Temporal coordination of glottalic gestures in Karitiana

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1 Introduction

Karitiana, an endangered language from the Arikém branch, Tupi family, spoken in the state of Rondonia in Brazil, shows interesting phenomena concerning glottalic consonants. Indeed, as several other languages of this linguistic family, Karitiana has no clear glottal stop in its phonological inventory, even though glottal stops do exist phonetically. Glottal stops in Karitiana are predictable in the onset of stressed syllables (Storto 1999). In addition, the language presents a number of interesting phenomena related to the phonetic realization of glottal stops and to the temporal realization of glottalic gestures, as do other Tupi languages. A frequent, but not systematic, phenomenon is the occurrence of vowels with a final burst in CVC words ending with a final unreleased voiceless stop (Figure 1). The phenomenon also appears word internally (Figure 4). In such instances, it is often the case that vowels which are ending with bursts precede most of the allophones of the Karitiana nasals, all of which are voiced. In order to understand the phenomenon, there are three main questions to be addressed: (1) why is there a burst at the end of vowels before stops and nasals? (2) How can we describe this phenomenon precisely? (3) Does it reflect anything particular about the phonological system of the language? To help answer these questions, an experiment was carried out with three speakers in which acoustic and electroglottographic data were recorded simultaneously. The answer seems to be that stops and nasals themselves involve a closure or adduction of the vocal folds in those examples. In these cases, the oral closure of a stop is superimposed – partially or completely - with a glottal closure, what is described in detail in the following sections. The findings have helped us explain some phonological phenomena in the language, such as the unreleased character of stops and nasals word-finally (Storto & Demolin 2002) and the lenition of morpheme final stops and nasals taking place before vowel-initial morphemes. We hope it will help us explain, in the future, prosodic functions of the glottalic gesture as well, since stress and glottal closure in the language are often superimposed in syllable-final positions.

2 Material and method

2.1 Method

Data were obtained in several recording sessions. First, data were collected with three male speakers who were recorded with acoustic and electroglottographic (henceforth EGG) signals
simultaneously. The second session involved four speakers recorded with acoustic signal, oral airflow (Oaf) and intraoral pressure (Ps) for bilabial consonants. Finally, data were obtained with six speakers with the acoustic signal during a session which was designed to obtain recordings from vowels in different contexts.

The EGG system was a Fourcin Laryngograph. Acoustic data were obtained with a Shure head microphone. This allows recording the sound signal with a constant distance from the lips of the speakers. The aerodynamic data were obtained with the MacQuirer system designed by Scicon.

Figure 2.1 about here (laryngograph photo)

2.2 Material

The relevant words were recorded in isolation and in short carrier sentences. Each word or sentence was repeated three times. Table 1 gives a sample of the words containing post-vocalic bursts which have been observed in the recordings.

Table 1 about here

2.3 Electroglottography

In order to clarify the interpretation of the data, a short word about electroglottography seems necessary. Most data analyzed for the paper, that is, those data elicited with three speakers, as mentioned above, show synchronized recordings of the audio waveform and of the EGG signal. The essential difference between both is that the EGG signal measures the impedance at the glottis, i.e. the contact between the vocal folds, while the acoustic recording (audio waveform) shows short time pressure variations produced by the opening and closure of the glottis (Figure 2.2).

The important thing to bear in mind is that the EGG technique essentially transduces the vocal fold contact area. Accordingly, we will not refer to ‘closing’ or ‘opening’ but to ‘contacting’ and ‘decontacting’ phases of the vibratory cycle. Therefore the electroglottogram is sensitive to the covert changes of the contact area during glottal closure, and it also reflects the growth and loss of contact area along the length of the vocal folds as glottal closure and opening succeed each other (Baken & Orlikoff 2000). During the closed phase of the vocal fold oscillation the electrical pathway is optimized by the contact of the vocal folds. There are, however, degrees of contact. Over the course of the ‘closed’ phase of each glottal cycle, the contact of the vocal folds varies from minimal (valley represented in the signal) to maximal (represented by a peak in the signal) as contact involves more of the vertical dimension of the vocal folds.
2.4 EGG and glottal stops in Karitiana

Figure 2.3 shows the spectrogram and audio waveform of the words [ʔōʔīsokōʔĩ] ‘not to tie up’. Figure 2.4 displays the EGG signal and the audio waveform of the same words. In order to make the discussion about the interpretation of the EGG recordings clear it is worth examining these data in detail.

Glottal stops are realized as a sharp beginning on the first vibratory cycle of the following vowel. This can be seen on the spectrogram and audio waveform of Figure 2.3 for each vowel coming after a glottal stop. The EGG and audio waveform of the same vowels, presented in Figure 2.4, show that glottal stops start by a sharp increase in the signal. This is due to the closed glottis giving little resistance to the electric flow. Then there is a gradual decrease of the signal because there is little change in the resistance during the glottal closure. The second and third [ʔ] show a couple of sharp opening and closure after the preceding vowel.

The other important thing to note on the EGG signal is the transition between a glottal stop and the following vowel. Since there is a sharp opening of the vocal folds, there is an abrupt drop in the signal at this moment. This is different from the transition between the voiceless consonants [s] and [k] where it can be seen that there is an increase in the EGG signal. This is due to the adduction of the vocal folds for the following vowel. When the glottis opens after a vowel before a voiceless consonant there is a gradual decrease in the signal.

3 Vowels with a closing burst

The phenomenon has been observed in two different contexts: before voiceless stops and before nasal consonants. The two contexts are presented separately in the following sections.
3.1 A glottal burst at the end of a vowel before a voiceless stop

Two examples of vowels ending with a burst are given in Figures 1 (representing the single vowel of the word *gep*) and 4 (the first vowel of the word *apimbik*). Both show that the last vowel’s cycle is realized by a sharp burst on the audio waveform. Figure 1 shows the waveform and spectrogram of a word ending with an unreleased voiceless bilabial stop while Figures 4a and 4b give the spectrogram, the audio waveform and the EGG of an intervocalic voiceless bilabial stop. The first question we must tackle is why would a vowel display glottal closure before a stop?

The EGG signal shows that the vowel with a burst and the following voiceless stop are produced with an adduced glottis. The initial glottal stop, observed phonetically in this instance of the word [ʔapimbik] ‘to push’ shows a sharp increase on the EGG followed by a gradual decrease of the signal. This is due to fact that there is a resistance at the glottis, as the vocal folds are in contact. The gradual decrease in the signal is the consequence of a change in the vocal fold contact area, as there is less contact in the lower part of the vocal folds. The final part of the glottal stop displays a sharp fall in the EGG due to the opening of the glottis. The vowel [a], shows a burst at the end in the waveform. The EGG signal shows an increase towards the end of the vowel, followed by a sharp reduction of the signal’s amplitude and leveling of the signal. This suggests that the intervocalic [p] is realized with a closed or adduced glottis. The EGG signal during the intervocalic stops stays almost flat confirming that there is little change in the impedance at the glottis. The final consonant, the unreleased final voiceless velar stop [k] shows a small opening at the beginning of the consonant, when the EGG signal goes down. This is immediately followed by an increase and a flattening of the EGG signal. This suggests that there is a glottal opening accompanying the beginning of the velar closure of the final consonant followed by a closure of the glottis.

Figures 3.1 and 3.2 about here (word apimbik)

3.2 A glottal burst at the end of a vowel before a voiced nasal consonant

A number of vowels ending with closing bursts have been observed before the allophones of voiced nasal consonants that are described by Storto (1999) as pre-oralized [bm, dn, g], and for this reason we choose to illustrate one of these cases. In these data, again, the final cycle of the vowel is realized with a burst on the audio waveform as can be observed with the word [kabm] presented in Figure 5. There is an increase in the amplitude of the EGG signal at the end of the vowel suggesting a greater contact of the vocal folds. This is followed by a ‘fall and rise’ movement of the EGG signal during the voiced segment.

Figure 3.3 about here (word kabm)

3.3 Sequences of oral and glottal gestures
Let us have a look at one example in which we find sequences of oral and glottal gestures in consonants. In Figure 6, an alveolar stop is followed by a glottal stop in the word [ʔət ʔət ˈspɪsɪs əv ˈɛgrɛt]. The interpretation of the EGG signal for the initial glottal stop is similar to what has been discussed for Figure 4b. The consonant cluster [t ʔ] constitutes a sequence of glottalic gestures. Indeed, there is a sharp increase in the EGG signal showing the glottal closure at the end of the voiceless alveolar stop, which is produced with an open glottis. The acoustics signal does not display this event. The observation of the final consonant shows that the unreleased voiceless alveolar stop is produced with a superimposition of the oral and glottal closures. The audio waveform does not show a release burst. The EGG shows that there is glottal closure accompanying the oral closure as the signal gradually goes down and is maintained steady for a while. This example is particularly important to understand the difference between what happens in a sequence of open and close glottis versus the superimposition of oral and glottal gestures in word-final position when a stop is unreleased.

4 Why is there a burst at the end of some vowels?

The explanation that we are proposing is that the burst at the end of the vowels (whether they precede voiceless stops or voiced segments) is the consequence of a greater or stiffer constriction of the glottis at the end of these vowels. This is happening in the environment of a following stop or nasal. What these two types of consonants have in common is an oral closure, and the data show a glottal closure or adduction associated with that oral closure. Before voiceless stops, the oral closure gestures for the stop and a glottal closure or adduction of vocal folds are partially or completely superimposed. This is contrary to the expected open glottis gesture of a voiceless stop. Before voiced segments, such as pre-oralized stops, there is a sharp increase of the glottis closure towards the end of the preceding vowel, suggesting a greater glottal resistance.

Therefore, the main factor involved in these vowels showing a final burst is a sharp final closure at the end the vowel’s cycles triggering a final pulse of the vibratory cycle having greater intensity.

5 Phonological consequences

The glottal closure or adduction observed above explains why the final voiceless stops in the language are not exploded (Storto & Demolin 2002), as there is no pressure (Ps) build up in the oral cavity. That is, with none or little air coming from the lungs into the oral cavity the
latter does not suffer a significant increase in pressure. In the case of the nasals, there is no Ps because of the lowered velum, that lets the air escape through the nasal cavity. The unreleased stops found in Karitiana are not an isolated case in Tupi languages. It would be interesting to check whether other Tupi languages also display an adduced or closed glottis simultaneous with the unreleased stop.

In Karitiana there is a phonological process of lenition, where a morpheme final voiceless consonant becomes a voiced approximant when a suffix starting with a vowel is added to the word. The same phenomenon occurs with nasal consonants. This phonological process has been described in the representation in table 2, adapted from Storto (1999):1

Table 2. Voicing and lenition of stops and nasal

| p → v | m → ů |
| t → r | n → ř |
| k → ʁ | ŋ → ŋ |
| j → j | ŋ → ŋ |

The following data illustrate the process:

(1) a + taktak + a → ataktaqu
2-to swim-imperative ‘swim!’

(2) a + tat + a → atara
2-to go-imperative ‘go!’

(3) a + hi.rip + a → aharĩwa
2-to cry-imperative 'cry'

1 Storto (1999:38) uses the IPA symbol of voiced bilabial and velar fricatives respectively to describe some of the sounds that result from lenition, whereas we use the symbol for a bilabial and velar approximant instead. The velar approximant symbol is used by Storto to indicate the sound resulting from lenition of bilabial stops and nasals in the environment of round vowels.
The phenomenon of lenition is easily explained taking into account the articulatory setting of the final voiceless stops or nasals. Since the oral closure is made with none or almost no pressure (Ps) in the oral cavity due to the glottal closure or adduction, the stop is (acoustically) weakened as there is no burst (or well defined release in the case of nasals). The adducted or closed glottis found with these consonants favors voicing when in contact with a following voiced segment. Therefore, the glottis setting (closed or adducted) (i) prevents Ps build up in the oral cavity which favors lenition and (ii) also weakens the oral closure which becomes ‘looser’ and more like an approximant at the same place of articulation. Voicing assimilation by the stop is favored by the glottis setting (closed or adducted) when a voiced segment follows, because glottal adduction it is a prerequisite for voicing.

6 Conclusion

The apparent random occurrence of vowels ending with bursts is related to a specific glottal setting following the vowel, motivated apparently by the anticipation of a stop and nasal. The voicing and lenition processes found in Karitiana are naturally explained by the superimposition of two gestures (one glottal and one oral) having a variable timing and amplitude.

The co-occurrence of glottal stops and stress at the end of words indicates, as well, that the closing gesture of the glottis may have a prosodic function in the language, and should be subject of further investigation.

Acknowledgements

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References

Baken and Orlikoff (2000).


Figure 1. Audio waveform of the word [gəpʰ] ‘flea’ showing a burst (indicated by the arrow) at the end of a vowel preceding a voiceless bilabial stop consonant in the final position of a monosyllabic word.
Figure 2. Audio waveform and electroglottographic (EGG) displays of the recording of a vowel, illustrating the difference between both signals. EGG shows maximum vocal fold contact area when the signal reaches its maximum and the minimum when it is low as indicated by the arrows. The comparison of both signals is given for one glottal cycle (T) as shown by the double arrows on both signals.
Figure 3a. Spectrogram and audio waveform of the word [apibimbik'] 'to push'. Arrows on the audio waveform indicate the vowel [a] ending with a burst and the initial burst of the following [p]. The final unreleased voiceless velar stop is identified by the F2/F3 approximation as indicated by the double arrow.

Figure 3b. Audio waveform and electroglottographic signal for the word presented in 3a. The arrow on the audio waveform indicates the burst at the end of the vowel. Arrows on the EGG show the signal during: the initial glottal stop [ʔ], the intervocalic voiceless bilabial stop [p] following the vowel with the final burst and the final voiceless velar stop [k'].
Figure 4. Electroglottographic signal and audio waveform for the word [ʔɔtʔɔːt′] ‘species of egret’. The vertical arrow on the EGG indicates the glottal closure at the beginning of the second glottal stop [ʔ] of the word. The two horizontal arrows show the sequence of the open and closed glottis accounting for the voiceless alveolar stop [t] and the glottal stop [ʔ]. The two superimposed horizontal lines between dots show the approximate timing of the glottal and alveolar closures made during the final unreleased voiceless stop [t′]. The vertical arrow between the audio waveform and the EGG show that no burst accounts for the alveolar stop, suggesting that the alveolar closure is lasting during the glottal closure. The horizontal arrow shows the signal during the sequence.
Figure 5. Audio waveform and electroglottographic signal for the word [kəbm̩] ‘xx’. The arrow on the audio waveform indicates the burst at the end of the vowel preceding the pre-oralized stop [bm̩]. Arrows on the EGG show the increase and decrease of the signal at the end of the vowel [ə] and during the final consonant [bm̩].
Figure 3a.

Figure 3b.
<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>apimbik’</td>
<td>‘to push’</td>
</tr>
<tr>
<td>ṁ’ap’</td>
<td>‘lame’</td>
</tr>
<tr>
<td>kabm’</td>
<td>‘now’</td>
</tr>
<tr>
<td>āmāŋ’</td>
<td>‘to plant’</td>
</tr>
<tr>
<td>₞op’</td>
<td>‘hole’</td>
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<tr>
<td>ṁobmā</td>
<td>‘pierced’</td>
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<td>‘to enter’</td>
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<td>‘basket’</td>
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<td>‘firefly’</td>
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<tr>
<td>āmb’hārabmā</td>
<td>‘stabbed’</td>
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<tr>
<td>hobmā</td>
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<td>‘to cut’</td>
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