

Glottalized stops and affricates in Eastern Mayan languages¹

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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, marking languages as K'ichean (K) or Mamean (M), these are Achi (K), Awakateko (M), Chalchiteko (M), Ixil (M), Kaqchikel (K), K'iche' (K), Mam (M), Poqomam (K), Poqomchi' (K), Q'eqchi' (K), Sakapulteko (K), Sipakapense (K), Tektiteko (Teko) (M), Tz'utujil (K), and Uspanteko (K). 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.

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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.

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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 (to appear). 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.

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 /k^ʲ/ or lamino-alveolar / $\widehat{t_s}$ $\widehat{ts}^?$ /, the latter of which are omitted from Table 1 (see also England 2017, Adell 2019, Bennett et al. 2022b).

Eastern Mayan languages typically contrast short /a e i o u/ with their long counterparts, though length contrasts are often limited to stressed syllables. In Kaqchikel and some dialects of K'iche', historical short and long vowels are instead realized as lax and tense, respectively (see Bennett 2016, England & Baird 2017, Wood 2025 for details and references).

	Bilabial	Alveolar	Post-alveolar	Retroflex	Palatal	Velar	Uvular	Glottal
Plain plosives	p	t \widehat{ts}	$\widehat{t_j}$	(\widehat{ts})		k (k ^ʲ)	q	
Glottalized plosives	$b, \{b, b, p^?\} (p^?)$	$t, \{t^?, d, d\} \widehat{ts}^?$	$\widehat{t_j}^?$	($\widehat{ts}^?$)		k ^ʲ (k ^{ʲʲ})	$q, \{q, q^?, q^?\}$	ʔ
Fricatives		s	ʃ	(ʂ)			χ	(h)
Nasals	m	n						
Approximants	w	l r			j			

Table 1 – Typical consonant phonemes in Eastern Mayan languages. Phonemes in parentheses (X) are restricted to particular languages or sub-branches within Eastern Mayan. Curly braces $T, \{X, Y, Z\}$ indicate common, non-contrastive phonetic variation within a phoneme category T , occurring both within and across languages. Within curly braces, the order of sounds corresponds to our own rough impression of which phonetic forms are more frequent within each phoneme

category, $X >_{freq} Y >_{freq} Z$ (though this should not be taken too literally). Phonetic variation for fricatives, nasals, and approximants is omitted; see e.g. Bennett (2016) for details.

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 in detail below. (On implosives more generally, see Sande this volume.)

Glottalized consonants are pervasive throughout the vocabulary of every Mayan language. Although detailed lexical and usage statistics are not generally available, some useful counts are provided by Smith-Stark (1983:Ch.3), who discusses the relative frequency of different consonants in the San Luis Jilotepeque variety of Poqomam (a K'ichean language). First, Smith-Stark reports lexical frequencies for stops and affricates across 732 /CVC/ roots (the canonical shape of roots in Mayan languages). These are summarized in Table 2. While Smith-Stark provides separate counts for C_1 and C_2 in / C_1VC_2 / roots, for reasons of space we present only the combined figures across both positions: the individual counts for C_1 and C_2 follow the same coarse patterns described below.³

/CVC/ roots	Rank frequency (most to least common) <i>Subscripts show counts and approximate % of total</i>
<i>Total number of stops and affricates: 785</i>	$p_{95/12\%} > \{t_{94/12\%}, k_{94/12\%}\} > ?_{79/10\%} > k^2_{72/9\%} > q_{66/8\%} > \widehat{tj}_{59/8\%} > q^2_{58/7\%} > \widehat{tj}^q_{52/7\%} > \widehat{ts}^2_{40/5\%} > \widehat{b}_{39/5\%} > p^2_{34/4\%} > t^2_{3/0\%}$
	<p style="text-align: center;"><i>Plain stops/affricates /p t k tj q/: 408 (52%)</i> <i>Glottalized stops/affricates /b p² t² k² ts² tj^q q² ?/: 377 (48%)</i></p>

Table 2 – Stop and affricate phoneme frequencies in a list of 732 /CVC/ roots in Poqomam (Smith-Stark 1983)

³ Some clarifying comments about Tables 2 and 3 are in order. First, what we've transcribed as /b/ is phonetically /w²/ in the variety of Poqomam described by Smith-Stark (1983:69,84,89-90,etc.): we transcribe it as /b/ because that is the historical form of this phoneme, and the one most commonly encountered in Eastern Mayan today; see section X.2.2 for more discussion. Second, plain /ts/ is absent because it has shifted to /s/ in Poqomam (Smith-Stark 1983:68). Third, the roots that Smith-Stark treats as /?VC/ might be analyzable as vowel-initial /VC/, with an epenthetic glottal stop when word-initial (e.g. Bennett 2018 and section X.2.4; cf. Smith-Stark 1983:94). Lastly, Smith-Stark (1983:89-92) argues in favor of the additional glottalized phonemes /m² n² j²/, which we omit because these would be highly unusual within Mayan, and because we do not find Smith-Stark's argumentation on this point compelling (see also Sobrino Gómez & Bennett to appear, and section X.2.3).

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The figures in Table 2 indicate a mild bias toward plain consonants, especially since there are only 5 plain vs. 8 glottalized stop and affricate phonemes in Poqomam, which inflates the count of the glottalized series (Smith-Stark’s data further implies that bias toward the plain series might be stronger in C_2 than C_1). Still, it is clear that glottalized stops and affricates are ordinary and widespread in Poqomam roots. (The exception is coronal /tʔ/, which has long been recognized as a marginal phoneme in Eastern Mayan and other Mayan languages.)

Second, Smith-Stark reports token frequencies for stop and affricate phonemes in two sets of transcribed texts, which we summarize in Table 3; see Smith-Stark (1983) for additional details and discussion.

Sample	Rank frequency (most to least common) <i>Subscripts show counts and approximate % of total</i>	Notes
Zinn (1966) (43 texts; 26,330 stop and affricate tokens)	$k_{7019/27\%} > t_{4011/15\%} > \widehat{tj}_{3847/15\%} > p_{3558/14\%} >$ $q_{3245/12\%} > k^?_{2253/9\%} > q^?_{1472/6\%} > \widehat{tj}^?_{721/3\%} >$ $ts^?_{159/1\%} > p^?_{42/0\%} > t^?_{38/0\%}$	/b ʔ/ not included in counts
“Permission to plant in the earth” (1 text; 627 stop and affricate tokens)	$?_{144/23\%} > k_{133/21\%} > p_{82/13\%} > t_{68/11\%} >$ $q_{67/11\%} > \widehat{tj}_{47/7\%} > q^?_{32/5\%} > \widehat{tj}^?_{23/4\%} > k^?_{21/3\%} >$ $b_{10/2\%} > \{p^?_{0/0\%}, t^?_{0/0\%}, ts^?_{0/0\%}\}$	

Table 3 – Stop and affricate frequencies in some Poqomam text samples (Smith-Stark 1983)

On the basis of the type frequencies in Table 2 and the token frequencies in Table 3, we can extract the ordering *Plain* > *Glottalized* > /pʔ/ > /tʔ/ (though we would again emphasize that glottalized stops and affricates are quite common). This ordering is consistent with the marginal status of /tʔ/ across Mayan, and the fact that /pʔ/ is an innovative phoneme, which historically split from /b/ and was diffused via language contact in the lowland Maya region (see e.g. Law 2014, Sobrino Gómez & Bennett to appear, for references and discussion). Further, within the plain and glottalized categories, velar /k kʔ/ seem relatively frequent.

These observations seem, at least to us, to hold more broadly within Eastern Mayan, though certainly the finer details are likely to vary from language to language. For example, Table 4 provides type and token frequencies for stops and affricates in Kaqchikel, which we’ve estimated from a corpus of about 700,000 word tokens (the corpus is described in more detail in Bennett et al. 2018). As this corpus is somewhat noisy, we focus here on relative frequencies

rather than more precise numerical values. These rankings replicate the basic tendency toward the ordering *Plain* > *Glottalized* > /tʰ/ (Kaqchikel does not have phonemic /pʰ/), as well as the preference for velar /k kʰ/ within the plain and glottalized series. Additionally, the orderings in Table 4 imply that affricates may be relatively less common within each series, a trend which is also perhaps evident in the Poqomam data in Tables 2 and 3. On the other hand, glottalized /b/ seems more prevalent in Kaqchikel than in Poqomam, particularly relative to plain /p/.

	Rank frequency (most to least common)
Token frequencies	ʔ > k > t͡ʃ > t > q > kʰ > b > p > qʰ > ts > t͡ʃʰ > tsʰ > tʰ
Type frequencies	k > t > ʔ > b > q > kʰ > p > t͡ʃ > qʰ > t͡ʃʰ > ts > tsʰ > tʰ

Table 4 – Stop and affricate frequencies in Kaqchikel (estimated from Bennett et al. 2018 corpus)

More in-depth study of these questions would be a welcome and important contribution.

In the following sections we provide a phonetic description of glottalized stops and affricates 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 aim to 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 (to the extent possible) 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, and pitch track for Uspanteko *tk'isk* [ʰtkʰiskʰ]. Recordings used for illustration are taken from spontaneous narratives unless otherwise noted; similarly, recordings were made by co-author Bennett unless otherwise noted.⁴

⁴ Audio files for all spectrograms provided in this chapter may be downloaded at <https://osf.io/s84qc/files/eyvcz>, along with associated Praat .TextGrid files. Audio examples provided by co-author Bennett were more-or-less

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

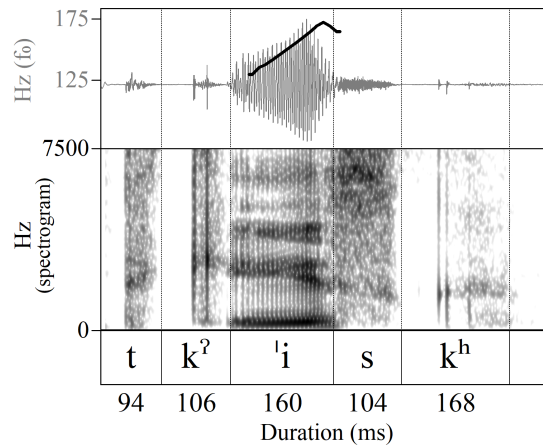


Figure 1 – Ejective [k²], Uspanteko *tk'isk* /t-k²is-k/ → ['tk²iskʰ] ‘he finishes’ (recorded 2021)

In Fig. 1, ejective [k²] 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, etc.). 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 [k²] (Russell 1997). Notably, there is no clear difference in the duration of the release phase (\approx ‘VOT’) for [k²] 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 [k²] with a relatively strong burst, and the top right panel a [k²] 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

randomly sampled from a large corpus of recordings compiled with speakers in Guatemala since 2010. Though the specifics of each recording session varied, all audio was recorded to .wav format using a high-quality solid-state recorder and headset microphone at a sampling rate of at least 48 kHz.

for two tokens of ejective [tʃʰ] within a single word (here, utterance-finally).⁵ Our impression is that individual speakers may vary, from utterance to utterance, as to whether they produce ejectives with strong vs. weak releases. At the same time, some speakers do seem to consistently favor either strong or weak ejectives: more targeted research on these points would be of interest.

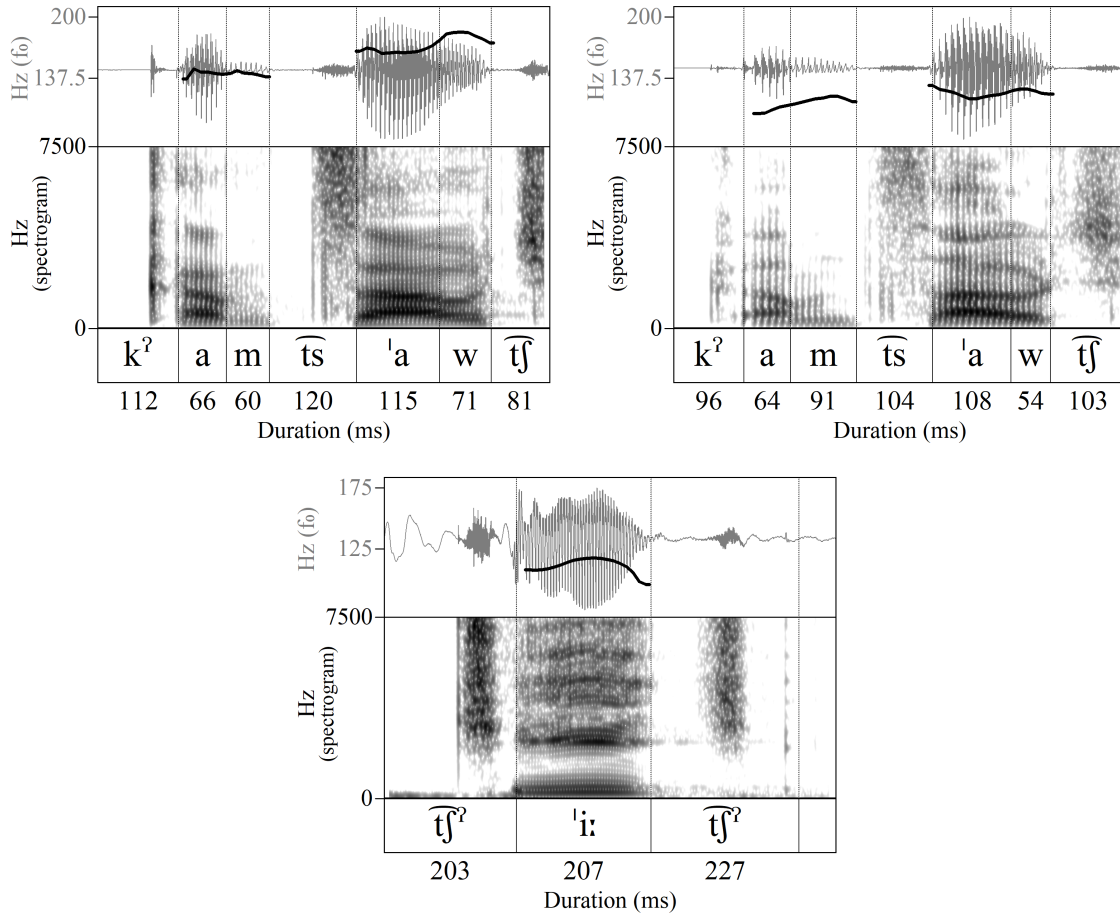


Figure 2 – ‘Strong’ vs. ‘weak’ [kʰ] in Uspanteko *kʰamtʃawch* [kʰam'tsawtʃ] ‘hello’ (top, recorded 2021) and *chʰiichʰ* [tʃʰi:tʃʰ] ‘metal, machine, car’ (bottom, recorded 2018)

In the top right panel, the onset of the vowel following [kʰ] is also produced with creaky or laryngealized voice, as a result of coarticulation with the glottal closure for [kʰ]: this is evident from the reduced amplitude of the vowel, reflecting glottal constriction (compare top left vs. top

⁵ The initial ejective [tʃʰ] in *chʰiichʰ* in Fig. 2 (bottom) has a substantial period of loud friction noise between the oral release of the affricate and the subsequent release of the associated laryngeal constriction (the later release of the laryngeal constriction can be inferred from the period of near-silence preceding the vowel onset). As John Kingston points out to us, since there is no airflow through the glottis while the vocal folds are closed, the production of this type of fricative noise may require a narrower oral constriction for glottalized [tʃʰ], relative to plain [tʃ].

right panels), and from the relatively wide, and somewhat irregular spacing of glottal pulses, particularly at vowel onset compared to later pulses (= low, quasi-periodic f_0). Glottalized stops very commonly cause adjacent vowels and sonorants to become creaky, or otherwise laryngealized, in Eastern Mayan languages.

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

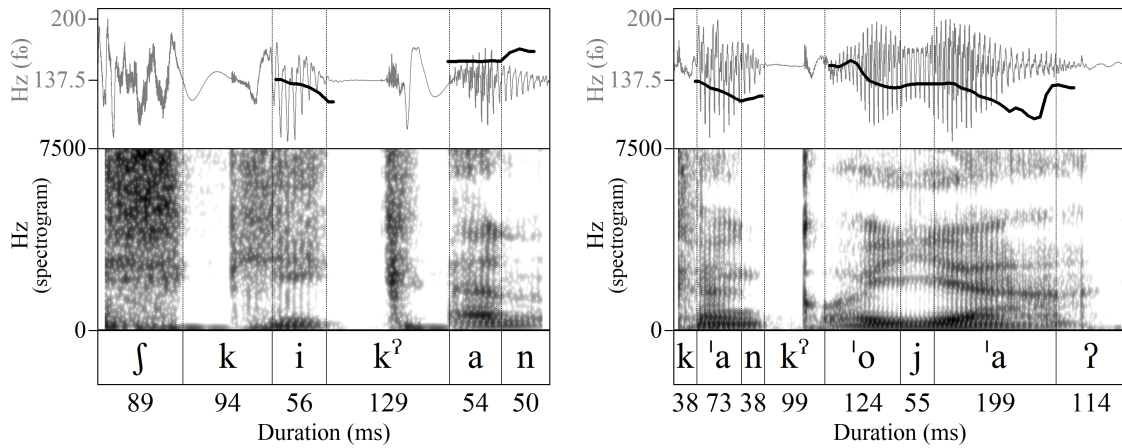


Figure 3 – Plain and glottalized /k k²/ in Kaqchikel *xkik'an* [ʃki'k²an] ‘they brought it’ and *kan k'o ya'* ['kan 'k²o 'jaʔ] ‘there’s (still) water’ (Sololá variety, recorded 2013)

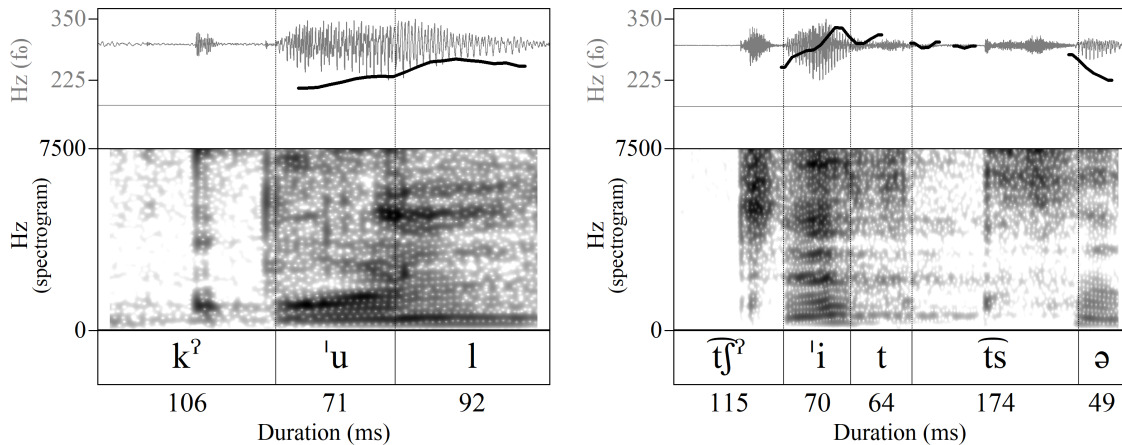


Figure 4 – Ejective stop /k²/ and affricate /tʃ²/ in Mam *k'ul* ['k²ul] ‘bush’ and *ch'it tza* ['tʃ²it=tsə] ‘almost=well’ (Todos Santos variety, Elkins 2023, Speaker ZC)

Poqomam, and some varieties of Poqomchi', have a phonemic labial ejective /p²/, yielding a three-way /p ɸ p²/ contrast not found elsewhere in Eastern Mayan. The emergence of a

phonemic ejective /pʰ/ owes to contact with lowland Mayan languages outside of the Eastern branch; see Law (2014), Sobrino Gómez & Bennett (to appear), and Avelino (this volume). See below on the phonetics of historical /b/ in Poqomam; Fig. 7 illustrates some purely allophonic cases of ejective [pʰ] 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 (particularly if any contraction of the lungs occurs while the vocal folds are closed). This pressure differential would then facilitate rapid transglottal airflow at the point the vocal folds separate, leading to brief, passive voicing.

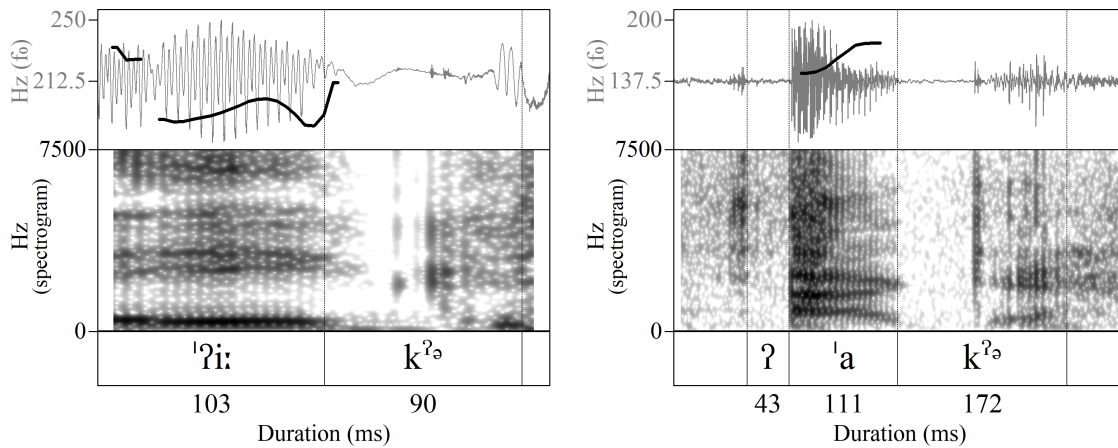


Figure 5 – Uspanteko *iik* [ʔi:kʰ] ‘month’ (sentence translation task, recorded 2017) and Poqomchi’ *ak* [ʔakʰ] ‘new’ with brief voiced releases (wordlist data, Bin 1998)

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* [χɔbʰ] ‘rain’. A similar aerodynamic mechanism could be at play here, provided that (i) voiceless implosives are produced with a sealed glottis, and (ii) sub-glottal air pressure builds while the vocal folds remain closed (e.g. if the lungs contract and expel air while the vocal folds are shut,

thereby increasing pressure below the glottis; see also Ladefoged & Maddieson 1996:78, 87-90). Alternatively, voiced releases in implosives like [ɓ̥] could be a kind of phonetic generalization from voiced releases in ejectives.

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.

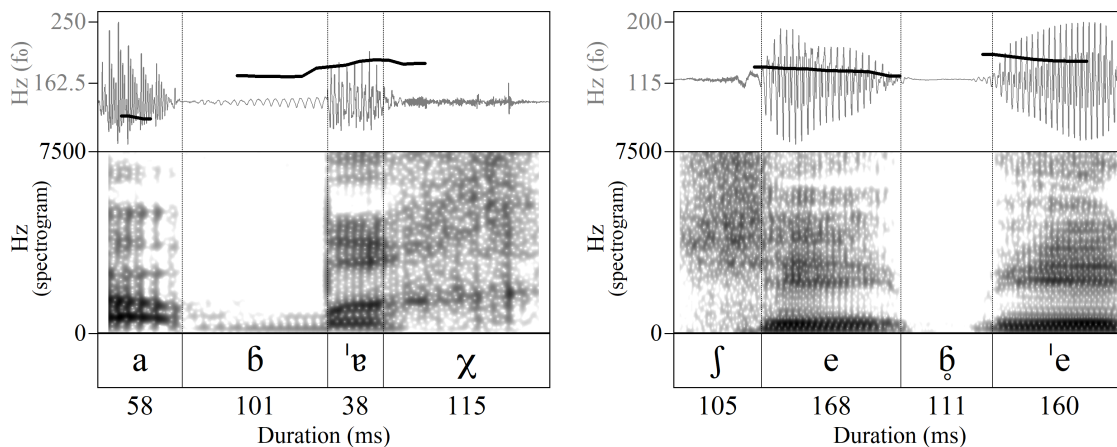


Figure 6 – Voiced [ɓ] in K'iche' *ab'äj* [a'ɓəχ] 'stone' (Chichicastenango variety, Wood & Chicoj Xirum 2019) vs. voiceless [ɓ̥] in Kaqchikel *xeb'e* [ʃe'ɓ̥e] 'they went' (Comalapa variety, recorded 2013)

Implosive [ɓ]/[ɓ̥] are acoustically characterized by the lack of a clear, strong release burst (Fig. 6; see also Lindau 1984, Pinkerton 1986, Henton et al. 1992, Clements & Osu 2002). 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, Mc Laughlin 2005, 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). (On voiced vs. voiceless implosives more generally, see Mc Laughlin 2005.)

The glottalized bilabial is frequently realized as an ejective [pʰ] or unreleased implosive [ḃ̥]/[ḃ̥̚] in word-final position.⁶ However, ejective realizations do occur with some frequency even in prevocalic position (Fig. 7). Apart from the tendency toward more [pʰ] 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.

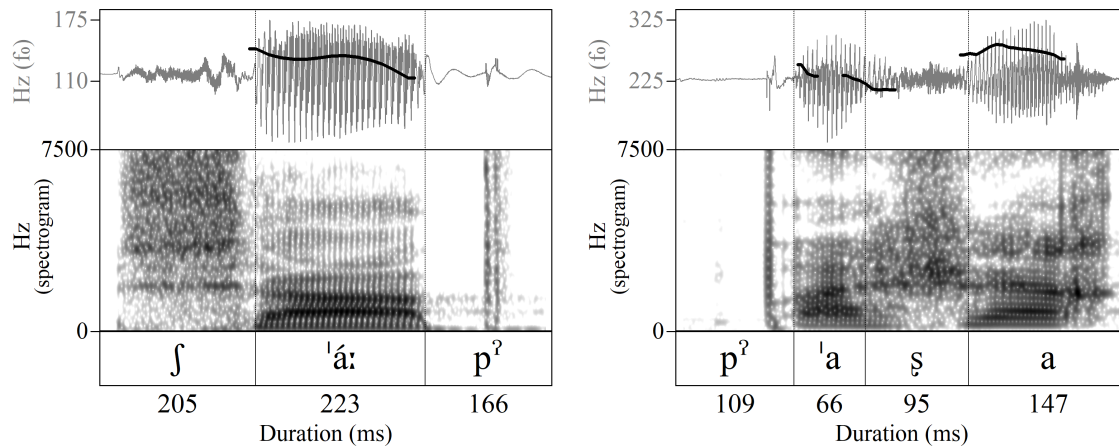


Figure 7 – Ejective [pʰ] realizations of the glottalized bilabial in Uspanteko *xáab* /ʃá:ḃ̥/ → [ʃá:pʰ] ‘vomit’ (wordlist data, recorded 2016) and Ixil *b’axa* /ḃ̥aʃa/ → [pʰaʃa] ‘first’ (Cotzal variety, Sánchez Toma et al. 2016)

In Poqomam and Poqomchi’, historical */ḃ̥/ may be realized as glottalized [wʰ], or as glottalized [mʰ] or [ḃ̥ʰ] word-finally or before a consonant (Fig. 8; see e.g. Campbell 1977:23, 38, 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 [mʰ], but more subtle on [wʰ].

⁶ Pinkerton (1986) provides intra-oral air pressure measurements documenting implosive ~ ejective variation across 5 K’ichean languages (Kaqchikel, Q’eqchi’, K’iche’, Tz’utujil, and Poqomchi’), as well as variation in the voicing of /ḃ̥/~ḃ̥̚/; see also Kuang (2019) for Q’anjob’al, a Western Mayan language.

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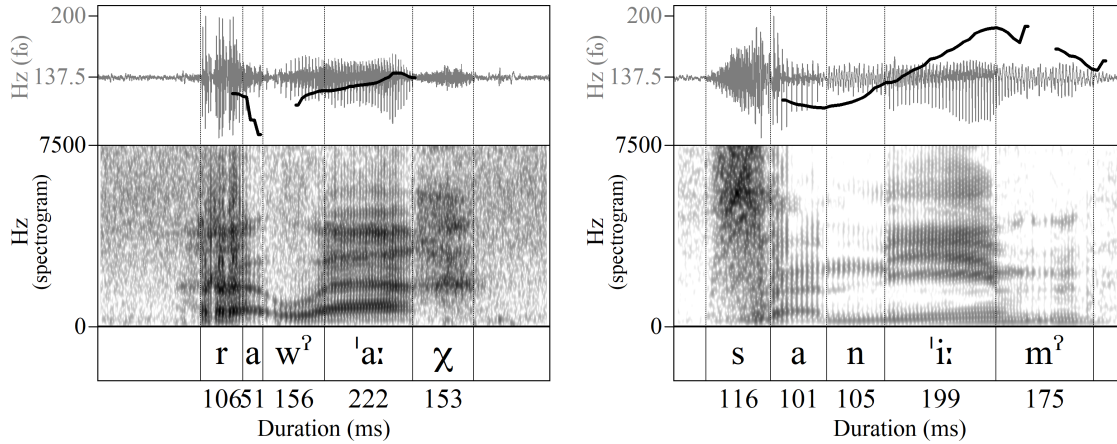


Figure 8 – Historically glottalized bilabial **b'* > [w², m²] in Poqomchi' *rab'aaɟ* [r-a'w²a:ɟ] 'his stone' and *saniib'* [sa'ni:m²] 'sand' (wordlist data, Belejú variety, Caal Morán 1998 (left), Bin 1998 (right); see also Fig. 6 above for cognate *ab'äj* [a'ɓɛɟ] 'stone' in K'iche')

Indeed, glottalization is not always phonetically evident on [w²] allophones of historical **b'*, even for speakers who do clearly glottalize [w²] in some tokens (Fig. 9). In the materials we've examined, glottalization of [w²] 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 [ɓ̚] in word-final position rather than glottalized [m²]/[m̚²] (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).

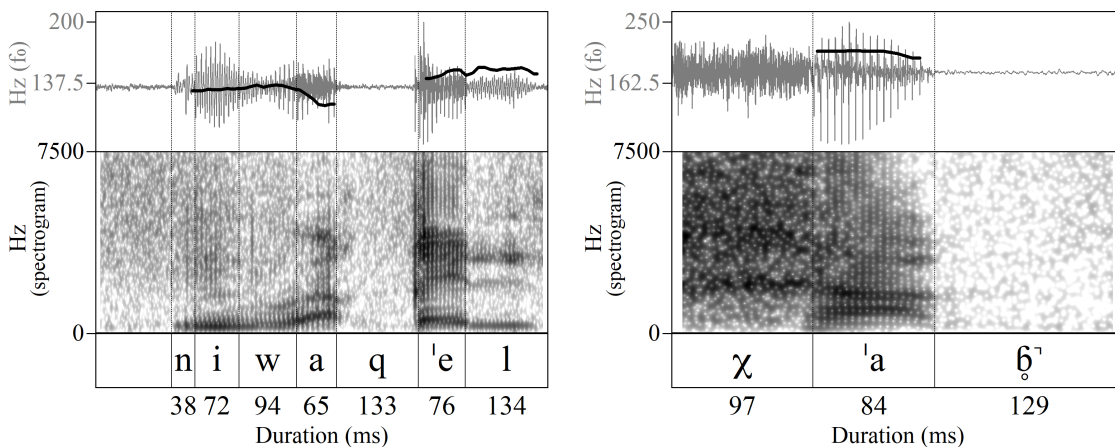


Figure 9 – Apparent plain [w] realization of historical **b'* in Poqomchi' *nib'aqel* [niw²a'qel] 'my bone' (wordlist data, Belejú variety, Caal Morán 1998; compare with Fig. 8, left), and final

[\bar{b}] realization in Poqomam *jab'* [$'\chi a \bar{b}$] ‘rain’ (wordlist data, variety unknown, López & Malchic Nicolás 1998)

To our knowledge, there are no dedicated studies of glottalized [$w^?$] or [$m^?$]/[$m^?$] realizations of historical */ b / 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 [$q^?$] as well. Unlike glottalized bilabial stops, implosive [$q^?$] realizations of the glottalized uvular stop are most commonly voiceless (e.g. Pinkerton 1986, Bennett et al. 2022b; see e.g. Adell 2019:83 on voiced realizations).

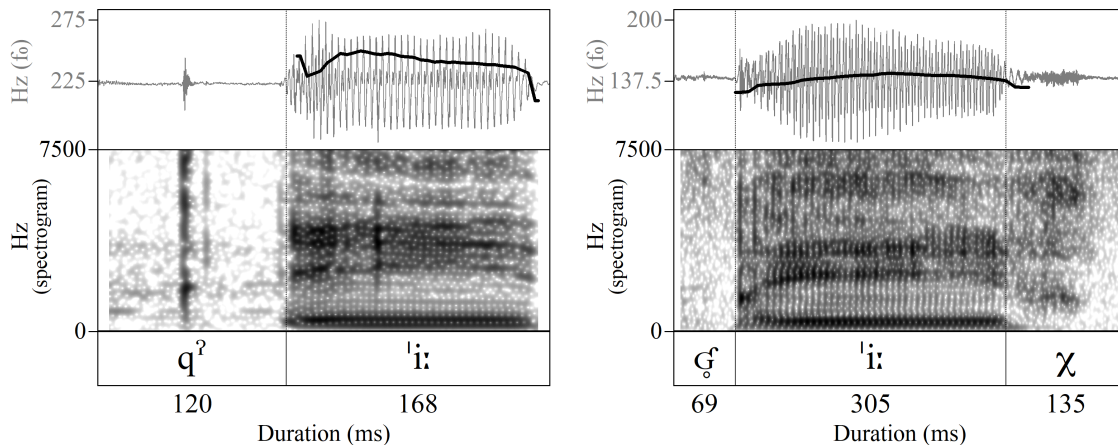


Figure 10 – Realizations of the glottalized uvular stop in Ixil *q'ii* [$'q'i:$] ‘day’ (Cotzal variety, Sánchez Toma et al. 2016) and Mam *q'ijj* [$q'i:\chi$] ‘day’ (Todos Santos variety, Elkins 2023, speaker FPM)

Other places of articulation

Glottalized / $k^?$ / and the affricates $\widehat{ts^?}$ $\widehat{tj^?}$ $\widehat{t\text{ʃ}^?}$ are almost always ejective in Eastern Mayan, though various lenited forms occur in connected speech (the same is true of less common phonemes like / $k^?$ $\widehat{t\text{ʃ}^?}$ /). Alveolar / $t^?$ / – 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 [d] and [ɖ] may occur as allophones of /tʰ/ in this language (Maya Wax Cavallaro, p.c.).

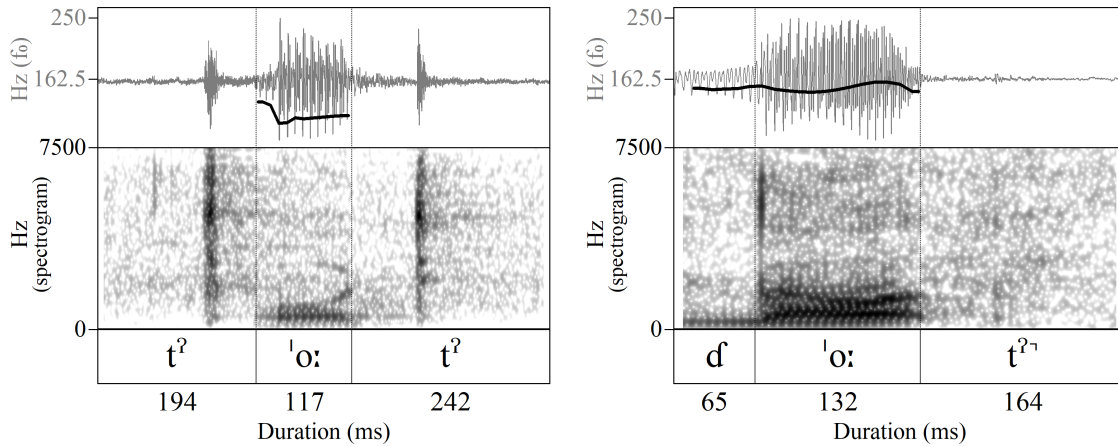


Figure 11 – Ejective and implosive realizations of glottalized alveolar stop in Tz’utujil *t’oot’* /tʰo:tʰ/ → [ʰtʰo:tʰ] ~ [ɖo:tʰ] ‘snail’ (wordlist data; San Pablo La Laguna variety, Culum 1998; San Pedro La Laguna variety, Sequec 1998)

Implosive realizations of /tʰqʰ/ 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 [pʰ] of implosive /b/ or /ɓ/.

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, in the sense that the release of [ʔ] may be followed by a clear period of [h]-like

noise.⁷ 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.

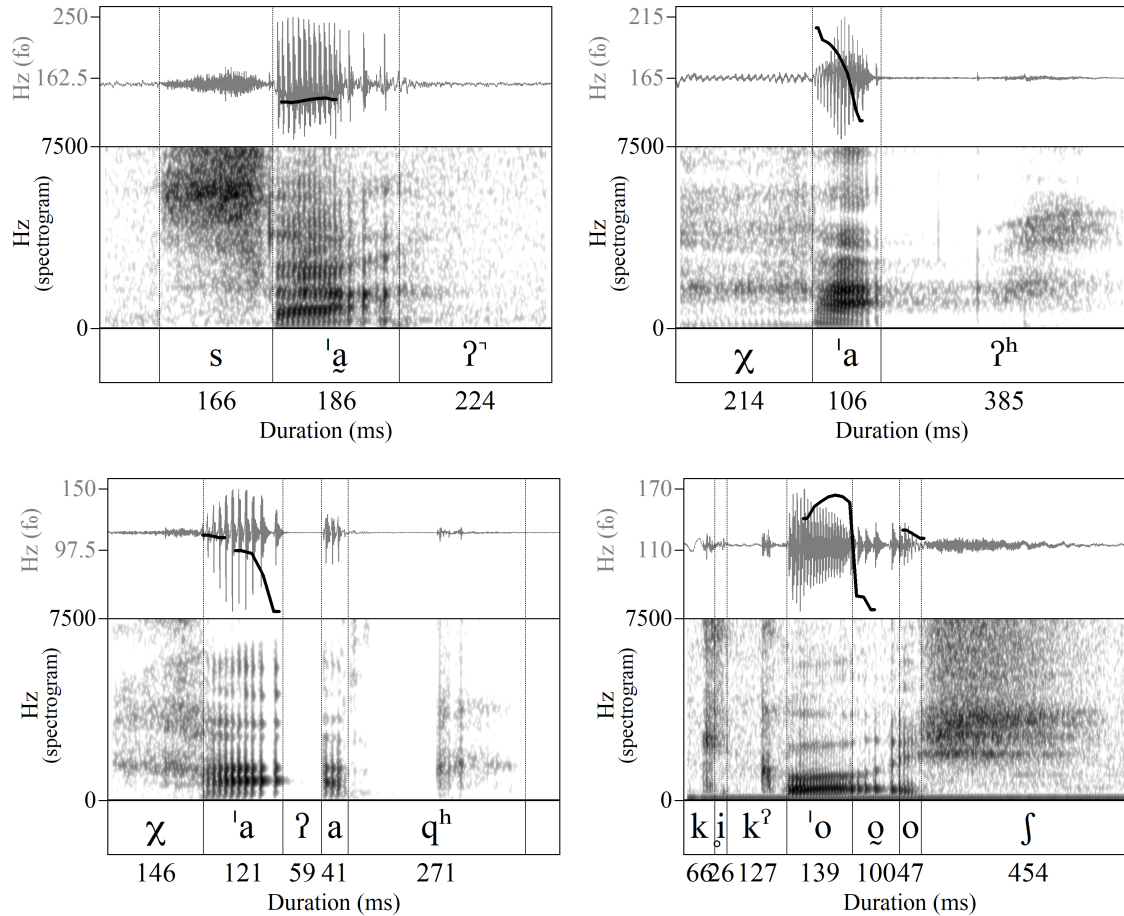


Figure 12 – Clockwise from upper-left: some phonetic realizations of glottal stop in Q’eqchi’ *sa’* /saʔ/ → ['sɑʔ̃] ‘stomach, inside’ (creak; wordlist data, Livingston variety, Chub 1998), Uspanteko *ja’* /χaʔ/ → ['χaʔʰ] ‘water’ (closure with aspiration; recorded 2019), Sakapulteko *kik'o'x* /ki-kʰoʔʃ/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

⁷ In utterance-final position, ‘aspiration’ following [ʔ] could simply reflect a transition from speech to non-speech breathing. However, some sources (e.g. Barrett 1999:37) describe the aspiration of [ʔ] to [ʔʰ] as occurring *word-finally*, not just utterance-finally.

Sobrino Gómez & Bennett (to appear) 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/ → [χteɛ] 'how many'. However, surface [ʔ] may also be derived by debuccalization of the glottalized uvular /q̟/ in the same environment, e.g. *leq* ' /leq̟/ → [leʔ] 'thief' (see also section X.3.3 below). 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 /tʃeʔw/ → [tʃêw] (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, or when 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. For example, it is possible that phonetic cues to 'neutralized' stops might still be present in the preceding vowel, in the form of differences in e.g. phonation, amplitude, f0, or

duration. Such phonetic differences would indicate that ‘neutralized’ coda stops are merely unreleased, and not neutralized as such.

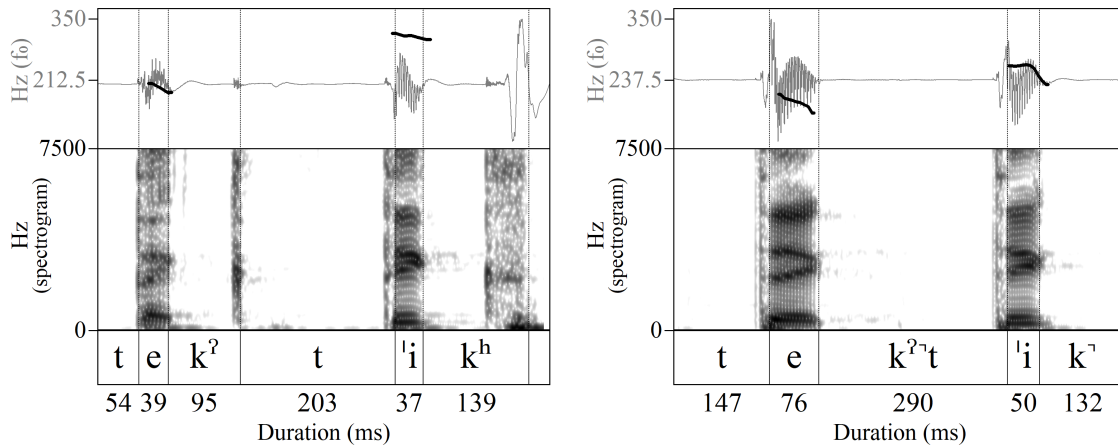


Figure 13 – Uspanteko *tek'ik* /tek²-C_{RED}-ik/ → [tek²tikʰ] vs. [tekʷtik] ‘tall and thin’, with both released and unreleased coda stops (wordlist data, recorded 2019, with two different speakers)

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* [ʃtqsb'χaχ] ‘we are going to whack him/her/it’ or *k'tul b'ey* [k²tul 'be:j] ‘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-ʔa:m] ‘their spider’ (Barrett 1999:24, 2011; see also Bennett et al. 2023b).

However, co-occurrence restrictions in morphological roots do limit the positions in which glottalized stops may occur. 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'* /q²a:q²/ ‘fire’ is a licit root in Tz'utujil, but /q²a:k²/ *q'aak'*, *t'aaq'* /ʔa:q²/, *ch'aaq'* /tʃ²a:q²/, etc. are not (Dayley 1985:31). The glottalized labial implosive and glottal stop are exempt from these restrictions, e.g. Q'eqchi' *b'ut'* /-bʉt²/ ‘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/ → [ʔi'ʃim] ‘corn’. 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/ → [ʃineʔo:’ki] (Dayley 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 $C \in /p\ t\ k\ q\ \text{ḱ}\ t^2\ k^2\ q^2\ \text{ʔ}/$ and $V \in /a\ i\ u/$. 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. Each participant heard 72 target pairs with different (mismatched) stops, 54 target pairs with the same (matching) stop, and 74 filler pairs. The overall ratio of same vs. different trials in the study was 3:4, including both filler and target pairs. To encourage errors, stimuli were embedded in noise at a signal-to-noise ratio of 0dB. 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.⁸

For each comparison (e.g. onset /k/ vs. /kʔ/), 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. 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.⁹

⁸ The value of d' was calculated as $z(H)-z(FA)$, where ‘H’ is the hit rate (proportion of correct responses to ‘different’ trials), ‘FA’ is the false alarm rate (proportion of incorrect responses to ‘same’ trials), and z is the z -transformation. The ‘same’ trials used to compute d' for a particular A~B comparison included both A~A and B~B trials.

⁹ d' scores are z -scores, so a d' of 1 corresponds to roughly 69% accuracy on both ‘same’ and ‘different’ trials, and a d' of 1.5 corresponds to roughly 77% accuracy on both ‘same’ and ‘different’ trials. The effective ceiling of d' is about 4.65; see Hautus et al. (2021).

Glottalized stops and affricates in Eastern Mayan languages

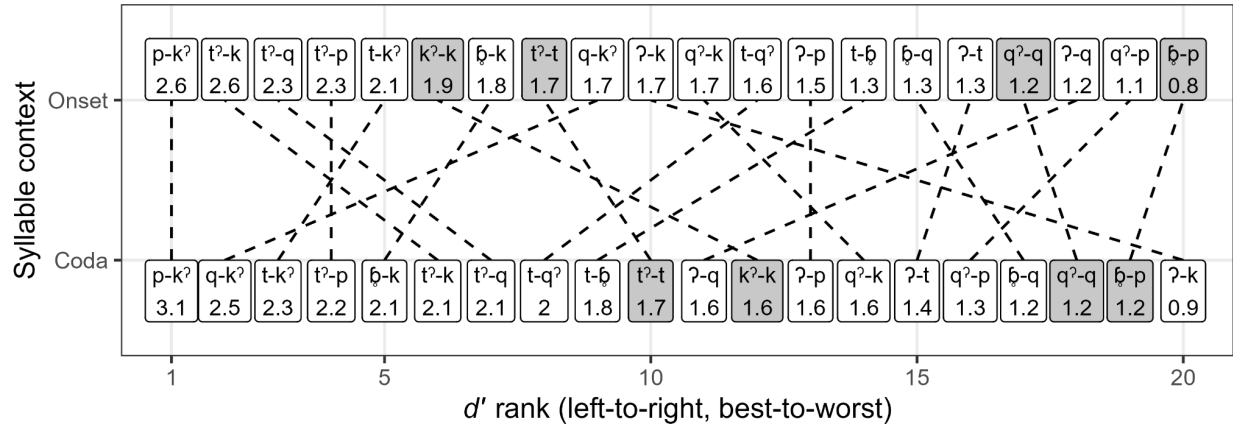


Figure 14 – ranking of relative d' scores across all plain vs. glottalized comparisons. Pairs shaded in grey have the same place of articulation. Approximate d' scores are provided beneath each pair. Range of d' values = [0.77, 3.1], mean = 1.73, median = 1.67, SD = 0.51.

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 many Mayan languages, including Kaqchikel (e.g. Bennett 2016, Bennett et al. 2018, and Tables 2-4 above). Comparisons involving velar /kʔ/ also seem relatively well-discriminated, never falling below the midpoint of the scale, apart from homorganic coda /k/ vs. /kʔ/.

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. /ʃ/ 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 /ʃ/, with the exception of /ʃ/ vs. /k/, and coda /ʃ/ 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/.

$T^{\text{?}}-T^{\text{?}}$, $p > .57$). And again in each case, there is a trend toward higher d' scores in coda position ($T-T$, $\Delta(\text{mean } d') = 0.39$; $T-T^{\text{?}}$, $\Delta = 0.1$; $T^{\text{?}}-T^{\text{?}}$, $\Delta = 0.31$).

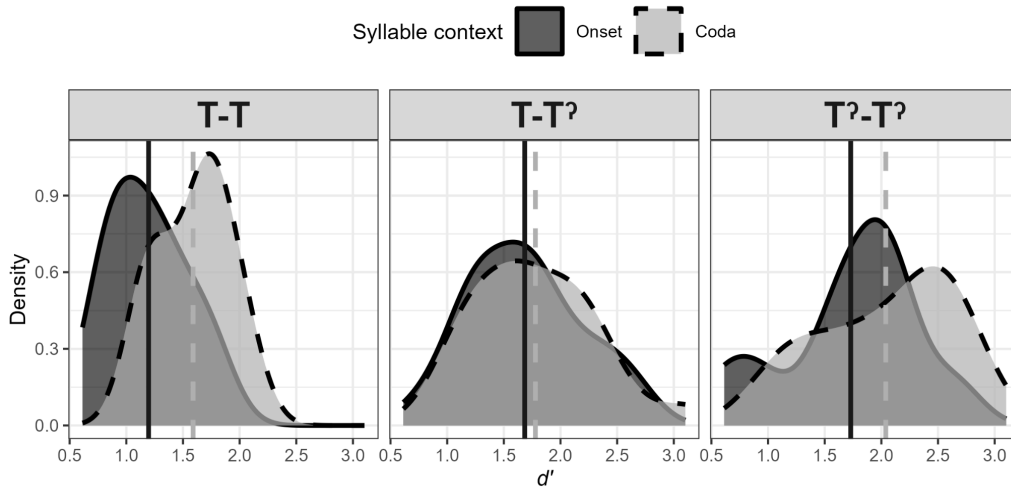


Figure 16 – Density plot of d' scores across syllable position, grouped by comparison type. Vertical lines indicate mean values for each condition.

We assume these results owe to several facts. First, coda stops were released in our stimuli, and aspirated $[T^h]$ in the case of plain coda stops. Since stop releases carry information about both place and laryngeal state, the presence of clear releases in word-final (coda) position likely facilitated stop discrimination in that context (as it does in onset position).¹⁰

Second, Kaqchikel listeners are accustomed to hearing stops of all kinds in both onsets and codas alike, because plain and glottalized stops can occur in any syllable position.

Further, given that contrasts between plain and glottalized stops (and affricates) are maintained across most environments in Kaqchikel (and Eastern Mayan in general), reasonably robust acoustic cues to such contrasts must be present in both onsets and codas. Cues to the laryngeal features of stops and affricates can be found in their releases, but also in their coarticulatory effects on neighboring sounds, such as the presence of coarticulatory laryngealization on vowels adjacent to glottalized consonants.

¹⁰ In a similar perception study, Nelson (2023) reports that Kaqchikel stops are more accurately perceived in onset position than in coda position, for both L1 and L3 listeners of Kaqchikel. (For the L1 Kaqchikel listeners, the effect of position was most evident for laryngeal state, rather than C place.) Given that onset/prevocical position is known to be perceptually advantageous, this result is not entirely surprising, though it does differ from our own findings (see Bennett 2018:20 for relevant citations). It is worth noting that Nelson’s study was carried out with different materials, methods, and a smaller group of speakers than the study we describe here (though the sample stimuli presented on p.147-50 of Nelson 2023 imply that final stops were also released in that study).

By way of illustration, Fig. 17 provides a pair of word-final plain and glottalized uvular stops, produced by a speaker of the Patzicía variety of Kaqchikel (Juan Ajsivinac, a co-author of Bennett et al. 2018 who recorded the stimuli used in that study). Final /q qʰ/ differ in the intensity and abruptness of their release bursts, and in the overall quality of the release phase. Additionally, a subtle decrease in f0 and amplitude is perhaps visible at the end of the vowel preceding glottalized /qʰ/ (Fig 17, right), which may be indicative of some brief, coarticulatory glottal constriction on the vowel.

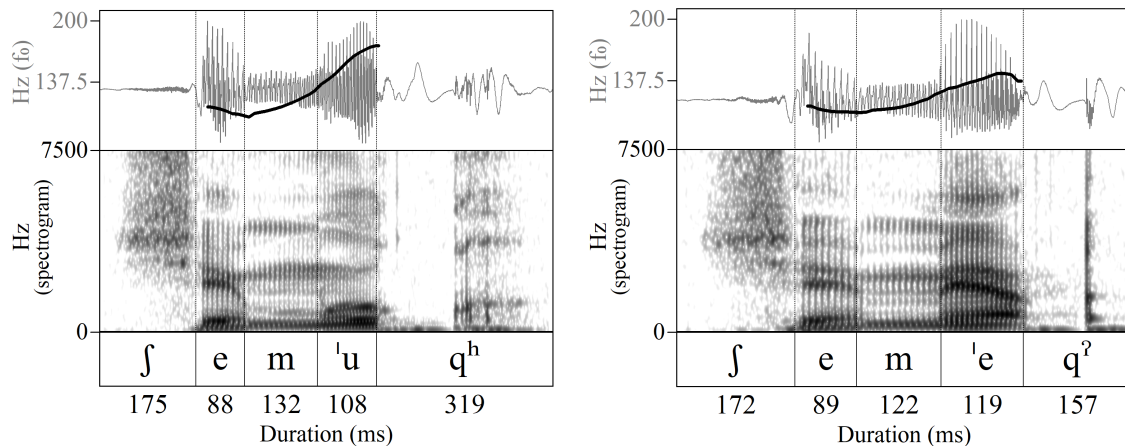


Figure 17 – Kaqchikel *xemuq* /ʃ-e-muq/ → [ʃe.'muqʰ] ‘they were buried’ vs. *xemeqʰ* /ʃ-e-meqʰ/ → [ʃe.'meqʰ] ‘they were heated’ (wordlist data, Patzicía variety, recorded 2019)

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 /ɓ/ were poorly discriminated in our study, across both onset and coda position (Fig. 15; see also Fig. 6). This result parallels the fact that /ɓ/ has sometimes merged with /ʔ/ in Eastern Mayan languages, either systematically or sporadically in certain lexical items (1) (e.g. Campbell 1977:69, Barrett 2007, Bennett 2016).

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

- (a) *xub'ij* [ʃuɓiχ] ~ [ʃuʔiχ] ‘(s)he said it’
- (b) *xb'e* [ʃɓe] ~ [ʃʔe] ‘(s)he went’
- (c) *jeb'el* [χeɓe] ~ [χaʔe] ‘lovely’
- (d) *-V'* [-Vʔ] ‘plural’ < proto-K'ichean **-Vb'* *[-Vɓ]
- (i) Kaqchikel: *ixoqi* [ʔiʃoq-iʔ] ‘women’

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

The same is true of /ʔ/ and /qʔ/: 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 [qʔ#] > [ʔ#] merger for San Juan Atitán Mam above (section X.2.3). Similarly, historical /qʔ/ has become a pharyngeal stop /ʕ/ in Achi (López & Sis Iboy 1992); and in certain varieties of K'iche' and Kaqchikel, /qʔ/ has become glottal stop /ʔ/, at least sporadically in certain words (Larsen 1988:45, Patal Majzul et al. 2000:25-6, Barrett 2007; see also Raymundo González et al. 2000:31-2 on Q'anjob'al, a Western Mayan language).

The perceptual similarity of both /β/ and /qʔ/ to /ʔ/ is likely related to the fact that both /β/ and /qʔ/ are often realized as the voiceless implosives [β̥] and [qʔ̥]. 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. /β/ were relatively poorly discriminated in our results (Fig. 14); however, to our knowledge diachronic mergers between /p/ and /β/ are essentially unknown in Eastern Mayan. The same point can be made for /q/ vs. /qʔ/ (Fig. 14) and /β/ vs. /qʔ/ (Fig. 15).

Conversely, /k² qʔ/ are well-discriminated (Fig. 15), even though the historical merger of **k² qʔ/ to /k²/ and **k q/ to /k/ is a prominent feature of Mayan languages outside of the Eastern branch of the family (e.g. Raymundo González et al. 2000:27-32, 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 **k² qʔ/ to /k²/ 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.

Data availability statement:

The datasets, data analyses, and supplementary information files reported in the current study can be found in the Open Science Framework repository <http://doi.org/10.17605/OSF.IO/S84QC>.

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