ACOUSTIC CHARACTERISTICS OF THE GLOTTAL STOP IN KAYABI

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ABSTRACT

Spectrograms of the recorded speech of one male and one female speaker of the Kayabí language of Brazil demonstrate voiced variants of the normally voiceless glottal stop.
The glottal stop is realized by several variants which are reflected in the spectrograms. These variants range from a period of complete closure, through various kinds of creak, to a more slowing down of vocal cord vibrations, or a combination of these.

INTRODUCTION

This presentation describes the Kayabí glottal stop in terms of their acoustic cues and cue patterns as observed in spectrograms. Some degreee of glottal stricture from glottal trill, flap to glottal stop is perceived and identified by the listener as a glottal stop.
Kayabí belongs to the Tupí-Guaraní language family of Brazil as classified by Rodrigues (Rodrigues 1958). The Kayabí language is spoken by about 400 Indians living in Central Brazil, were the material on which this study is based was gathered.

1. METHOD

Data used for this research were mainly lists of isolated words of varying syllable types and lengths taperecorded by one male and one female Kayabí speaker, using an Uher 4000 Report 'S' taperecorder with a Sennheiser microphone.
Spectrograms were produced with a Kay Digital Sona-Graph 7800 at the University of Edinburgh.

2. RESULTS

The glottal stop in Kayabí is phonologically an articulation type, being in contrast with other stops. It occurs in syllable initial position and functions as a consonant. Examples of contrast are:

/taʔɨt/	'offspring'	/tajtɨ/	'cloth'
/aʔu/	'he/she works'	/katu/	'good'
/aʔɨ/	'a sloth'	/aɨ/	'it hurts'
/ɔʔɔ/	'meat, flesh'	/ɔɔ/	'he/she goes'
/ɨʔa/	'a gourd'	/ɨat/	'canoe'

Preglottalized consonants also occur syllable initial at morpheme boundaries. They are mostly the result of metathesis, as seen in:

/ipiraŋ/ 'red' plus suffix /-ʔi/ 'diminutive'
⟶ /ipiraʔŋi/ 'a little red'

2.1 Intervocalic glottal stop

The acoustic cues reflecting the intervocalic glottal stop articulation are seen on spectrograms as:
a. a gap of shorter or longer duration, reflecting a momentary and voiceless articulation:

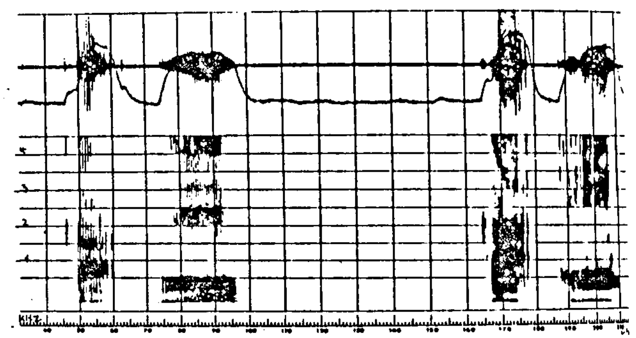

Figure 1: /kaʔi/ 'monkey'
left male speaker, right female speaker

b. a series of short and irregular gaps between stronger glottal pulses, with or without slowing down of vibrations before and after these gaps:

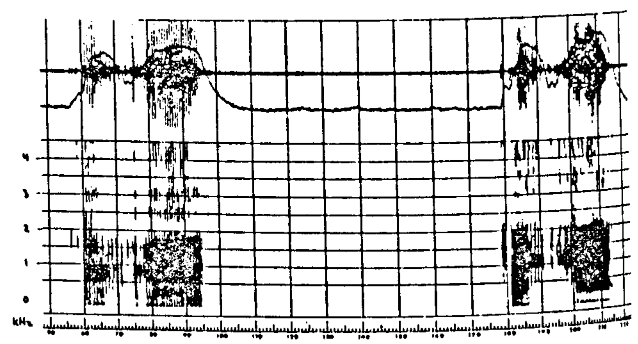

Figure 2: /kaʔa/ 'jungle, tree'
left male speaker, right female speaker

c. a rapid lowering and raising of F_0:

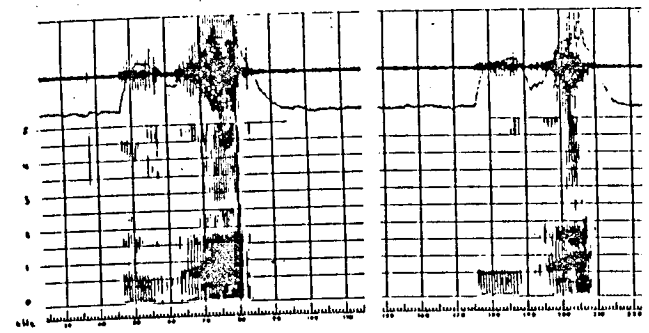

Figure 3: /ɨʔa/ 'gourd'
left male speaker, right female speaker

The various types of glottal activities are accompanied by a drop in intensity, which is maximum for the complete glottal closure.
The duration of the intervocalic glottal stop ranges from 80-160 msec, which is shorter than the duration of other stops.
The auditory effect is always that of a glottal stop, whatever the variation in degree and length of closure. Free variation of the acoustic cues for a glottal stop have been observed in the same utterance spoken on separate occasions by the same speaker.

2.2 Preglottalized consonants

A glottal stop preceding the consonants /m/ /n/ /ŋ/ /w/ /j/ /r/ /g/ can have the same variants as when occurring intervocally:

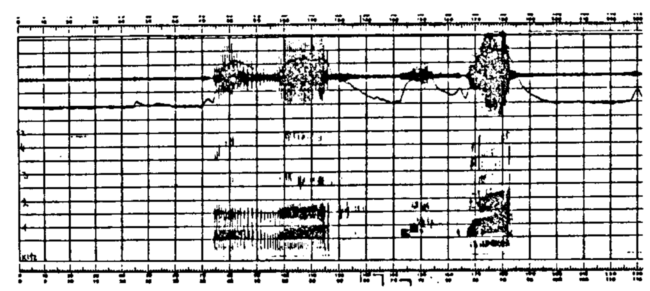

Figure 4: /kaʔra/ 'a root vegetable'
left male speaker, right female speaker

The duration of this glottal activity is about 70-150 msec, followed by a consonant of 20-60 msec. This consonant duration is shorter than the duration of the same consonant intervocalically. The auditory effect of the variants of the glottal stop preceding consonants is always that of a pre-stopped consonant.

3. FACTORS INFLUENTIAL IN THE CHOICE OF VARIANTS OF THE GLOTTAL STOP

Kayabí speech demonstrates a tendency towards a more lax articulation, especially in the speech of male adults. This results in incomplete or lax closures especially of /r/ and /ʔ/, and a more open aproximation for fricatives. Women tend to use a more tense and precise articulation with tighter closures and narrower constrictions, and often a longer duration of segments.
The creak variants are more prevalent in male speaker with a lower F_0. Female speakers do manifest creak, but show a tendency toward complete closure.
The creak variant is more common in open vowels than in close ones.
The glottal closure is longer the heavier the stress, with less closure or just creak with weaker stress. In faster speech and longer utterances the variants creak to slow vibrations are the more common.

4. CONCLUSIONS AND DISCUSSION

In Kayabí the target for the glottal stop articulation is of the category stop or closure, realized by a scale of glottal stricture from complete and prolonged closure, several short closures, through creak to tense voice.
The unit of perception is composed of acoustic cues and cue patterns as seen in the spectrograms, which reflect glottal activity of varying degrees, the totality of which is perceived and distinguished as the phoneme 'glottal stop'.

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GLOTTALIC STOPS IN GITKSAN: AN ACOUSTIC ANALYSIS

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ABSTRACT

A time series analysis of Gitksan ejectives provides additional evidence for a typological distinction between fortis and lenis glottalic stops.

INTRODUCTION

In the light of recent evidence of inter-language and inter-speaker variation [1, 2], it is apparent that the classical account of the glottalic airstream mechanism for ejectives [3] is in need of revision. This paper reports an acoustic investigation of plain and glottalized stops in Gitksan, a Tsimshianic language spoken in the Skeena River valley of British Columbia.

Glottalized stops in Gitksan are notable for their lenis character [4, 5], in contrast to the unmistakably ejective nature of glottalized stops in other Pacific Northwest Ameridian languages, such as Sahaptin or Kiksht (Upper Chinookan). For non-native listeners, Gitksan glottalized stops may, in certain instances, be perceptually confused with plain voiced stops, with which they are actually in phonemic contrast. Hoard [4] suggested that glottalized stops in Gitksan utilize an implosive airstream mechanism (in prevocalic position) and proposed a revision of the then current Chomsky & Halle [6] scheme for laryngeal features. Gitksan stops, because of their transitional status, provide an interesting testing ground for models of laryngeal features.

Hoard's conclusions were derived not from instrumental, but impressionistic phonetic observations, supported by then-known properties of glottalic consonants [7] and inferences based on the classical model of the glottalic airstream mechanism. We find no evidence to support Hoard's claim that Gitksan glottalized stops are implosive, but this negative result merely raises the question of precisely what the underlying articulatory mechanism may be. The question is significant for a model of glottalic features in general.

More recent instrumental studies of glottalic obstruents [1, 2] have revealed a greater range of cross-language and cross-speaker variation than was hitherto envisioned. In addition to the widely accepted distinction between ejective and ingressive mechanisms within glottalic consonants, it seems necessary to draw an additional typological distinction between fortis and lenis varieties of glottalic consonant.

Lindau [1] compared implosive and ejective glottalic stops acoustically in a number of languages, including Hausa, which has a labial implosive and a velar ejective as part of the same series of glottalic stops. She found greater speaker variation in Hausa glottalic stops than in the other languages examined (Degema, Kalabari, Orika, Bumo, Navajo). Comparison of Navajo and Hausa ejectives indicated substantial differences in manner of production, which we associate with a fortis-lenis typological distinction among glottalic stops.

Kingston [2], developing a theory of tonogensis for Athabaskan languages, distinguished between tense and lax ejectives, claiming that the following phonetic features of ejectives in Tigrinya, a Semitic language of Ethiopia, and Quiche, a Mayan language, exemplify the differences between the two types:

TABLE I
CHARACTERISTICS OF TENSE AND LAX EJECTIVES

Type of ejective:	Tense	Lax
F_0 of the following vowel:	raised	lowered
Voice onset time:	long	short
Intensity of release:	high	low
Vowel onset:	abrupt	gradual

(after Kingston, 1985)

The speakers: Two informants provided two tokens each of a word list elicited by one of the authors (BR) in 1985. One of the Gitksan speakers, LH a male in his late 30's, was the informant for Hoard's 1978 paper. The other Gitksan speaker, SH, is LH's mother. SH is the more conservative of the two speakers with respect to Gitksan norms of usage and also the more fluent. Both speakers are bilingual in Gitksan and English, but LH clearly favours English in his everyday speech.

Two examples from Chipewyan, an Athabaskan language with typical fortis ejectives, reported here for purposes of comparison, come from the speaker in Hogan's [8] study.

The Gitksan items were tape recorded on a Marantz cassette recorder (CP430) and then digitized at a sampling rate of 20 KHz for time domain and spectral analysis using the ILS signal processing package.

Acoustic analysis: Plain and glottalized stops in word initial pretonic position were examined from waveform displays comprising the whole word and a windowed frame of the first 358 msecs (see figure 1). The following acoustic features of the signal were examined by a combination of quantitative measurement and qualitative visual inspection of waveform characteristics:

1. The amplitude envelope of the oral release burst.
2. The voice onset time.
3. The amplitude envelope of the vowel onset.
4. The presence of aperiodicity and period by period fundamental frequency changes in the vowel onset.

These acoustic features are illustrated in Figure 1. Where qualitative judgements based on inspection of waveforms were used, rater reliability was checked by repeating the observations one month after the originals were made. Reliability rates, expressed as percentage agreement scores, ranged between 94% and 98%.

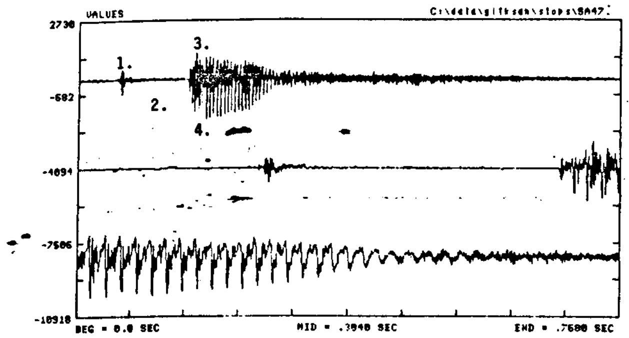

FIG. 1. Waveform of Gitksan ejective

Plosive release characteristics: Fortis and lenis varieties of glottalized stops may be expected to differ in the amplitude of the noise burst associated with the oral release gesture. It would be reasonable to infer that the amplitude of the release burst is monotonically related to intra-oral air pressure and the strength of the compression gesture just prior to release. In the case of fortis and clearly ejective glottalized stops, the release burst is highly damped and followed by a period of silence (approximately 100 msec.) before the onset of voicing. This contrasts with the release characteristics of voiceless aspirated stops, which typically also have a substantial voice onset time, but where the noise burst is relatively undamped and continues up to the onset of the vowel.

The contrasting release characteristics of the ejective and aspirated stops are attributable to two factors: a) higher intra-oral air pressure during the compression phase of the ejective as the larynx is raised, b) the open configuration of the glottis for aspirated stops, which permits sustained turbulent oral airflow up to the vowel onset.

In the case of (English type) plain voiced stops, where oral release occurs more or less simultaneously with voice onset, obviously no independent release burst is observable. In the case of prevoiced (Spanish type) or imploded stops, low amplitude voicing is observable in the waveform prior to oral release.

Measurements were made of the maximum amplitude of the oral release burst where it could be observed independently of the vowel onset. This was possible in all cases for the glottalized stops but generally not for the plain stops, except for the velars and uvulars. Figure 2 shows the observed distribution of release burst amplitude measurements for the Gitksan glottalized stops as well as for two reference tokens from Chipewyan. The amplitude measurements have been expressed as ratios of the maximum vowel amplitude for their respective tokens, so as to normalize the data for arbitrary variations in absolute signal strength.

Figure 2 illustrates the lenis character of the release burst in Gitksan glottalized stops in comparison with those of Chipewyan. It also indicates substantial variation in the relative strength of the release gestures.

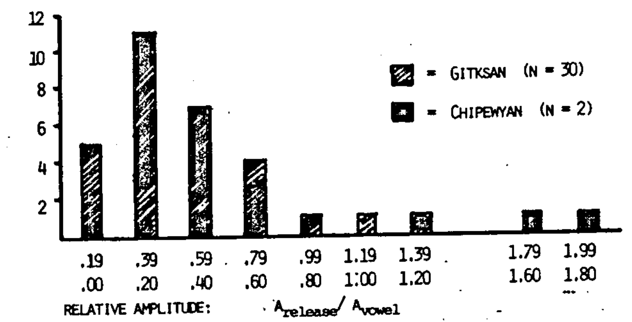

FIG. 2. Amplitude of release burst for Gitksan & Chipewyan ejectives

The envelope of each release burst was also classified by visual inspection of the waveform into one of four categories:

C (checked): a damped noise burst
A (aspirated): an undamped noise burst
V (voiced): noise burst coincides with voice onset
P (prevoiced): voice onset prior to oral release.

With only two exceptions all glottalized stops were judged to have a 'checked' noise burst, although the amplitude was very low in some cases, but still audible. The distribution of release types for the plain stops is shown in Table II.

TABLE II
Classification of plain stops by type of release burst and place of articulation.

	Prevoiced	Voiced	Aspirated	Checked
Alveolar	1	7	0	0
Velar	0	8	4	0
Uvular	0	3	0	3

It is typical of dorsally articulated stops to have some aspiration. The damped appearance of some uvular release bursts should not be taken as indicative of an ejective airstream mechanism, but it may explain why there is a tendency to mishear plain uvular stops as glottalized. Only one instance of a prevoiced stop was observed in the data set (SH, on second elicitation of /taw/, [daw], 'ice'). No examples of implosion were encountered, on phonologically glottalized stops or otherwise.

Voice Onset Time: Hogan [8] reports a mean Voice Onset Time of 114 milliseconds for Chipewyan ejectives in single word utterances elicited under comparable conditions to the present study. Voice onset times for the Gitksan glottalized stops were somewhat shorter with quite a high variance ($\bar{X}$ = 89.2, SD = 31.3 msec). Voice onset times for plain Gitksan stops fell within the range of English voiced stops ($\bar{X}$ = 11.1, SD = 36.1 msec). Figure 3 shows the distribution of voice onset times for all items. There is clear separation of plain and glottalized stops on the VOT continuum for SH but some overlap for LH whose VOT's are generally shorter for the glottalized series.

Amplitude envelope of vowel onset: For ejectives produced with a tense glottal configuration an abrupt vocalic onset may be expected, whereas with a more lenis configuration, the onset may be more gradual. A simple but adequate index of the abruptness of the vowel onset was provided by the peak amplitude of the third glottal pulse as a proportion of the maximum amplitude attained by the vowel. Figure 3 shows the distribution of this index for all tokens on the y axis of the graph. It is clear that the A3/Amax index does not distinguish glottalized from plain stops. It does however indicate a cross speaker difference. SH's vowel onsets are more abrupt than LH's.

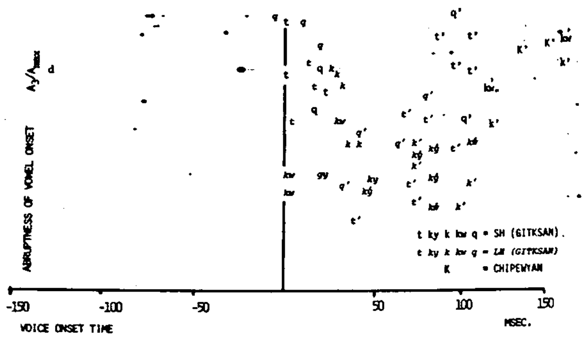

FIG. 3. Voice Onset Time and Abruptness of Vowel Onset in plain and glottalized stops.

Aperiodicity and frequency of vowel onset: Frequency characteristics of the vowel onset carry information about the glottal configuration. Kingston [2] distinguishes between tense and creaky voice onsets which follow tense and lax glottalized stops respectively. Tense voice is associated with stiff vocal folds, a high degree of general laryngeal constriction, and a higher than normal transglottal pressure differential to sustain phonation. Creaky voice, on the other hand, is associated with shortened but lax vocal folds, moderate medial compression of the vocal folds with a lax laryngeal configuration, and a lower than normal phonatory transglottal pressure differential [9].

There is some uncertainty about the acoustic features that distinguish tense and creaky voice. The most prominent difference lies in the fundamental frequency of phonation, which is very low in creaky voice and somewhat raised for tense voice. A greater degree of aperiodicity of vocal fold vibration may be expected for tense and creaky voice than in modal voice, though its time series and spectrographic expression may be different in the two non-modal voice qualities.

In creaky voice there is gross variation in the period of vocal fold vibration, pssibly due to insufficient airflow or subglottal pressure to sustain regular pulsation. In tense voice, the higher degree of stiffness in the vocal folds and surrounding laryngeal musculature, combined with higher levels of subglottal pressure produce a phonatory cycle that has a relatively longer closed phase than in modal voice and a spectrum characterized by increases in the amplitudes of higher harmonics. Frequency or amplitude variation in the higher vocal harmonics may result from inherent instabilities of the laryngeal configuration for tense voice.

Aperiodicity during the first 40 milliseconds or so of the vowel is evident from the whole waveform display in Figure 1, but this was atypical. Only 26% of the Gitksan glottalized stops in pretonic position showed obvious aperiodicity in the first 40 milliseconds or so of the following vowel. However, there are possibly significant speaker differences on this parameter. For SH, six of ten vowels following glottalized stops showed aperiodic onset, compared with two out of twenty for LH.

Measurements were also made of the periods of the first eight glottal pulses. Figure 4 summarizes the results.

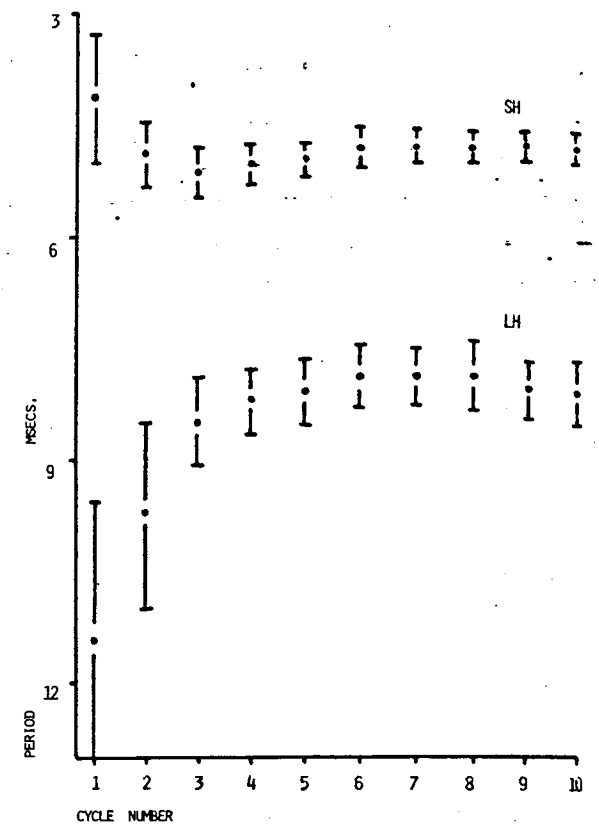

FIG. 4. Period by period frequency changes in vowel onset

There are notable speaker differences in the frequency contours of vowels following glottalized stops. For LH, whose glottalized stops are particularly lenis, the frequency at onset is low, well within the range of laryngealized voice, and rises nonlinearly to modal voice within the first five or six glottal cycles. SH's vocal frequency generally begins slightly high and drops to normal value within the first three cycles.

LH's vowel onset frequency contour follows that of lenis glottalized stops as observed for Hausa by Lindau [1] and Quiche by Kingston [2]. SH's frequency contour more closely approximates that of fortis Chipewyan stops (this paper) or Tigrinya [2]. A common feature of both speakers vowel onsets is the large and diminishing variance in the periods of the first two or three glottal pulses.

Summary and conclusions: To summarize, Gitksan glottalized stops in pretonic position are characterized acoustically by:

1) A relatively weak but damped release burst, consistent with a lenis ejective airstream mechanism.
2) A shorter VOT than is typically observed for (fortis) ejective stops.
3) A gradual rather than abrupt vowel onset in the majority of tokens, though this feature varied with the speaker and was correlated with:
4) An absence of visible aperiodity in the waveform of the following vowel-onset for the majority of tokens (contra illustration in Figure 1 above), but nevertheless:
5) Substantial, but declining, pitch period perturbation (jitter) over the first few glottal cycles of the vowel onset, with the f_0 contour rising (in the case of speaker LH) or steady-falling (SH).
6) Significant speaker variation on all of the above features, with LH consistently demonstrating a more lenis pattern of articulation.

It is possible that the observed speaker differences are attributable, not to inherent variation in Gitksan glottalized stops, but to the differential effects of language shift. As mentioned earlier, LH is less fluent than his mother, who maintains full native-speaker productive control over the language. Alternatively, the speaker differences may be at least in part attributable to stylistic variation. SH is a more conservative speaker, and her pronunciation may reflect the use of a more formal speech style. Regardless of the source of these speaker differences, it is possible to draw certain inferences about the underlying articulatory mechanism of Gitksan glottalized stops and to hazard some speculative comments as to their featural representation.

Analysis of the Gitksan data, taken in context of a growing body of data from other languages, suggests that a language typological distinction between fortis and lenis ejectives is warranted, where this term is understood in the traditional sense of the degree of vigour of the complex laryngeal and articulatory components which comprise the whole gesture [6, 10, 11]. Reduced upward movement of the larynx would produce a weaker and shorter compression phase. This is consistent with the lower observed amplitude release burst and shorter VOT's of Gitksan glottalized stops. A weaker medial compression, with lower overall muscular tension in the larynx will result in a non-abrupt vowel onset, but one which is more likely to begin with a creaky or laryngealized mode of vocal fold vibration. (While fortis ejectives have a glottal attack, lenis ones, begin with a laryngealized voice and hence both have a 'glottalized' voice quality.)

Of the variously competing laryngeal feature systems, that of Ladefoged [9] seems most naturally to accommodate the emerging picture of cross language variation in glottalic stops. The fortis-lenis contrast applied to ejectives is a **typological** rather than a **distinctive** phonetic feature. In Languages such as Hausa whose glottalic stops fall on the lenis end of the continuum, the contrast between ejective and implosive airstream mechanisms is less apparent, both perceptually and physiologically. Reduction of the laryngeal constriction and movement in the vertical plane will tend to result in half-way state that yields a brief period of laryngealized vocalization superimposed upon a weak plosive gesture that may be ejective in some environments and ingressive in others.

No evidence was found of an implosive airstream mechanism in Gitksan glottalic stops, but rather, a weakly ejective mechanism seems to be used. However, Hoard's important insight that a feature 'glottalized' is required, in order to adequately capture phonetic processes to which lenis glottalic stops may be particularly prone, still stands.

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