Phonological Data and Analysis

Decision Letter (PDA-2025-0008)

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Subject: Phonological Data and Analysis - Decision on PDA-2025-0008

Body: 17-Oct-2025

Dear Dr. Maselli,

Thank you for submitting the final version of your manuscript entitled "Nasal retroflexes in North Boma (Bantu B82, Mai-Ndombe, DRC)", which is acceptable for publication in Phonological Data and Analysis in its current form.

Your accepted manuscript will now be sent to Cambridge. Further information will follow regarding your publishing agreement.

Sincerely,

Dr. Matthew K. Gordon
Editor-in-Chief, Phonological Data and Analysis

Date Sent: 17-Oct-2025

Close Window

Nasal retroflexes in North Boma (Bantu B82, Mai-Ndombe, DRC)

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Abstract – Retroflex consonants represent a major class of language sounds, but our understanding of their phonetic and phonological properties remains limited. From the standpoint of acoustics, recent contributions are largely lacking. Few fully fledged empirical descriptive studies have been made available to establish their presence and characteristics in the world's languages. Within retroflex consonants, liquids and nasals are particularly rare, and very little descriptive, theoretical, or historical research has been conducted on them. Bantu languages from Africa are not included in most large-scale surveys. Recent fieldwork in the Mai-Ndombe Province of the Democratic Republic of Congo (DRC) in Central Africa confirms the existence of nasal retroflexes in North Boma (Bantu B82). This paper offers the first acoustic description of these rare nasal segments in any Bantu language. North Boma nasal retroflexes are shown to constitute a discrete class within the language's nasal inventory. Compared to their non-retroflex counterparts, they are significantly shorter; they also display spectral energy concentrated in the lower frequencies around their centre of gravity, more peaked energy concentrations, higher values of F1 and F1 bandwidth, and lower values of F2 bandwidth. Furthermore, we reconstruct the historical development of nasal retroflexes in North Boma and show that they are the regular outcome of the merger of Proto-Bantu *n and *nd to /n/ in stem-medial position. We hypothesise that retroflexion might be a phonological substrate feature originating in extinct non-Bantu languages once spoken by Batwa communities living and foraging in the region or by Ubangi speech communities now only attested further north. This contribution showcases how detailed phonetic documentation and description are an asset for historical research.

Key words: phonetic documentation, acoustics, retroflexion, nasality, Bantu, diachronic phonology, substrate interference

1. Introduction

Retroflex sounds are a class of language sounds often described by their articulatory property of being produced with the tip of the tongue 'curled up to some extent' (Ladefoged & Maddieson 1996: 25). The term 'retroflex' has long served as a descriptor for this specific tongue gesture (since at least Pike 1943; see also Dixit 1963, 1990: 190, and the literature reviewed therein). While this definition is not circumscribed to any one place of articulation, the notion that a contrast exists in a number of languages between retroflex and non-retroflex apical consonants led to the further specification of retroflexes as apical post-alveolars, thereby effectively treating the label 'retroflex' as that of a specific place of articulation (in line with IPA 1925/7; see Ladefoged 1971, Bhat 1974), albeit one with great cross-linguistic, and possibly idiolectal (see Catford 1968: 310), variability. This variability is expressed in terms of (i) tongue-tip position (apical to sub-apical, see Ladefoged & Maddieson 1996, *infra*) and (ii) nature of the gesture employed (Ladefoged & Bhaskararao 1983).

The observation that retroflex sounds are subject to considerable cross-linguistic variation dates as far back as Firth (1948), with notes on Urdu by Qadri (1930) (see also Dixit 1990, Simonsen, Moen & Cowen 2000). In the literature, the link between retroflexion and retraction has been the object of considerable debate. While originally rebutted by Bhat (1973, 1974), based on remarks by Emeneau (1939) on the vowel system of Dravidian Badaga from India, Hamann (2002) formalises this link as a monodirectional implication, meaning that all retroflex sounds would necessarily be retracted, but not vice versa. Building on this premise, Hamann (2003) proposes that the actual 'curling back' of the tongue tip is not a necessary part of retroflex articulations, which would be better described by the following properties: apicality, posteriority, presence of a sub-lingual cavity throughout the articulation, and retraction (Hamann 2003: 32-39; see Flemming 2003, Boersma & Hamann 2005 for further discussion on this point).

This contribution represents the first description of nasal retroflex stops (henceforth, nasal retroflexes) in North Boma (Bantu B82),[1] a West-Coastal Bantu language spoken on the fringes of the Congo basin rainforest in southwestern Democratic Republic of Congo (DRC). Nasal retroflexes were first reported in North Boma by Stappers (1986). Between 2021 and 2022, we conducted specific data collection to verify the presence of nasal retroflexes in the language. The interest of this line of research lies at the intersection of two issues.

First, North Boma retroflexes are exclusively nasal, which is an almost unique typological situation. The presence of a phonemic retroflex flap in North Boma is documented by Stappers (1986) but remains dubious based on our own data. Whenever sporadically present, retroflex flaps seem to be free variants of intervocalic laterals and trills in North Boma (see Section 3). Nasal retroflexes constitute the rarest class of retroflex consonants in the world's languages (Tabain et al. 2016, 2020). Out of 399 languages reported to have a nasal retroflex in their phonological inventory in the PHOIBLE database (Moran & McCloy 2019), only 43 (mostly from northern and western Australia) present inventories without any obstruent retroflexes, and only 2 (namely Syan or Saya, a Chadic language of Nigeria, see Schneeberg 1971; and Mandara or Wandala, another Chadic language spoken in Cameroon and Nigeria, see Fluckinger 1981) display a nasal as their sole retroflex phoneme. A detailed study of the acoustic properties of nasal retroflexes will allow us to compare available results in the literature (Hussain et al. 2017, Tabain et al. 2020), mostly drawn from languages outside Africa, with new information from one of the most severely under-documented linguistic areas of the planet (Hammarström 2016), to formulate preliminary hypotheses for future empirical research

[1] As per Guthrie's (1971) referential classification, as updated by Maho (2009).

in the field, and to lay the groundwork for further articulatory studies to be conducted with the necessary instrumental equipment.

Second, North Boma is spoken in the Mushie territory of the Mai-Ndombe Province of the DRC, north of the Kwa and Mfimi Rivers. The reason why this is interesting is that, while retroflexion itself is not documented in the immediate vicinity of the area where North Boma is spoken, retroflex flaps can be found in the Bantu Lotwa languages of eastern Mai-Ndombe's last surviving foraging communities (Motingea 2010, Maselli 2024). These relic groups, often referred to as 'Pygmy' or 'Batwa',[2] are generally considered the descendants of ancestral hunter-gatherers who inhabited the area before the advent of Bantu speakers (Saïdi Hemedi et al. 2012: 3). Nowadays, all Mai-Ndombe Batwa speak Bantu languages; they are presumed to have shifted to Bantu and to have abandoned their own original languages, which supposedly belonged to one or more unrelated and no longer extant language families (Bahuchet 2012). The occurrence of retroflexion in hunter-gatherer languages is consistent with earlier accounts by Vorbichler (1966/7), who reports retroflex flaps in Efe, a Central Sudanic (Nilo-Saharan) language spoken by Bambuti foragers in the Ituri forest (northeastern DRC). A pre-Bantu 'forest substrate' (Möhlig 1981, Pacchiarotti & Bostoen 2020, 2022, Motingea 2021) has already been hypothesised to explain specific phonological features of the Bantu languages of West-Central Africa, which are geographically less widespread but linguistically more diverse than their relatives further east and south (Bostoen 2018). The North Boma case is of particular interest as it could provide new information on retroflexion as another possible substrate feature.

This paper aims to offer an exploratory acoustic description of nasal retroflexes in North Boma. More specifically, it provides as complete a phonetic examination of the available data on North Boma nasal retroflexes as possible, given the following limitations: first, the scarcity of the available data, and second, the lack of balance in our small corpus. The present contribution is organised as follows. In Section 2, we present an overview of documentary efforts on retroflex sounds in the world's languages. In Section 3, we present a concise overview of North Boma phonology. In Section 4, we describe the technical and environmental aspects related to the data collection and processing phase of our research. In Section 5, we offer an acoustic analysis of North Boma nasal retroflexes and adjoining vowels, and discuss this in the context of the relevant literature on the acoustic correlates of nasal retroflexes in the world's languages. In Section 6, we present a historical-phonological account for the development of phonemic nasal retroflexes in North Boma. In Section 7, we discuss phonetic and historical phonological findings. Section 8 concludes the article.

2. Documentation of retroflex sounds in Africa and beyond

Several phonological accounts of the properties of retroflexes are present in the literature. A few language-specific phonetic studies (acoustics, articulation, etc.) are also available. Firth (1948) presents palatograms from Marathi (Indo-Aryan), while Švarný & Zvelebil (1955) display palatograms, linguograms, and X-rays of retroflex consonants in several Indian languages, with special focus on Tamil. Other contributions are available on a wide array of languages of India (Heegård & Mørch 2004, Arsenault & Kochetov 2011, Kochetov et al. 2020, Hussain & Mielke 2021 on Kalasha, Indo-Aryan; see also Morgenstierne 1973, Ohala 1994,

[2] Both 'Pygmy' and 'Batwa' are exonyms, and neither is altogether exempt from negative connotations in present-day politico-linguistic discourse (Woodburn 1997, Lewis 2006). We will use 'Batwa' as the more neutral of the two. This is a term which Bantu speakers across the continent use to refer to what they consider to be autochthonous groups, not only in Central Africa, but also in Southern Africa (Schadeberg 1999). 'Batwa' is the plural of 'Mutwa'; a language spoken by Batwa is called 'Lotwa' in Mai-Ndombe, with the noun class prefix *lo-* (class 11), commonly used for glossonyms in the Bantu languages of the region. Elsewhere, such languages are sometimes referred to as 'Kitwa.'

Spajić, Ladefoged & Bhaskararao 1996, Dart & Nihalani 1999, Hussain et al. 2017, Smith et al. 2013a,b, Kochetov, Faytak & Nara 2019), South-East Asian languages (Qiuwu 2001, Michaud 2006, Thurgood 2009), and Norwegian (Simonsen, Moen & Cowen 2008, Stausland Johnsen 2012, 2013). Numerous fine-grained phonetic analyses are available on several Australian languages (Dixit 1990, Butcher 1995, Hamilton 1996, Tabain 2009, Fletcher, Loakes & Butcher 2014, Tabain & Beare 2016, 2017, Tabain et al. 2016, 2020).

However, to this day, comparatively few studies have been conducted on retroflexes in African languages. Bhat (1973) treats what he calls 'Central Africa' as a 'major retroflex area':

> Another major retroflex area is central Africa -- coast to coast from Guinea to Somali Republic, and Tanzania. Languages belonging to different families and stocks spoken in this area such as SHERBRO (WEST ATLANTIC); EWE and BINI (KWA); HAUSA (CHAD); KANURI (SAHARAN); BAGIRMI, MORU, BIRRI, BONGO, LUGBARA and DAIR (SUDANIC); BERTA; BEDAUYE, GOLLA, and SOMALI (CUSHITIC); WELAMO (OMOTIC); KONDE and MOMBASA SWAHILI (BANTU) are reported to have retroflexed sounds. (Bhat 1973: 14; capitals in the original)

The author does, however, go on to specify that retroflexion is 'not a prominent feature in most of the languages of this area' (same page; see similar remarks by Ladefoged 1964: 18, Ladefoged & Maddieson 1996: 25f).

Within the Niger-Congo phylum, Merrill (2022) offers a survey of the occurrence of voiceless rhotic/retroflex consonants in Atlantic and posits that a sound similar to [ʈ] or [ʈʂ] likely goes back to the most recent common ancestor of these languages. Outside Atlantic, Laver (1994: 222) mentions the presence of 'voiced alveolar retroflex flapped stops' in Gbaya (Ubangi, Sudan;[3] see also Lekens 1952, Samarin 1959, Walker & Samarin 1997) and Shona (Bantu S10, Zimbabwe).

Within Bantu, which is considered a low-level offshoot of Niger-Congo's Benue-Congo subunit, besides Shona, the diachrony of non-nasal retroflex stops in Kizigua (Bantu G311, Somalia) has been studied by Tse (2013, 2015); another relatively well-documented case is that of retroflex/flapped consonants in Kinyarwanda (Bantu JD61, Rwanda), for which acoustic, articulatory, and phonological accounts are available (Sibomana 1974, Kimenyi 1979, Walker & Mpiranya 2006, Walker, Byrd & Mpiranya 2008). In some western and northern Bantu languages of the Equateur Province and greater Bandundu region of the DRC (Motingea 2010: 205; earlier accounts of a similar phenomenon in northeastern DRC can be found in Vorbichler 1966/7), the flapped/retroflex realisation of laterals, rhotics, and occasionally alveolar stops has been attributed to the presence of an alleged hunter-gatherer substrate (Möhlig 1981) based, among other circumstances, on the fact that lateral flaps are commonly used as free variants of intervocalic laterals by rainforest hunter-gatherer groups (Maselli 2024; see above). However, no detailed phonetic studies of this phenomenon are available. To the best of our knowledge, there are no acoustic studies of retroflex sounds in any Bantu language of the DRC besides the one presented here, and very few are available from other corners of the Bantu domain (see references above).

3. North Boma phonology

In the lexicon-based phylogeny of Pacchiarotti et al. (2019: 185-189), North Boma constitutes, along with Tiene (Bantu B81), Mpe (B821), and Nunu (B822), a discrete subclade called Kwa-

[3] It is unclear what variety of Gbaya Laver is referencing here, based on Westermann & Ward (1933: 76), but none are spoken in Sudan today. It is likely that Laver's information is about speech communities in present-day Central African Republic.

Kasai North within the Kwilu-Ngounie subbranch of West-Coastal Bantu, itself a major branch of the Bantu family also known as West-Western Bantu (Grollemund et al. 2015, Koile et al. 2022). A schematic representation of the main phylogenetic groups within West-Coastal Bantu is given in Figure 1. Nasal retroflexes were also found in Nunu. However, due to insufficient data, we do not report on them in this contribution.

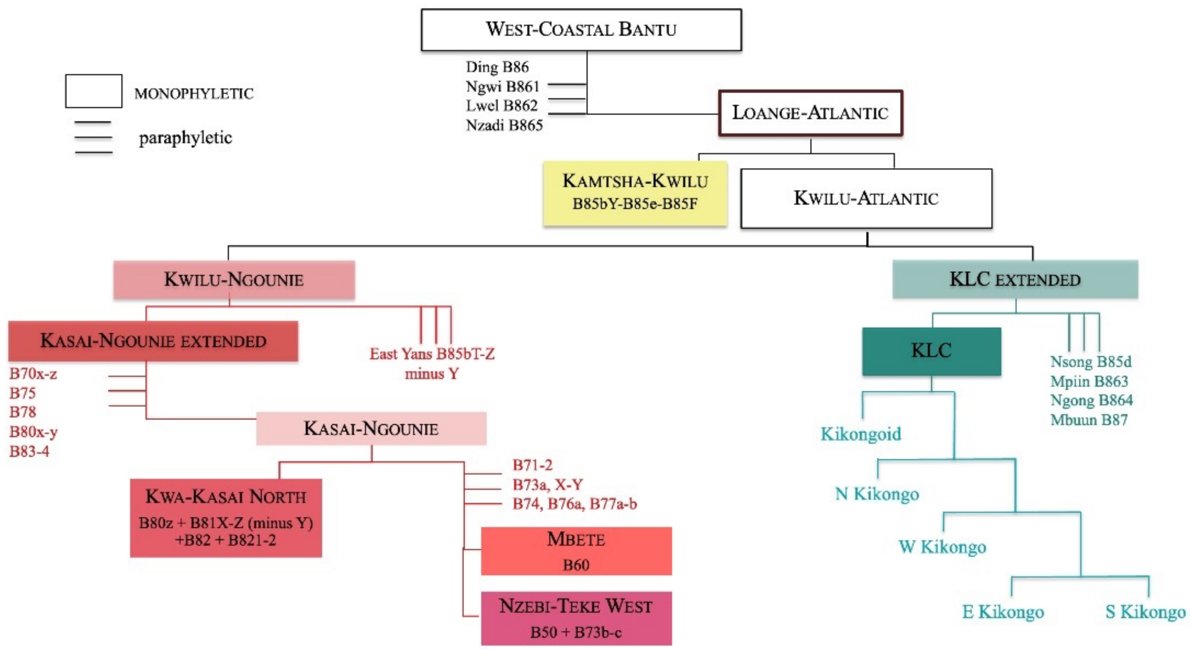


Figure 1 – Phylogenetic branches and subgroups within West-Coastal Bantu after Pacchiarotti et al. (2019) and de Schryver et al. (2015)

In Table 1 below, we present the consonantal inventory of North Boma as proposed by Stappers (1986: 1), the first to report the presence of nasal retroflexes in the language, with some modifications based on the data we collected during two fieldwork missions in 2021 and 2022 (see Sections 4 and 6); note that preN stands for 'prenasalised'.

	labial		*labiodental*		*alveolar*		*retroflex*	*palatal*		*velar*		*uvular*
nasal		m				n	ɳ		ɲ		ŋ	
lateral						l						
flap						ɾ	ɽ					
plosive	p	b			t	[d]		c	ɟ	k		
preN plosive	mp	mb			nt	nd		ɲc	ɲɟ	ŋk	ŋg	
fricative			f	v	s	z						ʁ
preN fricative			mf	mv	ns	nz						
affricate			tf	dv						kf	gv	
preN affricate			ntf	ndv	nts	ndz				ŋkf	ŋgv	
approximant									j		w	

Table 1 – Consonantal phonemes of North Boma according to Stappers (1986: 1) with our own addition of prenasalised obstruent series and the flap /ɾ/

According to Stappers (1986), all consonants in Table 1 are phonemic except [d], which is an allophone of /l/ when preceded by a nasal. This observation is fully confirmed by the data we collected in 2022. Based on our data, /ɽ/ appears to be a free variant of intervocalic /l/ and /ɾ/, the latter of which is not present in Stappers' consonantal inventory.

Stappers (1986) states that /g/ occurs only after /ŋ/. This is again confirmed by our own fieldwork data and in line with the fact that all languages belonging to the West-Coastal Bantu branch of which North Boma is part underwent a merger whereby Proto-Bantu (PB) *g and *k merged to /k/, except in contexts where *g was preceded by a homorganic nasal (see Pacchiarotti & Bostoen 2020 for a detailed account of this diachronic sound change). Post-nasally, the voicing contrast between *k and *g was preserved. For this reason, in Table 1, we included /ŋg/ instead of /g/ in the list of prenasalised plosives. In our data, we also find evidence for prenasalised fricatives and affricates, as can be seen in Table 1. All prenasalised obstruents, absent from Stappers' (1986) consonantal inventory, occur exclusively in stem-initial position. Like many other northwestern Bantu languages and Niger-Congo languages more generally, North Boma shows stem-initial prominence (Hyman 1998, 2008, Lionnet & Hyman 2018, Hyman et al. 2019: 196). This is visible, among other things, in the fact that only /m/, /ɳ/, /ŋ/, /ʁ/, /r/, /l/, /t/, and /n/ can occur in C_2 position in North Boma in a $C_1V_1C_2V_2$ template (where C stands for consonant and V for vowel), while all consonants in Table 1 with the exception of /ɳ/ and /ʁ/ can occur in C_1 position.

The phonemic status of /ɳ/ is confirmed by (near-) minimal pairs such as those in (1).

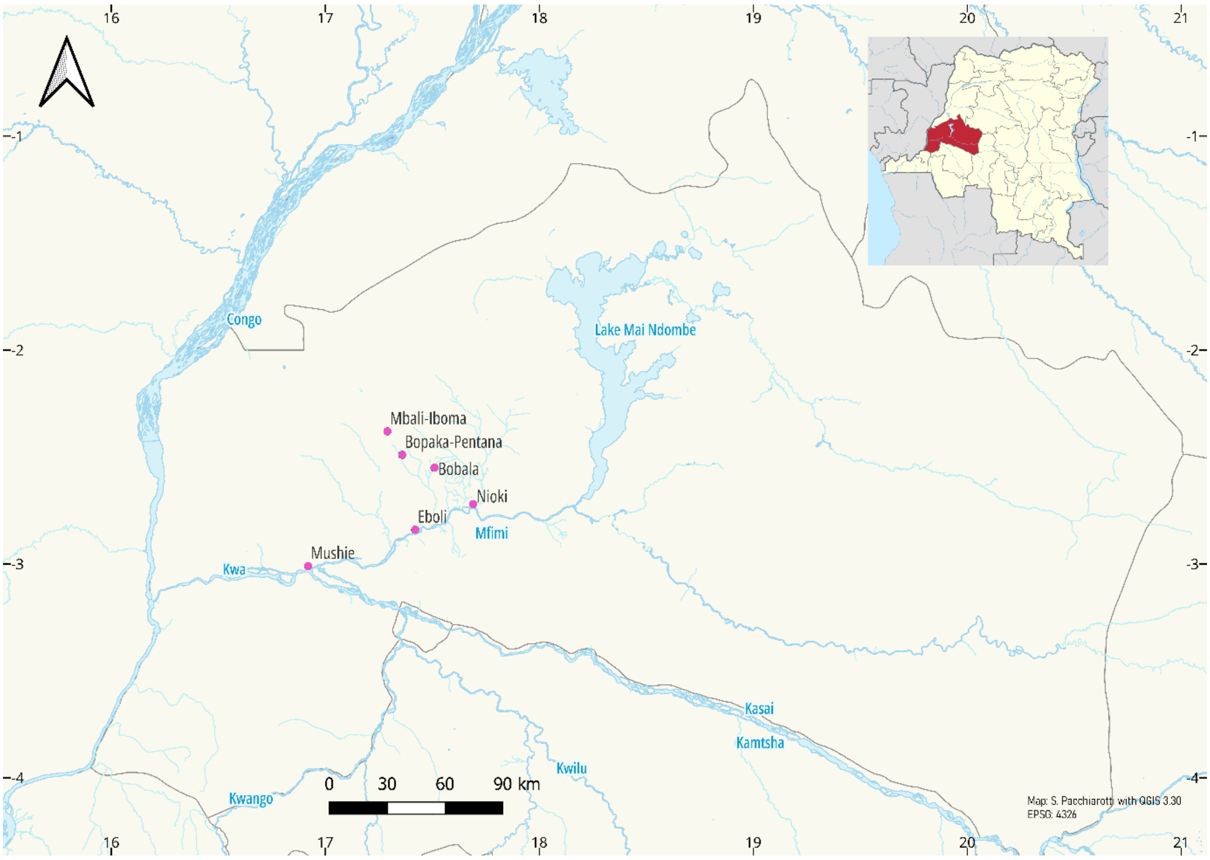
(1) a. ʁ/ɳ *mwáːʁà* 'year'
mwáːɳà 'child'
b. m/ɳ *ŋkːámá* 'hundred'
ŋkːáɳà 'I dance'

Stappers (1986: 4) provides contrasts for /n/ vs. /ɳ/ in C_2 position with the minimal pair *ɛkání* 'we had wished' vs. *ɛkáɳí* 'we had danced.' This pair as well as all others present in Stappers have been confirmed by our main consultant, the late Léon Mabwakha ma Bonkako, whose memory we wish to honour with the present contribution (see Acknowledgments). Nonetheless, there are very few words in the North Boma variety described by Stappers (1986), which appears to be nearly identical to the one spoken by Léon Mabwakha ma Bonkako, where /n/ occurs in C_2 position within a $C_1V_1C_2V_2(C_3V_3)$ template. This is because, as we show in Section 6, most PB *n and *nd in C_2 position merged into /ɳ/ in North Boma.

4. Data collection and processing

The data used for the phonetic analyses presented in this venue (available on OSF: https://osf.io/cmezd/?view_only=a0465124c79a4782bad819a830d21f0e) were collected by the first and third authors between June and July 2021, on a field mission to the Mai-Ndombe Province of the DRC. Data collection took place in Nioki (-2.72037, 17.69001), in the southern part of Mai-Ndombe; see Map 1.[4]

[4] Following the constitutional reform of 2006 (with subsequent modifications, or 'repartitioning,' in 2015), the DRC's local governance has been organised into a variety of hierarchical levels of administration (Province > territory > sector/chiefdom > grouping > village). Despite its relatively low level in this hierarchy, Nioki (part of the Kutu territory) represents the second-largest economic centre in the Province, and by far its second most multilingual municipality (after Inongo, the provincial capital), which is why several North Boma and Nunu speakers could be found and interviewed there.



Map 1 – The Mai-Ndombe Province of the DRC with consultants' locations

The authors recorded word lists, including basic Swadesh-100 lexical items, sentences, and free connected speech, with three local consultants. Additional data were collected at a later stage by the last three authors during a mission in Kinshasa in August 2022 through elicitation with the late Léon Mabwakha ma Bonkako. Elicited materials in 2022 included a list of approximately 800 words. An overview of the relevant information on the four speakers is provided below, with their places of birth indicated on Map 1:

- Subject A: 35 years, male, first language: North Boma, place of birth: Mbali (a.k.a. Mbali-Iboma, -2.38, 17.29), mother's place of birth: Mbali, father's place of birth: Izana (possibly Izono,[5] -2.60, 17.56);
- Subject B: 37, male, North Boma, place of birth: Bobala (-2.56, 17.52), mother's place of birth: Bobala, father's place of birth: Izono;
- Subject C: 50, male, North Boma, place of birth: Mushie (-3.02, 16.92), mother's place of birth: Mushie, father's place of birth: Mushie;
- Léon Mabwakha ma Bonkako (no pseudonymisation provided): 80, male, North Boma, place of birth: Bopaka (-2.49, 17.36), mother's place of birth: Bopaka, father's place of birth: Bopaka.[6]

Recording sessions took place indoors, in a relatively quiet environment with no echo discernible in the background. Part of the data was recorded on Roland R-26 and Zoom H-5 devices with their built-in directional microphones, and the rest on the same Roland R-26

[5] Izono is organised into four *de facto* semi-independent villages. No further information could be retrieved from our consultant as to the exact origin of his father.
[6] The fact that all speakers are male is merely an accident of circumstance and does not reflect language endangerment in any way.

device with an external plug-in omnidirectional microphone (Saramonic Lavalier Microphone SR-XLM1) clipped onto the speakers' clothes (sideways from the mouth). The sampling rate was kept at 44.1 kHz; maximum input, whenever verifiable, was set at 75% to minimise clipping; depth was set at 24 bits. The data were then imported into Praat (Boersma 2001) for annotation and analysis. Annotation and transcription of the data collected in 2021 were carried out by the first author and checked against preliminary descriptions of the sounds of interest by Stappers (1986). The transcription of the data collected in 2022 was carried out by the fourth author, and phonetic annotation of the relevant segments was performed by the first author. The relevant acoustic variables (duration, formant, and spectral moment values; see below) were semi-automatically extracted from Praat by dint of a script specially written by the second author.

Formant values were sampled at 10%, 30%, 50%, 70%, and 90% of the duration of the segments of interest, i.e. nasals and adjacent vowels. Both consonants and vowels were considered given that key cues to consonant acoustics can be found in segment transitions (see, among others, Catford 1977, Johnson 2012). We extracted F1, F2, F3, and F4 median values with their relative bandwidths, average bandwidth over F1 to F4, as well as F1 and F2 onset and offset slopes (for vowels: offset slopes for pre-consonantal, and onset slopes for post-consonantal ones). Onset slopes were calculated as a function of F1/F2 formant values at 50% of the total duration of the sound of interest minus the same value at the 10% temporal mark, divided by 40% of the total duration of the sound. Conversely, offset slopes were calculated as formant value at 90% minus formant value at 50% on 40% of the segment's total duration:

$$\text{Onset slope} = \frac{\text{Formant value at 50\% of the total duration of the sound of interest} - \text{Formant value at 10\%}}{\text{Total duration of the sound of interest} * (40/100)}$$

$$\text{Offset slope} = \frac{\text{Formant value at 90\% of the total duration of the sound of interest} - \text{Formant value at 50\%}}{\text{Total duration of the sound of interest} * (40/100)}$$

Formant transitions have been the focus of a lot of research on coronal oppositions, especially in relation to retroflexion (Halle, Hughes & Radley 1957, Delattre, Liberman & Cooper 1962, Butcher 1995, Iskarous, Fowler & Whalen 2010, Rhone & Jongman 2012). In particular, a lowered F3 both on the vowel preceding the sound and on the first part of the sound itself is considered an indicator of retroflexion (Steriade 1995, 2001a, Tabain 2009, 2011, 2012). F4 is also, to some extent, affected by the same phenomenon and a lowered F4 has been associated with retroflex articulations (Hussain et al. 2017). Importantly, Tabain et al. (2016, 2020) found F3 to be the most relevant correlate to retroflexion in the Australian languages that they surveyed, but they described the contrast between retroflexes and other coronal articulations as comparatively weak in their pool. Retroflexes also appeared to pattern with other coronals in terms of bandwidth values for F1-F4, which the authors took to suggest coronals undergo less acoustic damping than other nasals.

Less attention has been paid to spectral moments as cues to articulatory configurations of the vocal tract in the production of retroflexes (Tabain et al. 2016, Themistocleous, Fyndanis & Tsapkini 2021). Spectral moment values correspond to a sound's centre of gravity, standard deviation, skewness, and kurtosis (Forrest et al. 1988, Nittrouer 1995, Tanner et al. 2005, Li, Edwards & Beckman 2009, Schindler & Draxler 2013). In spectral moment analysis, the sound's power spectrum is treated as a probability distribution and its mathematical moments are calculated accordingly (Li et al. 2009: 3), as shown in Figure 2.

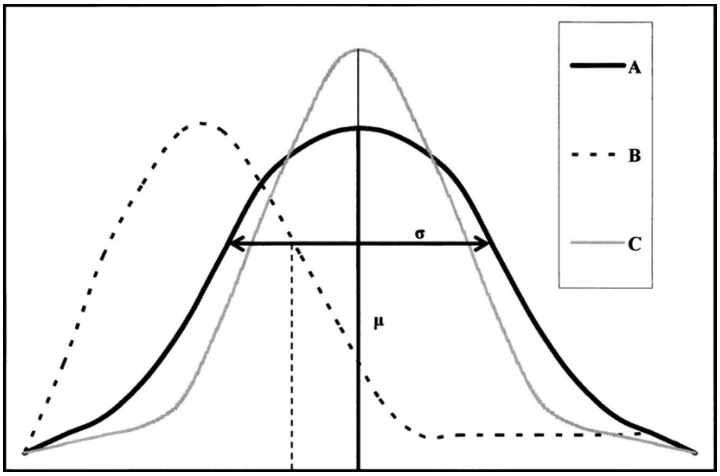


Figure 2 – Centre of gravity (μ), standard deviation (σ), skewness, and kurtosis of a probability distribution. A = normal distribution, with corresponding μ and σ; B = positively skewed distribution and corresponding shift in mean (dotted vertical line); C = peaked distribution with positive kurtosis (source: Tanner et al. 2005)

Spectra displaying one dominant mode tend to exhibit a negative correlation between the first moment (centre of gravity) and the resonant cavity's length, offering a rough indication of constriction position. The second spectral moment (standard deviation) serves the primary purpose of distinguishing between a broad, dispersed spectrum and sharper, more concentrated energy distributions. The third spectral moment (skewness) correlates to articulation placement. Broadly, a positive value suggests an accumulation of energy in the lower frequencies below the mean. The fourth spectral moment (kurtosis) can help distinguish tongue posture differences with higher tongue positions leading to higher kurtosis, in turn contributing to alterations in the spectral shape's peak concentration (see Li et al. 2009: 3). Spectral moment analysis has been applied most profitably to the study of noisy spectra such as those of fricatives; in the case of nasals, spectral moment analysis has been used most recently by Tabain et al. (2016), though their study is limited to centre of gravity and standard deviation. We believe that, given the nature of our corpus and the suboptimality of acoustic data collection in field settings, spectral moment analysis is better suited than other, traditional methods of nasal spectrum analysis (Recasens 1983), such as antiformant analysis, to provide a preliminary description of nasal retroflexes in North Boma.

Spectral moments were calculated differently for vowels and consonants. For vowels, the analysis range was set at 0 to 5,000 Hz,[7] and for consonants at 1,000 to 5,000 Hz (in a way similar to Tabain et al. 2016). This is because, in voiced consonants, energy concentrations lower than 1,000 Hz essentially correspond to voicing, and the aim of moment measurements is rather to capture place of articulation (i.e. features of the supralaryngeal tract). On the other hand, in the case of vowels, information related to F1 is typically located below 1,000 Hz, which justifies the range selection mentioned above. Vowel and consonant values are never compared directly in this study, which allows for the adoption of two different set ranges.

For the purposes of this contribution, spectral moment values were sampled at 10%, 50%, and 90% of the duration of the segments of interest. We obtained average formant and spectral-moment values for the whole segment (from 10% to 90% of the duration). Spectral moments were calculated in two separate ways:

[7] To account for potential Direct Current (DC) offset, the first 100 Hz were filtered out using a Hann band-pass filter.

- *Over the entire segment*. This method is largely inspired by DiCanio's (2021) script,[8] based (among others) on Shadle (2012) and Forrest et al. (1988). This method was originally developed for fricatives. It involves: (i) analysing the central 80% of the consonant by calculating several spectra over consecutive windows within this larger 80%-duration window, and then (ii) averaging the spectra before measuring the moments: "Within time-averaging, a number of DFTs [discrete Fourier transforms] are taken from across the duration of the fricative. These DFTs are averaged for each token and then the moments are calculated. The analyzed duration of the fricative is always equivalent to the center 80% of the total duration, cutting off the transitions" (DiCanio 2021). Analysis parameters were adjusted to account for duration variations across the corpus, which contains very short segments (retroflex: average approx. 50 ms ± 20) and others over twice as long (other consonants: average approx. 110 ms ± 55). Thus, the number of windows used to calculate the spectra equals 5 windows of 15 ms each. In practice, if the segment was 110 ms, we discarded the first 11 and the last 11 ms, which results in 5 almost consecutive windows of 15 ms (inter-window signal portions of 3 ms were not analysed). If the segment was shorter, windows were permitted to overlap up to a maximum of 50% of their duration (to avoid overanalysing the central portion of the segment), which accounts for segments down to 45 ms;
- *In a single window positioned at specific points of the segment*. This second method is based on Tabain et al. (2016): a 20-ms window centred around the middle portion of the segment, with analysis over a frequency range of 1,000 to 5,000 Hz (for consonants). The main difference from Tabain et al.'s (2016) previous method is that we performed the measurement of spectral moments directly via Praat's algorithm. Note that, unlike Tabain et al. (2016), we also adopted the same procedure at 10% and 90% of the segment's total duration, both for vowels and consonants. For segments shorter than 100 ms, this includes a very short portion of the adjacent segment in the relevant window. For example, in the case of a nasal segment of 50 ms, centring our analysis window around 10% of the sound's duration (i.e. at 5 ms from the start of the segment), our analysis would start at -5 ms (5 ms before the segment boundary, or the last 5 ms of the preceding vowel) and end at +15 ms. Given that (i) we want to capture transition effects, and (ii) the values remain very small, roughly overlapping manual segmentation error (5 ms), we hold this is an acceptable trade-off for a method which is overall better tailored to our specific needs.

It should be mentioned that the way values were measured for 'duration' and 'spectral moments' might risk obfuscating the effect of place of articulation on the phonetic realisation of the sounds at hand. This is because nasal retroflexes and non-retroflexes mostly occur in different contexts where duration differences are expected irrespective of place of articulation. Additionally, spectral moments are sensitive to lots of different factors, such as background noise and how much vowel is included in the measurement window, which might compound the duration issue. In order to address these points, modified versions of the dataset were produced, one balanced for duration (i.e. only including observations with duration values lower than 0.1 s) and one without spectral moment values (see below, Section 5.3).

The datasets resulting from the extraction of the parameters listed above were then imported into R and RStudio (RStudio Team 2019, R Core Team 2020), for the purposes of statistical analysis and modelling (including the production of all relevant graphs and averaged

[8] Available at https://www.acsu.buffalo.edu/~cdicanio/scripts/Time_averaging_for_fricatives_4.0.praat. Version nr. 4.0, updated in 2021.

Fast Fourier Transform, or FFT, spectra) and mined with FactoMineR (Lê, Josse & Husson 2008).

5. Acoustic characteristics of nasal retroflexes in North Boma

5.1 Preliminary observations – Broadly speaking, clear spectral cues to tease retroflex and non-retroflex nasal sounds apart in North Boma are scarce. However, a few preliminary observations can be drawn from the comparison of word-internal nasal oppositions as shown in Figure 3 with [inấɳa] 'eight.'

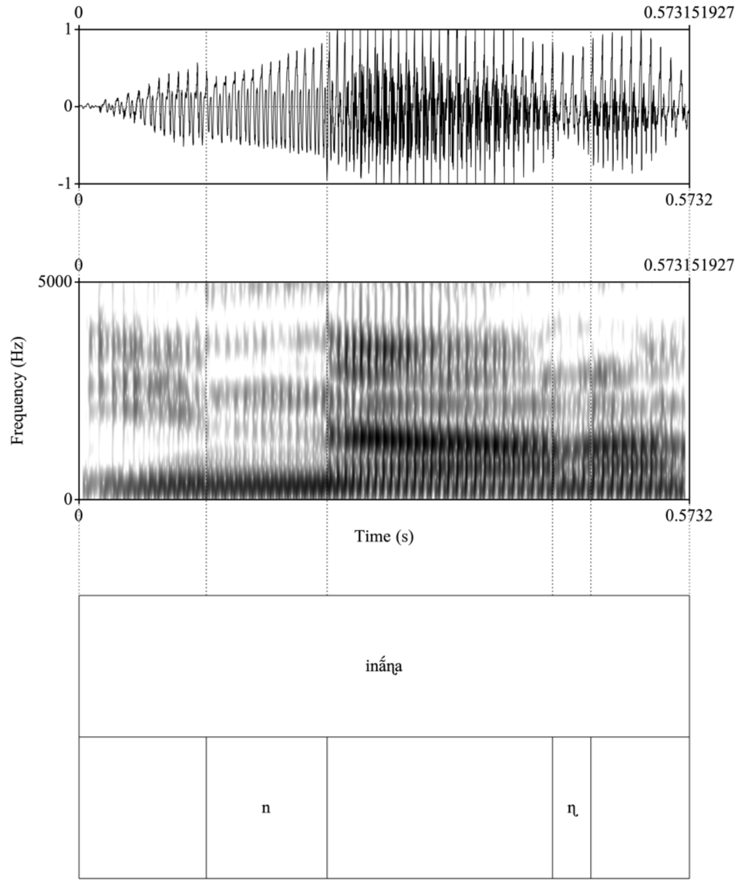


Figure 3 – Oscillogram, spectrogram, and segmentation of one repetition of the word [inấɳa] 'eight' as produced by Subject C; audio file available on OSF (name: Figure 3 audio)

The retroflex segment is considerably shorter than the alveolar; this is compatible with our understanding of transient articulations such as those of flaps and taps (see Laver 1994: 221-227, Bickford & Floyd 2006: 141-142, Warner et al. 2009, Derrick & Gick 2011).[9] However, effects of position may also come into play, with consonants in C_2 position (see Section 6) undergoing shortening (see below, Section 5.2).

[9] Following Bickford & Floyd's (2006) indications, the articulatory difference between a nasal retroflex and a nasalised flap ([ɳ]/[ɽ̃]) is minimal (possibly limited to segment duration and/or the presence of a flicking articulation). It is worth mentioning that a similar descriptive problem is tackled tangentially by Thayer (1974: 212) in sketching a comparative phonology of Sara-Bongo-Bagirmi languages from the Central African Republic-Chad-South Sudan border area; see also Bhat (1973: 30), Stevens & Blumstein (1975: 231-232), Harnsberger (1998: 29, 56), Arsenault (2017: 24fn).

In a handful of interesting cases, a high-frequency spike in intensity (circled in red in Figure 4) can be observed in the spectrogram when a nasal retroflex occurs (especially in the speech of Subject C).

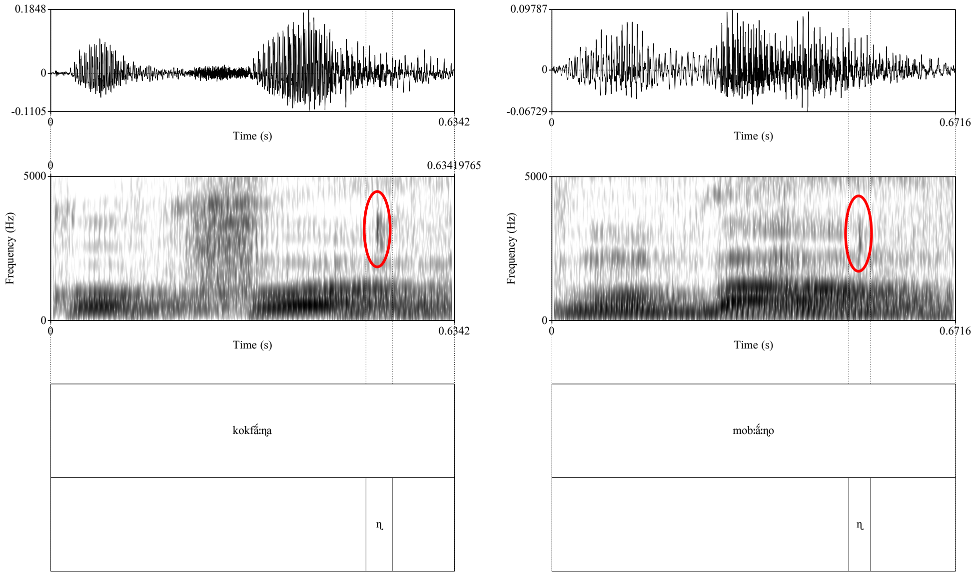


Figure 4 – To the left: oscillogram, spectrogram, and segmentation of [kokfá̃:ɳa] 'to bury;' to the right: [mob:á̃:ɳo] 'expensive;' both pronounced by Subject C (audio files available on OSF as Fig 4 – 1 audio and Fig 4 – 2 audio respectively)

This very short span of higher-frequency noise might indicate the presence of a transient percussion, such as the one effected by the tongue against the palate in some flapped articulations (see also Švarný & Zvelebil 1955: 390). However, we are dealing with a weak indicator at best since it does not occur consistently across realisations.

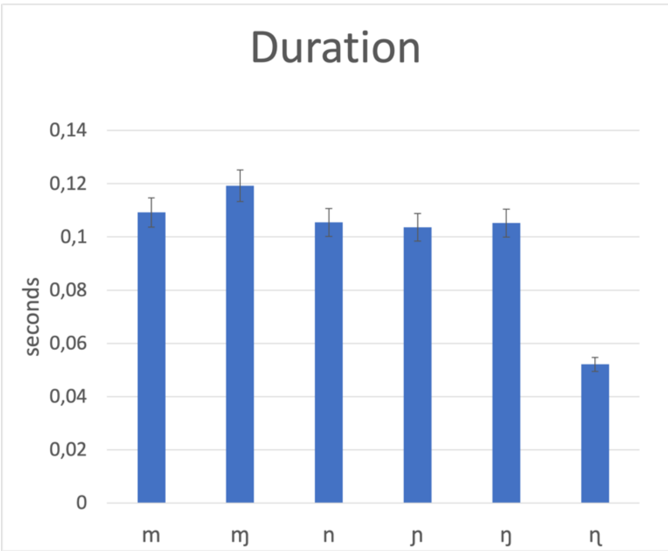


Figure 5 – Average duration of North Boma nasals (see below)

5.2 Descriptive statistics – A series of descriptive statistics was performed to summarise our dataset (which includes [m], allophonic [ɱ] in pre-labiodental position, [n], [ɲ], [ɳ] and [ŋ]).[10]

[10] The relevant datasets are available on OSF (Data folder).

Full results are displayed in the Appendix (part 2). On average, nasal retroflexes appear to be markedly shorter than their non-retroflex counterparts (their length is roughly half that of the other nasals; see Figure 5 above). This might be in keeping with our preliminary observation (see above) that nasal retroflexes behave more like flaps than nasal stops.

This effect may also be enhanced by blurriness at the relevant segmental edges. Considering that these sounds are particularly subject to internal changes in articulatory targets, it becomes apparent that assigning clear-cut segmental boundaries can be complicated and possibly result in the identification of a core section without its more coarticulated boundaries.

Figure 6 summarises averaged median formant and bandwidth values for the six nasal places of articulation.

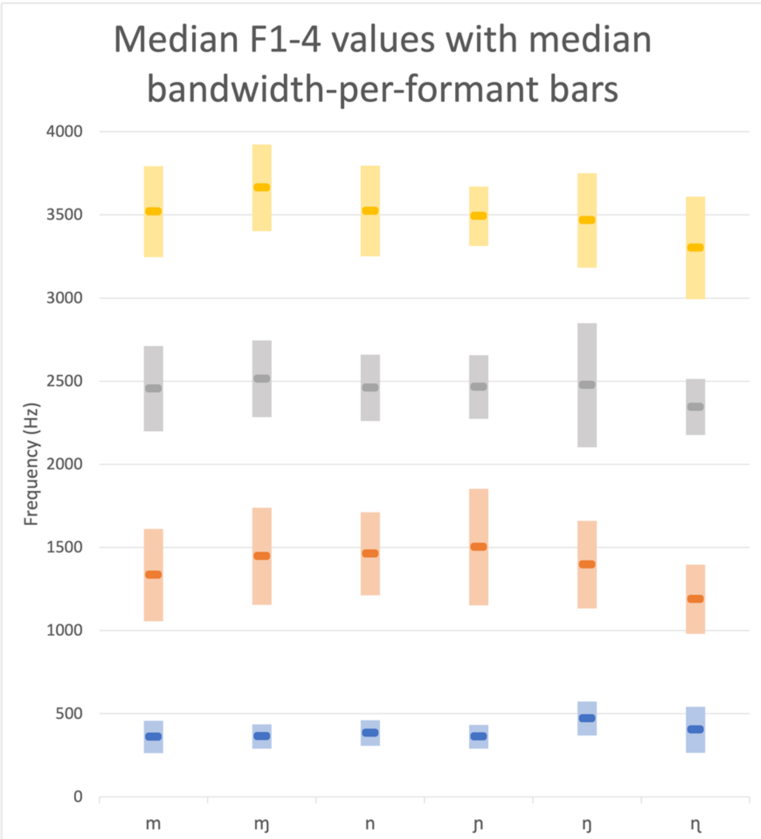


Figure 6 – Averaged median formant values (horizontal lines) for six types of North Boma nasals with their relative average median bandwidth (bars)

F2-F4 values appear to be lower for retroflexes than their non-retroflex counterparts; contrary to our expectations, this effect is greater for F2 and F4 than for F3. Retroflex consonants’ F2 trajectories are expected to be largely language-dependent (Hamann 2003: 59). Since articulatory predictions concerning the acoustics of retroflex sounds suggest that the presence of a posterior articulation would result in raised F2 (via the insertion of a low-frequency resonance between F2 and F3, see, e.g., Stevens 1998: 436ff), it can be hypothesised that nasal retroflexes in North Boma are characterised by tongue retraction, resulting in lower F2 values, more than by other cross-linguistically well-attested retroflexion mechanisms; see Dart & Nihalani’s (1999) data on Malayalam. In turn, the inter-F3/4 spectral region in retroflexes has often been claimed to be narrower than in other articulations (Stevens & Blumstein 1975: 219), which would explain why F4 is more significantly lowered than F3.

F1 bandwidth values are higher for nasal retroflexes than for their non-retroflex counterparts. This could be achieved through lengthening of both the front and back cavity, which is compatible with a more perpendicular position of the tongue against the passive articulator (thereby minimising the tongue-palate contact area); if coupled with the notion that F2 values tend to be lower on retroflexes than on their non-retroflex counterparts, this observation points in the direction of a (sub-)apical alveolar articulation. A wide F1 bandwidth has also been linked to more important acoustic losses in the nasal cavity, bringing F1 closer to the fundamental frequency (Stevens 1998). Additionally, wider bandwidths are an indicator of higher damping, which in turn could point to a tighter constriction in the vocal tract (Tabain et al. 2016; notably, the authors found the opposite to be true in their sample of Australian languages, see Section 7).

Figure 7 summarises spectral moment values in North Boma. Centre of gravity values are lower for retroflexes than non-retroflexes, while the effect of standard deviation (SDev) is less patent.

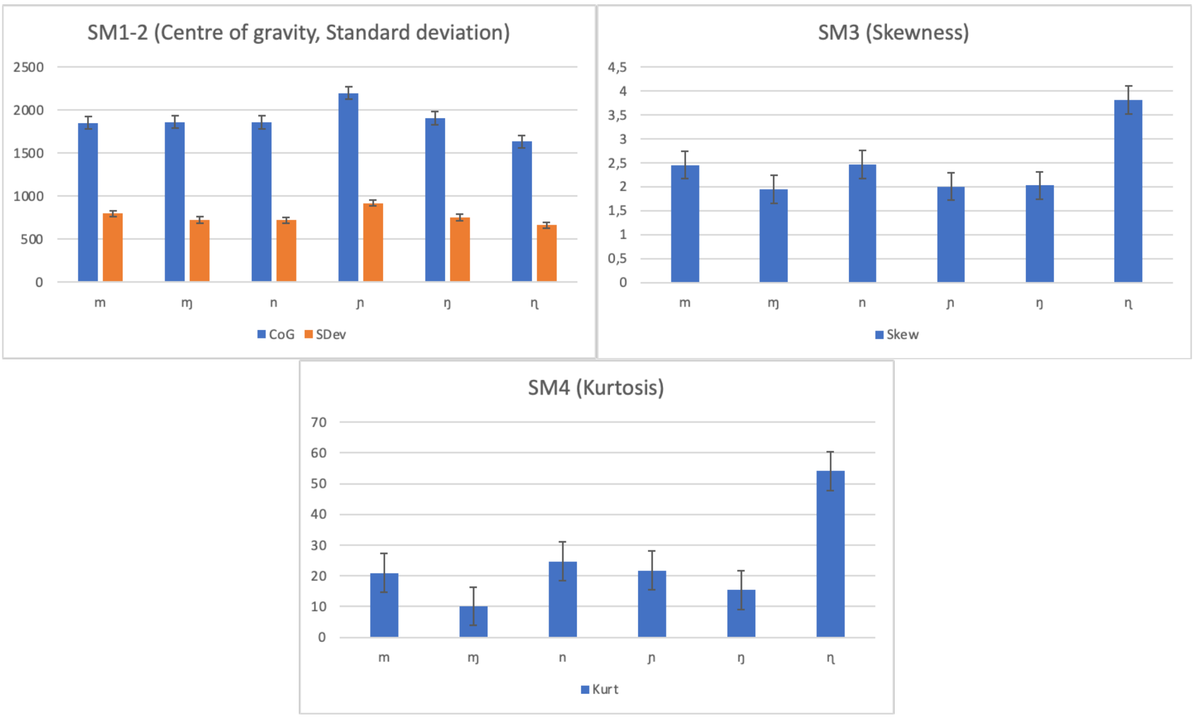


Figure 7 – Average spectral moment values for six types of North Boma nasals (95% confidence interval); centre of gravity and standard deviation are expressed in Hz, while skewness and kurtosis are dimensionless (see Harrington 2010: 41)

Skewness and kurtosis values also distinguish nasal retroflexes from their non-retroflex counterparts, with the former scoring higher average values than the latter. This is compatible with higher (and more peaked)[11] concentrations of energy in the spectral area below their centroid frequency. In order to further illustrate this point, we computed averaged FFT spectra across multiple windows within each segment; results are shown in Figure 8. This averaging reduces the influence of transient fluctuations and provides a more stable representation of the sound's overall spectral shape. The script used to extract the information presented in Figure 8 was written by the second author and is available on OSF (FFT folder). As hypothesised based

[11] Skewness and kurtosis, the way they are defined above, are not entirely independent of one another; see the following passage: 'Skewed distributions are always leptokurtic […]. Among the several alternative measures of kurtosis that have been proposed (none of which has often been employed), is one which adjusts the measurement of kurtosis to remove the effect of skewness […]. There is much confusion about how kurtosis is related to the shape of distributions […]. It is easy to confuse low kurtosis with high variance, but distributions with identical kurtosis can differ in variance, and distributions with identical variances can differ in kurtosis' (Wuensch 2005: 3).

on the preliminary descriptive statistics presented earlier in this Section, nasal retroflexes display lower centres of gravity with higher energy, especially below their centroid frequency.

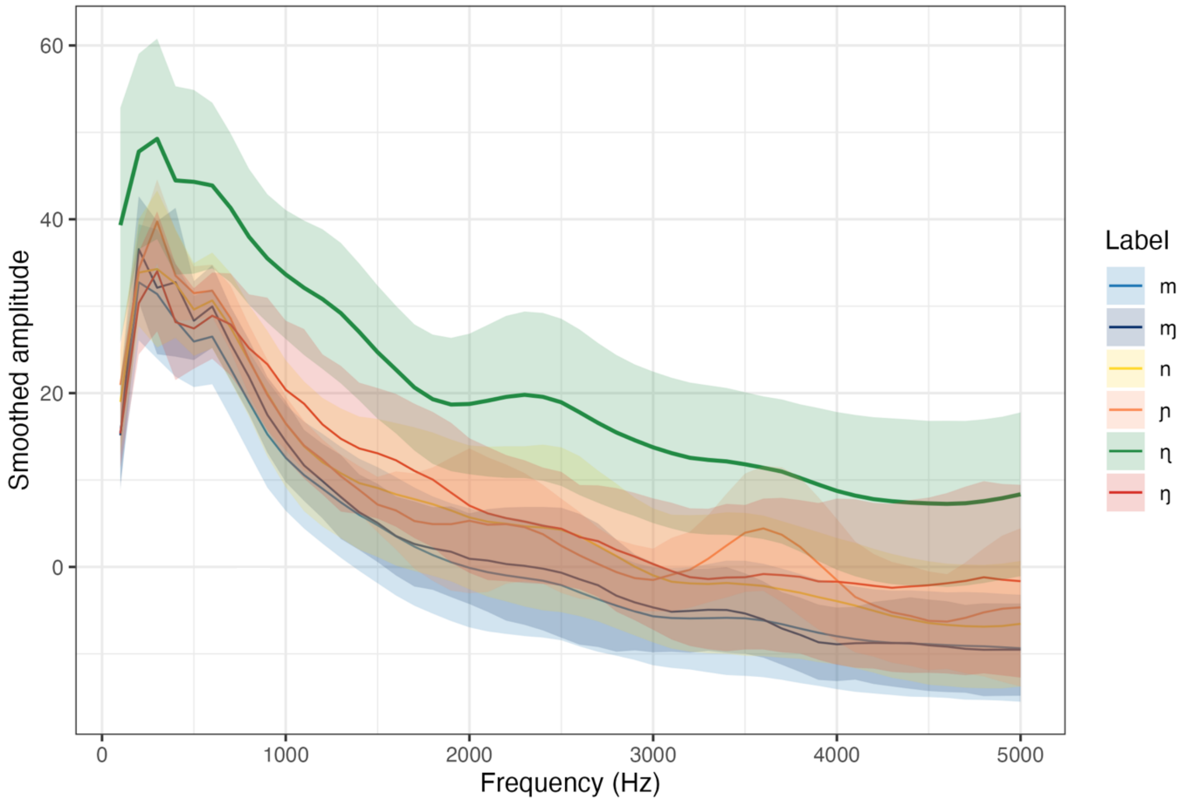


Figure 8 – Averaged FFT spectra for six types of nasals in North Boma
(mean smoothed amplitude across all nasal segments, with ribbons for standard deviation)[12]

5.3 Factorial analyses – A Multiple Factor Analysis (MFA) was performed on the dataset. MFA is an extension of Principal Component Analysis (PCA). In order to understand how MFA works, we first review the fundamentals of PCA. PCA is a dimensionality reduction technique used to simplify complex datasets by transforming them into a new set of variables called 'principal components.' These principal components are linear combinations of the original dimensions. They are arranged in order of importance, with the first component explaining the most variation in the data, the second component being the second most indicative, and so on. In PCA terms, 'dimension' refers to the original variables or attributes that were used as input data. Dimensions are defined as percentages of total inertia (a measure of the points' weighted spread), and their correlation to specific variables indicates to what extent those variables can explain the percentage(s) of inertia they express. PCA aims to reduce these dimensions into a smaller set of components, i.e. the principal components, that capture the essential information in the data while minimising redundancy. These principal components are the new dimensions explaining the structure of the data.

MFA is a factorial method specifically designed to analyse datasets where variables are structured into groups. It is 'tailored to handle multiple data tables that measure sets of variables collected on the same observations' (Abdi et al. 2013). In practice, MFA takes a set of

[12] An interesting feature of these spectra, otherwise not highlighted by our research, is that the overall amplitude of the nasal retroflex is higher than that of its non-retroflex counterparts. We do not have a conclusive explanation of this phenomenon as yet, but can hypothesise that this is probably a side effect of kurtosis, with energy concentrated below the centroid frequency raising the overall level. In addition, the sound's transient, sometimes non-continuous nature may also contribute to increased energy, a fact possibly reinforced by lower damping or reduced turbulence due to shorter duration.

observations described by a certain number of variables and yields a measure of the degree to which each variable group (as opposed to individual variables) explains variance in the set (see Abdi & Valentin 2007). Several sets of variables (continuous or categorical) are analysed in two steps. First, a PCA is run on the quantitative variables (in our case, clustered into the following groups: 'duration,' 'formant values,' 'bandwidth values,' 'slope values,' and 'spectral moments'). Second, an estimate and *p*-value of the correlation between all (supplementary) qualitative variables (in our case, 'segment' and 'retroflexion') and the dimensions (principal components) produced by the first PCA are provided.

MFA is used when more than one set of variables has been measured for the same observations. In our case, several sets of variables (both quantitative and qualitative, see above) have been measured for the same individual observations (in this case, North Boma nasals). Therefore, MFA allows us to see what quantitative variables best explain variance in the corpus, and which of the two qualitative variables ('segment' and 'retroflexion') better describes the North Boma nasal acoustic space – in other words, we aim to determine whether nasal retroflexes constitute a compact and separate group from the other nasals of North Boma, and what acoustic parameters best explain their difference from those other nasals.

MFA have also been conducted on slightly modified versions of the dataset, one balanced by duration (i.e. only including observations with duration values lower than 0.1 s) and one without spectral moment values (see Section 4).

For the purposes of this presentation, we will only comment on individual factor maps;[13] these graphically represent each group of observations (average values) with the extracted values for all the variable sets and its barycentre on the plane described by the two top dimensions of the PCA. See, for example, Figure 9.

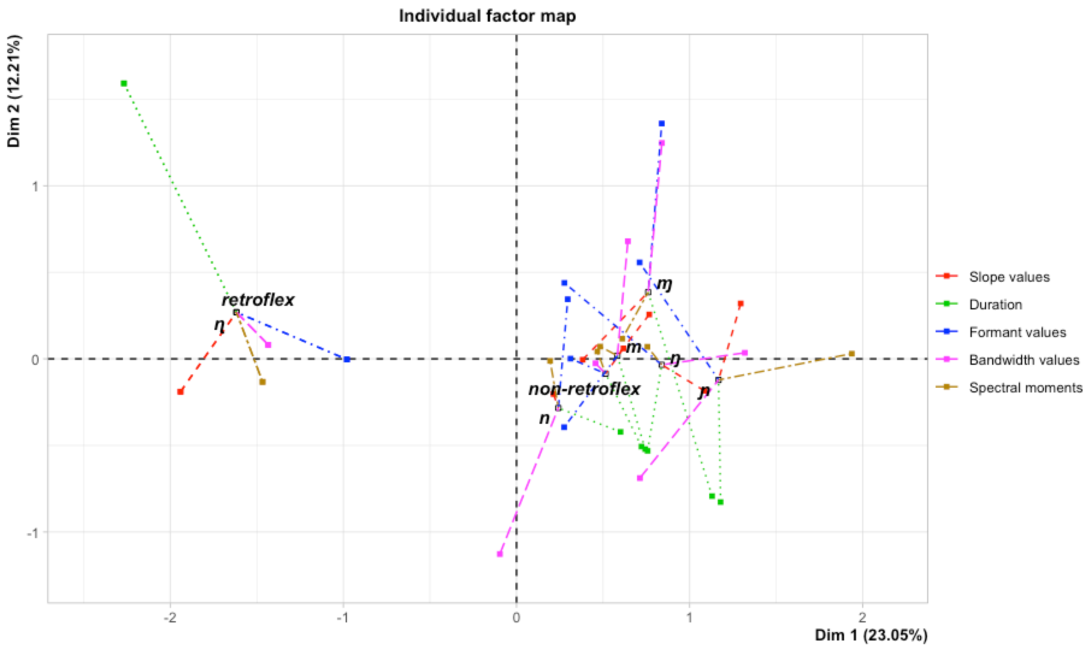


Figure 9 – Individual factor map of the entire dataset

In Figure 9, an individual factor map is presented for the entire dataset (all consonants, all duration values) with all variable groups. Each observation set (labelled in bold in Figure 9) is connected to small, coloured squares (at the end of every dotted line) representing its average value for the five variable group measurements of interest; the label itself is placed at the barycentre of these average values on the plane. The plane is defined by the first two principal

[13] Other graphs are made available on OSF, see MFA folder.

components (here, dimensions 1 and 2)[14] of the PCA. As can be seen, retroflex and non-retroflex segments constitute two separate groups with very distinct acoustic characteristics. Along the dimension 1 axis, which accounts for around one fourth of the dataset's total inertia (in other words, it explains one fourth of the variance, i.e. the 'behaviour' of the data), retroflex and non-retroflex segments exhibit inverse correlations for almost every variable, with the exception of bandwidth values for the nasal alveolar. Dimension 1 is described by the following characteristics (Table 2): [15]

Top variables	*Correlation (r)*	*p-value*
Duration	0.71	<.001
F2 bandwidth	0.68	<.001
Centre of gravity	0.68	<.001
F2 onset slope	0.65	<.001
F1	-0.29	<.001
F1 bandwidth	-0.29	<.001
Kurtosis	-0.52	<.001
Skewness	-0.53	<.001

Table 2 – Top 8 quantitative variables correlated (4 directly and 4 inversely) with dimension 1 of the MFA summarised in Figure 9 (values rounded up, only two decimal points shown)

Retroflexes are significantly shorter than non-retroflexes; they exhibit lower F2 bandwidth values, have a lower centre of gravity, and tend to be characterised by negative F2 onset slopes; at the same time, they show higher spectral tilt (skewness) values, higher kurtosis, and higher F1 and F1 bandwidth values. This is due to the fact that nasal retroflexes show higher concentrations of energy in the lower regions of the spectrum around the centre of gravity; duration values are compatible with the possibility that North Boma retroflexes behave like nasalised flaps.

As mentioned above, MFA were also run on modified versions of the dataset to account for duration biases and other related issues, including the sensitivity of spectral moment values to background noise and vocalic context. Because nasal retroflexes and non-retroflexes mostly occur in different contexts where duration differences are expected irrespective of place of articulation, the duration-balanced set was restricted to segments shorter than 0.1 s (see above, Section 4). Figure 10 (next page) presents individual factor maps of this duration-balanced set and of the same set as above (Figure 9) without spectral moment values.

As can be seen in Figure 10, the acoustic distinction between retroflex and non-retroflex segments remains sharp whether the sets are balanced for duration or not. Nasal retroflexes remain negatively correlated with dimension 1, with non-retroflexes on the positive side of the same axis (the only exception being nasal palatal duration values). The main variable groups defining dimension 1 are now 'formant values' and 'spectral moments,' with retroflexes exhibiting once again lower F2 bandwidth values and higher F1 and F1 bandwidth values than their non-retroflex counterparts, along with higher skewness and kurtosis and a lower centre of gravity.[16] When spectral moment values are excluded from the analysis, a newly defined dimension 1 (mostly correlated with duration, slope, and bandwidth) is inversely correlated with the dataset's retroflexes and directly correlated with their non-retroflex counterparts

[14] Let the reader be reminded that, in PCA terms, 'dimension' refers to the original variables or attributes that were used as input data, and PCA aims to reduce these dimensions into a smaller set of components that capture the essential information in the data while minimising redundancy. Therefore, on the plane at hand, the variables of interest are plotted against the two principal components of the PCA originally performed on the dataset; these principal components are known as 'dimension 1' and 'dimension 2.'

[15] Complete dimension descriptions are available on OSF; only immediately relevant ones will be commented on in the prose.

[16] See ConsMedShortMFAlog.docx on OSF.

(except for labiodental and alveolar slope values, as well as alveolar bandwidth values, which tallies with the situation presented in Figure 8). Taken together, these supplementary analyses suggest that duration alone does not account for the retroflex/non-retroflex opposition in North Boma and show how other acoustic variables (chiefly bandwidth and formant values) contribute to informing the distinction.

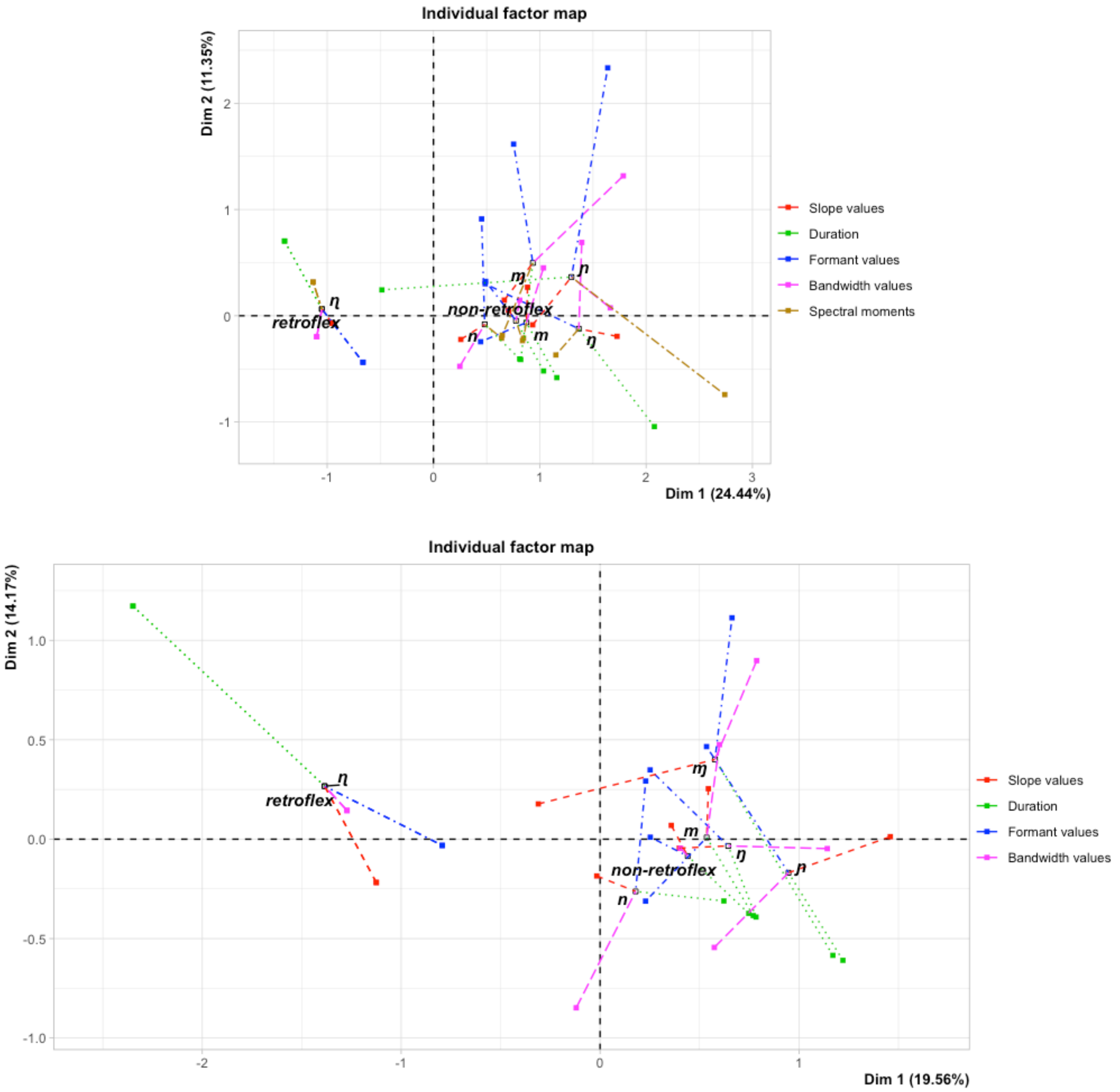


Figure 10 – Individual factor maps of: above, a duration-balanced set (restricted to segments shorter than 0.1 s); below, the entire dataset without spectral moment values

MFA were also performed on the entire dataset with values measured at 10% and 90% of the sounds' total duration, to account for the hypothesis advanced earlier in this Section regarding flicking in the speech of Subject C; it has been mentioned (see above) that retroflexes can affect different targets throughout their articulation, with the tongue tip 'flapping out' of a curled-up position. In their typology of the sounds of the world's languages, Ladefoged & Maddieson (1996) claim that the 'tongue tip first bends back into the retroflex position, and then, during the closure phase, straightens out somewhat, so that by the time of the release of the closure it is in a less extreme position' (p. 28). This does not appear to be the case in North Boma; see Figure 11 (next page).

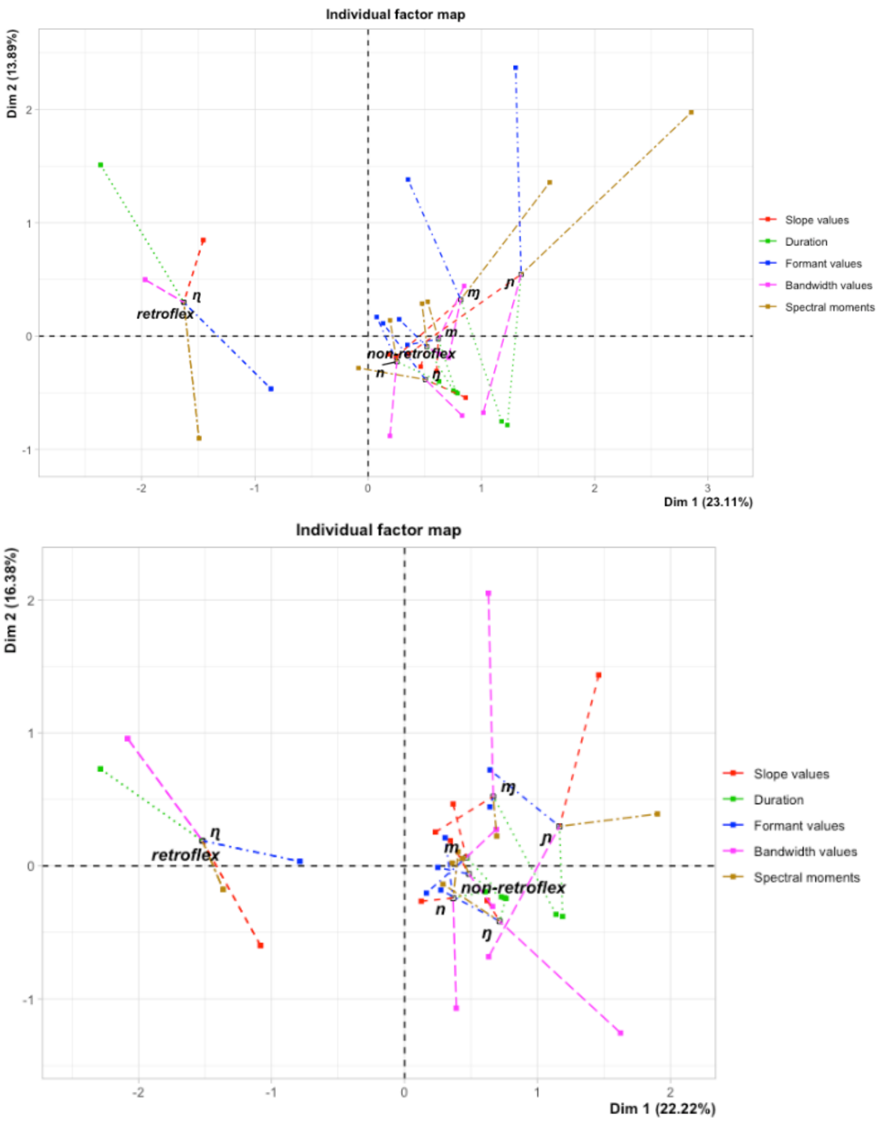


Figure 11 – Individual factor maps of: above, the entire dataset with values measured at 10% of the sounds' total duration; below, the entire dataset with values measured at 90% of the sounds' total duration (see below)

The important similarities between the two planes at 10% and 90% of the sounds' total duration indicate that nasal retroflexes in North Boma behave rather uniformly throughout their articulation, apart from slope and formant values (as would be expected in onset vs. offset position). Regardless, 'retroflexion' remains the most important variable in the definition of the planes, as was the case in all other MFA performed and shown above.

Based on the results summarised up to this point, North Boma nasal retroflexes constitute a discrete class within the language's nasal inventory. Compared to their non-retroflex counterparts, they are significantly shorter, exhibit lower concentrations of energy in the spectrum with more energy concentrated around their centre of gravity (as well as more peaked energy concentrations), show higher values of F1 and F1 bandwidth and lower values of F2 bandwidth; they are not characterised by different acoustic properties in onset vs. offset position, suggesting that they do *not* in fact behave like quickly flicking flaps as had been hypothesised based on some features of the speech of Subject C. This, coupled with the phonological information provided above, backstops their characterisation by Stappers (1986) as fully fledged nasal retroflexes.

5.4 Vowels – Nasal-adjacent vowels have also been analysed to account for coarticulation effects and to determine whether any effects attributable to proximity to a nasal retroflex can be detected (full results available in the Appendix, part 2). Figure 12 compares duration values for the three cardinal vowels /a/, /i/, and /u/.

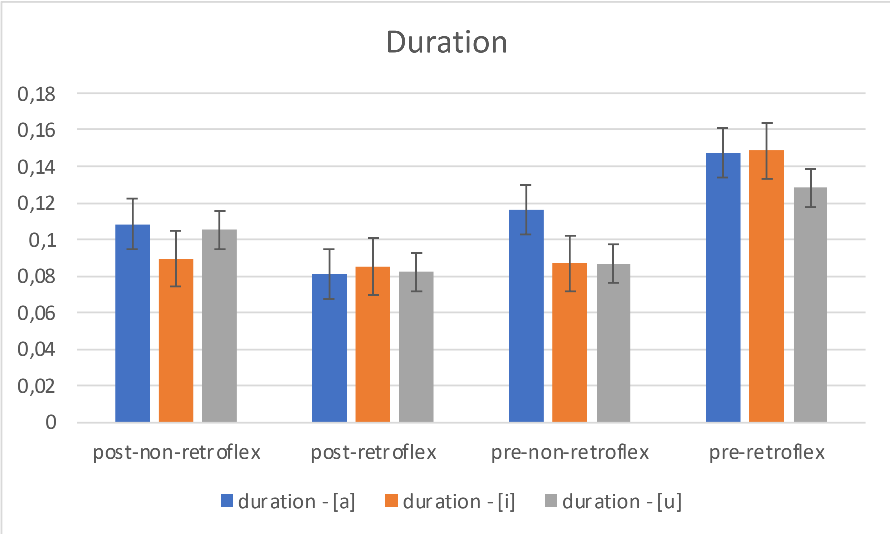


Figure 12 – Average duration values for three nasal-adjacent cardinal vowels in North Boma

All three vowels appear to be longer in pre-retroflex position, but only two of them (/a/ and /u/) display similar adjacency effects in post-retroflex position, where they are shorter.[17] A MFA was performed on the same vowels; the results are shown in Figure 13.

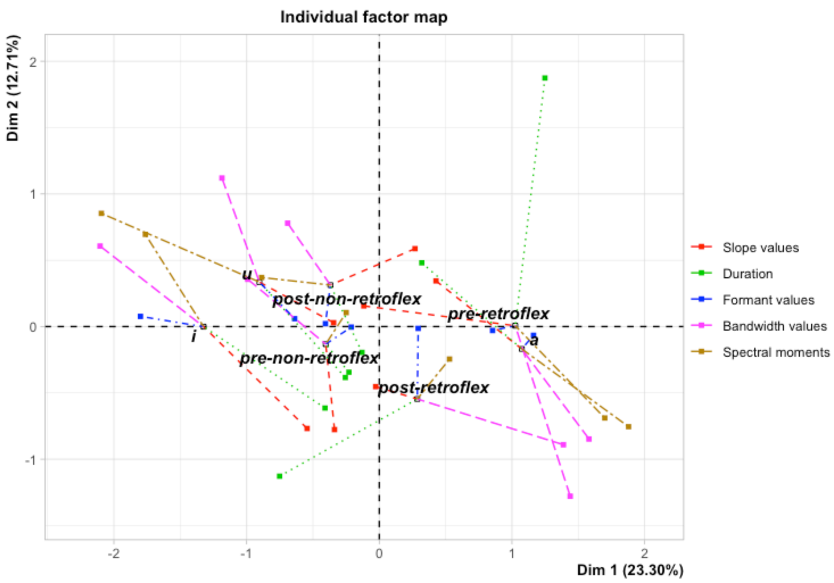


Figure 13 – Individual factor map of the entire cardinal vowel dataset

Retroflex adjacency is positively correlated with dimension 1 of the plane (which alone accounts for around one fourth of the set's total inertia); however, as one can clearly see, the

[17] In this regard, Matt Gordon (pers. comm.) notes that, in the Australian language Martuthunira, a stem-final [i] asymmetrically selects a suffix allomorph beginning with an alveolar (rather than its counterpart allomorph beginning with a retroflex; Dench 1995). In line with Steriade (2001a), this may be due to the fact that the high front tongue position for [i] is relatively incompatible with the tongue configuration characteristically associated with retroflexes.

distinction is a lot less sharp than was observed for the consonants, with vowel quality effects (e.g., high vs. low) weighing more in the definition of the plane than vowel position. As a matter of fact, Table 3 clearly shows that of the two qualitative variables at hand, ‘position’ is a lot less significantly correlated with dimension 1 than ‘segment’:

Qualitative variables	*Correlation (r)*	*p-value*
Segment	0.54	<.001
Position	0.14	<.001

Table 3 – Qualitative variables correlated with dimension 1 of the MFA summarised in Figure 13

In other words, acoustic vowel measurements differ by vowel phoneme considerably more than by context. No specific effects of retroflexion could be detected on the nasal’s vocalic environment.

6. Diachronic phonology of North Boma nasal retroflexes

We now move away from phonetic analysis and turn to the discussion of the historical origins of /ɳ/ in North Boma; in Section 7, we present a comprehensive review of all results, both phonetic and diachronic-phonological.

Historically, /ɳ/ is the regular reflex of PB *n and *nd in C_2 position within the root, as can be seen in (2).[18] In (2), slashes separate singular and plural forms of the same noun and hyphens show morphological segmentation of noun class prefixes and noun roots. In North Boma, /ɳ/ never occurs in C_1 position within a $C_1V_1C_2V_2(C_3V_3)$ template. Throughout this Section, a given North Boma synchronic form is posited as the reflex of a protoform. This protoform, conventionally preceded by an asterisk in historical linguistics, is accompanied by a number which identifies a unique entry in the Bantu Lexical Reconstruction (BLR) 2/3 database (Bastin et al. 2002). This database contains nearly 10,000 Bantu lexical reconstructions of variable time depth (Bostoen & Bastin 2016). The meaning of a given reflex in North Boma is specified only when it differs from that of the protoform.

(2)	C_2 *n	BLR 3203	*jánà	‘child’	>	*mw-áɳà/mj-áɳà*
		BLR 3472	*jínò	‘tooth’	>	*zj-úɳù/mj-úɳù*
		BLR 5531	*tínì	‘piece’	>	*kè-tːíɳì/bè-tːíɳì*
		BLR 1805	*kín	‘dance’	>	*kò-kːáɳ-à*[19]
		BLR 2041	*kʊ́n	‘plant’	>	*kò-kwáɳ-à*
		BLR 661	*còn	‘write’	>	*kò-cːɔ́ɳ-ɔ̀*
	C_2 *nd	BLR 579	*cíndí	‘squirrel’	>	Ø-*nsíːɳí*/ Ø-*nsíːɳí*
		BLR 1446	*gòndé	‘crocodile’	>	Ø-*ŋgɔ̀ːɳé*/ Ø-*ŋgɔ̀ːɳé*
		BLR 543	*céndé	‘thorn’	>	Ø-*nsjɛ́ɳɛ́*/ Ø-*nsjɛ́ɳɛ́*
		BLR 1628	*jʊ̀ndʊ̀	‘hammer’	>	Ø-*nɟúːɳù*/Ø-*nɟúːɳù*
		BLR 6697	*pònd	‘rot’	>	*kò-pɔ̂ɳ-ɔ̀*
		BLR 2044	*kʊ́nd	‘love’	>	*kò-kwáɳ-à*
		BLR 2125	*kùnd	‘bury’	>	*kò-kfwáɳà*

[18] We only have one example out of 130 words with /ɳ/ or /n/ in C_2/C_3 where /ɳ/ is the reflex of *nt but this nasal + plosive sequence is found in a reconstruction which is only tentative, namely *tant ‘bite.’ Certainly, historical *nt simplified to *n but the evidence is virtually non-existent to claim that this outcome also underwent the shift to /ɳ/.

[19] In North Boma, the onset consonant in a syllable carrying a high tone is phonetically realised as a geminate, except when followed by a diphthong, see, e.g. *kò-kwáɳ-à* ‘to plant’ and *kò-kfwáɳà* ‘to bury’ in (2). We thank an anonymous reviewer for pointing out this exception. While this pattern is systematic in our data, we do not know what explains lack of gemination in the presence of a diphthong.

By contrast, /n/ in C_1 is the regular reflex of PB *n as shown in (3). Note that *nd did not occur in C_1 position in PB except across morpheme boundaries, i.e. whenever *d was preceded by a homorganic class 9/10 nasal prefix N-. This noun class prefix was often reanalysed as part of the root as shown in (3), see, e.g., *Ø-ndúːɳú/ Ø-ndúːɳú*, historically *n-dúːɳú*.

(3)	C_1 *n	BLR 5428	*nuku	'meat'	>	*mù-nːúʁù/mì-nːúʁù*
		BLR 3683	*nàì	'four'	>	*nî*
		BLR 2286	*nók	'rain'	>	*kò-nːɔ́ʁ-ɔ̀*
		BLR 2342	*nʊ́	'drink'	>	*kò-nw-á*
		BLR 1561	*jàdí	'lightning'	>	*Ø-ndzàlí/Ø-ndzàlí*
		BLR 4340	*dʊ̀ndà	'fish sp.'	>	*Ø-ndúːɳú/Ø-ndúːɳú* 'electric fish'

In North Boma, nasal + plosive sequences in C_2 position underwent reduction in favour of the nasal, i.e. *mb > /m/, e.g., *Ø-ndzàːmí* 'God' (< BLR 3196 *jàmbé), *ŋg > /ŋ/, e.g., *è-káŋà/ŋ-káŋà* 'guineafowl' (< BLR 1720 *káŋgà). /ŋ/ is the only outcome of this cluster reduction process which further underwent total loss (/ŋ/ > Ø) in the vast majority of relevant lexical items, e.g., *è-báá/m-báá* 'jaw, chin' (< BLR 108 *báŋgá). The reduction of NC_{+voice} > N happened not only in North Boma but in many other West-Coastal Bantu languages (Pacchiarotti et al. 2024, Bostoen et al. 2025). Given the pervasiveness of /ɳ/ in the lexicon of North Boma, the most likely scenario is that this sound change occurred only after the simplification of *nd > /n/, once the historical simple nasal C_2 *n had merged with *n historically originating from the simplification of C_2 *nd.[20]

In Bantu languages, the vowel preceding a nasal cluster (nasal + plosive) usually gets lengthened (Hyman 2019). This can be seen in words such as *n-síːɳí/n-síːɳí* 'squirrel' and *ŋ-gɔ̀ːɳé/ŋ-gɔ̀ːɳé* 'crocodile' in (2). In turn, lengthened vowels are an ideal phonetic environment for the emergence of diphthongs in West-Coastal Bantu languages (Koni Muluwa & Bostoen 2012; Pacchiarotti, Maselli & Bostoen 2021). Indeed, there is evidence that diphthongisation of long vowels also happened in North Boma, see, e.g., *n-sjɛ́ɳɛ́/n-sjɛ́ɳɛ́* 'thorn' and *kò-kwáɳ-à* 'to love' in (2), but diphthongisation is also found in words containing historical short vowels preceding *n such as *kò-kwáɳ-à* 'to plant' in (1), as well as *ì-kjáɳá/mà-kjáɳá* 'dance' (< BLR 1807 *kínà) and *kò-mjáɳ-à* 'to swallow' (< BLR 2190 *mìn). This might have happened by way of analogy with historically lengthened vowels preceding nasal clusters while the merger *n, *nd > n was ongoing. Similarly, and perhaps also due to analogical change, not all vowels historically preceding a nasal cluster were lengthened, see, e.g., *mù-kàɳú/mì-kàɳú* 'news' (< BLR 1706 *kàndá 'letter').[21]

Nevertheless, there are a few lexical items which appear to have escaped the change *n, *nd > /ɳ/ in C_2 and rather preserved /n/, giving rise to the minimal pair *ɛkání* 'we had wished' vs. *ɛkáɳí* 'we had danced,' which Stappers (1986) uses to show that /ɳ/ contrasts with /n/ in C_2 position in North Boma. In most instances, we find no readily identifiable conditioning environment that could have blocked this diachronic sound change. Although several nouns preserving /n/ in C_2 end in /i/ as can be seen in (4), there are just as many cases where a final /i/ is preceded by /ɳ/, as shown in (5). In the same vein, the different vowels preceding C_2 /n/

[20] An anonymous reviewer wonders why the merger of PB *n and *nd happened only in stem-final position in North Boma. We believe there are at least two possible explanations for the absence of this merger in stem-initial position. The first is that North Boma is a language with stem initial prominence, where contrasts are more likely to be maintained in stem-initial position because more segments can occur there. The second is that there is a strong crosslinguistic bias for phonological neutralisation to favour word ends rather than beginnings (Wedel et al. 2019).

[21] *mù-kàɳú/mì-kàɳú* 'news' could alternatively be a reflex of BLR 1317 *gànò 'wisdom' or BLR 1318 *gànò 'tale; proverb,' in which case the short vowel would be expected.

in (4) cannot be considered a conditioning environment preventing the merger *n, *nd > /ɳ/ from occurring because /u/, /ʊ/, and /a/ are also found in lexical items where C_2 *n/*nd did become /ɳ/, see (2).

(4)	BLR 1545	*kùndú	'stomach'	>	*ì-kfǔní/mà-kfǔní*	'belly'
	BLR 1627	*jʊ̀nì	'bird'	>	*Ø-ɲúnì/Ø-ɲúnì*	
	BLR 2390	*pándà	'branch, fork'	>	*Ø-mpánì/ Ø-mpánì*	'branch'
	BLR 8292	*jání	'sun'	>	*mw-ání/mj-ání*	'light, day'

(5)	BLR 2206	*món	'see'	>	*kè-mːɔ́ɳ-ì/bè-mːɔ́ɳ-ì*	'fortune teller'
	BLR 579	*cíndí	'squirrel'	>	*Ø-nsíːɳí/Ø-nsíːɳí*	
	BLR 2577	*pínd	'(be) black'	>	*m-pìɳ-í*	
	BLR 9667	*jini	'pubes'	>	*mù-zìːɳí/mì-zìːɳí*	'anus'

Additionally, three lexical items indicate that some of the few synchronic occurrences of /n/ in C_2 position originate from PB *nj, phonetically probably [ɲɟ] or [ɲd͡ʒ], e.g., *kè-kánì/bè-kánì* 'hand' (< BLR 1329 *gànjà), *n-zénːé* 'cricket' (< BLR 1583 *njénjé), or PB *ny, phonetically probably [ɲ], e.g., *kò-ŋɔ́n-ɔ̀* 'to twist' (< BLR 1945 *kóny), *kò-ɲán-à* 'to swim' (< BLR *nyány). The fact that *n as the reflex of *nj and *ny did not merge with *n originating from either PB *n or *nd in C_2 possibly indicates that the simplification *ɲɟ > ɲ and the merger with *ɲ > n occurred after the merger *n, *nd > n > ɳ. Otherwise, /n/ originating from *ɲ (from PB *ɲɟ and *ɲ) would have undergone retroflexion too.

Finally, we discuss occurrences of /ɳ/ in C_3 position. In this position, /ɳ/ in North Boma is the reflex of a historical *n in the same phonotactic position, e.g., *mù-sámúɳù* 'six' < (BLR 433 *cààmànò 'six'), or the outcome of a common Bantu nasal harmony process whereby a stop becomes a nasal usually maintaining the same place of articulation as the stop, whenever the root contains a nasal consonant, e.g., *è-bɛ́mɛ́ɳɛ́/m-bɛ́mɛ́ɳɛ́* 'mosquito' (< BLR 7535 *bémbédé 'mosquito'). In such cases, /d/ in a form such as *bémbédé underwent nasal harmony to *bémbéné in earlier stages of North Boma. Nasal harmony must have happened before the change *n > ɲ took place in order to account for the synchronic outcome *è-bɛ́mɛ́ɳɛ́/m-bɛ́mɛ́ɳɛ́* 'mosquito.' The same seriation of nasal harmony *d > n followed by retroflexion of *n > ɲ also occurred in verb stems with derivational suffixes such as *-ad, *-ɪd, and *-ʊd and without any synchronically retrievable corresponding root. Some instances are: *kò-zímàɳ-à* 'to forget' (< BLR 5716 *dímbad 'to forget'), *kò-sɛ́mɔ̀ɳɔ̀* 'to slip' (< BLR 509 *cèdɪmʊk 'to slip', likely to have undergone metathesis to *cèmɪdʊk), *è-ŋ-kfúmɛ̀ɳɛ̀* 'stuttering' (< BLR 5379 *kʊ́kʊmɪd 'to stammer'), *kò-kːámɔ̀ɳ-ɔ̀* 'to squeeze' (< BLR 1691 *kámʊd 'to wring, to squeeze'); see also *kò-bímàɳ-à* 'to sleep' (< BLR 6025 *bítam 'to lie down', likely to have undergone metathesis to *bímat).

Yet, there is evidence that in a few cases the nasal harmony process did give rise to /n/ instead of /ɳ/; see, e.g., *kò-zíɣìnà* 'to learn' (< BLR 3338 *jíg 'to learn, to imitate'), *kò-záʁánè* 'to spread out in the sun' (< BLR 3206 *jánɪk 'to spread to dry in the sun'), and *kò-sːíɣínè* 'push back' (< BLR 2934 *tíndɪk 'to push back'). The last two examples suggest that metathesis might have played a role in these seemingly irregular outcomes, e.g., *jánɪk > *jakɪn* > *jakan* > *záʁánè*; *tíndɪk > *tíkɪnd* > *tíkɪn* > *sːíɣínè*.[22] Metathesis in verb stems is known to be common in Tiene (Ellington 1977, Hyman 2010), one of North Boma's closest relatives, see Figure 1.

[22] With possible spirantisation of /t/ > [s] (see Schadeberg 1995, Bostoen 2008). Note that in North Boma /ʁ/ is the expected reflex of Proto-West-Coastal Bantu *k (Pacchiarotti & Bostoen 2020). /ʁ/ has /ɣ/ as an allophone whenever it is followed or preceded by /i/ (Stappers 1986: 3).

Whatever the case might be, synchronically, the consonantal portion of a typical PB derivational suffix such as applicative *-ɪd always surfaces as /ɳ/ if the verb stem contains a nasal, see /kò-túm-ɪd-à/ ‘INF-send-APPL-FV’ > [kòtúmὲɳɛ̀], /kò-tfúm-ɪd-a/ ‘INF-sew-APPL-FV’ > [kòtfúmὲɳɛ̀], but /kò-kàb-ɪd-a/ ‘INF-offer-APPL-FV’ > [kòkàbέrì]. Whenever the verb root contains /ɳ/ in C_2 and is followed by an applicative suffix which is then realised as /ɳ/ due to nasal harmony, the outcome of a sequence of two [ɳ] after vowel apocope yields [nː]. This is shown in Table 4 with the synchronic derivation of the applicative form *kò-mːánn-è* [kòmːánːè] from its corresponding root *kò-mːáɳ-à* ‘to finish.’

	kò-mːáɳ-à ‘to finish’
applicative derivation	*kò-mːáɳ-ɪd-à*
nasal harmony	*kò-mːáɳ-ɪɳ-à*
final vowel height harmony	*kò-mːáɳ-ɪɳ-è*
applicative vowel apocope	*kò-mːáɳ-ɳ-è*
retroflex > alveolar gemination	*kò-mːán-n-è*

Table 4 – Synchronic derivation of the applicative form *kò-mːán-nè* [kòmːánːè] from its corresponding root *kò-mːáɳ-à* ‘to finish’ in North Boma

The emergence of [nː] out of a sequence of two [ɳ] is also observed with derivational suffixes other than the applicative. Compare *kò-kfwáɳ-à* ‘to bury’ (< BLR 2125 *kùnd ‘to bury’) and *kò-kfúnːò* ‘to dig up’ (< BLR 2126 *kùnd-ʊd ‘to dig up’, derived from BLR 2125 *kùnd by the so-called reversive suffix *-ʊd; see Schadeberg & Bostoen 2019). Based on the evidence we have gathered so far, one could imagine a chain of changes like the following: *kùndʊd > *kfú:nʊd > *kfú:ɳʊd > *kfúɳʊɳ/kfúɳʊn > *kfúɳɳ/kfúɳn > kfúnː.[23] The verb form *kò-bːínːò* ‘to dig up’ (< BLR 209 *bínd ‘obstruct’) probably underwent a similar chain of changes. Thus, it seems that C_2 [nː] derives from a $C_1V_1C_2V_2C_3V_3$ templatic structure where C_2 was /ɳ/ and C_3V_3 is a derivational suffix which underwent nasal harmony and was realised by default as /ɳ/.

In sum, /ɳ/ is a phonotactically restricted phoneme in North Boma which only occurs in C_2/C_3 position within a $C_1V_1C_2V_2C_3V_3$ template. Historically, /ɳ/ is the reflex of PB *n and *nd. The *nd sequence simplified to *n at some point in the history of this language and merged with PB *n. Both etymological *n as well as *n deriving from the cluster reduction *nd > n developed into /ɳ/ in C_2/C_3 position. In C_1 position, PB *n and *nd were maintained as such. However, this merger did not affect all lexical items, so much so that some historical *n (whether from PB *n or *nd) were maintained as alveolar nasals in C_2 instead of undergoing retroflexion. Other synchronic C_2 /n/ in North Boma originate in PB C_2 *nj, phonetically [ɲdʒ] or [ɲɟ], and PB *ny, phonetically [ɲ].

In the Appendix (part 1), we provide a comparative list of all lexical items we found which contain /ɳ/ or /n/ in C_2 and C_3 positions in the data from our fieldwork missions (2021 and 2022) as well as in the grammar sketch of Stappers (1986).

7. Discussion

In this article, we have shown that nasal retroflexes in North Boma differ significantly from their non-retroflex counterparts. A first visual inspection of the available samples allowed us to identify a tendency for nasal retroflexes to display greater concentrations of energy in the lower regions of the spectrum and fewer or less identifiable higher-frequency intensity peaks, i.e. less clear formant structure throughout the sound. Following this first step, a series of descriptive statistics were run to summarise the dataset. Nasal retroflexes were found to be

[23] In this hypothetical chain, the spirantisation of *k > /kf/ and the tonal dissimilation of *LL (low-low) to HL (high-low; BLR 2125 *kùnd-ʊd ‘to bury’ > *kfwáɳ-à* ‘to bury’) are arbitrarily placed at the beginning. We have no evidence for their seriation with respect to other changes.

shorter than their non-retroflex counterparts, and to exhibit lower F2, F3, and F4 average values than all other nasals in the set, while no effect of bandwidth could be identified at this stage, apart from F1 (greater F1 bandwidth values for retroflexes than non-retroflexes). This is at odds with the finding of Tabain et al. (2016) that coronal nasals exhibit the lowest bandwidth values in their sample of Australian languages, and points to the presence of a more diffuse murmur, as well as a tighter (and more perpendicular to the palate) constriction in retroflex articulations in North Boma. Nasal retroflexes appear to have the sharpest F1 slopes both in onset and offset position, but no specific effect of retroflexion could be detected on F2 onset and offset slopes. Nasal retroflexes show higher skewness and kurtosis values than their non-retroflex counterparts, suggesting higher or more peaked concentrations of energy in the spectral area below their centroid frequency; lower centre of gravity values also appear to point in the same direction.

In order to substantiate these preliminary findings, a series of MFA were performed on the dataset (quantitative variables grouped as follows: 'duration,' 'formant values,' 'bandwidth values,' 'slope values,' 'spectral moments'; qualitative variables grouped as follows: 'segment,' 'retroflexion'). A first MFA, run on the relevant sounds' median values, showed that the retroflex vs. non-retroflex opposition is better suited to explain the plane's inertia than the 'segment' variable. Retroflexion was shown to be significantly correlated (inversely) with segment duration, F2 bandwidth, centre of gravity, and F2 offset slope values, and (positively) with skewness, kurtosis, F1 bandwidth, and F1. This indicates that North Boma nasal retroflexes are shorter than their non-retroflex counterparts and exhibit more energy concentrated in the lower regions of the spectrum, while no specific effect of retroflexion was found on F3.

This is interesting as it appears to set the North Boma case apart from others presented in the available typological literature (see Hussain et al. 2017). Perhaps, this might indicate that retroflexes in North Boma have a relatively advanced constriction location. In line with the available acoustic literature (Stevens & Blumstein 1975), an F3-F4 pinch was observed, but no effect of F2-F3 convergence, which, again, sets the North Boma case apart from other well-documented cases (see Hamann 2002, 2003). Lower centre of gravity and standard deviation on the one hand, and higher skewness and kurtosis on the other, might indicate a position of the tongue perpendicular to the hard palate, which is consistent with the F3 findings (as a less retracted constriction location also requires less 'curling' of the tongue tip).

MFA were also performed on nasals with values sampled at the 10%- and 90%-duration temporal marks, to test whether retroflexion in North Boma were a dynamic articulation targeting different places at the sound's onset and offset (Ladefoged & Maddieson 1996). This was not found to be the case, suggesting that nasal retroflexes in North Boma do not behave as quickly flicking flaps as we had previously hypothesised.

Vowel adjacency effects were also analysed. MFA were performed on three cardinal vowels (/a/, /i/, and /u/). No significant effect of retroflexion was found on nasal-adjacent vowels. This also sets the North Boma case apart from other cases documented in the literature, where adjacency to a retroflex has been linked to lowered F3 values on the vowel.

While no other retroflexion phenomena could be found in the immediate vicinity of the North Boma area (with the exception of nasal retroflexes in closely related Nunu; see Section 3), some are detectable in the Bantu Lotwa languages of the last surviving Batwa groups of the eastern corner of Mai-Ndombe (Maselli 2024), where flapping as a realisation of intervocalic laterals is a common phonetic possibility, also attested in other Congo Basin Lotwa languages (see Bokula 1970, Kutsch Lojenga 1994, Motingea 2010). Although this is hard to prove given the absence of historical language data, the occurrence of nasal retroflexes in North Boma could be diagnostic of substrate interference through language shift (Thomason 2006). Those shifters might have been erstwhile Batwa people who once became part of the ancestral North Boma speech communities as L2 speakers whose L1 language was not a Bantu language but an indigenous language no longer attested. Another possibility is that the shifters might have come from the Ubangi-speaking area further north, where retroflex realisations of intervocalic laterals are also amply attested (see, e.g., Bouquiaux and Thomas 1977: 216f, 220). In support of this hypothesis, recent population genetic research shows that some West-Coastal and Central-Western Bantu speech communities in the vicinity of the North Boma area display a specific component in their genetic make-up that points to past admixture with Ubangi speakers (Fortes-Lima et al. 2025).

In the process of foreign language acquisition, some degree of structural phonological impact of source languages on recipient languages is very common and known as 'imposition' under 'source language agentivity' (Van Coetsem 1988). If these foreign language speakers shifted in sufficiently large numbers to ancestral North Boma, the imposition of the phonotactic structure of their non-Bantu source language on their Bantu recipient language would have undergone horizontal (through space) and vertical (through time) transmission along with the language community itself. While the overall rarity of nasal retroflexes in Bantu is a first indication of loan phonology, their positional restrictions are further evidence of the contact-induced intrusion of a phonotactic constraint from a non-Bantu source language, and so is our acoustic finding concerning their apparent salience within North Boma nasals. As a matter of fact, as Blevins (2017: 12) puts it, 'the more salient the phonetic pattern, the more likely it will spread areally' (see also Fleischhacker 2000, Kenstowicz 2001, 2003, Steriade 2001a,b, Kang 2002, among others). To what extent retroflexion is stable in the Mai-Ndombe languages which display it is a matter for further research. In fact, while /ɳ/ appears in C_2 (or, less often, C_3) position within a $C_1V_1C_2V_2C_3V_3$ template, our comparative data suggest that /ɳ/ is not equally frequent in all varieties (see part 1 of the Appendix).

Even if /ɳ/ was originally a loan phoneme, this does not mean that it is found in loanwords – quite the opposite, as it did not enter the language through lexical borrowings from an unknown source language. Thanks to our diachronic phonological analysis, we could determine that /ɳ/ is the regular reflex of both PB *n and *nd in word-final position, i.e. C_2 in disyllabic stems or C_3 in trisyllabic stems. While the regularity of the sound change points towards a firm integration of this alleged loan phoneme into North Boma's sound system, its restriction to word-final position might betray the phonotactics of a non-Bantu substrate language. Additionally, the regular correspondence of /ɳ/ to both PB *n and *nd informs us about the sound shift's relative chronology: this must have happened after the reduction of nasal - voiced oral stop (NC+voice) clusters such as *nd to simple nasals like *n. This type of consonant cluster simplification is widespread in the Bantu languages of the Lower Kasai region (Pacchiarotti et al. 2024). Since this simplification also occurs in North Boma's closest relatives, i.e. Mpe (B821), Nunu (B822), and Tiene (B81), it probably took place in the most recent common ancestor of these four languages. However, /ɳ/ itself is not attested in North Boma's closest relatives except Nunu. Consequently, its adoption in the sound inventory of North Boma (and Nunu) must, all in all, be a relatively recent phenomenon, which reinforces our hypothesis of a contact-induced origin. Tse (2015) also posits shift-induced substrate interference for the adoption of retroflex nasal + consonant clusters, i.e. /ɳʈ/ and /ɳɖ/, in Somali Bantu Kizigua (G111), though here the putative source language would be another Bantu language, i.e. Chimwiini, commonly considered to be a northern Swahili variety (Nurse & Hinnebusch 1993).

8. Conclusions

The present contribution represents the first in-depth analysis of a severely understudied class of sounds, i.e. nasal retroflexes, in a severely understudied Bantu language, i.e. North Boma, spoken in a severely understudied area of the planet, i.e. the Mai-Ndombe Province of the DRC. By integrating low-level phonetics and synchronic and diachronic phonology, we have been able to push our analysis of nasal retroflexes beyond the scope of each individual field.

Our original fieldwork with different North Boma speakers allowed us to document the nasal retroflex /ɳ/, which is rare both in Bantu and in the rest of the world's languages, and to confirm the phonemic status of this sound as reported by Stappers (1986). Our comparative synchronic study also showed that this sound is not equally frequent across speakers and varieties of North Boma, suggesting a position of particular volatility in the language's consonantal inventory. The cross-speaker and cross-variety instability of /ɳ/ in present-day North Boma could suggest that this sound was originally a loan phoneme. In support of this hypothesis, other retroflex sounds such as [ɽ] have been found in Bantu languages spoken by several Batwa communities in the wider area, commonly considered the descendants of populations who already lived in the region before the arrival of Bantu speakers. Hence, phonological substrate interference from shifting non-Bantu speakers could well be the historical source of North Boma /ɳ/.

By going beyond historical phonology and grounding our findings in acoustics, using, among other features, advanced methods of statistical analysis such as MFA (a first in the region), we have been able to show that retroflexes in North Boma are a particularly salient class of nasals. The retroflex/non-retroflex opposition is the most significant one in explaining our acoustic dataset's variance regardless of duration and spectral moment values. This reinforces the hypothesis that the nasal retroflex is in fact a loan phoneme integrated into the North Boma inventory through contact, in the light of Blevins's (2017) observations on the impact of acoustic salience on the ease of spread of phonetic patterns.

Finally, our factorial overview of the main acoustic correlates of retroflexion in North Boma shows that our data both match and flout acoustic expectations. These key typological data from a severely under-researched area of the world contribute to the debate on the acoustics of retroflex consonants in the world's languages. Admittedly, considerably more research remains to be conducted, specifically aimed at the collection of articulatory data to further ground the acoustic considerations presented here. The possibility of perceptual studies should also be explored if we are to further assess the degree of salience of retroflexion in North Boma. Additional evidence should be collected on neighbouring Nunu, where nasal retroflexes have also been detected in our preliminary fieldwork data.

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Appendix

1. Words with /ɳ/ or /n/ in C_2 and C_3 position across three North Boma varieties

This Appendix presents all lexical items containing either /ɳ/ or /n/ in C_2 and C_3 position across three North Boma varieties, i.e. that documented in Stappers (1986) and our own fieldwork missions of 2021 and 2022. The reader will see that the variety we documented in 2022 is (nearly) identical to the one documented by Stappers (1986). Lexical items in this Appendix are ordered alphabetically by concept name. All words are transcribed using the International Phonetic Alphabet (IPA), except in Stappers (1986) where <y> = [j], <r> = [ɽ], and <j> [ɟ]. In Stappers (1986) and Fieldwork 2021, low tone is left unmarked. The last column presents the historical form of which the lexical items on the same row are likely to be the reflex. All historical forms with an index number are taken from the Bantu Lexical Reconstructions (BLR) 2/3 database (Bastin et al. 2002). Those without an index number are tentative reconstructions based on comparative evidence from West-Coastal and Central-Western Bantu branches. A blank cell indicates lack of data. An em-dash — means that in a given variety the concept is expressed by a root which does not contain /ɳ/ or /n/ in C_2/C_3 position.

As the reader will notice, our comparative data suggest that /ɳ/ is not equally frequent across varieties. We found that, out of 104 collected in 2022, 82 had /ɳ/ in C_2/C_3 (79%) and 22 had /n/ in C_2/C_3 (21%). Similarly, of the 61 lexical items having /ɳ/ or /n/ in C_2/C_3 in Stappers (1986), 53 have /ɳ/ (87%) and 8 /n/ (13%). By contrast, out of the 77 lexical items collected in 2021, 40 have /ɳ/ (52%) and 37 have /n/ (48%). North Boma speakers who participated in the 2021 elicitation sessions were younger than the speaker we worked with in 2022 and have lived away from their community and in non-rural environments for longer than he had. It is possible that these younger speakers are losing the nasal retroflex by producing it as an alveolar, possibly under the influence of speakers of other languages of the region which do not have nasal retroflexes in their phonological inventories. It is worth noting that our 2022 speaker never produced /n/ as a free variant of /ɳ/ in C_2 position.

Concept	**Stappers 1986**	**Fieldwork 2021**	**Fieldwork 2022**	**BLR index**	**BLR protoform**
1. (red) ant		ikfúni	ìkfúnì/màkfúnì èkámúɳú/ ŋkámúɳú	BLR	*kúndà
2. anus	muzi:ɳí	muʒi:ɳí	mùzì:ɳí/mìzì:ɳí	BLR 9667	*jini 'pubes'
3. bamboo			ìzá:ɳá/màzá:ɳá		
4. belly		ipfu:ní	ìkfùní/màkfùní	BLR 1545	*kùndú
5. big	bɔnɛ́ɳɛ	bon:é	bòn:ɛ́ɳɛ̀ ~ bòn:ɛ́nɛ̀	BLR 2252	*nén
6. bird		ɲíni	ɲúnì/ɲúnì	BLR 1627	*jɔ̀nì
7. black	mpi:ɳí		mpìɳí	BLR 2577	*pínd
8. branch		ep:áni	mpánì/mpánì	BLR 2390	*pándà
9. brother	nâ:ɳa			BLR	*nándà
10. calabash	mbjá:ɳá	mbjáɳa	mbjáɳá/mbjáɳá	BLR 212	*bíndá
11. chameleon			mbwílùɳú/ mbwílùɳú		
12. caterpillar		kémbaɣaní	kèzìnà/bèzìnà		
13. carved image			ŋkò:ɳí		
14. child	mwá:ɳa	mwáɳa	mwáɳà/mjáɳà	BLR 3203	*jánà
15. cricket		nzén:é	—	BLR 1583	*njénjé

16. crocodile	ngɔ:ɳɛ́	ŋgɔ́ɳé	ŋgɔ̀:ɳé/ŋgɔ̀:ɳé	BLR 1446	*gòndé
17. deep		nʒja:ɳá	nzjàɳá	BLR 6275	*dìndʊ́
18. dignitary	nju:ɳu				
19. dirt		mbiúɳu	mbjúɳù	BLR 249	*bìndò
20. eel		mutʃóni	—	BLR 6725	*condi
21. eight	ìn:áɳà		inâ:ɳa	BLR 6434	*nàinài
22. electric fish		ndú:ɳu	ndú:ɳú/ndú:ɳú	BLR 4340	*dòndà
23. encampment		ŋá:ɳo	ŋgâɳù/ŋgâɳù	BLR 1324	*gàndá
24. family			ìkjáɳà/màkjáɳà	BLR 1321	*gàndá
25. fin			màl:áʁànù		
26. five	ta:ɳu		táɳù/bètáɳù	BLR 2768	*táànò
27. friend	m̀bɛ̂:ɳí		mbè:ɳí	BLR 8504	*bandi 'eminent man'
28. full	musia:ɳa	muʃjáɳa	mùsáɳà/mìsáɳà	BLR	*kìnà
29. grudge			ŋgwàɳá		
30. hail		éŋgu:nú			
31. hammer			ɲɟú:ɳù	BLR 1628	*jòndò
32. (palm of) hand	kani	ké:k:áni	kèkánì/bèkánì	BLR 1329	*gànjà
33. heel		kéb:uɳú			
34. hill	ngina			BLR 5527	*gìnà 'ant-hill'
35. host, stranger	ngjɛ:ɳé	ŋgje:ɳé	ŋgjèɳɛ̀/ŋgjèɳɛ̀	BLR 7614	*gèndì
36. hot		ke:dʒuɣún:i	kèɟùʁúnì/ bèɟùʁúnì		
37. how		zébúni	mùzá múɳì mùzá:n:à		
38. jigger, louse		nsána	nsáɳà/nsáɳà	BLR	*kínà
39. judge	ǹté:ɳi			BLR 2846	*ténd 'to say, speak'
40. light, day	mwání	mwáɳi ~ m:wáni	mwání/mjání		
41. maternal aunt		ŋgó zə ɣaŋgáni			
42. moon, month	ǹgɔ:ɳɔ	ŋɔ́ɳo	ŋgɔ̂ɳɔ̀/ŋgɔ̂ɳɔ̀	BLR 1447	*gòndò
43. mosquito, fly	bɛ́mmɛ́ɳɛ́	eb:émene	èbɛ́mɛ́ɳɛ́/ mbɛ́mɛ́ɳɛ́	BLR 7535	*bémbédé
44. mother	nâna:	—	—		
45. mouth	muna/mina			BLR 4709	*nʊ̀à
46. name	zá:ɳà/mjáɳà	ʒáɳa	zjá:ɳa/mjá:ɳa	BLR 3464	*jínà
47. news	—	—	mùkàɳú/mìkàɳú	BLR 1706	*kàndá 'letter'
48. paternal uncle		ta:rá zi: zéni			
49. pepper		izáni	ìzánì/màzánì		
50. piece		kets:íni	kèt:íɳì/bèt:íɳì	BLR 5531	*tínì
51. plantation			ŋgù:ɳú/ŋgù:ɳú	BLR 1509	*gòndà
52. post in the center of a hut			mwáɳù/mjáɳù		
53. pot, pan	ɛkɛ:ɳɛ/ŋkɛ:ɳɛ				

54. price	muba:ɳu	mob:áɳu	mùbáɳù	BLR	*bándʊ̀
55. pus	tfwá:ɳá				
56. rainbow		muŋkáni	mùŋkání/ mìŋkání	BLR 1708	*kándà ‘strap, belt’
57. raw		kop:jáɳa			
58. savanna, field		ntáɳa	ntáɳà	BLR	*tándʊ̀
59. sixty	samuɳu		mùsámúɳù	BLR 433	*cààmànò
60. skin bag			mpɔ̌ɳí/mpɔ̌ɳí		
61. skinny			ìtâɳù/màtâɳù		
62. spark	mwa:ɳá			BLR 3225	*jànjá ‘daylight’
63. spider	sá:kɔ:ɳɛ́	nsákɔ:ɳé ~ nséŋko:ɳé	nsǽkɔ̀:ɳɛ́/nsǽkɔ̀ :ɳɛ́	BLR 6734	*kòndé ‘spider net’
64. split post	ik:ún:i				
65. squirrel	sí:ɳí	ɲʃĩ:ɳi	nsí:ɳí/nsí:ɳí	BLR 579	*cíndí
66. stump, trunk (of tree)		ket:íni (trunk)	nsáɳà (stump) mùmbúʁúnú/ mìmbúʁúnú (trunk)	BLR 2926	*tínà[24]
67. stuttering			èŋkfúmɛ̀ɳɛ̀	BLR 5379	*kʊ́kʊmɪd
68. sun	vwá:ɳá	wáɳa	vwáɳá	BLR 8292	*jání
69. (queen) termite	mutfwáná	mutswána			
70. there		kunɛ́	kúɳɛ̀		
71. this X there			kjákìɳɛ̀:		
72. thorn		nsjéɳe	nsjɛ́ɳɛ́ / nsjɛ́ɳɛ́	BLR 543	*céndé
73. to be sideways			kòzímàɳà mbíì	BLR 3354	*jímad
74. to be tired		kòkɔ̂ɳɔ̀	kokó:ɳo	BLR 1934	*kónd ‘to be thin, emaciated’
75. to bite	táɳa		kot:áɳa	BLR	*tant
76. to bury	kɔfwa:ɳa	kokfwáɳa	kòkfwáɳà	BLR 2125	*kùnd
77. to chat	kɔdvwa:ɳa	kod:zwáɳa	kòdvwáɳà	BLR	*duand
78. to dance	ɛkáɳí [past]	kok:áno	kòk:áɳà	BLR 1805	*kín
79. to dance > dance		ik:jáɳa	ìkjáɳá/màkjáɳá	BLR 1807	*kínà
80. to deny		kozána	kòzánà		
81. to desire, love	kwâ:ɳa		kòkwáɳà	BLR 2044	*kʊ́nd
82. to despise	ɲaɳá!				
83. to dig up			kòkfún:ò kòb:ín:ò	BLR 2125 BLR 209	*kùnd

[24] Although the synchronic roots *t:ínì* and *sáɳà* ‘stump/trunk of tree’ look formally different enough that their cognate status might be called into question, they are in all likelihood cognates. In the variety documented in 2022, the historical form tínà first underwent Bantu Spirantisation (Schadeberg 1995; Bostoen 2008), whereby /t/ > [s] when followed by the high vowel /i/, yielding the intermediate (but unattested) form *síɳà*. Then, the second vowel was copied in V1 position so that *síɳà* > *sáɳà*. The same process happened in *kámà* ‘monkey’ (< BLR 1798 *kímà ‘monkey’), *kò-káɳ-à* ‘to dance’ (< BLR 1805 *kín ‘to dance’), *n-sáɳà* ‘jigger, louse’ (< BLR *kínà ‘louse’) and and *mù-sáɳà* ‘whole’ (< *kina ‘whole’).

					*bínd ‘to obstruct’
84. to fight	nwa:ɳa			BLR 1151	*dòan
85. to finish	maɳá!	kom:á:na	kòm:áɳà	BLR 2148	*màn
86. to forget	zímiɳa		kòzímàɳà	BLR 5716	*dímbad
87. to hoe			kòv:únò ntɔ̀rɔ́		
88. to learn	zíʁiɳa		kòzíɣìnà	BLR 3338	*jíg
89. to marry with	lámɛɳɛ				
90. to mold a pot			kòbwáɳà kèlèè		
91. to munch			kòt:áʁàn:ò		
92. to pass by	kɔcwa:ɳa				
93. to pierce		kotʃwáɳa			
94. to plant	kɔkwáɳa	kok:wáɳa	kòkwáɳà	BLR 2041	*kón
95. to plant > fallow land			mùkwáɳà/ mìkwáɳà	BLR 2041	*kón
96. to plant >seed		bek:úni	bjá bì bà kwáɳà	BLR 2041	*kón
97. to push	síʁiɳɛ	kos:íɣene	kòs:íɣìnè	BLR 8076	*cègeni
98. to put away			kot:áɣane		
99. to put down	naɳá!			BLR 8242	*nàn ‘to pull, to spread out’
100. to resemble, be equal	fâ:ɳa	kof:áɳa	kòfâɳà	BLR 2670	*púan
101. to limit oneself	bɔmɛɳɛ				
102. to rot	pɔ:ɳɔ	kop:óɳo	kòpɔ̂ɳɔ̀	BLR 6697	*pònd
103. to run		kol:áɣa e nsúno	kòl:áʁà ì nsûɳù	BLR 9582	*dák ‘to walk’
104. to see	mɔ̂: [past: móɳí]	kom:ó	kòmɔ̂ [past: móɳí]	BLR 2206	*món
105. to see > to meet	mɔ̂no		kòm:ɔ́n:ɔ̀	BLR 2206	*món
106. to see >fortune teller			kèm:ɔ́ɳì/ bèm:ɔ́ɳì	BLR 2206	*món
107. to see > encounter	kɛmónú			BLR 2206	*món
108. to send (for)	túmiɳɛ		kòt:úmɛ̀ɳɛ̀	BLR 3055	*tóm
109. to shout	ŋaɳá	koŋ:ána	kòŋáɳà	BLR 2339	*NàN ‘grumble’
110. to sleep	bímiɳa	kob:ímena	kòbímàɳà	BLR 6025	*bítam
111. to slip			kòsɛ́mɔ̀ɳɔ̀	BLR 509	*cèdɪmʊk
112. to start		kob:án:e	kòb:ánè	BLR 88	*bánd
113. to swallow	mjaɳa	kom:jána	kòmjáɳà	BLR 2190	*mìn
to swallow >mouth	—	mə́na	m:énà/m:énà	BLR 2190	*mìn
114. to swell	bímiɳɛ			BLR 240	*bímb

115. to swim		koɲána	kòɲánà	BLR	*njánj
116. to thank	ǹtóːɳi [past]				
117. to twist		koŋwána	kòŋɔ́nɔ̀	BLR 1945	*kónj
118. to write	cɔ́ɳɔ	kotʃwáɳa	kòcːɔ́ɳɔ̀	BLR 661	*cón
119. tooth	zjúːɳu/mjúːɳu	ʒóɳo	zjúɳù/mjúɳù	BLR 3472	*jínò
120. torch			mwàɳá/ mjàɳa	BLR 3609	*mʊ̀nì
121. water well		ídzwáːɳá	ìdwàɳá/màdwàɳá		
122. what			kjánːà		
123. when	kɛsie kíɳǐ		lúːnà, kèsínà		
124. where	kúɳǐ	váni	kúɳì, váɳì		
125. who	ze búɳǐ	n:á	ɟwánːà		
126. why	kɛtɔ́ːɳɔ́ mbe, nsáɳá mbe		nsáná mbè		
127. wine		máɳa	—	BLR 8255	*jáná
128. worm			mùkènú/mìkènú		
129. yesterday		mbálitʃú:ɳi	—		

2. Full acoustic data

This Appendix contains all acoustic data for the six nasal places of articulation present in North Boma. All measurements (except slopes and duration) consist of the median of the values calculated over the duration of the consonant (from 10% to 90% of its duration).

Average values (consonants)	**m**	**ɱ**	**n**	**ɲ**	**ŋ**	**ɳ**
Duration (s)	0.117	0.127	0.114	0.127	0.117	0.05
F1 (Hz)	331	367	361	338	361	394
F2 (Hz)	1347	1488	1410	1502	1294	1213
F3 (Hz)	2365	2477	2369	2481	2388	2314
F4 (Hz)	3501	3634	3504	3493	3603	3356
Bandwidth F1 (Hz)	149	146	125	119	117	251
Bandwidth F2 (Hz)	627	637	559	782	788	377
Bandwidth F3 (Hz)	428	461	359	363	338	295
Bandwidth F4 (Hz)	625	640	480	409	688	566
Bandwidth (general) (Hz)	457	471	381	418	483	372
F1 onset slope (Hz/s)	-1	-2	-1	-1	0	-1
F1 offset slope (Hz/s)	1	-1	0	1	-2	1
F2 onset slope (Hz/s)	-2	4	0	-9	2	0
F2 offset slope (Hz/s)	-1	5	2	5	-5	0
F1 (10%) (Hz)	343	400	379	361	366	423
F2 (10%) (Hz)	1388	1428	1406	1628	1318	1229
F3 (10%) (Hz)	2412	2531	2367	2716	2415	2330
F4 (10%) (Hz)	3511	3546	3478	3538	3551	3343
Bandwidth F1 (10%) (Hz)	197	175	176	146	136	289
Bandwidth F2 (10%) (Hz)	633	654	618	827	682	368
Bandwidth F3 (10%) (Hz)	623	443	456	499	430	301
Bandwidth F4 (10%) (Hz)	645	625	538	495	947	736
F1 (30%) (Hz)	330	376	366	354	364	395

F2 (30%) (Hz)	1371	1504	1438	1504	1375	1223
F3 (30%) (Hz)	2395	2540	2373	2577	2393	2325
F4 (30%) (Hz)	3523	3603	3532	3536	3631	3345
Bandwidth F1 (30%) (Hz)	164	126	136	155	116	276
Bandwidth F2 (30%) (Hz)	695	608	651	1131	885	456
Bandwidth F3 (30%) (Hz)	526	422	423	437	403	353
Bandwidth F4 (30%) (Hz)	709	896	540	525	754	757
F1 (50%) (Hz)	328	368	362	335	375	388
F2 (50%) (Hz)	1353	1491	1392	1468	1357	1225
F3 (50%) (Hz)	2384	2394	2370	2265	2436	2311
F4 (50%) (Hz)	3529	3605	3498	3413	3613	3356
Bandwidth F1 (50%) (Hz)	166	141	159	127	115	261
Bandwidth F2 (50%) (Hz)	754	817	684	1440	1003	447
Bandwidth F3 (50%) (Hz)	486	549	380	367	429	329
Bandwidth F4 (50%) (Hz)	708	777	634	367	830	655
F1 (70%) (Hz)	332	361	360	334	356	392
F2 (70%) (Hz)	1341	1333	1427	1441	1345	1219
F3 (70%) (Hz)	2399	2441	2387	2443	2377	2316
F4 (70%) (Hz)	3554	3577	3525	3441	3640	3380
Bandwidth F1 (70%) (Hz)	185	150	134	111	116	269
Bandwidth F2 (70%) (Hz)	758	880	586	974	890	439
Bandwidth F3 (70%) (Hz)	470	570	450	705	375	372
Bandwidth F4 (70%) (Hz)	755	668	560	413	757	534
F1 (90%) (Hz)	349	344	364	349	342	415
F2 (90%) (Hz)	1336	1499	1433	1516	1281	1225
F3 (90%) (Hz)	2391	2475	2378	2564	2398	2325
F4 (90%) (Hz)	3520	3578	3519	3537	3593	3408
Bandwidth F1 (90%) (Hz)	176	179	134	136	131	285
Bandwidth F2 (90%) (Hz)	747	703	614	908	794	378
Bandwidth F3 (90%) (Hz)	502	1045	442	450	497	398
Bandwidth F4 (90%) (Hz)	746	577	557	424	793	489
Centre of gravity (Hz)	1853	1861	1858	2198	1905	1632
Standard deviation (Hz)	796	721	718	920	751	662
Skewness	2.5	1.9	2.5	2	2	3.9
Kurtosis	20.9	10.1	24.7	21.7	15.4	54.1
Centre of gravity (10%) (Hz)	1824	1927	1811	2359	1803	1540
Standard deviation (10%) (Hz)	759	784	668	872	691	522
Skewness (10%)	2.8	1.4	2.6	0.7	3.2	3.8
Kurtosis (10%)	70	6.8	50.5	12.2	74.4	120.1
Centre of gravity (50%) (Hz)	1847	1838	1840	2092	1910	1607
Standard deviation (50%) (Hz)	760	761	655	795	704	595
Skewness (50%)	2.7	2	2.4	2	3	3.4
Kurtosis (50%)	58.1	15.5	44.5	45.1	84	89.8

Centre of gravity (90%) (Hz)	1836	1791	1879	2172	1902	1570
Standard deviation (90%) (Hz)	748	789	678	793	728	554
Skewness (90%)	2.9	2.1	2.3	1.3	3	4
Kurtosis (90%)	55.9	18.4	39.5	24.2	72	125.8