʔaqʰ] 'their water' (full closure; recorded 2021)

Sobrino Gómez & Bennett (submitted) argue that phonetic glottal stop corresponds to two distinct phonological units in Mayan languages: it may reflect either a true consonantal glottal stop [ʔ], or it may be an abstract laryngeal feature (e.g. [+constricted glottis]) associated with vowel nuclei. Evidence for a featural analysis of some instances of [ʔ] comes, among other things, from interactions between glottal stop and stress assignment; see also DiCanio & Bennett (2021) and Elkins & Kuo (2022). The phonetic realization of glottal stop appears to be essentially the same regardless of its phonological status as a feature or segment.

In at least one variety of Mam (San Juan Atitán), derived instances of [ʔ] have a different phonetic profile than underlying /ʔ/ (Scott 2023:Ch. 2). Phonemic /ʔ/ is realized as creak in word-final or preconsonantal position, e.g. *jte'* /χteʔ/ → [χteɰ̰] 'how many'. However, surface [ʔ] may also be derived by debuccalization of the glottalized uvular /ɢ̰/ in the same environment, e.g. *leq'* /leɢ̰/ → [leʔ] 'thief'. This produces a pseudo-contrast between creaky vowels and vowel+[ʔ] sequences on the surface.

Post-vocalic [ʔ] also appears to be participating in tonogenesis in Teko and certain varieties of Mam, e.g. Todos Santos Mam *che'w* /t͡ʃeʔw/ → [t͡ʃɧ̂ːw] (Elkins 2023:70; see too England 1983:32-41, Pérez Vail 2007, England & Baird 2017, and Scott 2023). Historically,

post-vocalic [h ʔ] played a role in the development of lexical tone in Uspanteko, though a full accounting of the diachrony of tone in Uspanteko remains to be undertaken (Bennett et al. 2022a,b).

X.2.4 Distributional properties of glottalized stops

Glottalized stops have relatively free distributions in Eastern Mayan languages, and are not often affected by phonological rules which would neutralize the plain vs. glottalized contrast. This is even true in contexts where neutralization or assimilation might otherwise be expected on typological grounds, such as coda position, preceding a plain stop (e.g. Fig. 13).

However, stops of all types may be unreleased in coda position, particularly preceding obstruents (Fig. 13; see also Smith-Stark 1983:87, Adell 2019:Ch. 2.1, among others). This can lead to apparent neutralizations in coda position. Whether such apparent neutralizations are in fact categorical and phonological, rather than spurious, should be carefully determined on a case-by-case basis.

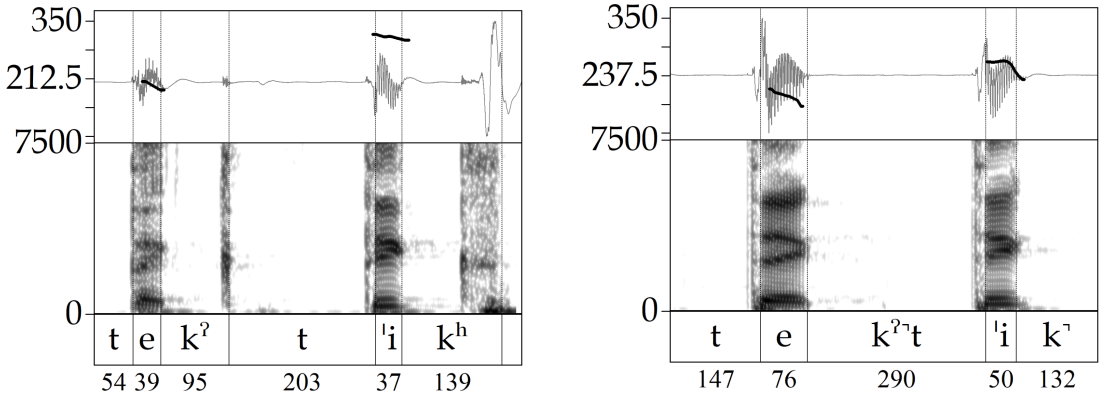


Figure 13 – Uspanteko *tek'tik* /tekʔ-C$_{RED}$-ik/ → [tekʔˈtikʰ] vs. [tekˀ̚tik̚] ‘tall and thin’, with both released and unreleased coda stops (wordlist data, recorded 2019, with two different speakers)

Otherwise, glottalized stops can occur essentially without restriction in the same kinds of environments and clusters where plain stops may occur. This may include clusters which are quite complex, depending on the language, e.g. Sipakapense *xtqsb'jaj* [ʃtqsɓˈχaχ] ‘we are going to whack him/her/it’ or *k'tul b'eey* [ˈkʔtul ˈɓeːj̥] ‘guide’ (Barrett 1999:23-42). Clusters which contain glottal stop are typically only possible when glottal stop is vowel-adjacent, as in

Sipakapense *k-'aam* [k-ʔaːm] 'their spider' (Barrett 1999:24, 2011; see also Bennett et al. 2023b).

An important exception involves co-occurrence restrictions in morphological roots. The canonical shape of root morphemes in Mayan languages is (C)VC, especially for verbs and so-called 'positional roots'. Glottalized stops may not generally co-occur within the same root unless they are identical: hence *q'aaq'* /qʔaːqʔ/ 'fire' is a licit root in Tz'utujil, but /kʔaːqʔ/ *k'aaq', t'aaq'* /tʔaːqʔ/*, ch'aaq'* /t͡ʃʔaːqʔ/, etc. are not (Dayley 1985:31). The glottalized labial implosive and glottal stop are exempt from these restrictions, e.g. Q'eqchi' *b'ut'* /-ɓutʔ/ 'fill' (Stewart 1980:131). See Bennett (2016), Bennett et al. (2022b) for discussion and references.

Vowel-initial words are often realized with an epenthetic [ʔ] in Eastern Mayan languages, e.g. Kaqchikel /iʃim/ → [ʔiˈʃim] 'corn' (see also Fig. 7). Initial epenthetic glottal stops are not always phonetically salient, particularly in running speech and post-pausal position, due in part to the lenited realizations which are typical of [ʔ] in Eastern Mayan (Fig. 12). The application of initial [ʔ]-epenthesis may also be conditioned by stress, syllable count, the lexical vs. function word/morpheme distinction, phrasal position, and morphology, depending on the language and dialect; see Bennett (2016, 2018), Bennett et al. (2022b), Wood (2023, 2024) and references there for details.

Glottal stop epenthesis may also be used to resolve hiatus, e.g. Tz'utujil *xinee'ooki* /ʃ-in-e:-o:k-i/ → [ʃineʔoːˈki] (Daley 1985:51). However, underlying vowel sequences are not particularly common in Eastern Mayan languages, so the generality of [ʔ]-insertion as a hiatus repair strategy is somewhat unclear (Bennett 2016).

X.3 The perception of glottalized stops in Eastern Mayan: data from Kaqchikel

In this section, we present some qualitative results from a prior study of the perception of plain and glottalized stops in Kaqchikel (Bennett et al. 2018). Our primary goal is descriptive, as Bennett et al. (2018) do not provide a detailed breakdown of pairwise confusability between particular stop consonants in their study; we provide such a breakdown here. We also try to connect the results of that study to patterns of sound change in the Mayan family.

There are surprisingly few studies of how native speakers perceive ejectives and implosives, in any language or family. Bennett et al. (2018) provide a fairly comprehensive list of work prior to that date; Percival (2023, 2024) has since discussed the perception of glottalized

stops in Q'anjob'al, a Mayan language of the Western branch, and Nelson (2023) has provided results for a study similar to Bennett et al. (2018), but with fewer Kaqchikel-speaking participants (5 vs. 44 in Bennett et al. 2018), and a different empirical focus (non-native vs. native listening in Nelson 2023 and only native listening in Bennett et al. 2018).

X.3.1 Study background

Bennett et al. (2018) present the results of an AX ('same-different') discrimination task with 44 native speakers of Kaqchikel. Participants listened to pairs of [CV] or [VC] syllables over headphones, with C ∈ /p t k q ɓ tˀ kˀ qˀ ʔ/ and V ∈ /a i u/. Vowel quality and stimulus shape ([CV] vs. [VC]) were always matched within a pair. The stimuli were edited from recordings by a native speaker of Kaqchikel (Juan Ajsivinac, a co-author on Bennett et al. 2018). Onset /ʔ/ differed from other consonants in being phonologically epenthetic rather than phonemic (section X.2.4).

Participants were asked to respond whether each [CV] or [VC] pair was 'the same' or 'different' with respect to the sounds involved. More details of the study are provided in Bennett et al. (2018).

X.3.2 Patterns of confusability

We assessed the discriminability of different stop consonant pairs using d', a measure of sensitivity (see Hautus et al. 2021 and Bennett et al. 2018 for more details). Higher d' scores indicate that participants were more likely to correctly identify a non-identical, contrasting stop pair as 'different', rather than 'the same'. Higher d' scores thus imply greater perceptual distinctiveness for a particular contrast.

For each comparison (e.g. onset /k/ vs. /kˀ/), we pooled responses across all participants in order to compute d'. This was done because we did not have enough per-participant data to reliably calculate d' for each comparison of interest.

X.3.2.1 Discriminability of individual stop pairs

Fig. 14 compares d' scores for all plain vs. glottalized pairs in our data, grouped by onset (= [CV]) vs. coda (= [VC]) position. The number line provides a ranking of pairs according to their relative d' scores: pairs which are further to the left on the scale were better-distinguished (=

higher d') than pairs which are further to the right on the scale. The onset and coda positions of each stop pair are connected with a dashed line to highlight differences in their d' rankings across syllable positions.

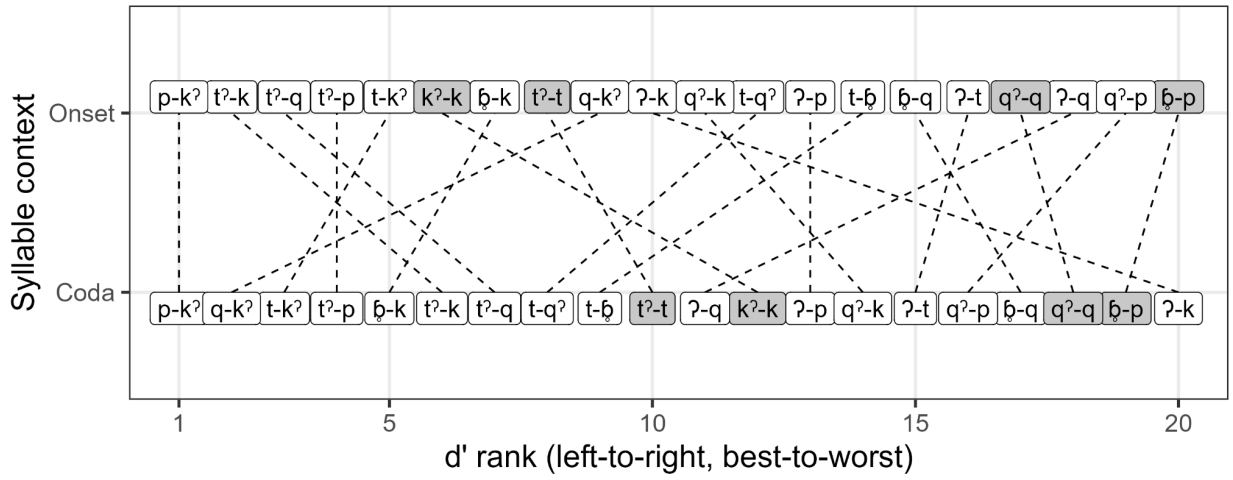


Figure 14 – ranking of relative d' scores across all plain vs. glottalized comparisons. Pairs shaded in grey have the same place of articulation. Range of d' values = [0.77, 3.1], mean = 1.73, median = 1.67, SD = 0.51.

Several observations can be made about the rankings in Fig. 14. First, comparisons involving glottalized coronal /tʔ/ are generally high-ranked (= relatively discriminable). This is notable, given that /tʔ/ is an infrequent, marginal phoneme in Mayan languages (e.g. Bennett 2016, Bennett et al. 2018). Comparisons involving velar /kʔ/ also seem relatively well-discriminated, never falling below the midpoint of the scale, apart from homorganic coda /k/ vs. /kʔ/.

Indeed, plain vs. glottalized pairs at the same place of articulation seem relatively liable to confusion. The same-place pairs /q/ vs. /qʔ/ and /p/ vs. /ɓ/ are generally low-ranked (= more poorly discriminated). This is also true for coda /k/ vs. /kʔ/, as just noted. Coronal /t/ vs. /tʔ/ is again the exception, being well-discriminated.

Comparisons involving glottal stop /ʔ/ are generally low-ranked, never rising above the midpoint of the scale. The same is true for bilabial /ɓ/, with the exception of /ɓ/ vs. /k/, and coda /ɓ/ vs. /t/. Uvular /qʔ/ also tends toward relatively low discriminability, apart from coda /t/ vs. /qʔ/.

Fig. 15 shows the d' rankings for plain vs. plain and glottalized vs. glottalized comparisons, again grouped by syllable position. For plain vs. plain comparisons (top panel), no clear pattern emerges, apart from the relatively good discriminability of /p/ vs. /k/ and /t/ vs. /q/.

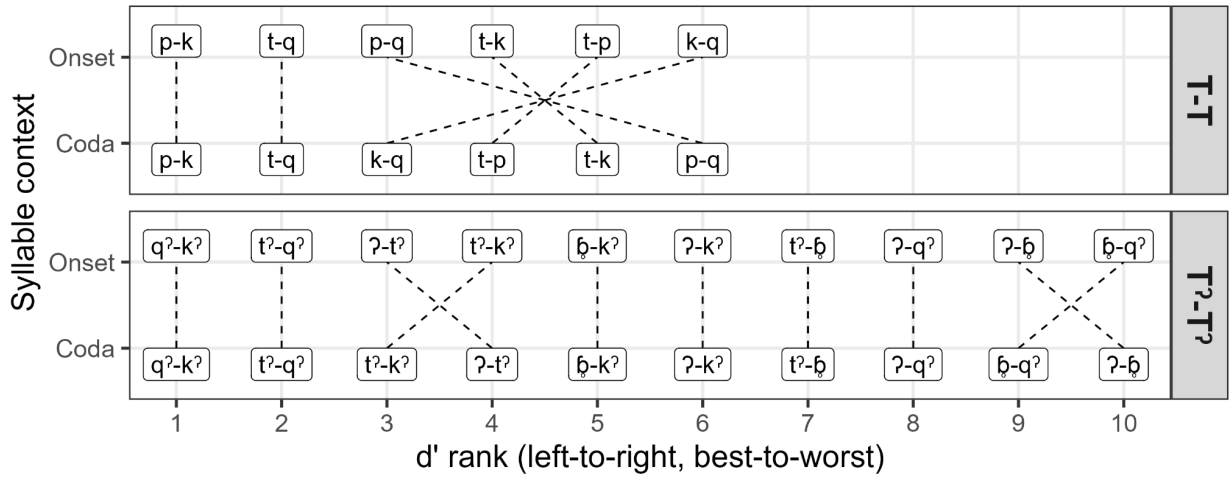


Figure 15 – ranking of relative d' scores across all plain vs. plain (top panel) and glottalized vs. glottalized (bottom panel) comparisons. For T-T, range of d' values = [0.82, 2.02], mean = 1.39, median = 1.35, SD = 0.38. For $T^{ʔ}$-$T^{ʔ}$, range = [0.61, 2.67], mean = 1.88, median = 1.96, SD = 0.6.

For glottalized vs. glottalized comparisons (bottom panel), the main finding is that glottal stop /ʔ/ is relatively confusable with both /ɓ/ and /$q^{ʔ}$/; /ɓ/ and /$q^{ʔ}$/ are also confusable with each other. Comparisons involving /$t^{ʔ}$/ or /$k^{ʔ}$/ are once again relatively well-discriminated, though /$t^{ʔ}$/ vs. /ɓ/ is surprisingly low-ranked.

X.3.2.2 Syllable context: [CV] vs. [VC]

As noted above, Eastern Mayan languages generally preserve contrasts between plain and glottalized stops and affricates in coda (≈ non-prevocalic) position. Place of articulation for stops is, in general, similarly preserved in both onsets and codas.

In our results, the discrimination of stop pairs is not significantly different across onset vs. coda position ($p > 0.1$ by two-sided *t*-test). If anything, d' scores tend to be slightly higher in codas than in onsets: mean(onset d') = 1.62, SD = 0.53; mean(coda d') = 1.82, SD = 0.53.

These results also broadly hold if our d' scores are grouped by comparison type (Fig. 16). In each panel of Fig. 16, the difference between onset and coda d' scores is non-significant

(though narrowly so in the case of plain stops, T-T, $p > .07$ by two-sided *t*-test; for T-Tʔ, $p > .26$; Tʔ-Tʔ, $p > .57$). And again in each case, there is a trend toward higher d' scores in coda position (T-T, Δ(mean d') = 0.39; T-Tʔ, Δ = 0.1; Tʔ-Tʔ, Δ = 0.31).

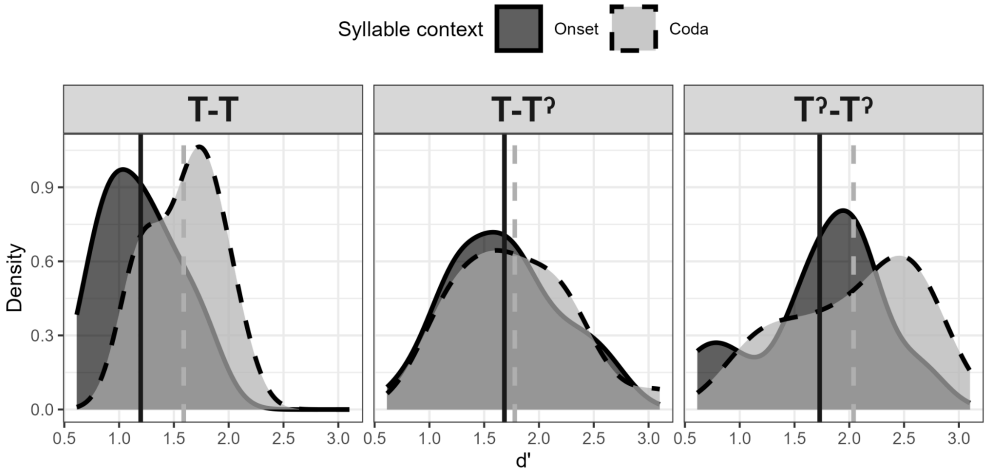


Figure 16 – Density plot of d' scores across syllable position, grouped by comparison type. Vertical lines indicate mean values for each condition.

We assume these results owe to several facts: (i) coda stops were released in our stimuli, and aspirated [Tʰ] in the case of plain coda stops; (ii) Kaqchikel listeners are accustomed to hearing plain vs. glottalized stop contrasts in both onset and coda position; and (iii) given the preceding, it must be the case that there are reasonably robust acoustic cues to the plain vs. glottalized stop contrast in coda position in Kaqchikel, including not only release cues but also contextual vowel glottalization and other coarticulatory effects. (See Nelson 2023 for a slightly different result, with different materials, methods, and a smaller group of speakers.)

X.3.3 Connections to sound change in the Mayan family

Some of the discriminability results reported above are reflected in recurrent patterns of sound change in the Eastern Mayan family. For example, /ʔ/ and /ɓ̥/ were poorly discriminated in our study, across both onset and coda position (Fig. 15; see also Fig. 6). This result parallels the fact that /ɓ̥/ has sometimes merged with /ʔ/ in Eastern Mayan languages, either systematically or sporadically in certain lexical items (1) (e.g. Barrett 2007, Bennett 2016).

(1) Debuccalization of /ɓ/ to /ʔ/ in Kaqchikel (e.g. Patal Majzul et al. 2000: 24-5)

(a) *xub'ij* [ʃuɓ̥iχ] ~ [ʃuʔiχ] '(s)he said it'

(b) *xb'e* [ʃɓ̥e] ~ [ʃʔe] '(s)he went'

(c) *jeb'ël* [χeɓ̥ɛl̥] ~ [χaʔɛl̥] 'lovely'

(d) *-V'* [-Vʔ] 'plural' < proto-K'ichean *-*Vb'* *[-Vɓ]

(i) Kaqchikel: *ixoqi'* [ʔiʃoq-iʔ] 'women'

(ii) K'iche': *ixoqiib'* [ʔiʃoq-iːɓ] 'women' (Larsen 1988:104)

The same is true of /ʔ/ and /qˀ/: these sounds were poorly discriminated in our study (Fig. 15), and have undergone occasional mergers in Eastern Mayan languages (see also Fig. 10). We noted a /qˀ#/ > /ʔ#/ merger for San Juan Atitán Mam above (section X.2.3). Similarly, historical /qˀ/ has become a pharyngeal stop /ʕ/ in Achi (López & Sis Iboy 1992); and in certain varieties of K'iche' and Kaqchikel, /qˀ/ has become glottal /ʔ/, at least sporadically in certain words (Larsen 1988:45, Patal Majzul et al. 2000:25-6, Barrett 2007).

The perceptual similarity of both /ɓ̥/ and /qˀ/ to /ʔ/ is likely related to the fact that both /ɓ̥/ and /qˀ/ are often realized as the voiceless implosives [ɓ̥] and [ɠ̊]. Like [ʔ], voiceless implosives typically lack clear release bursts, and are associated with creakiness on neighboring vowels and sonorants (sections X.2.2-3).

At the same time, some patterns of confusability in our data have no clear analog in Eastern Mayan sound changes. For example, /p/ vs. /ɓ/ were relatively poorly discriminated in our results (Fig. 14); however, to our knowledge diachronic mergers between /p/ and /ɓ/ are essentially unknown in Eastern Mayan. The same point can be made for /q/ vs. /qˀ/ (Fig. 14) and /ɓ/ vs. /qˀ/ (Fig. 15).

Conversely, /kˀ qˀ/ are well-discriminated (Fig. 15), even though the historical merger of */kˀ qˀ/ to /kˀ/ and */k q/ to /k/ is a prominent feature of Mayan languages outside of the Eastern branch of the family (Law 2014:42). Perhaps it is relevant here that /k q/ are relatively poorly discriminated in our study, particularly in onset position (Fig. 15): for example, a */kˀ qˀ/ to /kˀ/ merger could follow a prior */k q/ to /k/ merger through a pressure for symmetry in phonological inventories.

We conclude that while perceptual similarity has mostly likely conditioned several sound changes in Eastern Mayan languages (and in the Mayan family more broadly), perceptual

similarity on its own does not offer a complete explanation for the overall landscape of diachronic mergers involving stop consonants in these languages.

X.4 Conclusion

Eastern Mayan languages maintain contrasts between plain vs. glottalized stops across a range of places of articulation, and across most phonological environments. The robustness of plain vs. glottalized stop contrasts in Eastern Mayan provides us with an opportunity to study the phonetics, phonology, and diachrony of these sounds at a level of detail that is not equally available in languages where these contrasts are neutralized or lost in particular contexts.

Eastern Mayan languages and dialects also show extensive microvariation in the phonetics and phonology of glottalized stops. Such microvariation offers an important window on the fundamental characteristics of glottalized sounds, and their relationships with each other and their plain counterparts. Studying these patterns of microvariation in greater detail, using instrumental and experimental methods in the tradition of Pinkerton (1986), will surely deepen our understanding of glottalized stops in the Mayan family, and in human languages more broadly.

References

Adell, Eric. 2019 The phonetics, phonology, and morphology of Chajul Ixil (Mayan). UT Austin PhD thesis.

Aissen, Judith, Nora England & Roberto Zavala Maldonado (eds.). 2017. The Mayan languages. New York: Routledge.

Avelino, Heriberto. This volume. Title TBA.

Barrett, Rusty. 1996. The effects of Mamean/K'ichean contact in Sipakapense. In David Librik and Roxanne Beeler (eds), BLS 22S: Proceedings of the Berkeley Linguistics Society, 25-36. Berkeley, CA: Berkeley Linguistics Society.

— . 1999. A grammar of Sipakapense Maya: UT Austin PhD thesis.

— . 2003. The Huehuetenango Sprachbund and Mayan language standardization in Guatemala. In Mary Andronis, Erin Debenport, Anne Pycha and Keiko Yoshimura (eds), CLS 38-2: Proceedings of the 38th Chicago Linguistics Society, The Panels, 309-18.

— . 2007. The evolutionary phonology of glottal stops in K'ichean. In *Proceedings of the 33rd*

Berkeley Linguistics Society (BLS), Berkeley, CA: University of California Press.

— . 2011. Morphological conditioning in Sipakapense phonology. In Kirill Shklovsky, Pedro Mateo Pedro & Jessica Coon (eds.), Proceedings of Formal Approaches to Mayan Linguistics (FAMLi), 51–63. Cambridge, MA: MIT Working Papers in Linguistics.

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

— . Recursive prosodic words in Kaqchikel (Mayan). 2018. *Glossa* 3(1): 67.

Bennett, Ryan, Robert Henderson & Meg Harvey. 2022a. Tonal variability and marginal contrast: Lexical pitch accent in Uspanteko. In Haruo Kubozono, Junko Ito, and Armin Mester (eds.) *Prosody and prosodic interfaces*, 187–226. Oxford, UK: Oxford University Press.

— . 2023. Phonetic variability in the realization of glottalized stops in Uspanteko (Mayan). In Radek Skarnitzl & Jan Volín (eds.), *Proceedings of the 20th International Congress of Phonetic Sciences, Prague, Czech Republic 2023*, 3301–3305. Prague: Guarant International.

— . 2023. Vowel deletion as grammatically controlled gestural overlap in Uspanteko." *Language* 99(3): 399-456.

Bennett, Ryan, Robert Henderson, Meg Harvey & Tomás Alberto Méndez López. 2022b. The Phonetics and phonology of Uspanteko (Mayan). *Language and Linguistics Compass* e12467. doi: 10.1111/lnc3.12467.

Bennett, Ryan, Kevin Tang & Juan Ajsivinac Sian. 2018. Statistical and acoustic effects on the perception of stop consonants in Kaqchikel (Mayan). *Laboratory Phonology Journal of the Association for Laboratory Phonology 9*(1). 9.

Bin, Cirilo Alejandro (speaker). 1998. Swadesh list. OKMA Mayan Languages Collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/12599/, Access: Login Required.

Brown, Linda K. 1979. Word formation in Pocomchi (Mayan). Stanford University PhD thesis.

Caal Morán, Valerio (speaker). 1998. Swadesh list and OKMA special list. OKMA Mayan Languages Collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/12599/. Access: Login Required.

Campbell, Lyle. 1973. On glottalic consonants. International Journal of American Linguistics 39(1). 44–46.

Chub, Félix (speaker). 1998. Swadesh list and OKMA special list. OKMA Mayan languages collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/12411/. Access: Login Required.

Culum, Pablo (speaker). 1998. Swadesh list and OKMA special list. OKMA Mayan languages collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/12610/. Access: Login Required.

Dayley, Jon. 1985. *Tzutujil grammar*. Berkeley, CA: UC Press.

DiCanio, Christian & Ryan Bennett. 2021. Prosody in Mesoamerican languages. In Carlos Gussenhoven & Aoju Chen (eds.), *The Oxford handbook of language prosody*, 408–427. Oxford, UK: Oxford University Press.

Elkins, Noah. 2023. The interplay of syntax and prosody in Mam. UCLA PhD thesis.

Elkins, Noah & Jennifer Kuo. 2022 A prominence account of the Northern Mam weight hierarchy. *Proceedings of the Annual Meetings on Phonology*. http://doi.org/10.3765/amp.v10i0.5433

England, Nora. 1983. *A grammar of Mam, a Mayan language*. Austin, Texas: UT Press.

England, Nora & Brandon Baird. 2017. Phonology and phonetics. In Judith Aissen, Nora England & Roberto Zavala Maldonado (eds.), The Mayan languages, 175–200. New York: Routledge.

Garellek, Marc, Yuan Chai, Yaqian Huang & Maxine Van Doren. 2023. Voicing of glottal consonants and non-modal vowels. *Journal of the International Phonetic Association* 53(2): 305-332.

Hautus, Michael J., Neil A. Macmillan, and C. Douglas Creelman. 2021. *Detection Theory: A User's Guide*. New York: Routledge.

Ladefoged, Peter & Ian Maddieson. 1996. *The sounds of the world's languages*. Oxford: Blackwell.

Larsen, Thomas. 1988. Manifestations of ergativity in Quiché grammar: University of California, Berkeley dissertation.

Law, Danny. 2014. *Language contact, inherited similarity and social difference*. Amsterdam: John Benjamins.

— . 2017. Language Contacts with(in) Mayan. In Judith Aissen, Nora England &

Roberto Zavala Maldonado (eds.), The Mayan languages, 175–200. New York: Routledge.

López, Bernarda (speaker) & Manuel Bernardo Malchic Nicolás (researcher). 1998. Swadesh list. OKMA Mayan languages collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/12372/. Access: Login Required.

López, Manuel Antonio & Juliana Sis Iboy. 1992. Gramática del idioma Achi. Antigua, Guatemala: PLFM.

Malchic Nicolás, Manuel Bernardo, Romelia Mó Isem & Augusto Tul Rax. 2000. *Rub'iral ruk'ihaal wach Poqom q'orb'al: variación dialectal en Poqom*. Ciudad de Guatemala, Guatemala: Cholsamaj.

Patal Majzul, Filiberto, Pedro Oscar García Matzar & Carmelina Espantzay Serech. 2000. *Rujunamaxik ri Kaqchikel chi': variación dialectal en Kaqchikel*. Ciudad de Guatemala, Guatemala: Cholsamaj

Nelson, Brett C. 2023 Learning the sounds of silence: adult acquisition of Kaqchikel (Mayan) plain and glottalized stop consonants. University of Calgary PhD thesis.

Percival, Maida. 2023. Perceptual cues to ejective stops across languages. In Radek Skarnitzl & Jan Volín (eds.), *Proceedings of the 20th International Congress of Phonetic Sciences, Prague, Czech Republic 2023*, 282-286. Prague: Guarant International.

— . 2024. Production and perception of ejective stops across languages. University of Toronto PhD thesis.

Pérez Vail, José Reginaldo. 2007. *Xtxolil yool b'a'aj: gramática Tektiteka*. Antigua, Guatemala: OKMA.

Pinkerton, Sandra. 1986. Quichean (Mayan) glottalized and nonglottalized stops: a phonetic study with implications for phonological universals. In John Ohala & Jeri Jaeger (eds.), Experimental phonology, 125–139. Orlando: Academic Press.

Russell, Susan. 1997. Some acoustic characteristics of word initial pulmonic and glottalic stops in Mam. Simon Fraser University MA thesis.

Sánchez Toma, Edelmira Catarina (speaker), Eric Adell (creator), and Antonio Moisés Toma Cruz (transcriber and translator). 2016. A brief description of a typical week. Ixil Collection of Danny Law. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/10323/. Access: Login Required.

Santos Nicolás, José Francisco & José Gonzalo Benito Pérez. 1998. Rukorb'aal poqom q'orb'al: gramática Poqom (Poqomam). Ciudad de Guatemala, Guatemala: Cholsamaj.

Sequec, Nicolás (speaker). 1998. Swadesh list and OKMA special list. OKMA Mayan languages collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/12612/. Access: Login Required.

Scott, Tessa. 2023. Pronouns and agreement in San Juan Atitán Mam. UC Berkeley PhD thesis.

Smith-Stark, Thomas. 1983. Jilotepequeño Pocomam Phonology and Morphology: University of Chicago PhD thesis.

Sobrino Gómez, Martín & Ryan Bennett. Submitted. Fonética y fonología de los rasgos y segmentos laríngeos en la familia maya. In *Rasgos laríngeos en lenguas indomexicanas*, eds. Francisco Arellanes, Mario Hernández, and Fidel Hernández. Language Science Press.

Stewart, Stephen. 1980. Gramática kekchí. Guatemala City: Editorial Académica Centroamericana.

Tandy, James Brenden. 2023. Diachrony of the perfect paradigm in Mayan languages: UT Ausin PhD thesis.

Uluán Espinoza, Juan (consultant) and Vásquez Aceytuno, Juan Carlos (recorder, researcher, transcriber). 2004. Making black salt. OKMA Mayan languages collection. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/11891/. Access: Login Required.

Wagner, Karl &Wendy Baker-Smemoe. 2013. An investigation of the production of ejectives by native (L1) and second (L2) language speakers of Q'eqchi' Mayan. *Journal of Phonetics* 41(6): 453–67.

Wood, Elizabeth (researcher) and Manuel Chicoj Xirum (speaker). 2019. K'iche' Collection of Elizabeth Wood. A story about fishing. The Archive of the Indigenous Languages of Latin America, https://ailla.lib.utexas.edu/sets/5110/. Access: Login Required.

Wood, Elizabeth. 2023. Vowel-initial words and glottalization: a corpus study of Chichicastenango K'iche'. In Radek Skarnitzl & Jan Volín (eds.), *Proceedings of the 20th International Congress of Phonetic Sciences, Prague, Czech Republic 2023*, 1766-1770. Prague: Guarant International.

— . 2024. Prosodic structure in spontaneous speech: Phrase-final marking, word-initial

glottalization and vowel deletion in Chichicastenango K'iche'. UT Austin PhD thesis.