On the Acoustic Characterization of Ejective Stops in Waima'a

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Abstract

We examine some acoustic properties of ejective stops in Waima'a (an Austronesian language spoken in East Timor), and compare them with other voiceless stop types that occur in the language. Previous studies of ejectives in other languages have suggested that they may fall into two classes, strong and weak. We compare our Waima'a results with some existing findings in the literature, and suggest that while Waima'a ejectives might appear to be more appropriately characterized as strong on some criteria, they do not sit squarely in either category.

1. Introduction

Ejective stops are distinguished from other voiceless, non-glottalized, stop types by having a closed glottis as well as a supralaryngeal closure gesture. As the larynx is raised the air between the glottal and oral closures is compressed. This increased pressure in the oral cavity results in a strong, distinctive burst on release of the oral closure. The glottis remains closed at the point of oral release, and is not opened until some time after [1; p. 78].

Although ejective stops occur frequently in different parts of the world, e.g. Africa and the Caucasus, they are extremely rare amongst Austronesian languages. Of the approximately 1260 members of the Austronesian family, the world's largest, only two are reported to have ejectives (Yapese and Waima'a). Ejective stops have arisen independently in each language.

While there have been a number of recent experimental studies of ejectives in North American languages in particular, e.g. [2], [3], [4] we still have very limited phonetic information on ejectives in Austronesian (see [5] for Yapese and [6] on Waima'a). Our previous experimental investigation of Waima'a ejectives ([6]) focused on a comparison with other voiceless stop types that occur in Waima'a in terms of voice onset time (VOT) and closure duration.

More detailed experimental data on ejectives from the Asia-Pacific region would be a useful contribution towards a better understanding of the phonetics of ejective stops in general. This is particularly relevant to ongoing discussion of the acoustic characteristics of ejectives, and the suggestion that these segments may fall into two classes, strong (also: tense, stiff) v. weak (also: lax, slack) in different languages, e.g. [7], [8], [9].

A number of potential criteria have been proposed in this discussion to distinguish between tense and lax ejectives, as well as between ejectives and other stop types. In this study we look specifically at some of these: across stop types (i) voice onset time (VOT); (ii) closure and overall duration; (iii) F0 in the following vowel, and specifically with reference to ejective stops only, (iv) contextual creak and (v) amplitude rise. After an initial presentation of our results, we then consider the implications these have for a characterization of ejective stops in Waima'a.

2. The Data

2.1. Waima'a stop series

Waima'a has a four-way system of supralaryngeal stops. As shown in Table 1, stops are either: (a) voiced; (b) voiceless unaspirated; (c) voiceless aspirated; and (d) voiceless ejective.

Table 1. Stop contrasts in Waima'a

Voiceless unaspirated	(p)	t	k
Voiceless aspirated	p^h	t^h	k^h
Voiceless ejective	p'	t'	k'
Voiced plain	b	d	g

Lexical sets contrasting the four stop types are easily found: /gama/ 'shark', /kama/ 'bed', /k'ama/ 'scratch' and /kha ma/ 'eat already'. Voiceless coronals /t t^h t'/ are dental in Waima'a.

The status of the voiceless aspirate /p/ is less secure than that of other stops – it occurs only in recent loans from Portuguese and Tetum, and tends to merge with its aspirated counterpart /p^h/. Because of its unusual characteristics, no further reference is made to /p/ in this study. Following [7], voiced stops /b d g/ are also excluded, since the negative VOT associated with voiced stops quite clearly separates them from ejective stops in both acoustic and perceptual terms.

3. Methods

3.1. The data

The data consist of a series of target words read in a simple carrier sentence by one adult male speaker of Waima'a, recorded in a laboratory setting. While the investigation is limited by the use of only one speaker subject at this stage, we note that other experimental studies also involve single speaker studies (e.g. [3], [7]).

The frame *ehe*_____ "say_____" was used so that the stop was always in post-vocalic position and closure duration could be measured. All target consonants used for this preliminary study preceded /a/ except the 8 /t'/ tokens which preceded /i/ in the word /t'iba/, as no corresponding word-initial /t'a/ tokens could be found at the time of recording. Up to 5 repetitions were made for each word, giving 71 tokens in total which were distributed as follows:

Table 2. Number of tokens examined and their distribution across place of articulation and stop type.

	Bilabial	Coronal	Velar	All
Aspirated	8	8	12	28
Unaspirated	-	8	13	21
Ejective	10	8	4	22
All	18	24	29	71

Using spectrographic and waveform displays within the PCQuirer program, durations of the closure period and VOT were measured for each token. We also measured F0 in the following vowel at 2 time points (using the pitch trace function within Praat): the start of modal voicing in the vowel and at vowel mid-point. We were unable to measure F0 in the following vowel for a handful of aspirated tokens because a phonemic glottal stop that occurred later in the word induced creak throughout the vowel.

Through direct visual inspection we also noted: (1) the quality of the onset of the post-stop vowel, since creak has been reported to occur after ejectives in some other languages; and (2) the rate of amplitude increase to peak levels in the following vowel.

3.2. Measurement criteria

In all cases the closure period was defined as the interval between the offset of the vowel and the onset of the oral release burst. For all three stop types examined (voiceless aspirated, unaspirated and ejective) the VOT was measured from the start of the oral release burst to the first glottal pulse associated with the vowel, following [3], [4], [5]. This is shown in Figure 1 where the arrow points to the glottal release following the oral release for the ejective stop /k'/:

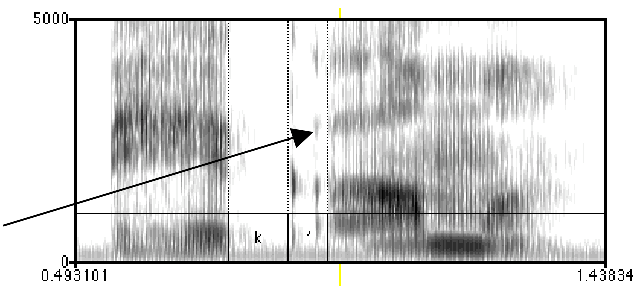

Figure 1. The ejective velar stop in /k'ama/, showing measurement of VOT from the oral burst to the onset of voicing rather than to the glottal release shown by the arrow.

4. Results

4.1. Preliminary acoustic observations

Initial acoustic inspection of the data showed that ejectives could be clearly distinguished from other stop types in the data, most notably in the nature of the burst and VOT, which differed across all three stop types.

Ejective stops typically involved a clearly visible oral release, a weaker glottal release and a slightly delayed onset of voicing (as in Figure 1). There was, however, some variation in the spectral appearance of ejectives across tokens analyzed. The release of the glottal closure was not always distinguishable on the spectrogram or waveform displays from the onset of voicing, as below:

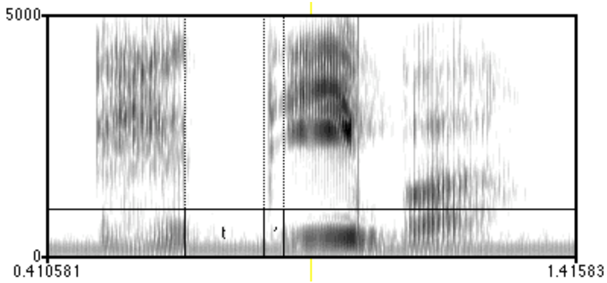

Figure 2. The coronal ejective in /t'ibu/ which does not have the expected silence after the release of the oral burst because glottal closure is released immediately after.

The relative timing of the oral and glottal release gestures in Figure 2 corresponds to a weak ejective, following [9]. However other cases (c.f. Figure 1), where there was a delay between the release of the glottal closure and the onset of voicing associated with the vowel, would correspond to descriptions of strong ejectives [9]. We discuss this point further in §5.

Returning to our visual inspection of ejectives, in some cases the first few periods of the following vowel were characterized by aperiodicity, which occurred as the glottis returned to the normal position for modal phonation following complete adduction:

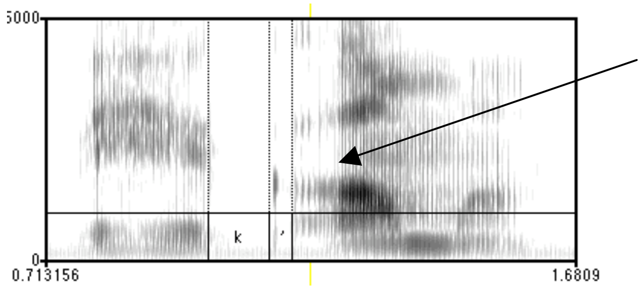

Figure 3. The velar ejective stop in /k'ama/ showing creak in the onset of the following vowel. The arrow indicates the onset of modal voicing.

In Waima'a, extensive creak was seen in the vowel following only two of the velar /k'/ tokens, none of the /t'/ tokens nor any of the /p'/ tokens. Post-release creak is therefore not frequent, and in this respect ejectives in Waima'a are similar to reported descriptions of ejectives in Western Apache [2] and Chipewyan [10] for which some contextual creak is reported to occur occasionally, though not consistently.

Regarding the amplitude of the following vowel, inspection of the waveform showed that it was consistently slow to rise for ejective tokens.

4.2. VOT duration

According to our measurements, the duration of the VOT for ejectives in Waima'a was intermediate between that recorded for aspirated and unaspirated stops across all places of articulation:

Table 3. Average VOT values across stop places of articulation and type (standard deviations in parentheses).

	P	t	k
Aspirated	60 (6)	96 (15)	103 (13)
Ejective	33 (6)	30 (6)	66 (19)
Unaspirated	-	22 (4)	22 (3)

The difference in VOT between ejective stops and all other stops was found to be statistically significant (at least $p < 0.05$) for each comparison across stop type, and within all three places of articulation. Amongst the ejective stops themselves, VOT was significantly longer in velar (66ms.) than in bilabial or coronal stops, which show similarly shorter durations ($p < 0.001$).

4.3. Closure and overall stop duration

We first compared the closure durations for ejectives with those of other stop types. ANOVAs across stop types did not distinguish between the closure durations of aspirated and ejective stops ($p = 0.767$), unaspirated and ejective stops ($p = 0.820$) or aspirated and unaspirated stops ($p = 0.691$).

VOT and closure duration measurements were then added, to calculate the overall duration of the stop at each place of articulation:

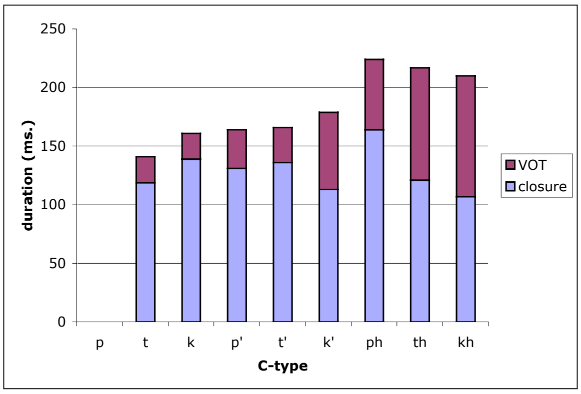

Figure 4. Overall stop durations (VOT & closure) according to type (voiceless unaspirated, ejective, and aspirated) and place of articulation.

From Figure 4 we see that aspirated stops had the longest overall durations, ejectives had intermediate overall durations, and plain unaspirated stops were the shortest. ANOVAs conducted on overall durations (closure + VOT) across stop series (aspirated v. ejective v. unaspirated) showed the differences in stop type to be statistically significant (at least $p < 0.05$) for all comparisons.

4.4. F0 in the following vowel

For each stop token F0 values were measured in the following vowel, and are listed in Table 4. They showed very different patterns depending upon the preceding stop type. In the case of the non-ejective stops, F0 showed a decline from vowel onset to mid-point, and was much higher at the onset of aspirated stops than for their plain unaspirated counterparts. F0 remained higher throughout the vowel following aspirated stops, although the fall in F0 was greater (12 Hz).

Turning to the ejective stops, F0 was relatively high at onset, albeit just below the average value for aspirated stops. However, in contrast to the other stop types, F0 continued to rise to the mid-point (average of 10 Hz).

Table 4: F0 measurements at onset and midpoint of the following vowel (std deviations in brackets).

	V onset	No.	V midpoint	No.
/t k/	133 (0.2)	21	128 (1)	21
/ph th kh/	153 (14)	25	141 (14)	21
/p’ t’ k’/	148 (5)	22	158 (12)	22

After the vowel onset, the F0 contour for ejectives typically rose immediately to the level of the mid-point, whereas pitch movements in the vowel following other stop types were more gradual. We suggest that the slightly lowered F0 at onset and sudden rise to peak reflects the adjustment from irregular fold vibration (which, as we have observed, may continue well into the vowel as extensive creak) to normal, modal voice.

5. Discussion

Based on our results, a number of general observations can be made about the acoustic characteristics of ejective stops vis-à-vis other voiceless stops in Waima’a. Along a VOT continuum, ejectives are located midway between plain unaspirated and aspirated stops, as has been reported for many other languages, e.g. Western Apache, Navajo and Tlingit [2]. Within the ejective series itself, VOT is significantly longer at velar place in Waima’a, as in other languages e.g. Western Apache [2], Kiowa [3], Dakelh, [8]. Although closure duration on its own was not found to be a reliable distinguishing criterion, the same cannot be said for overall duration: once again ejectives find themselves between unaspirated and aspirated stops. We are led to suggest that with respect to both VOT and overall duration, either factor could serve as a useful perceptual cue in the identification of ejective stops.

With respect to a closer comparison between ejective stops in Waima’a and other languages, we return to the issue of whether ejectives can be classified as either strong or weak, according to specific acoustic criteria. In Table 5 we summarize results based on some of these criteria for four languages (including Waima’a).

Table 5: A comparison of some acoustic features of ejective stops in four languages. Cells were left blank where information was not available Sources: [7], [9].

	Tigrinya	Quiché	Ingush	Waima’a
VOT /k’/	~80ms	50ms	50ms	66ms
F0 in V	high	low	high	high
V amp rise	fast	slow	slow	slow
V voice quality	modal	creaky	aperiodic	aperiodic/ modal

Ejective stops are described as strong in Tigrinya, and weak in Quiché (see [9]). With respect to Ingush, Warner [7] is more circumspect: she notes that Ingush ejectives are more similar to those in Quiché than Tigrinya (and by implication weak), but reports several differences, e.g. the high pitch of the following vowel.

With respect to specific criteria, VOT duration is considered to be one of the most critical distinguishing factors between strong and weak ejectives (e.g. [8]). Increased VOT is always associated with strong ejectives. For Waima'a, a relatively high VOT value for velar /k'/ was found, however VOT was much lower (~30ms) in non-velar /p' t'/. The same pattern is reported for ejectives in Dakelh, which prompted Bird [8] to suggest that the latter are weak, while /k'/ is strong in that language. A similar place-based strength distinction could be applied to ejectives in Waima'a. However, an alternative interpretation would be that VOT for ejectives is subject to the same more general place-governed effects known to affect other stop types - whereby velars have inherently longer VOT durations (see [6]). On this basis, one could argue that Waima'a ejectives are all weak, rather than strong or weak depending upon place. More investigation is needed on this point,

Turning to the other criteria, the F0 of the following vowel is reported to be higher in strong ejectives across languages. On this criterion, ejectives are strong in Waima'a, Ingush and Tigrinya, and weak in Quiché.

With respect to peak amplitude in the post-ejective vowel, a slow rise into the vowel is generally thought to be characteristic of weak ejectives. In Waima'a, slow rise to peak amplitude was evident after all places of articulation. Therefore on this criterion, Waima'a ejectives are weak, as in Quiché and Ingush.

Cross-linguistic comparison suggests contextual creak is associated with ejectives in languages reported to have weak ejectives, whereas modal voicing in the following vowel is associated with strong ejectives of Tigrinya and Navajo (see [7]). In Waima'a extensive creak was found in 2 velar tokens, but not at all after /p' t'/. Otherwise voice quality at vowel onset was often briefly aperiodic but quickly adjusted to modal voice.

The timing of the glottal release relative to the onset of voicing in the vowel is also considered to be useful in distinguishing strong from weak ejective stops: it is typically coincident with the onset of voicing for weak ejectives, whereas a delay between the two is associated with strong ejectives [9]. Results for Waima'a are somewhat mixed, where both patterns were found to occur (cf. Figures 1 and 2).

In summary, on the basis of VOT, /k'/ is arguably strong but /p' t'/ are clearly weak. Based on the F0 values, which were consistently high, Waima'a ejectives are strong, yet the consistent slow rise to peak amplitude across tokens suggests Waima'a ejectives should be considered weak.

These conflicting results are problematic for a simple view of ejectives as either strong or weak in a specific language. As Warner [7] reports for Ingush and other languages, the distinction is not clear-cut, and there is evidence of mixed behaviour. It might be more feasible, as Bird [8] argues for Dakelh, that a language may have both in its system. Alternatively, we suggest that the distinction between strong and weak ejectives would be better treated as a continuum, involving a number of different parameters, rather than a binary distinction.

Also problematic to any simple classification of ejectives within the same language is the problem of possible interspeaker variation, as described in detail for Witsuwit'en [4]. The potential impact of this factor on the characterization of ejectives in Waima'a requires further investigation.

6. Conclusions

Ejectives were found to be distinguishable from other voiceless stop types in Waima'a in terms of a number of acoustic properties analyzed (VOT, overall duration and F0 effects). Cross-linguistic comparison of ejectives alone showed mixed results for Waima'a: ejectives patterned with strong ejectives in terms of some phonetic parameters (F0), weak ejectives in terms of others (amplitude rise), and also showed behavior depending upon consonant place (VOT). In view of these results we suggest that it would be more useful to treat the distinction as lying along a continuum rather than as a simple strong-weak opposition.

7. Acknowledgements

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8. References

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