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Nasal Air Flow During Speech Production In Korebaju

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Abstract

Korebaju, also known as Koreguaje (ISO 639-3: coe), is a tonal language spoken by approximately 2,000 people in the Amazonian foothills of Colombia. As part of an ongoing research project, a native female speaker participated in our key study at our laboratory in France. Using the EVA2 station, we recorded synchronized acoustic signals (WAV), electroglottographic signals (EGG), vertical larynx movements (LT), and oral (OAF) and nasal (NAF) airflows to highlight the specific features of nasal consonants in this language. Previous research has noted the presence of a burst noise at the end of nasal consonant production. Our results reject the implosive or ejective realization of nasal consonants and dismiss the possibility of an oral release of the labial or buccal articulation. Simultaneously, our study aims to observe a potential nasal carryover effect on adjacent vowels due to the reported nasal harmony.

Index Terms: Koreguaje, nasal consonant, aerodynamics, nasal harmony, burst.

1. Introduction

1.1. Some characteristics of nasal production

Nasal sounds result from lowering the velum, opening the velopharyngeal port to allow airflow from the lungs through the larynx, pharynx, and nasal cavity. Nasal consonants and vowels involve oral articulation with varying closure in the oral cavity and vocal fold vibration as the sound source. The velopharyngeal port opening while the oral cavity is partly closed enables resonance through the nasal cavities [1], [2]. Studies like [3] estimated velopharyngeal opening (VPO) using the pressure-flow method [4]. Further developments by [5] and [6], employing aerodynamic measurements, shed light on how different oral articulations affect nasal airflow, with greater airflow for velar sounds compared to bilabials. Numerous studies globally, e.g., [7]-[11], revealed nasal airflow depends on both velum movement and oral articulation [5], while [4], [12] explored lower nasal vowel production with reduced velum displacement. Velum displacement occurs around 5 Hz (less than 200 to 300ms) [2], facilitating nasal sound propagation during nasal production. Nasal coarticulation with nasal segments has been studied by [9], [10], [13]-[17], varying by language [18]. Recently, [19] presented a nasality continuum based on velopharyngeal opening, ranging from pauses to nasal vowels and consonants, with closure during oral vowels and consonants. Another phenomenon is nasal consonants with oral release at the end, found mainly in African languages, like [1], [20], [21], aiming to prevent nasality from spreading to the

following vowel by decreasing nasal airflow at the consonant's end [22].

1.2. Aerodynamic studies of nasals in Amerindian languages and Tukanoan languages

Few studies have explored nasality from an aerodynamic perspective. In [22], the Karitiana language, an isolated indigenous language from Brazil, demonstrates a post-stopped nasal allophone (e.g., [m^b]), characterized by increased intraoral pressure (Ps) and nasal airflow, elucidating the contrast between nasal segments. Another study [23] examines Kakataibo, a language in Peru, revealing nasal coarticulation near a nasal vowel. However, this phenomenon varies based on process directionality, stress presence, syllable boundaries, and Kakataibo's prosody. In Tukanoan languages, including Korebaju (the focus of this study), only one phonetic analysis [24] has been conducted, examining nasal productions in Siona, a Western Tukanoan language spoken in the Ecuadorian Amazon. Using the earbuds method, researchers observed velum movement based on intensity and amplitude in nasal and oral cavities, revealing progressive and regressive nasal harmonies influenced by suffixes. Anticipatory and carry-over nasal coarticulation has also been documented at the phonological level in Western and Eastern Tukanoan languages [25]-[31].

1.3. Korebaju, a Western Tukanoan Language

Korebaju (autonym [kòrèβàhí], also known as koreguaje, ISO 639-3: coe) is a tonal language [32], belonging to the Western Tukanoan family [33]. It is spoken in southeast Colombia, along the Orteguaza, Peneya, Consaya, and Caqueta rivers [34], with approximately 2,000 native speakers [34]. Korebaju is categorized as an endangered language by UNESCO [35]. Although described in [36] and [37] as featuring nasal harmony, detailed phonetic information and acoustic-spectrographic data supporting this claim are lacking. Since our initial investigation in 2017, a consistent observation has been made: most nasal consonants in Korebaju exhibit a burst at the end of their production, noted among all surveyed speakers over several years. Previous studies [38] and [39] conducted by us have explored the origin of this burst through glottic signal analysis, initially suggesting it resulted from glottic cycle modifications, though we later refuted this hypothesis. Notably, no other study, whether on Korebaju or other languages in the Tukanoan family or beyond, has addressed this phenomenon.

2. Objectives and hypotheses

One goal of this paper is to describe nasality in Korebaju, and more specifically to verify through aerodynamic data previous findings of studies [36] and [37] on the presence of progressive

nasal harmony in Korebaju. Another goal is to explain the fairly systematic presence of bursts in nasal consonants. Since intra-oral pressure cannot be the same as a plosive, as part of the airflow escapes through the nasal passage, what mechanism causes a burst? Does the presence of a burst modify nasal coarticulation?

A first hypothesis suggests that the presence of a burst at the end of nasal consonants occurs through a vertical movement of the larynx before or at the moment of the oral closure release. On one hand, lowering of the larynx corresponding to the moment of release of the constriction in the oral cavity during nasal consonants is described by [20] and [21] for African languages, and [22] observed that it serves to contrast two nasal segments in Karitiana. On the other hand, nasal consonants could be produced with releases enhanced by non-pulmonary airflow mechanisms caused by abrupt elevation of the larynx and generating an ejective nasal [1], [40]. Furthermore, implosiveness has not been described in nasal consonants, but this phenomenon, in general, is characterized by a lowering of the larynx [41]. A third hypothesis is that nasal productions end with an oral release like in Karitiana [22] which could be one of the mechanisms limiting nasal propagation.

3. Material and recording procedures

3.1. Corpus

A corpus of 54 words in isolation, repeated three times in a random order, was analyzed in the framework of this study. This corpus encompasses all potential occurrences of nasal consonants within roots and morphemes, although the entirety of the tones is not incorporated into the analysis due to the ongoing investigation of the tonal system. In this way, each word in this corpus will have at least one nasal consonant, and events include CV, NV syllables in both initial and medial positions within words, as well as in some affix morphemes. The segments under investigation are the 5 nasal consonants of the language [m], [n], [ɲ], [ɱ], and [ɳ], a series of 5 unvoiced stops [p], [tʰ], [c], [k], [kʰ], as well as the 6 vowels from the vowel inventory of the language [i], [e], [a], [o], [u], and [ɨ]. It should be clarified that Korebaju does not have voiced stops consonants in its phonetic or phonological inventory. In this way, we have a total sample of 979 segments to analyze, of which 715 will be part of this analysis, as the other segments fall outside the consonantal and vocalic limitations of this study (so $N=715$).

3.2. Material

A synchronized recording of five channels (acoustic, electroglottographic (EGG), nasal flow (NAF), oral flow (OAF) and larynx tracking (LT) was conducted using the EVA2-S.Q.Lab workstation [42]. This device enabled the simultaneous recording of audio signals, nasal airflow (NAF), oral airflow (OAF), electroglottography (EGG), and larynx tracking (LT). The station was connected to a computer, and the signals were recorded at GIPSA-lab in France using the Phonedit Signaix software [43]. Before starting the recording, a calibration of the NAF and OAF cameras was carried out with the help of this same software.

3.3. Participant

A 65-year-old woman, a native speaker of Korebaju, was the sole participant in the current study. Until now, she had never left her community for more than two weeks, and her stay in

France marks her first extended absence, spanning a period of 88 days. Spanish is her second language, acquired during her schooling.

3.4. Measurements and Analyses

Once the data is acquired, any nasal airflow below 0 has been replaced with 0, as it is assumed to result from the speaker's inhalation due to a large quantity of air in the mask, and therefore, this physiological process is not part of the observed productions. The data segmentation was done manually using the Praat software [44]. Here, each phone was segmented. Additionally, for nasal productions with a 'burst,' the burst was segmented in a different tier, including its respective consonant (see Figure 1). The analysis of the data was performed in Matlab. The segmentation of each word was carried out using the PRAAT software. The analysis of speech signals, namely nasal airflow (NAF) and oral airflow (OAF), was performed using a MATLAB script, while the analysis of electroglottographic signals (EGG) and larynx tracking (LT) was conducted using the MATLAB TRAP program [45].

For statistical analyses, we utilized the R statistical software [46]. Four different models for larynx height were conducted, with measures taken for each segment as proposed by [47]. The glottographic measurement used in this study corresponds to the vertical position of the larynx (VPL). Initially, four events were semi-automatically identified on the VPL trajectory: the acoustic onset (On) and offset (Off) of the target segment, the closest maximum VPL position (Max) to the segment boundary, and the closest minimum VPL position (Min) to the segment boundary. Generally, the maximum VPL value coincided with the acoustic onset of the target segment, while the minimum value corresponded to its acoustic offset. To describe the vertical displacement movement of the larynx during segment production, four VPL difference calculations (ΔVPL) were performed: ΔVPL_{Off-On} , $\Delta VPL_{Min-Max}$, ΔVPL_{Max-On} , and $\Delta VPL_{Min-Off}$. Among these calculations, ΔVPL_{Off-On} was deemed the most relevant for accounting for the amplitude and trajectory of the larynx. Thus, we focused our analysis on this variable. We examined the impact of different types of glottal productions, as categorized by [48], along with factors such as TONE, SYLLABLE_RANK, BURST, and LABEL, encompassing vowels, plosives, and nasals. After model selection, we retained the dependent variable Off-On, representing the difference between larynx height values at the end and beginning of consonantal segments. The factor significantly impacting Off-On was LABEL ($\chi^2(17) = 137.3$, $p < 0.0001$), guiding our larynx height analysis. For each factor, we created four different models and studied their impact on response variables NAF and RATIO (i.e. Nasal Rate = $NAF/(NAF+OAF)$) through linear mixed-effects modeling. This approach accounts for measurement repetition and residual variance variations between factor modalities. For this, we used the *lme* function from the *nlme* package in the R statistical software. We conducted a nested model test each time using the *anova* [49] function to measure the factor's impact on the response variable. If the result was significant, we performed multiple comparisons with the *glht* function from the *multcomp* package, following the method presented by [50], and relying on the *emmeans* package to construct contrast matrices.

4. Results and discussion

A burst at the end of oral productions for 4 out of the 5 Korebaju nasal consonants [m], [n], [ɲ], and [ɳ], has been observed. In

addition to indicating the presence of a burst on the acoustic signal and the corresponding spectrogram of the nasal production, Figure 1 presents the 4 other channels recorded in synchrony during the production (EGG, LT, NAF and OAF).

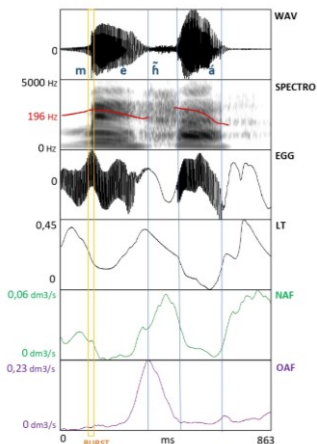


Figure 1: Word [mèhã] 'sand'

4.1. Relation Burst - VPL

Figure 2 presents the amplitudes of the vertical position of the larynx for three different sets of consonants: 0N representing nasal consonants that do not exhibit a burst in their production; 1N representing nasal consonants that exhibit a burst in their production, and, finally, 1P for the set of voiceless occlusive consonants in the language. In general, nasal consonants are realized with a more pronounced laryngeal descent compared to plosive consonants. The results suggest that the comparisons between 0N and 1P, as well as 1N and 1P, are statistically significant at a conventional significance level ($p < 0.0001$), while the comparison between 1N and 0N is not statistically significant ($p = 0.559$).

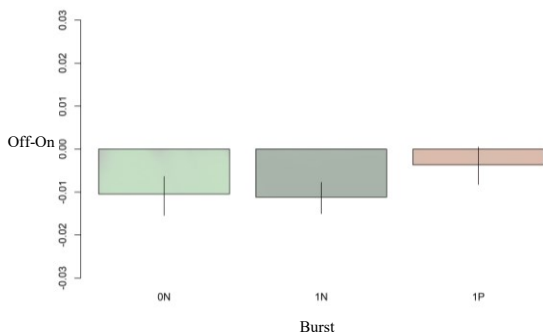


Figure 2: Mean and SD of Off-On larynx height in relation to the type of target consonant: nasal without burst 0N, nasal with burst 1N, and plosive 1P

Subsequently, we wanted to observe more precisely the amplitude of the laryngeal vertical movement for the entire set of segments included in this analysis: nasal consonants with and without burst, plosive consonants, and the set of vowels following the target consonants (Figure 3).

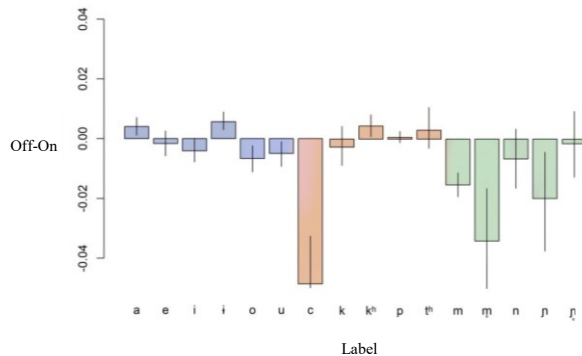


Figure 3: Mean and SD of Off-On larynx height (in relation to full set of target consonants and vowels (Label).

From Figure 3, it is clear that the bilabial and palatal nasal consonant show a more noticeable laryngeal lowering compared to other nasal consonants. However, it is important to note that nasal consonants in languages worldwide typically do not involve laryngeal descent [51]. Additionally, the voiceless palatal plosive consonant [c] exhibits laryngeal descent without a clear phonetic explanation. Other factors like tone [41] or vowel quality [52] may also influence laryngeal descent. These findings contradict our initial hypothesis that laryngeal movement causes the observed burst, suggesting possible implosive or ejective features in nasal consonants, as depicted in Figure 2. Nasal consonants with burst 1N and those without burst 0N show distinct laryngeal lowering compared to plosive consonants, but this is not exclusively associated with implosiveness; factors like tone and vocalic height contribute to this laryngeal movement [41]. Hence, these productions cannot be strictly classified as implosive.

4.2. Relationship between Nasal Rate and burst within the consonants

In order to test our hypothesis of oral release at the end of nasal consonant production, we have analyzed nasal rate (RATIO = $\text{NAF}/(\text{NAF}+\text{OAF})$) of nasal consonants with burst 1N, without burst 0N, and we have added the nasal rate of occlusive consonants 1P as a control (Figure 4).

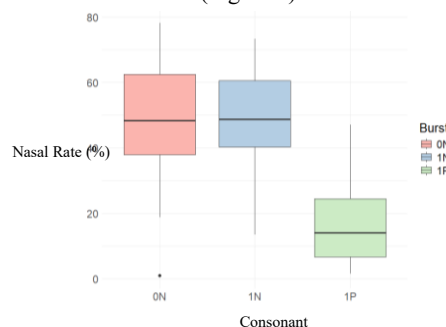


Figure 4: Nasal Rate (axe y) of nasal consonants with burst 1N, nasal consonants without burst 0N, and occlusive consonants 1P (axe x).

An ANOVA test was conducted among the pairs of consonants 1N-0N, 1N-1P, and 0N-1P. The burst factor showed significance with $p < 0.0001$ between the pairs of consonants 1P-0N and 1P-1N. However, when testing the transition from consonants 1N-0N, no significance was found in the nasal rate between the two sets of nasal consonants ($p = 0.929$).

Although the nasal rate does not change within the pair of nasal consonants, we wanted to distinguish the labels of each consonant to see if there is an impact by label (Figure 5).

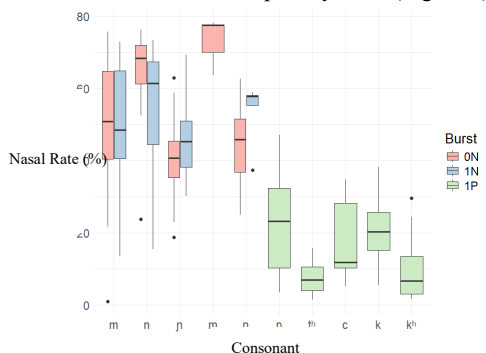


Figure 5: Nasal Rate (axe y) of full set of target consonants (axe x).

Figure 5 reveals no consistent pattern of nasality in nasal consonants with or without a burst (1N or 0N), as the variation depends on the specific consonant. The voiceless bilabial nasal consonant [ɱ] lacks a burst but exhibits the highest nasal rate among all target consonants, attributed to the need for friction noise due to the absence of nasal murmur resulting from vocal fold non-vibration. However, plosive consonants may exceed the 20% nasality threshold [53], surpassing expectations for a canonical voiceless oral plosive consonant like [p]. Further data is needed to confirm nasalization in plosive segments. Our hypothesis of potential oral release in nasal consonants with bursts, observed in other languages, including Karitiana, has been rejected for Korebaju. Thus, we propose that this burst serves no function in Korebaju. To further investigate the obtained results, investigations are underway to explore the synchronicity between the release of the occlusion and the phase of the glottal cycle.

4.3. Relationship between Burst and Vowels Adjacent to the Target Consonants

In order to observe the carryover propagation of nasalization, we analyzed the nasal rate in the vowels following the target consonants (Figure 6).

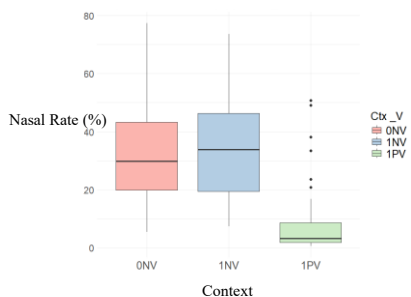


Figure 6: Nasal Rate (axe y) of vowels following a nasal consonant without burst 0NV, nasal consonant with burst 1NV, and occlusive consonants 1PV (axe x).

As for the set of target consonants, the adjacent vowels exhibit the same pattern, where the ANOVA test shows no significance for the pair of vowels following a nasal consonant with burst (1NV) and without burst (0NV) ($p = 0.906$). Regarding the pairs 1PV-0NV and 1PV-1NV, these are significant according to the conducted test ($p < 0.0001$).

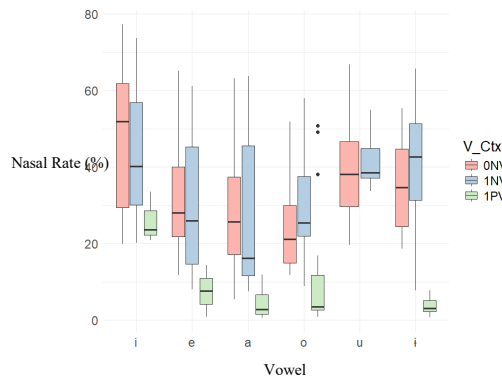


Figure 7: Nasal Rate (axe y) of full set of vowels that follow any target consonant (axe x).

In turn, we wanted to distinguish nasality by vowel label (Figure 7), where a higher nasality index is observed for the closed vowels [i], [ɨ], [u], followed by the mid vowels [e], [o], and the low vowel [a], showing a lower nasality rate.

Our hypothesis of a nasalization carryover has been confirmed for the entire set of vowels following a nasal consonant. We use the term 'nasalization carryover' as the nasalization rate is lower than that of nasal consonants, consistent with the continuum presented by [19], where nasalized vowels exhibit a lower rate than those that are intrinsically nasal. Additionally, in Korebaju, the nasal rate is higher for high vowels compared to mid and low vowels, as observed in other languages [3], [7], [20], as emphasized by [19].

5. Conclusion

This study is part of an ongoing exploration into the relationship between nasality, glottalization and tone in Korebaju. Conducted with the EVA2 system in a controlled environment, it lays the foundation for analyzing acoustic and electrophysiological recordings of 24 Korebaju speakers collected in the Amazon where we utilized the EGGD800 equipment, although it does not allow synchronized recording of laryngeal vertical movement and EGG. Our findings challenge hypotheses of implosiveness, ejectives, or oral release in nasal consonants and suggest that bursts have no significant impact on nasal consonant or vowel production. This study proposes further exploration of the synchronicity between the release of the occlusion and the phase of the glottal cycle and emphasizes the need for future analyses considering Korebaju's tonal and vocalic glottalization features. Additionally, our study confirms the hypothesis of nasalization carryover, suggesting potential extension to plosive segments. Future aerodynamic studies will delve into the relationships between nasality and tone, nasality and glottalization, and glottalization and tone, addressing the unresolved status of glottal sounds in Korebaju and the broader Tukanoan language family.

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