Aerodynamic and acoustic evidence for the articulation of complex nasal consonants

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1. Introduction

Indigenous languages contribute in an essential way to understand variation in speech production and perception and to identify the constraints that act on natural languages. These constraints play a crucial role to make, to test or to revise hypotheses made in phonology.

The paper examines data from Karitana, a Tupi language of Brasil, from Movima, an isolated language from the Bolivian Amazon, and from Rwanda, a Bantu language from Africa. These languages show rather uncommon data. Karitiana has pre and post oralized consonants, e.g. [bmb], as allophones of plain nasals. Movima has voiceless nasally released glottalized plosives [pʔm] and [tʔn]. Rwanda has a very complex set of prenasalized consonants e.g. [mbg, mvg, ndgw, nzgw, nʒgw, ŋgw, m̥hn̥, n̥hŋ̊w, nskw, nʃkw, ŋ̊hw].

These data are crucial to discuss issues on phonological patterning and variation and also to test the articulatory control hypothesis formulated by Kingston and Diehl (1994). The hypothesis, to be valid, crucially depends on data and on experimental observations, made in as many languages as possible or at least on a set of crucial examples. This hypothesis differs from others about the control of articulations both in the degree and kind of control it is thought that speakers regularly exercise, and in the perceptual rationale that is offered for their articulatory control. This hypothesis also differs in kind from other studies of articulatory control in thoroughly integrating articulatory, acoustics, and perceptual evidence into a complete model of the speaker's and listener's phonetic knowledge. The model of that knowledge is then incorporated into a larger model of the phonetics-phonology interface.

The objectives of this paper are to make an experimental study of the variation in the production of complex nasal consonants of these languages; to show that aerodynamic measurements provide strong evidence for the timing of articulatory movements; to discuss the articulatory control hypothesis and to determine whether these consonants are complex nasals or make a complex onset in the syllable structure of the languages where they are observed.

2. Tupi and Jê languages

Several languages from South America such as Karitiana (Storto & Demolin Submitted ms), Kaingang (Wiesemann 1972, Wetzels 1995, D'Angelis 1999, D'Angelis and Reis Silva 1999, Salanova 2001) and Maxacali (Callow 1962, Burgess and Ham 1968 and Salanova 2001) show a quite rare process affecting nasal consonants. They can be pre or/and post oralized when preceded or/and followed by oral vowels. This phenomenon, occurring also in other Jê languages spoken in Brazil, such as Apinayé, has rarely been described.

From observations based on experimental data in Karitiana and acoustic data in some other languages, Storto & Demolin (submitted ms) hypothesized that the pre- or/and post-oralized nasal allophones (i.e. pre- and post-oralized (medionasals) nasals, pre-oralized, post-oralized[1], post-stopped-nasal and even fully oral) of these languages are controlled to produce the correct contrasts between segments. (See Table 1 for a sample of the data). The Karitiana data suggest that articulatory covariation is perceptually motivated and the objects of speech perception are auditory rather than articulatory.

Pre and post oralized	Post oralized
/kina/ [ki.dnda] ‘thing’	/osẽnda/ [o.sẽ.nda] ‘waistline’
Pre oralized	Oral
/enã/ [e.dnã] ‘pregnant’	/neso/ [de.so] ‘mountain’

Table1. Karitiana data, from Storto & Demolin (submitted ms), showing pre- and post-oralized nasals, pre-oralized, post-oralized, post-stopped and oral allophones of the alveolar nasal.

The complete set of allophones of the bilabial nasal /m/ is presented in table 2. Note that the same set exists at the alveolar and velar place of articulations, see Storto (1999) and Storto and Demolin (submitted ms) for a full description.

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[1] The term post-oralized is used instead of pre-nasalized because it refers to the pattern of allophones of the language rather than to the specific sound that can be also be observed in languages like Rwanda where it is called a prenasalized stop. It is obvious that phonetically both sounds have similar characteristics but for the sake of coherence we use post-oralized when we discuss issues related to Karitiana or to the other South American languages that have the same pattern of allophones.

[m˺]	in environment	ṽ_#
[bmb]	in environment	v_v
[bm˺]	in environment	v_#
[bm]	in environment	v_ṽ
[mb]	in environments	ṽ_v & #_v
[m^b]	in environments	#_ṽ & ṽ_ṽ
[b]	in environment	#_ṽ

Table 2. Set of allophones for the alveolar nasal /n/ in Karitiana from Storto & Demolin (submitted ms).

As table 2 shows, there is an allophone that presents an orally released burst at the release of the nasal when it is followed by a nasal vowel. Such segments are rare and have been identified before in Zhongshan and Taishan, two Chinese dialects, (Chan 1987) and in Achenese and Rejang, two Austronesian languages, (Durie 1985) and (Coady and McGinn (1982).

In terms of their distribution inside the syllable, it must be mentioned that the most complex allophones bmb, dnd and gŋg, that we call medionasals, are limited to onset position. Other allophones that can only occur in the onset are the fully oral b, d, g, and the the post-oralized mb, nd, ŋg.

Furthermore, for most speakers, the medionasal allophone may be realized, alternatively, as post-oralized or fully oral. This variation in the pronunciation of the complex medionasal allophones can be regarded as a simplification process available to speakers inside the phonological system. It respects the syllabic restrictions of each allophone and the environmental restrictions that disallow contact between nasal consonants and oral vowels. As a consequence, when the post-oralized variant is used, the preceding oral vowel is nasalized.

In order to understand how these complex segments are produced, acoustic and aerodynamic measurements were made.

2.1 Material and Method

Five male subjects participated in the experiments. The words used for the present experiments are shown in table 3.

Acoustic data were recorded in two sessions: the first time separately from the aerodynamic measurements, the second time with these measurements. In each recording session, subjects were asked to repeat a word containing the relevant data three times, once in isolation and then three times in a small carrier sentence: 'Karitiana haadna pip X nakaat Y' (where Y is the gloss of X in Portuguese). This sentence can be translated as: "In Karitiana X is Y".

The aerodynamic data consist of pharyngeal pressure, nasal and oral airflow measurements. Oral airflow measurements were taken with a small flexible silicon mask placed against the mouth. Nasal airflow was measured with a nasal mask set around the nose of the subjects. Pharyngeal pressure was recorded with a small flexible plastic tube (ID 2mm) inserted through the nasal cavity into the oro-pharynx for one subject.

One session involved the recording of acoustic and all aerodynamic parameters simultaneously and another session recorded acoustics and only oral and nasal airflow. In both cases the microphone was placed next to the mask used to record oral airflow.

As most subjects did not tolerate the tube used to make pharyngeal pressure measurements, they were only made for labial consonants with these subjects. This was done by asking the subjects to hold a plastic tube (ID 5mm) sideways between the lips.

[apibmbik]	to pierce	[m^{b}ãm˺]	roasted
[kidnda]	thing	[ãmbo]	to climb
[sopagŋgɨɟ˺]	eyebrows	[e.dnã]	pregnant
[neso]	mountain	[osẽnda]	side

Table 3. Set of words processed for this paper.

2.2 Results

2.2.1 Pre- and post-oralized consonants

Figure 1 shows a spectrogram and the audio waveform of the word kidnda 'thing', showing the pre- and post-oralized consonant [dnd]. The oral parts that precede and follow the nasal part of the complex consonant have a duration of 59 and 58 ms (see Storto and Demolin submitted ms, for more details).

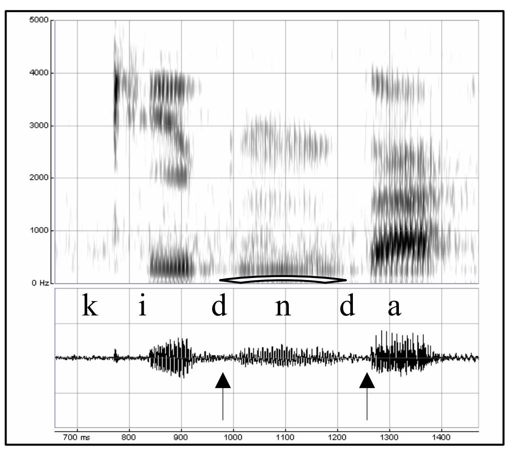

Figure 1. spectrogram and audio waveform of the word kidnda 'thing' in Karitiana.

2.2.2 Post-stopped and post-oralized nasals

Acoustic and aerodynamic measurements for the post-stopped and post-oralized nasals are presented in Figure 2 to 5. Figures 2 and 3 show the acoustic and aerodynamic realizations of a post-stopped nasal. Figure 2 show that post-stopped nasals can be characterized as nasals that have a burst. Indeed, there is a strong burst at the time of the nasal release, with a very sharp increase in amplitude which is more abrupt than what is usually observed in the transition from a simple nasal to a following vowel. Figure 3 shows that pressure and nasal airflow increase simultaneously during the initial (post-stopped) bilabial nasal. There is also a noticeable increase in pressure towards the end of the nasal.

Figures 4 and 5 show the acoustic and aerodynamic realizations of a post-oralized nasal. 4 shows a spectrogram of the word [ãmbo] 'to climb' containing this sound. These consonants always have a burst at their release, but in this case there is also an important oral part preceding the burst. Figure 5 shows that pressure increases only in the second part of the consonant while at the same time nasal airflow rapidly diminishes.

2. 3 Discussion

The observations made in Karitiana support the articulatory control hypothesis because they show that the phonetic interpretation of phonological representations may be controlled as well as automatic. Indeed the covariation between oral and velic closures found with nasal allophones in Karitiana suggest that contrasts between nasal consonants and nasal vowels must be maximal since it seems that the least favorable context in which to identify a nasal vowel is in the context of nasal consonants (Kawasaki 1986). These contextual variations account for the controlled aspect of phonological representations, while free variation accounts for the automatic part of phonological representations. The possible variations of the allophones show this clearly. For example, the two possible variations of [b] and [mb] show this automatic aspect of phonological representations. Apart from the already rare presence of pre-and post-oralized nasal consonants, the remarkable phenomenon in Karitiana is the presence of a post-stopped nasal allophone. The mechanism that produces this consonant, i.e. a simultaneous rise of Ps and nasal airflow is also quite. It explains how it is possible to maintain a sharp contrast between two consecutive nasal segments.

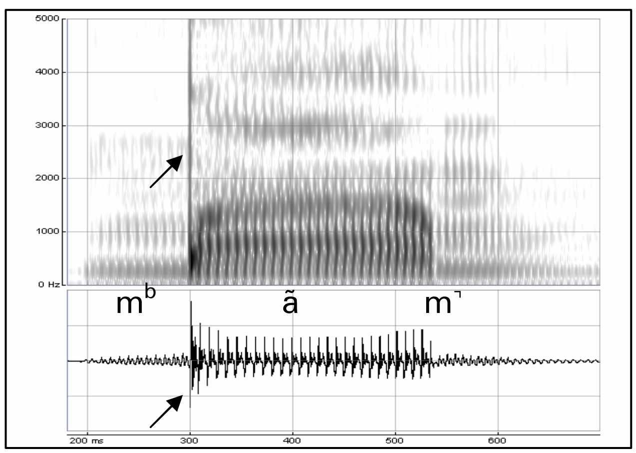

Figure 2. Spectrogram and audio wave form of the word [m^bãm˺] 'to tighten'.

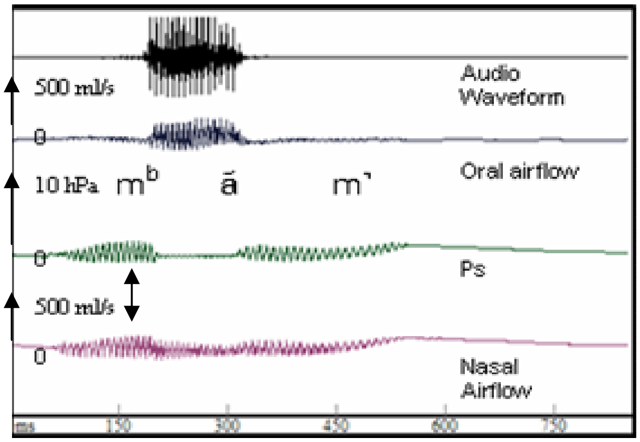

Figure 3. Audio Waveform, Oral airflow, Intra-oral pressure (Ps), nasal airflow of the word in Figure 2.Flow values are given in ml/s and Ps in hPa.

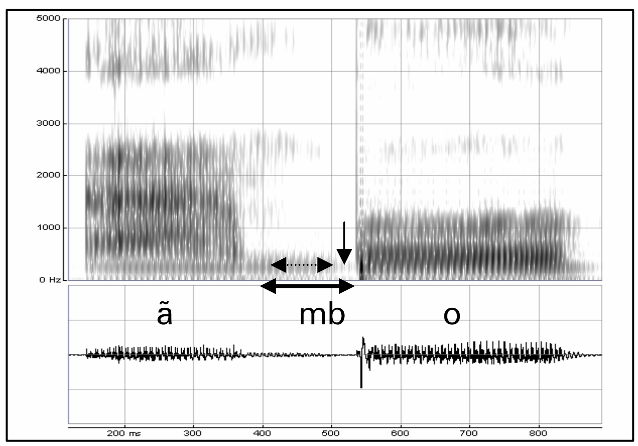

Figure 4. Spectrogram and audio wave form of the word [ambo] *'to climb'.*

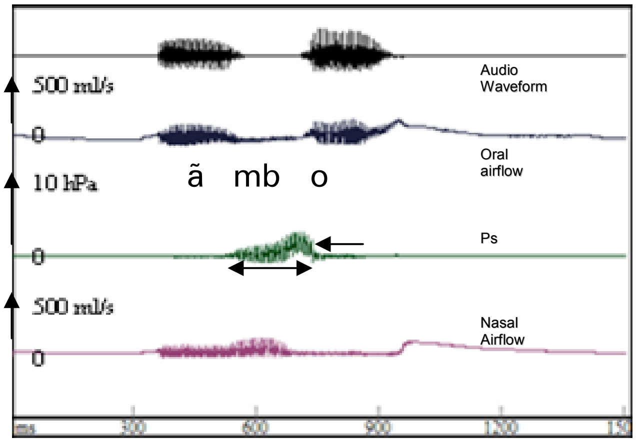

Figure 5. Audio Waveform, Oral airflow, Intra-oral (Ps), nasal airflow of the word in Figure 4.

3. Movima

The importance to collect aerodynamic data to infer the articulatory movements in complex consonants is well exemplified from the set of observations made Judy and Judy (1962) and Haude (2006) who show that in Movima several consonants involve a glottal closure: the simple glottal stop, and the voiceless nasally released glottalized plosives [pʔm] and [tʔn]. All are allophones of the voiceless plosives /p/, /t/ and /k/. The plosives /p/, /t/ and /k/ realized as [p], [t] and [k] in onset position, have thus special allophones in coda position.

/k/ → [ʔ] /__ .

/p/ → [pʔm] /__ .

/t/ → [tʔn] /__ .

Haude (2006: 30) refers to the complex consonants [pʔm] and [tʔn] as nasalized stops and describes them as follows. The glottal closure is immediately preceded by an oral closure (bilabial or alveolar, respectively). This closure is maintained during the release of the glottal stop while the velum is lowered, leading to a voiceless nasal release. Thus Movima has in the case of labial and alveolar consonants a sequence stop + glottal stop followed by a nasal release. On important question is to understand how this nasal release is produced and to see if it is voiced or voiceless. The Movima data suggest that the gestures of the stop and the glottal stop overlap and that this prevents the stop burst to be realized. Note that many South American languages have unreleased stops word finally (see for example Storto and Demolin 2002 for an example in Karitiana) and that these kinds of stops can be produced with an open or a closed glottis. As there are no aerodynamic data available for Movima it is difficult to describe exactly what happens in the vocal tract during the realization of these sounds. However, acoustic data collected by Haude (2006) in the field allow making some observations about the realizations of these sounds. Table 4 show the words analyzed in this paper. This set of data was recorded with three subjects.

[hopkaʔjeːna]	I despatch them
[tapʔm̰βoseɬ̥]	To fall down
[sitʔn̥loto]	To be deaf
[ɓaʔtsananeɬti]	Put it on the table
[enaʔiɦnisaɓ̥eʔen]	Have you already wiped it clean?
[hajnakweʔitʔnjeʔɬami]	I have just poured the water
[intʔnhaʔasnaɬinahʔɓ̥etʔi]	We only lived in the grassland
[tʃipɬaa̰hoʔme]	The bird whistles

Table 4. honetic transcription of Movima words analyzed.

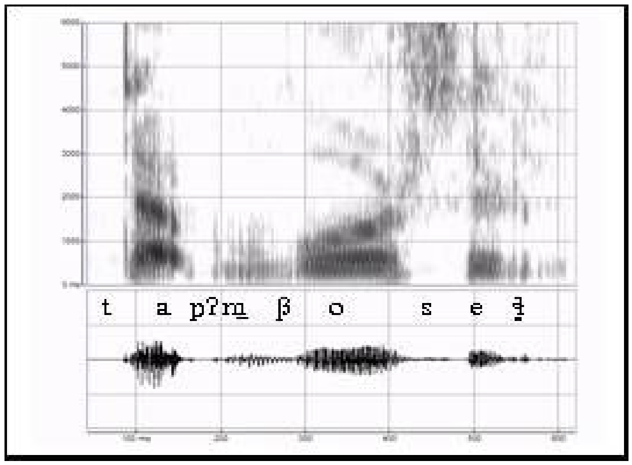

Figure 6. Spectrogram and audio wavefrom of the word [tapʔm̱βoseɬ̥] 'to fall down'

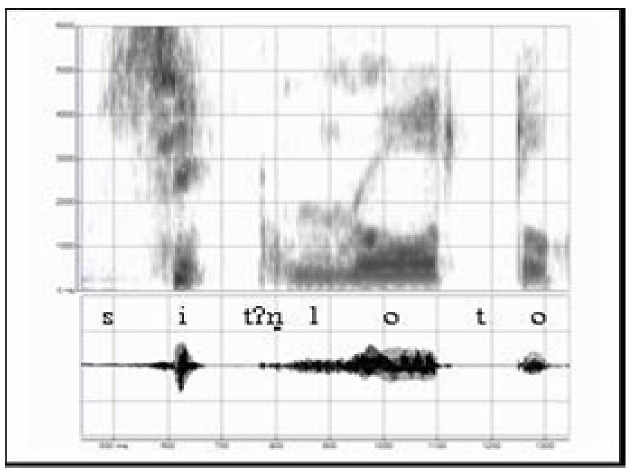

Figure 7. Spectrogram and audio wavefrom of the word [sitʔn̥loto] ‘ to be deaf’

3.1 Results

Figures 6 and 7 show the spectrograms of two words that contain the consonants [pʔm] and [tʔn]. Figure 6 shows a sequence at the labial place of articulation. The main features to be noticed are that the formant transition preceding the sequence clearly shows that a labial consonant is involved and also that the nasal part is voiced and partially laryngalized. Note that the bilabial fricative [β] acts as a labial off-glide. Figure 7 shows a sequence at the alveolar place of articulation in which the formant transition that precedes the sequence shows a F2 that is rising (note that it is quite high because it is a woman's voice). In this case the nasal part is devoiced.

3.2 Discussion

From the available acoustic data we can reasonably speculate that the glottal closure occurs after the labial or the alveolar closure and that this happens before the release of the front (labial or alveolar) closure. The consequence of this is that there is some air sealed the between the glottal closure and the front closure for a small period of time. The nasal release might then happen to let the air escape from the vocal tract. This may happen as a reflex or to prevent an unwanted event such as a burst that is too strong. The exact timing of the articulatory coordination of these gestures will be better understood when aerodynamic data will be available.

4. Rwanda

Jouannet (1983) presents an interesting set of data of complex consonants (prenasalized and velarized – plain and secondary) in Rwanda. The phonetic variation observed in the realization of complex consonants help to understand and to explain the phonological patterning of consonants and syllables in the language. For example, are sequences such as [nhŋw] complex nasals or sequences of nasals? Rwanda has three

groups of prenasalized stops in its phonetic inventory: (i) a set of voiced and voiceless prenasalized stops; (ii) a set of voiced and voiceless labiovelarized prenasalized stops [mbg, mvg, ndgw, nzgw, nʒgw, ŋgw, m̥hn̥, n̥hŋ̊w, nskw, nʃkw, ŋ̊hw] and (iii) a set of voiced and voiceless palatalized prenasalized stops (Jouannet 1983).
The labiovelarized and voiceless sounds are quite unusual and present a number of problems that require an accurate description if one whishes to understand their production. In the voiceless set of sounds [m̥h, n̥h, ŋ̊h, m̥hn̥, n̥hŋ̊w,ŋ̊hw, n̥hŋ̊, ŋ̊hy] there are voiceless nasals both preceding and following the aspirated part of the consonant. This quite rare phenomenon must also be demonstrated and explained.

4.1 Material and method

Aerodynamic recordings (intraoral Ps, oral and nasal airflows) were made using the Physiologia workstation (Teston and Galindo 1990) linked to a data collection system equipped with different transducers.
Acoustic recordings were made with the same material via a High Fidelity microphone set on the hardware piece of equipment connecting the transducers to the computer.
Spectrograms and audio waveforms were processed with the *signal explorer* software.
Seven speakers took part in the experiment. They were asked to read words containing prenasalized consonants in a small carrying sentence vuga__itʃumi, ‘say__ten times’. Table 5 show the data analyzed for this paper.

Rwanda[2]	Gloss
[imɦamba]	Food for traveling
[iŋgoɟi]	Mountain gorilla
[iŋɦa]	Cow
[imɦŋemŋe]	Chest hair
[inɦŋwaro]	Weapon
[iŋɦwano]	Dowry
[ingwe]	Leopard
[inɦɲooza]	Eloquent person
[im̥fiizi]	Bull
[intʃuti]	Friend

Table 5. List of Rwanda words recorded and analyzed in this paper.

4.1 Results

The observations that we can make from our measurements show that voiceless nasals are not very frequent in our set of data from Rwanda. When they are found, they exist mainly in front of voiceless fricatives. Most aspirated sounds are fully voiced (Demolin and Delvaux 2001) and voiceless prenasalized stops in Rwanda should rather be described as whispery voiced nasal stops. However, we would like to draw the attention to the fact that the set of data analyzed here does not necessarily represent all the possible variations that exist in Rwanda and that Jouannet's observations might be observed with other speakers of the language.

[2] Since there are differences between our observations in the phonetic realizations of Rwanda words and what is presented in Jouannet (1983), the data are presented in phonetic form. More data are needed to know if these differences are due to dialectal variations or to different interpretations in the analysis of the data. Tones are omitted in all transcriptions.

Figures 8 and 9 show two realizations of the word inha ‘cow’. The seven speakers of our study showed important variations in the realizations of this word. Figure 8 [iŋ̥ha] shows that the first part of the complex consonant is produced with a rather important Ps (max 3.4 hPa). At the same time, there is an increase of nasal airflow and a decrease of oral airflow. In fact, the oral airflow decrease starts from the beginning and accounts for a lowering and backward movement of the tongue. The fact that oral airflow is slightly negative is accounted by a leakage in the alveolar closure during the backward movement of the tongue. The aspirated part of this word is voiceless. Figure 9 [iŋɦa] shows a very different realization. An increase in Ps is also observed but it is less important (max 1.9 hPa). Nasal airflow increases to the end and decreases just after the burst that precedes the voiced aspirated part. Oral airflow, after a short negative period of time increases during the voiced aspirated part.

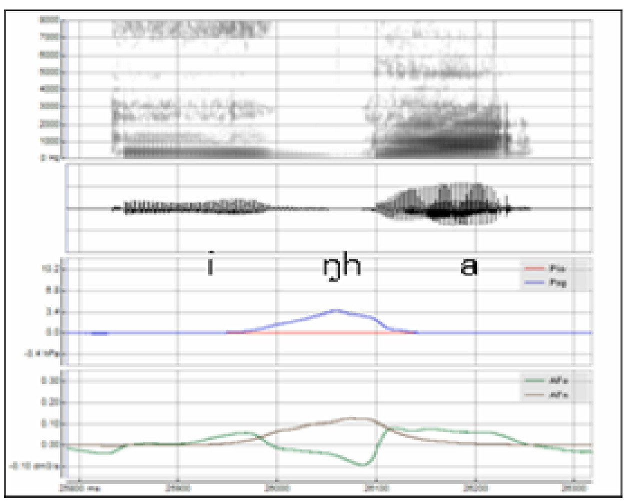

Figure 8. Spectrogram, audio waveform, Ps(Pio), oral(AFo) and nasal airflow (AFn) of the word [iŋ̥ha] ‘cow’.

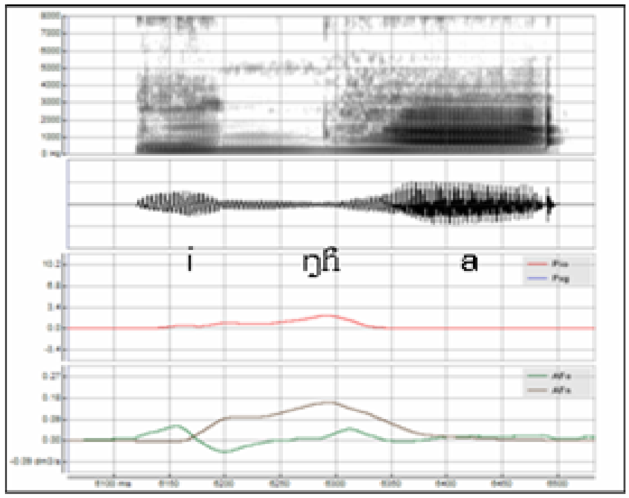

Figure 9. Spectrogram, audio waveform, Ps(Pio), oral (AFo) and nasal airflow (AFn) of the word [iŋɦa] 'cow'.

Several phenomena that are direct consequences of the temporal variations in articulatory gestures have also been observed. In sequences of nasal consonants such as [mŋ] and [nŋw], there can be a burst between the nasal consonants that is sometimes interpreted as the burst of a stop, homorganic to the first nasal. The burst is in fact an epiphenomenal click that is not phonologized in the language. Figures 10 and 11 show the realizations of such epiphenomenal clicks in the word ingwaro 'weapon'. Figure 10 shows that after the click burst, the velar nasal is voiceless. This can be seen on the audio waveform that shows no voicing after the burst while the nasal airflow shows that the sequence is fully nasal. There is a short voiceless aspiration before the labio-velar glide [w]. Figure 11 shows that after the click burst, the nasal is voiced and the aspiration is voiced. The aerodynamic data from Figures 10 and 11 suggest that the velaric airstream accounting for the clicks is realized because there is an overlap of the alveolar and velar place of articulations of the nasals for a short period of time. During this period there is an expansion of the volume of air sealed between the two closures. The click burst is produced after the release of the alveolar closure that precedes the velar release.

There is sometimes the phonetic realization of a vocoid between consonants (nasal or plain) when the second consonant is velar and the first labial or alveolar. This is nicely illustrated in Figures 12 and 13 that show realizations of the word imbga ‘dog’ and in Figure 14 that shows another variant of the word ingwaro ‘weapon’. Figure 12 shows that there is a burst produced at the end of the bilabial nasal. This burst is attributed to an oral stop when it occurs. There is an increase in Ps at the beginning that diminishes when nasal airflow starts to increase. Figure 13 shows another realization of the word. The spectrogram shows the presence of a small vocoid between the bilabial nasal and the voiced velar stop. There is also a small negative oral airflow during the voiced velar stop that accounts for the backward movement of the tongue because there is a leakage at the place of articulation. Figure 14 also shows the presence of a voicoid between the initial alveolar nasal and before the velar nasal where a click burst was observed in Figures 10 and 11.

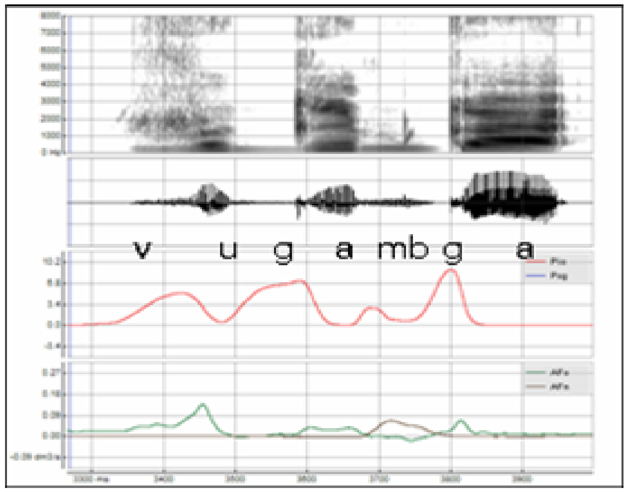

Figure 10. Spectrogram, audio waveform, Ps(Pio), oral (AFo) and nasal airflow (AFn) of the words [vugambga] 'say dog'.

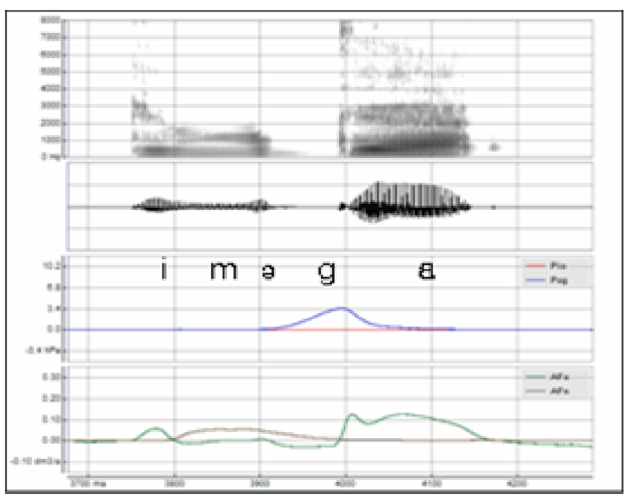

Figure 11. Spectrogram, audio waveform, Ps(Pio), oral (AFo) and nasal airflow (AFn) of the word [iməga] 'dog'.

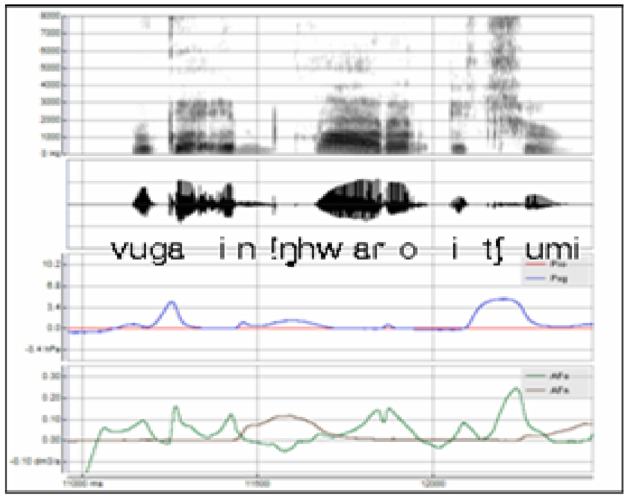

Figure 12. Spectrogram, audio waveform, Ps(Pio), oral (AFo) and nasal airflow (AFn) of the words [vuga in!ŋɦwaɾoitʃumi] ' say weapon ten times'.

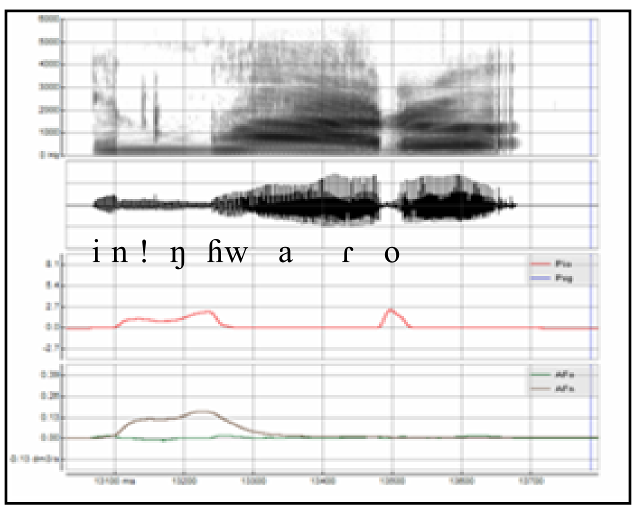

Figure 13. Spectrogram, audio waveform, Ps(Pio), oral (AFo) and nasal airflow (AFn) of the word [in!ŋɦwaɾoi] 'weapon'.

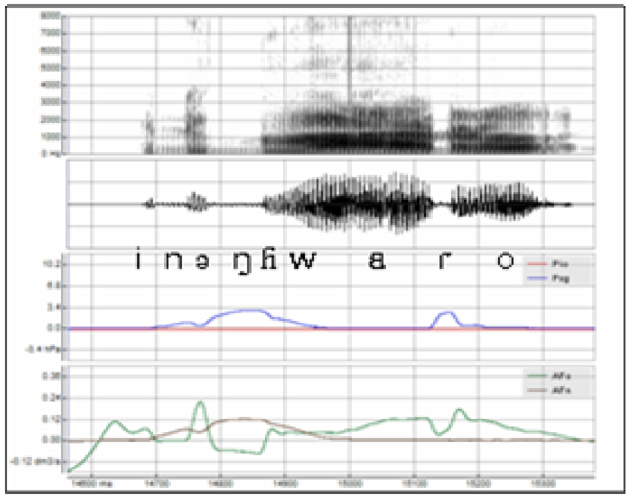

Figure 14. Spectrogram, audio waveform, Ps(Pio), oral (AFo) and nasal airflow (AFn) of the word [inəŋɦwaɾo] 'weapon'.

5. General Discussion

Although the data that are processed in this paper come from a rather limited number of subjects for each language, they show several striking features that are set forward by aerodynamic data in the case of Karitiana and Rwanda. One of the most remarkable is the way bursts are produced at the end of some nasal consonants. In Karitiana, Storto and Demolin (submitted ms) suggested that the increase of Ps that is observed during the post-stopped nasals is likely to be accounted by a closing movement of the velum towards the end of the nasal. This increase of Ps is maximal at the end of the nasal. Similar facts are observed in Rwanda, but for different reasons. The phenomenon of increase of Ps and nasal airflow is observed in Figures 8 and 9. Ps, measured in the pharyngeal cavity, increases because the volume of the pharynx is reduced as a consequence of the backward movement of the tongue that is accounted by the slightly negative oral airflow. Nasal airflow gradually increases as a consequence of the progressive reduction of the velum port opening that is provoked by the backward movement of the tongue during the velar closure. The main consequence of the phenomenon of Ps and nasal airflow simultaneous increase is that, in both languages, there are bursts at the end of nasals. Karitiana, speakers maintain a sharp contrast between nasal and oral segments. In Rwanda, the effect is likely an automatic consequence of the complex articulatory movements. However, more work has to be done to establish this firmly.

Acoustic data from Movima show a rare phenomenon. The explanation and the description of the nasalization of a sequence stop + glottal stop is only speculative as stated in section 3.2. In the absence of any aerodynamic data it is difficult to know when the velum lowers and how this gesture is coordinated with the glottal closure and opening. For the understanding of the phenomenon, it is important to know whether the air that escapes from the nose starts during the glottal closure or after it.

The epiphenomenal clicks that are observed in Rwanda are very interesting for several reasons. First, because they corroborate observations made earlier by Ohala (1995) for Indo-European languages and by Marchal (1987) for French about the emergence of clicks in sequences of stops. Second, because they show that the relation between the bursts of clicks and stops may be a matter of the degree of the burst's intensity. This has been suggested by Traill (1985) and Traill and Vossen (1997), who made the claim that the difference between clicks and stops is rather a matter of acoustic and perceptual saliency of the bursts rather than a problem of articulation. This may explain why the first

Europeans who described Rwanda did confuse what could have been click bursts with stop bursts that they were used to hear in their phonological systems. There is no doubt that much more work is needed to establish this hypothesis and to understand the phonetics and phonology of prenasalized consonants and stops in this language. These observations are a first step in this direction. A third important reason is that it provides an example of clicks (that are not phonological) in Bantu languages outside of the Nguni group of languages, the only Bantu group that has clicks in its inventory. As far as we know, it is still difficult to establish why and how those languages did acquire clicks other than by borrowing (which is still not clearly established either). The same kind of emerging burst phenomena might have existed in Nguni languages. The conjunction of the overlap of a front articulation (labial or alveolar) with a velar articulation for a short period of time might have produced click bursts that have been amplified by the contact with speakers of Khoisan languages. Of course, this is still very speculative and only systematic work that will compare the place of occurrence of clicks in Nguni lexical items with Proto-Bantu reconstructions will likely reject or confirm this hypothesis.

Another interesting phenomenon comes from the presence of a short vocoid in sequences of nasals where bursts are observed. The realization of this vocoid depends on the timing of the nasal sequence and of the closure release in sequences such as [mŋ] or [nŋw]. As we have seen above to account for the presence of click busts, if the two closures are made simultaneously for a short period of time and if the front closure is released first, then a click is produced and interpreted as a voiceless stop burst that is homorganic to the preceding nasal. If the closures are made as a sequence, a vocoid is produced between the two nasals as in [mŋ] > [məŋw] or [nŋw] > [nəŋw]. The presence of this vocoid varies from one subject to the other in our data but each subject seems to have one strategy, i.e either a click or a vocoid. In our data, when there is a vocoid, the overall duration of the sequence of nasals has on average 45 ms greater duration. Systematic observations of this phenomenon should be made to account for the timing in the coordination of articulatory movements. The main point is to know whether this is a strategy used by the speakers of Rwanda to break complex syllabic onset or whether it is an automatic phenomenon, consequence of the way articulatory movements are coordinated.

The variants observed in the realizations of the word imbga 'dog' in Figures 8 and 9 are interesting because they exemplify changes in a phenomenon known in the diachronic evolution of Bantu languages. Ohala (1978) shows the evolution from Proto-Bantu for the word dog : *ɲ–bua > m-bua (Oli) > m-bwa (Swahili) . The form m-bga found in Rwanda, in some Shona dialects and in Ikalanga (see Doke 1931, Maddieson 1990 and Mathangwane 1999) accounts for the velarization of the sequence of consonants. Note also that both Shona and Kinyarawanda show many variations in the realizations of this word, but this will not be discussed here. The synchronic variants observed in Rwanda, i.e the presence of a vocoid between the two stops, might reflect a possible evolution, consequence of a constraint that prevents sequences of stops in the language.

The complex nasal consonants of Rwanda (i.e the whole set of prenasalized) are generally a sequence of nasal consonants that make a complex syllabic onset.

Conclusion

This paper described data from three languages, Karitiana, Movima and Rwanda, having complex nasal consonants in their phonemic inventory. It was shown that the combination of aerodynamic acoustic data allow to make accurate inferences about the coordination of articulators involved in the production of these sounds.

Acknowledgments
We wish to thank all the Karitiana, Movima and Rwandan speakers who took part in the experiments. We would like to thank John Ohala and John Kingston for helpful comments on various parts of the manuscript; Mats Exter, Rik van Gijn and Carlos Gussenhoven for their help with the Movima data.
The research was supported by a FNRS grant n°: 1.5.223.06 'Connaissance phonétique et contrôle articulatoire'.

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Aerodynamic and acoustic evidence for the articulations of complex nasal consonants

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Abstract

This paper gives evidence that aerodynamic and acoustic measurements of complex nasal consonants help to understand their articulations. Data from Karitiana, a Tupi language from Brazil, suggest that the complex nasal allophones of nasal consonants are controlled to enhance the contrast between oral and nasal segments. Movima, an isolated Bolivian language, shows nasally released complex consonants and Rwanda data show that the articulation of the prenasalized stops is far more complex and variable than usually assumed.

Key words: Aerodynamics, acoustics, complex nasals, indigenous languages

Résumé
Cet article montre que les mesures aérodynamiques et acoustiques aident à comprendre les articulations des consonnes nasales complexes. Des données du Karitiana, une langue Tupi parlée au Brésil, suggèrent que les allophones nasals complexes des consonnes nasales sont contrôlés pour maximaliser le contraste entre les segments oraux et nasals. Le Movima, une langue isolée de Bolivie, montre des consonnes complexes avec un relâchement nasal et les données du Kinyrawanda montrent

que l'articulation des consonnes pré-nasalisées est beaucoup plus complexe et variable que ce que l'on pense généralement.

Mots clés : Aérodynamique, acoustique, nasales complexes, langues indigènes