

# CONTEXTUAL VARIATION OF GLOTTALIC STOPS IN Q'ANJOB'AL

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## ABSTRACT

Although distinct in both aerodynamic and articulatory properties, ejectives and implosives are rarely contrastive in languages. The realization of glottalic stops is also highly variable across languages and speakers, due to the complex coordination between laryngeal and supralaryngeal articulations. It is therefore important to understand the range of variation and the articulatory target of the glottalic stops. Like other Mayan languages, the glottalic stops in Q'anjob'al vary between implosives and ejectives. This study aims to test whether the phonetic realization of glottal stops in Q'anjob'al systematically varies based on phonetic context. Examining both aerodynamic and acoustic measures, we found that 1) glottalic stops are mostly distinguished from plain stops by glottal constriction (not the direction of airflow), and that 2) word-initial glottalic stops are more ejective-like while word-medial glottalic stops are more implosive-like. This study supports the hypothesis that variation of glottalic stops is continuous and conditioned by phonetic context.

**Keywords:** Q'anjob'al, Mayan languages, glottalic stops, aerodynamics, articulation

## 1. INTRODUCTION

By definition, implosives and ejectives are quite distinct from each other in terms of both aerodynamics and glottal gestures. For example, implosives involve negative oral pressure, ingressive airflow and lowering of the larynx; whereas ejectives are produced with strong positive oral pressure, egressive airflow and raising of the larynx[12]. Implosives and ejectives in theory should also have distinctive acoustic characteristics. For example, ejectives are associated with strong release burst, long positive voice onset time, and higher F0, while implosives are usually voiced and lower in F0.

However, based on the survey of WALS [21], it is typologically rare to have both types of glottalic stops in the same language. Out of 567 languages in the database, it is not uncommon to have either type (57 languages have only ejectives, and 55 have only implosives). However, only 13 languages have both

ejectives and implosives, but the majority of these languages do not contrast ejectives and implosives at the same place of articulation. Only a couple of languages are reported to contrast ejectives and implosives at the same place of articulation.

This is probably because the realization of glottalic stops varies from language to language [10, 7, 1, 6], and the boundary between ejectives and implosives is not always clear. For example, the ejectives in K'iche' are likely to be lax ejective, which is different from the tense ejective in Tigrinya[10]. The F0 of the following vowel is higher for tense ejectives but lower for lax ejectives. Furthermore, implosives are typically voiced, but voiceless implosives are attested in some languages[7, 13, 12]. The actual realization of the glottalic stops is determined by a number of factors (c.f. discussions in [10, 11, 23, 12, 14]), such as raising or lowering larynx, stiffness of the vocal folds, tightness of the oral closure, extent of glottal constriction, size of oral cavity, and the timing and coordination between oral and glottal articulations. As a result, glottalic stops can be at least divided into four subcategories, namely tense ejectives, lax ejectives, voiced implosives and voiceless implosives [10, 7, 12, 13, 23, 8].

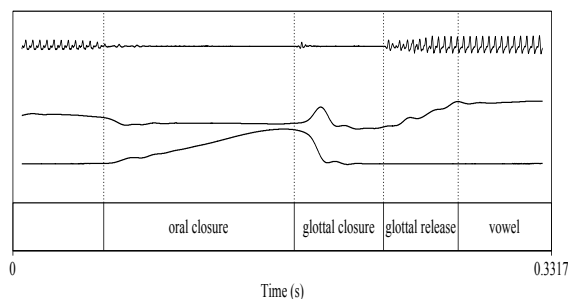
In Mayan languages, glottalic stops are generally ejectives, but bilabial (and sometimes uvular) glottalic stops can vary between implosives and ejectives[5, 4, 3, 19, 9, 22]. This variation can happen across different language varieties and different speakers, and all the four subcategories of glottalic stops can be the possible variants. Moreover, Pinkerton[16] found that the bilabial glottalic stop can even vary within the same speaker, based on different phonetic contexts. Therefore, it is quite possible that the variation of glottalic stops is continuous rather than categorical.

To better understand the range of variation of glottalic stops in Mayan languages, it is important to systematically study the contextual variation of these sounds. However, few such studies have been undertaken (only [2]). Moreover, since acoustic cues for glottalic stops are rather ambiguous, it is desired to use aerodynamic data to examine the phonetic realization of the glottalic stops. However, again aerodynamic data was only reported in [20, 16]. To date,

no study has systematically investigated the contextual variation of glottalic stops with aerodynamic data.

Q'anjob'al is a member of the Q'anjob'alan branch of the Mayan language family. It is spoken primarily in Guatemala and part of Mexico. Like other Mayan language, the bilabial glottalic stop in Q'anjob'al also varies. During the elicitation sessions, we observed that our speaker sometimes produced more implosive-like stops, but other times produced more ejective-like stops. This study aims to test whether the phonetic realization of glottal stops in Q'anjob'al systematically varies based on phonetic contexts using both acoustic and aerodynamic data.

**Figure 1:** Segmentation and the timing of the articulatory events. (Channel 1= audio; channel 2= oral flow; channel 3= oral pressure)



## 2. METHODS

### 2.1. Data

Simultaneous audio, oral flow and oral pressure data were collected from a native Q'anjob'al speaker (female, 26 years old at the time of data collection) through PCquire[15]. A wordlist containing /b'/ (we follow the convention of transcribing the bilabial glottalic stop in Q'anjob'al here to indicate the abstract phonological category) and /p/ were retrieved for elicitation. The wordlist was designed to test several phonetic contexts: 1) position in the word: word-initial, word-medial and word-final; 2) surrounding vowels (both preceding and following): /a/, /o/, /e/, and /i/. A total number of 417 Words containing bilabial stops were confirmed and produced by the speaker. Each word was repeated three times.

### 2.2. Measurements

The timing of oral and glottal events were carefully measured based on both audio and aerodynamic signals. As indicated in Fig. 1, we measured the dura-

tion of oral closure (beginning of the building up of the oral pressure to the beginning of the oral release), the duration of glottal closure (beginning of the oral release to the beginning of the glottal release, usually the onset of voicing), and the duration glottal release (beginning of the glottal release to the plateau of the oral flow, also indicated by creaky voice in the audio signal).

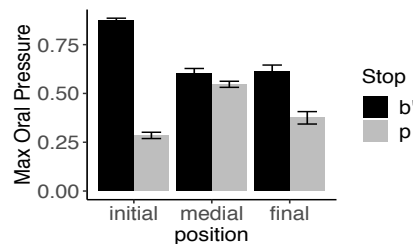
Moreover, two important aerodynamic measures were extracted: maximum oral pressure during oral closure and maximum oral flow at oral release. The maximum oral flow is a more reliable measure than burst energy from the audio signal. Since we only care about the relative variation across phonetic contexts, for both oral pressure and flow, the relative amplitudes (range between -1 and 1, with zero as the default) were used for analysis without calibrating them into actual height of water and liter/sec values. In addition, as an important indicator of the glottal articulation, the F0 onset of the following vowels was also measured with the autocorrelation algorithm in Praat[17].

## 3. RESULTS

Linear regression models were constructed to evaluate context effects on each phonetic measure. Stop categories (glottalic vs. plain), word position (initial, medial and final) and following vowels (front vs. back) as well as their interactions were set as the predictors. The general effects of categorical factors were summarized with anova function in R[18]. Due to limited space, only significant effects are reported here.

### 3.1. Oral pressure during closure

**Figure 2:** Maximum oral pressure during oral closure.

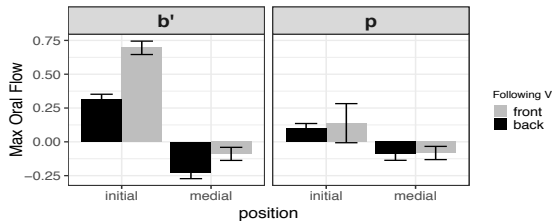


Word position has significant effects on the oral pressure of the stops ( $F(1, 424)=32.857, p<0.01$ ), and the interaction between word position and stop categories is also highly significant ( $F(2, 423)=67.925, p<0.01$ ). As illustrated in Fig. 2, com-

pared to /p/, oral pressure during closure is generally greater for /b'/. The difference between /b'/ and /p/ is especially large at the word-initial position, but not significantly different at the word-medial position.

### 3.2. Oral flow at the oral release

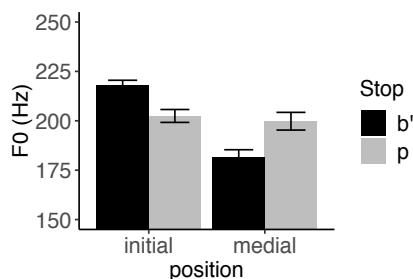
**Figure 3:** Maximum oral flow at the oral release



Maximum oral flow at the oral release is significantly conditioned by word positions ( $F(1,285)=302.81, p<0.01$ ) as well as the following vowel ( $F(1,285)=14.975, p<0.01$ ). The interactions are also significant ( $F(1,285)=6.760, p<0.01$ ). As shown in Fig. 3, /b'/ is produced with a strong positive oral flow at the word-initial position, especially when it is followed by front vowels (e.g. /i/ or /e/). Conversely it is produced with a negative flow at the word-medial position, especially followed by back vowels (e.g., /o/ and /a/)

### 3.3. F0 of the following vowel

**Figure 4:** F0 of the following vowel

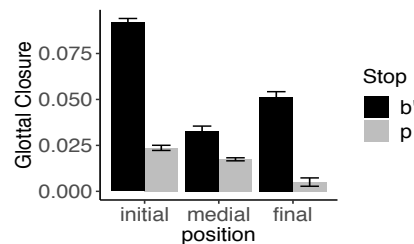


F0 perturbation effect in the vowel following the bilabial glottalic stops is also significantly affected by the word positions ( $F(1,377)=52.828, p<0.01$ ), and there is a significant interaction between word position and stop categories ( $F(1,377)=17.638, p<0.01$ ). As shown in Fig. 4, the F0 of the following vowel is greater for /b'/ at the word-initial position, but greater for /p/ at the word-medial position.

### 3.4. Timing of oral and glottal articulation

The timing of oral and glottal articulation also varies in different phonetic contexts. Significant main effects of word-position and interaction between word position and stop categories are found for both glottal closure duration (main: ( $F(2,407)=144.93, P<0.01$ ); interaction: ( $F(2,407)=48.62, P<0.01$ )) and glottal release duration (main: ( $F(2,407)=95.205, P<0.01$ ); interaction: ( $F(2,407)=8.683, P<0.01$ )). As shown in Fig. 5, the duration of glottal closure is generally longer for the glottalic stop, but the difference between /b'/ and /p/ is smaller at the word-medial position. Initial /b'/ has the longest glottal closure, followed by final /b'/, and medial /b'/ has the shortest glottal closure. By contrast, Fig. 6 shows that, for /b'/, the duration of glottal release (i.e., the time for achieving full glottal release) is longest at the word-medial position, but shortest at the word-initial position.

**Figure 5:** Duration of glottal closure



**Figure 6:** Duration of glottal release

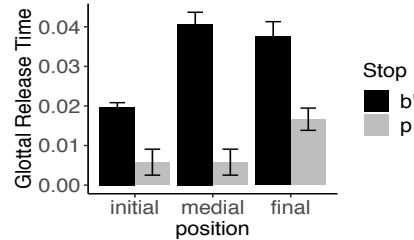
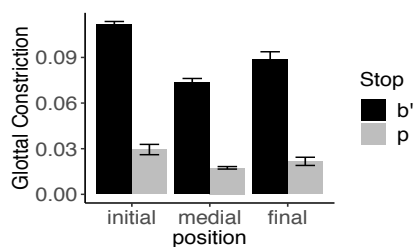
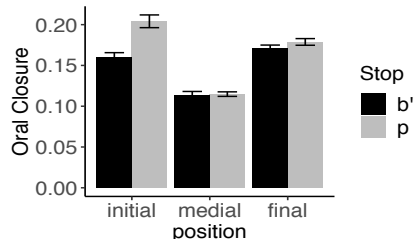


Fig 5 and 6 together suggest that the alignment between voicing and glottal constriction varies substantially by the position in the word. For word-initial /b'/, it takes much longer to start voicing, but much less time to reach full glottal release. By contrast, voicing starts relatively early for word-medial /b'/, but glottal release time is longer. As a result, there is a considerable portion of creaky voice at the onset of the following vowel. Or in other words, there is creaky voicing release.

Fig. 7 shows the total duration of glottal constriction by adding up the duration of glottal release and glottal closure. /b'/ generally has a longer duration

**Table 1:** Summary of the contextual variation of /b'/.

Position	Glottal closure	Glottal release	Oral pressure	Oral flow	F0 of the following V
word-initial	long	short	positive	strongly positive	higher than /p/
word-medial	short	long/creaky	positive	weak positive/negative	lower than /p/
word-final	medium	medium/long	positive	positive	–

**Figure 7:** Overall duration of glottal constriction**Figure 8:** Duration of oral closure

of glottal constriction than /p/. Moreover, /b'/ is produced with the most glottal constriction at the word-initial position and with the least glottal constriction at the word-medial position. Finally, as shown in Fig. 8, the duration of oral closure is generally shorter for /b'/, but this difference is only significant at the word-initial position.

**Table 2:** The output of logistic regression model.

	Estimate	SE	z value	Pr(> z )
(Intercept)	-2.78	0.59	-4.72	<0.001
glottal closure	-3.96	0.85	-4.65	<0.001
glottal constriction	-2.65	0.42	-6.29	<0.001

#### 4. DISCUSSION AND CONCLUSION

The contextual variation of /b'/ is summarized in Table 1. The overall finding of this study is that the phonetic realization (i.e., airstream, F0 perturbation, and timing of oral and glottal release) of the bilabial glottalic stop is rather gradient and highly dependent on the phonetic contexts. The bilabial glottalic stop for our speaker is generally an ejective, since this sound is most often produced with posi-

tive oral pressure and positive airflow. The positive oral pressure and oral flow is especially strong for word-initial position. But importantly, it is possible for our speaker to produce the sound with a negative airflow at the oral release for the word-medial /b'/, especially when the following vowel is low-back /a/.

Compared to the word-initial /b'/, the word-medial /b'/ is produced with a slightly less tight glottal closure, and thus the glottal release is often very early, sometimes even before the oral release. Meanwhile, the larynx is lowered during the oral closure (especially when followed by /a/), so the oral pressure is reduced quickly, and at the time of oral release, the oral flow is either weakly positive or even sometimes negative. In other words, word-medial /b'/ can be sometimes a (creaky-voiced) implosive and sometimes a lax ejective.

To determine which phonetic correlates contribute to the stop contrast between /b'/ and /p/ the most, a logistic regression with both forward and backward step-wise variable selection was run with all the measures discussed in the previous section. The result is summarized in Table 2. Two measures were selected by the model: glottal constriction and glottal closure. Neither aerodynamic measures nor F0 of the following vowels were selected by the model. Therefore, it is confirmed that the most important distinction between glottalic stops and plain stops in Q'anjob'al appears to be the extent of glottal constriction, and glottalic stops generally have a more constricted glottis. The actual cues of glottal constrictions vary with contexts: it is indicated by a long and complete glottal closure word-initially and word-finally, but realized as creaky voice word-medially. The actual realization of aerodynamics and F0 perturbation is heavily determined by phonetic contexts, and so not reliable cues for the native speakers.

Finally, we speculate that glottal constriction is also the most important phonetic properties for glottalic stops in other languages as well. Due to the complex coordination between laryngeal and oral articulations, the airstream and timing of oral release and glottal release are highly variable across different contexts, different speakers and different languages.

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