PHONETIC AND PHONOLOGICAL PROPERTIES OF CREAKY VOICE IN MUNDURUKÚ (TUPI)

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RESUMO: Neste trabalho, aspectos fonéticos e fonológicos da laringalização (creaky voice) são examinados em Mundurukú. A investigação fonética tem como foco as várias propriedades acústicas que sinalizam o traço [constrição glotal] enquanto uma propriedade que diferencia vogais na língua. Busca-se, com isso, determinar que pistas acústicas estão disponíveis aos falantes de Mundurukú para diferenciar os dois tipos de fonação – modal e laringalizado. No lado fonológico há também a interação com o sistema tonal da língua que restringe a ocorrência de vogais laringalizadas a um tom Baixo. Análises de frequência fundamental demonstram que há uma tendência ao abaixamento na frequência fundamental de vogais laringalizadas, em comparação àquela de vogais modais. Isso se deve, principalmente, à produção dos diferentes tipos de fonação que, durante a laringalização, exige uma configuração incompatível com uma frequência mais elevada. Essa restrição fonética é refletida na fonologia como uma restrição na realização tonal de uma vogal laringalizada: o tom Baixo.

PALAVRAS-CHAVE: Laringalização; Tom; Propriedades acústicas; Fonologia; Mundurukú (Tupi).

ABSTRACT: This study examines phonetic and phonological aspects of creaky voice in Mundurukú. The phonetic investigation focuses on several acoustic properties that signal the feature [constricted glottis] as a contrastive property of vowels in the language. This is done with a view to determining what acoustic cues are available to Mundurukú speakers, and which can be used for differentiating both types of phonation—modal and creaky. Phonologically, creaky voice also interacts with the tone system by occurring only with L tones. An examination of the fundamental frequency of creaky

vowels shows that creakiness has a lowering effect on pitch, compared to that of modal vowels. This occurs mainly because of the differences in glottal configurations during the production of phonation types; in the case of creaky voice, this configuration is incompatible with high pitch. This phonetic restriction is manifested phonologically as a restriction on the tone that a creaky vowel can bear: Low tone.

KEYWORDS: Creaky voice; Tone; Phonetics and Phonology; Mundurukú (Tupi).

1 BACKGROUND

This paper deals with different patterns generated by the feature [constricted glottis] in Mundurukú. This feature is associated with vowels in the form of nonmodal (creaky) phonation. This is one of the various glottal states in the continuum of phonation types as proposed by Gordon and Ladefoged (2001; see also CATFORD, 1977; LADEFOGED, 1971).

Continuum of phonation types (GORDON; LADEFOGED, 2001, p. 384)

Most open	⟷	Most closed
Phonation type Voiceless	Breathy Modal Creaky	Glottal Closure

Mundurukú contrasts two modes of vocal fold vibration on vowels: modal (the normal way) and creaky, which is produced by pressing the arytenoids cartilages tightly together as to allow only the front portion of the vocal cords to vibrate (LADEFOGED, 1971); the result is a sound produced as 'a rapid series of taps' (CATFORD, 1964, p. 32), and at a low frequency (LADEFOGED, 1971; LAVER, 1980).

The language distinguishes five vowel qualities, /i, e, ɤ, a, o/ but the system is expanded by contrasts of nasality and creaky voice (PICANÇO, 2002, 2005; BRAUN; CROFTS, 1965; CROFTS, 1973,

1985), resulting in an inventory with four series of vowels: oral and nasal modal vowels, and oral and nasal creaky vowels.

(1) Mundurukú vowels

Modal			Creaky		
i ĩ	ə ə̃	o õ	ḭ ḭ̃	ɤ̰ ə̰̃	ɤ̰ õ̰
e ẽ	a ã		ḛ ḛ̃	a̰ ã̰	

(2) Modal-creaky contrast in oral vowels

a.	/i/:/ḭ/	dʒeʃiʃim 'spit'	dʒeʃḭʃḭʃḭm 'tremble/shiver'
b.	/e/:/ḛ/	dʒededem 'play (instrument)'	idḛdḛm 'to grate'
c.	/ə/:/ɤ̰/	oítʃək 'It broke.'	kadʒɤ̰k 'cold'
d.	/a/:/a̰/	wida 'clay'	wḭda̰ 'jaguar'
e.	/o/:/o̰/	irore 'It's loose.'	ḭro̰rḛ 'It's ripe.'

The two modes of phonation correspond phonologically to the distinctions in (4). Creaky vowels differ from modal vowels by having a specification for [constricted glottis], represented by [c.g.].

(3) a. Modal vowels

Root Node
|
Laryngeal

b. Creaky vowels

Root Node
|
Laryngeal
|
[c. g.]

Creaky voice has been previously analyzed as a tonal feature (BRAUN; CROFTS, 1965) because it is usually accompanied by a pitch lower than that of modal vowels. However, Picanço (2002, 2005) shows that the phonological behavior of creaky vowels paralles that of modal vowels. Thus, I differ from Braun and Crofts's proposal in treating creaky voice as a feature of vowels, and not as a tone feature. §2 examines the phonetic aspects of creaky voice to determine the acoustic cues that better signal the creaky-modal contrast in the language. Then I proceed to investigating the phonology of creaky voice and its interaction with tones (§3).

2 ACOUSTIC PROPERTIES OF THE MODAL-CREAKY CONTRAST

The various laryngeal configurations produce certain acoustic outcomes that can be used to quantify the nonmodal-modal opposition in a given language (LADEFOGED, 1988; KIRK, 1993; GORDON; LADEFOGED, 2001). Gordon and Ladefoged, in particular, list a number of acoustic properties that are typically associated with phonation types, five of which can be applied to the creaky-modal pairs of vowels in Munduruku: (i) formant frequencies, (ii) overall duration, (iii) fundamental frequency, (iv) periodicity, and (v) spectral tilt.

2.1. PROCEDURES AND RESULTS

The five modal-creaky vowel pairs, [i-i¼], [e-e], [«-«¼], [a-a¼] and [o-o¼], were recorded by a male speaker, AK, and measured for the five properties. The words used for the creaky-modal contrast are those in (3) above, all of which were recorded in the Munduruku carrier sentence "*ijop* _ *Nas«*)" 'This is _ now'.

Each vowel token was divided into two halves and the measurements were obtained from the second half. The reason for

this is that creakiness is more salient towards the end of the vowel. The formants were measured as close as possible to the middle of the vowel (between 50 and 75%) in order to avoid consonant transition effects on both ends, but still at a point where creakiness was relatively salient. Duration was measured from the first complete or near complete pulse until the last complete or near complete one. Fundamental frequency (F0) was measured at five points of the vowel, and each point was 1/6 apart from the other. Measurements at different points are necessary in order to obtain a representative picture of the changes in F0 over time. For example, if the duration of a vowel was 150 ms, these were divided by 6 (150/6=25), so F0 was measured every 25 ms of the vowel: 25, 50, 75, 100, and 125 ms. For periodicity, the last 6-10 successive pulses were measured, depending on the length of the vowel. Spectral tilt was also measured at the same point the formant values were obtained.

2.1.1. Formant frequencies

Creaky phonation has little effect on vowel height in Munduruku (see also PICANÇO, 2005). As shown in Table 1, mean values for the frequency of the first formant (F1), which is an indication of vowel height, are higher for the creaky vowels [e¼] and [o¼] than for their respective modal counterparts, but are about the same for the pairs [«-«0], [a-a¼], and [i-i¼].

Quadro 1 - Mean values (in Hertz) and standard deviations of formant frequencies for modal and creaky vowels.

	I	ḭ	e	ḛ	ə	ə̰	a	a̰	o	o̰
F1	351	353	535	580	503	449	872	860	402	442
s.d.	18	15	19	37	30	29	34	39	14	16
F2	2445	2545	2311	2287	2052	2040	1745	1849	998	1004
s.d.	116	162	86	145	95	86	70	26	57	62
F3	3461	3357	2985	3086	2644	2719	2696	2933	2441	2459
s.d.	197	214	138	152	207	185	122	161	83	72

2.1.2. Duration

Overall duration does not seem to play an important role in differentiating modal and creaky vowels either, except for the pair [o-o0] in which modal [o] is considerably longer than its creaky counterpart. This is shown in Table 2.

Quadro 2 - Means (in ms) and standard deviations for duration of modal-creaky vowels.

	I	ḭ	e	ḛ	ə	ə̰	a	a̰	o	o̰
Mean	67	75	91	91	63	79	175	163	239	217
s.d.	9	6	10	2	9	12	26	29	15	18

2.1.3. Fundamental frequency

The primary manifestation of creaky phonation in Mundurukú is perhaps lowering of fundamental frequency (F0). For all vowels, creaky voicing is associated with a pitch lower than the pitch of modal voicing, but for some vowels there is overlap between creaky and L-tone vowels (PICANÇO, 2005); H-tone vowels, on the other hand, are clearly distinct.[1]

Specifically with respect to the realization of pitch across vowels, the results indicate a correlation between F0 and vowel quality. Many studies have examined intrinsic F0 (IF0) in tone languages and found correlations between IF0 and vowel height (WHALEN and LEVITT, 1995, provide an excellent overview; Connel, 2002, is another good example). The assumption is that high vowels have

[1] Mundurukú contrasts two tones, High (H) and Low (L) (Picanço 1997, 2002). The following words with High-tone vowels were used for the comparison with corresponding Low-tone and creaky vowels: [í]: ipo**ʃ́im** 'It'll be heavy'; [é]: dá**psém** 'deer'; [ə́]: o**kə́k** 'Take care of me.'; [á]: wi**tá** 'grater'; [ó]: a**ró** 'parrot'.

higher F0 values than low vowels. Whalen and Levitt observed that tone languages are also subject to IF0, but that the differences in F0 are only attested for H-tone vowels and neutralized for L-tone vowels. The differences observed in Mundurukú vowels with H-tone, more or less conform to the observations made for other languages. There is still not sufficient data for this correlation, but some observations are worth being addressed here.

As shown in Table 3, the high front vowel has higher F0 than any other vowel, a difference that is carried over to L-tones and nonmodal phonation. The low vowel has F0 slightly higher than that of the mid vowel [o] when H-toned, but has the lowest values in both L-tone and creaky voice. If IF0 is a function of vowel height, the overlap in F0 between Low toned [i] and creaky [i¼] discussed earlier is expected. Because creaky phonation is produced with lowered F0, there would be a conflict between the lowered F0 characteristic of creakiness and higher F0 characteristic of high vowels, forcing creaky [i¼] to be realized with higher pitch relative to other vowels. One implication is that IF0 is a property that is carried over to, not only tones, but also nonmodal phonation.

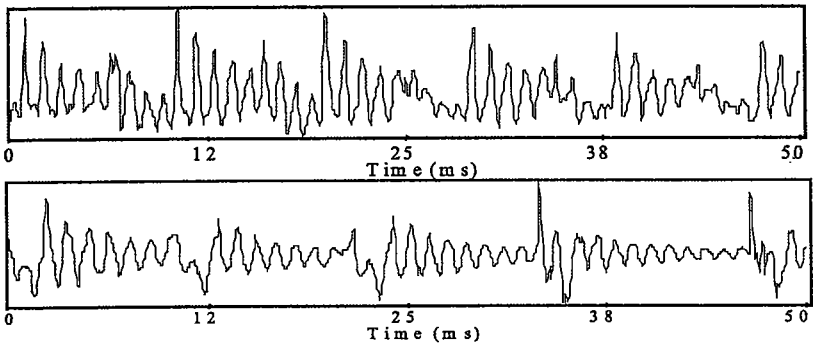
Quadro 3 - Means (in Hz) and standard deviations of fundamental frequency for all vowels.

	i	e	ə	a	o
H-tone	139	133	132	129	127
s.d.	1.9	2.6	5.4	4.8	3.3
L-tone	122	117	118	109	115
s.d.	2.7	5.1	4.2	4.3	1.6
Creaky voice	118	109	107	68	101
s.d.	4.6	2.6	9	6.7	3.7

2.1.4 Periodicity

Jitter, the variation in the duration of adjacent glottal pulses, is another property examined in modal-creaky pairs of vowels in Munduɾukú. The results indicate that the degree of variation in creaky phonation is not much higher than the variation observed in modal voice. Creaky vowels have relatively regular glottal pulses, but they are longer. This is illustrated in Figure 3, which shows 50 ms displays of waveforms for modal [a], at the top, and creaky [a¼], at the bottom, in the words *wida* 'clay' and *wi¼da¼* 'jaguar'.

Gráfico 1 - Waveforms (50 ms) illustrating duration of adjacent glottal pulses of modal [a] and creaky [a̰], respectively.



The results are given in Table 4. Creaky vowels tend to have more aperiodic glottal pulses, as can be inferred from the respective standard deviations. These values are higher than standard deviations for modal vowels, but for most vowels the difference is not significantly higher. The difference becomes evident when we compare the reference values for the duration of individual pulses. Overall, mean values for creaky vowels are higher, indicating that they are longer in duration.

Quadro 4 - Means (in ms) and standard deviations for jitter.

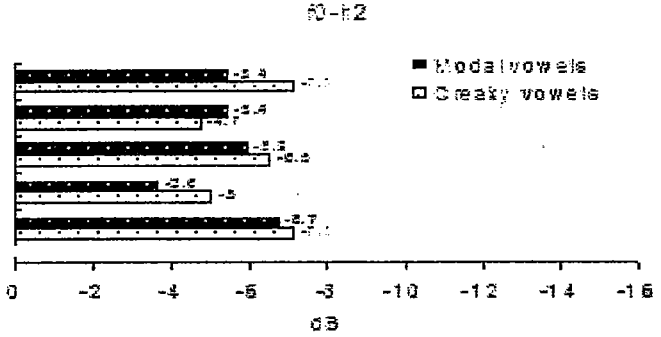
	i	e	ə	a	o
Modal voice	8.2	8.6	8.7	9.3	8.7
s.d.	0.25	0.32	0.45	0.44	0.15
Creaky voice	8.6	9.4	9.7	13.8	10
s.d.	0.37	0.39	0.84	0.9	0.23

2.1.5. Spectral tilt

Gordon and Ladefoged also suggest that spectral tilt provides "one of the major parameters that reliably differentiates phonation types in many languages" (2001: 397). Spectral tilt compares the difference between the amplitude of the fundamental and the amplitude of the higher harmonics. Here I compare the amplitude of the fundamental (F0) to that of the second harmonic (h2) and the greatest harmonic in F1. In both modal and creaky phonation, the fundamental tend to have less energy than h2 and F1, but the differences F0-h2 and F0-F1 are usually higher for vowels with creaky phonation.

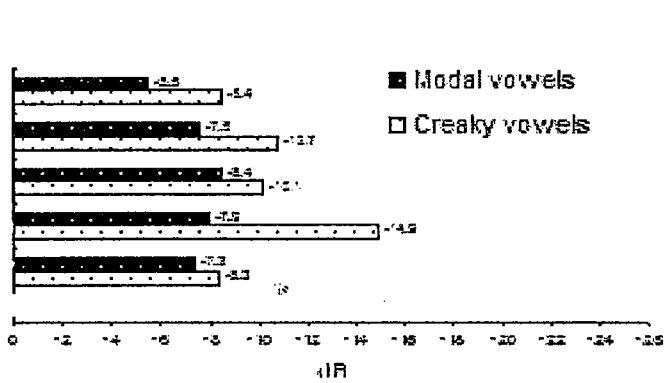
The differences between the amplitudes of F0 and h2 (F0-h2) for all vowels are given in Figure 3. The amplitude values for creaky vowels are higher than the values obtained for modal vowels, with the exception of the modal vowel [e] whose value is higher (-5.4 dB) than the value of the corresponding creaky vowel (-4.7 dB), but overall the amplitude difference F0-h2 is an important indicator of phonation types in the language.

Gráfico 2 - Amplitude differences between the fundamental (F0) and the second harmonic (h2) for all vowels. The vowels appear in the following order: [i-e-ə-a-o].



Modal and creaky phonation can also be quantified by comparing the amplitude difference between the fundamental and the harmonic closest to F1 (F0-F1). The results are given in Figure 5, which shows that creaky vowels have much greater energy in the region of F1 than modal vowels.

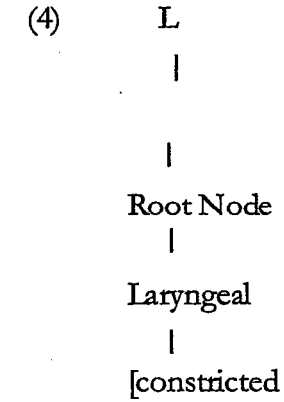
Gráfico 3 - Means for amplitude differences between the fundamental (F0) and harmonic closest to F1 for all vowels. The vowels appear in the following order: [i-e-ə-a-o].



In summary, the three acoustic properties that better signal the creaky-modal distinction on Mundurukú vowels are thus (i) periodicity, (ii) fundamental frequency, and (iii) spectral tilt. Here I will focus on the importance of fundamental frequency for the phonology, in particular for the tone-creaky voice interaction.

3 THE TONE-CREAKY VOICE INTERACTION

Unlike modal vowels, creaky vowels do not contrast for tone in Mundurukú: if a vowel is [c.g.], then it is also Low toned.

(4)


This requirement is formulated in the form of a grounded constraint (ARCHANGELI; PULLEYBLANK, 1994).

(5) [c.g.]/L – If [c.g.] then L-tone.

The language has a process of tone dissimilation by means of which an underlying L tone triggers dissimilation of the following L, changing it to H (PICANÇO 2002, 2005). This is illustrated in (7). Toneless vowels surface on a L tone but this tone is inert in the sense that it does not trigger tone dissimilation, as shown in (8).

(6) L-tone dissimilation

	UR	SR	
a.	e-diŋ	ediŋ	'tobacco smoke'
	| |	| |	
	L L	L H	
b.	o-ba-boŋ	obaboŋ	'My arm is big.'
	| | | | |		
	L L L L H		

(7) Default L-tones

	UR	SR	
a.	ka-diŋ	kadiŋ	'dust'
	|	| |	
	L	L L	
b.	o-bə-boŋ	obəboŋ	'My finger is big.'
	| | | |		
	L L L L		

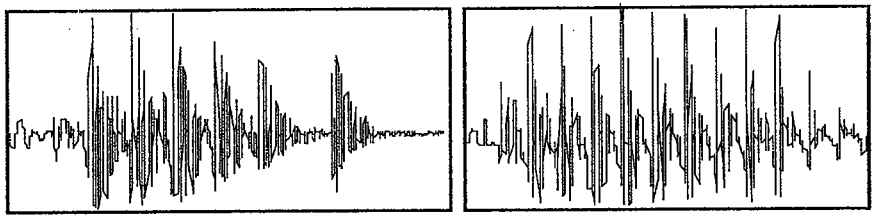
Like modal vowels, creaky vowels not only trigger dissimilation, as seen above, but also undergo it, as in (9)a, which shows that if the L-tone associated with the creaky vowel changes to H, creakiness disappears with it. This is because of the requirement that if a vowel is [constricted glottis] then it must be L tone. (9)b shows a case of a creaky vowel preceded by a default L.

(8) L-tone dissimilation with creaky vowels

	UR	SR	
a.	waje - ba	wajeba	'cocoa fruit'
	↘ |	↘ |	
	L L	L H	
b.	ako - ba	akoba	'banana'
	| |	| | |	
	H L	H L L	

The waveforms below illustrate the realization of the classifier *-ba0* in the words *a • koba0* 'banana' (on the left), and *wajeb a* • 'cocoa fruit' (on the right). They show that creaky voice is only realized in the former because the tone is L.

Gráfico 4 - Waveforms of [ba̰] in áko-ba̰ (left) and [bá] in waje-bá (right). Speaker JT.



Dissimilation of L tone associated with a creaky vowel can be accounted for in Optimality Theory (McCARTHY; PRINCE, 1993; PRINCE; SMOLENSKY, 1993), by assuming the grounded constraint in (6) above, and the OCP constraint *LL, which prohibits L-tones in sequence. Both of these must be ranked higher than faithfulness constraints preserving both a L-tone and a feature [c.g.], as in (10).

(9) Constraints
- a. *LL – A sequence of L-tones is prohibited.
- b. Max[c.g.] – A feature [c.g.] in the input must have a correspondent in the output.
- c. MaxL – A L tone in the input must have a correspondent in the output.
- d. DepH – A H tone in the output must have a correspondent in the input.
- e. Ranking: *LL >> [c.g.]/L >> MaxL >> Max[c.g.] >> DepH

The following tableau shows the conflict between creaky voice and H tone. The preceding L of *waje* triggers dissimilation of the L tone of the classifier *-ba0*. Because *LL is ranked above Max[c.g.], the creaky vowel is forced to surface on a H tone; and

because of the restriction that associates [c.g.] with L, the feature disappears from the vowel along with tone

Quadro 5 - Creaky voice in L-tone dissimilation.

wadʒe - ba L L	*LL	[c.g.]/L	MaxL	Max[c.g.]	DepH
a. wadʒe-ba L L	*!				
b. wadʒe-ba L H		*!	*		*
c. ☞ wadʒe-ba L H			*	*	*

4 CONCLUSION

I examined some phonetic and phonological aspects of the feature [c.g.] which is associated with vowels in Mundurukú. Among the five acoustic properties that have proven to reliably distinguish phonation types, three –periodicity, fundamental frequency and spectral tilt – turned out to be good indicators of the modal-creaky contrast in the language. Fundamental frequency in particular is crucial for the phonology. Creaky vowels not only have lower pitch relative to modal vowels, but are also restricted to L tone phonologically. I showed that such a requirement is strongly adhered to in the phonology, so that if the L tone of a creaky vowel changes to H, the feature [c.g.] disappears from the vowel. Other aspects of the tone-creaky voice interaction could not be examined here for lack of space, but see Picanço (2005) for a complete analysis of the the interaction.

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