THE PHONETICS OF NDUMBEA[1]

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1. INTRODUCTION. This paper discusses the phonetic properties of Ndumbea, one of the indigenous Austronesian languages of the southernmost part of New Caledonia, a French “Overseas Territory” in the South Pacific. The name Ndumbea more properly belongs to a people who have given their name to the present-day capital of the territory, Nouméa, as well as to Dumbéa, a smaller town to the north of Nouméa. Rivierre (1973) uses the phrase [nɖa) nɖumbea] “language of Nouméa” for the name of the language. The spelling Drubea, using orthographic conventions based on those of Fijian, is preferred in Ozanne-Rivierre and Rivierre (1991). We prefer to represent the prenasalization overtly in the spelling of the language name, but our spelling does not note the post-alveolar place of articulation of the initial stop. In the titles of the books by Païta and Shintani (1983, 1990) and Shintani (1990) the language is referred to as Païta. This is the name of one of the clans speaking the language and it has also become the name of a modern town, Païta. The language is no longer spoken in Dumbéa or Païta but survives in a few rural settlements to the northwest of Nouméa, and in an area reserved for the indigenous inhabitants around Unya (also spelled Ounia) on the east coast. The locations referred to are shown on the map in Figure 1. The total number of remaining speakers of Ndumbea is probably on the order of two or three hundred at most.

Previous work on Ndumbea includes a small grammatical sketch and word list by Leenhardt (1946), a detailed phonological sketch by Rivierre (1973), a grammatical sketch by Païta and Shintani (1983), an outline grammar by Païta and Shintani (1990), and a dictionary by Shintani (1990). Rivierre’s work is primarily aimed at comparison of the southern New Caledonian languages, a topic that is taken further in Ozanne-Rivierre and Rivierre (1991). Ndumbea is very closely related to the Numee language, spoken in Goro and on the Île Wen, and in a slightly different form ([kwe≠ii]) on the Île des Pins. These locations are also shown in Figure 1.

This paper will concern itself with describing certain salient phonetic properties of Ndumbea. Ndumbea’s phonological and phonetic system is of interest for several reasons. The language is one of relatively few Austronesian languages which is tonal, and it has a larger inventory of vowels than many other languages in this family. It also has a three way place contrast between coronal stops, a relative rarity in the languages of the world — only 3.54% of languages in Maddieson’s (1984) survey of 317 languages contrast more than two coronal stops. This rather unusual contrast will be the primary focus of this paper. Ndumbea provides a further opportunity to examine if the acoustic properties of coronals conform to a general pattern based on simple place of articulation distinctions, or whether they vary in a language-specific way and

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depend on differences of detail in the shape of the constriction and the nature of the release (see Ladefoged and Maddieson 1996 for an overview of this issue). However, a general description of the acoustic properties of the vowels and comments on other aspects of the consonant system will also be provided.

Materials for the present study were collected in New Caledonia in February 1993 by the second-named author, and include data provided by two groups of Ndumbea speakers. The principal type of data consists of audio recordings of lexical items selected from Rivierre (1973) and Shintani (1990). One group of four adults, three women and a man, was recorded at Naniouni on the west coast. Two of these subjects also provided palatographic data. A second group of two speakers, one man and one woman, was recorded in Unya.

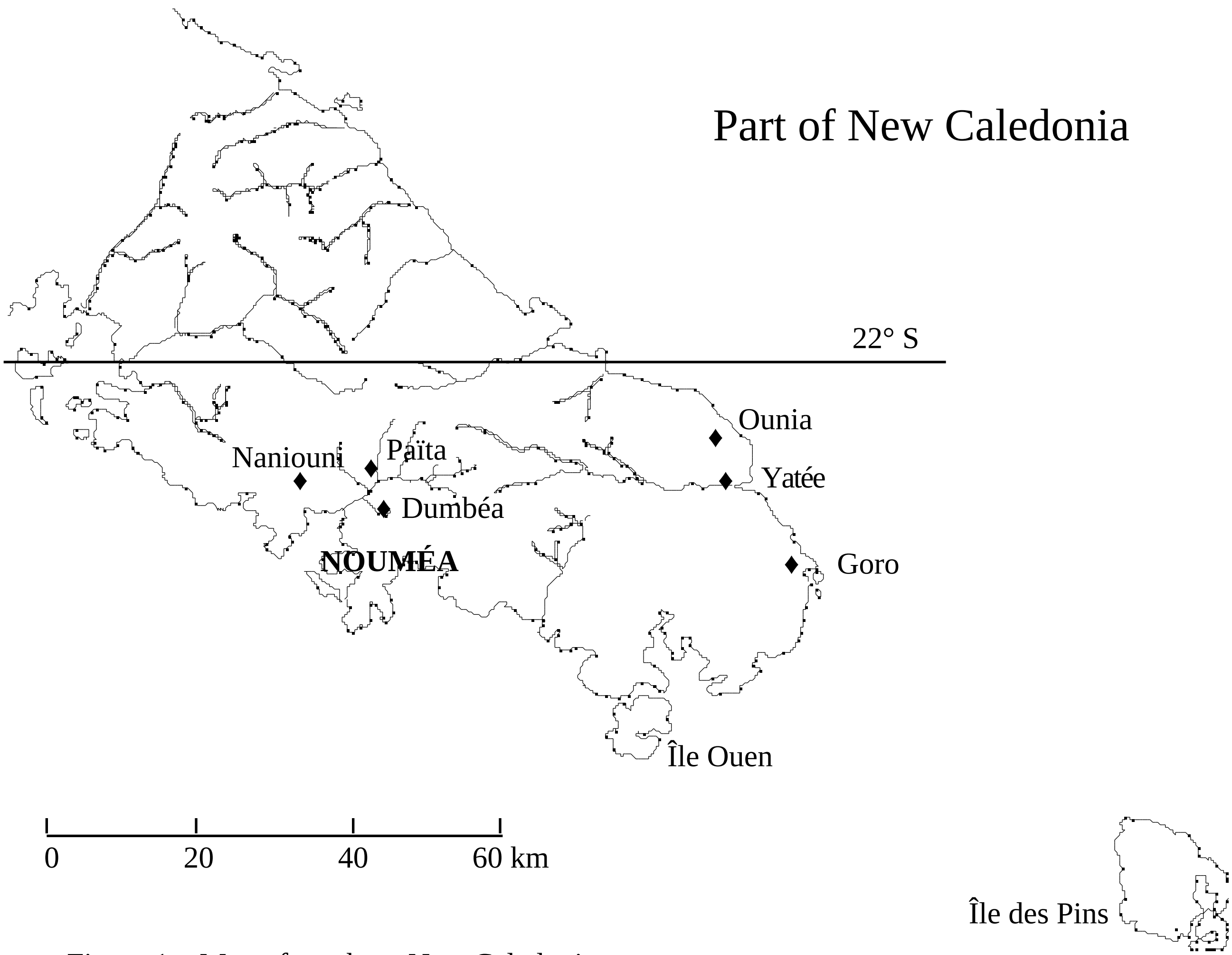


Figure 1. Map of southern New Caledonia.

2. VOWELS. Interpretations of the Ndumbea vowel system differ somewhat. According to Rivierre (1973), the Unya dialect of Ndumbea has seven long and seven short oral vowels. The qualities of the long and short vowels are similar except that /I…/ has no short counterpart and /E/ has no long counterpart. It would this be possible to consider /e/ to be the short counterpart of /IÜ/ and /E/ the short counterpart of /eÜ/. There are also five nasalized vowel qualities [i) u) e) o) a)], which occur both short and long. This system agrees with that used in Shintani (1990), but Païta and Shintani (1983) had noted three additional vowel qualities, [0, ´, ¨], and the nasalized vowel [´]. These appear to be non-systematic variants reflecting underarticulated pronunciations. What is striking about this vowel system is the presence of two pairs of high vowels, a distinction rarely found in Austronesian vowel systems.

Table 1. Ndumbea vowels (after Rivierre 1973)

Oral

Short	i	u
		U
	e	o
	E	
	a	
Long	iÜ	uÜ
	IÜ	UÜ
	eÜ	oÜ
	aÜ	

Nasalized

Short	i)	u)
	e)	o)
	a)	
Long	iÜ)	uÜ)
	eÜ)	oÜ)
	aÜ)	

Long and short vowels contrast in most environments, but in Rivierre's analysis (1973: 83) only short vowels may precede the post-alveolar tap within a morpheme. The words that Rivierre and Shintani represent as containing a CV_1|¢V_2 string where V_1=V_2 and V_1 is short seem might well be interpreted as containing a consonant cluster with /|¢/ as second member. The first vowel in such positions is usually very short and of indistinct quality. It seems primarily to serve only as onset to the tap, which, given its ballistic nature, requires an articulatory approach from a more open position to be fully realized. Back vowels do not follow the labialized bilabials and velars (/pW, mbW, mW, kW, NgW/, nor the velar nasal /N/ and the velar fricative /V/.

2.1 ORAL VOWELS. In order to describe the phonetic qualities of the vowels more precisely, values for the first three formants (F1-F3) in oral vowels in selected words spoken by the four speakers from Naniouni were measured using the Kay Elemetrics Computerized Speech Lab (CSL). The three female speakers are labeled speakers F1, F2, F3 respectively, and the male speaker is labeled speaker M1. (The two speakers from Unia will be designated F4 and M2.) Data was sampled at 10 kHz. Formants were calculated for a steady state portion of the vowel at about the mid-point of its duration, as selected by eye on a spectrographic display. Superimposed LPC and FFT spectra, calculated over windows 30 and 25.6 ms long respectively beginning with this halfway point, were displayed. Formant values are usually those calculated by the LPC analysis, with the FFT spectrum being used to check the accuracy of the LPC analysis. The LPC window was calculated using 12 or 14 coefficients in most cases, though up to 20 coefficients were sometimes used in problematic cases, particularly for the back vowels.

The measured vowels were preceded by stop consonants and appeared, in virtually all cases, in monosyllabic words (there is, however, no apparent difference in formant values according to the position of the vowel in the word). The consonants preceding the vowel were coronals before the front vowels and /a/, and velars and bilabials before the back vowels. These environments were chosen to minimize the length of consonant transitions, particularly of F2, and to provide 'prototypical' exemplars of the front and back vowels. No consistent differences were found between long and short vowels, although short vowels were sometimes sufficiently short that formants had not reached their steady state by the midpoint of the vowel, in which case measurements were taken from a slightly later point in the vowel. The number of tokens for each vowel varied, but ranged from a high of 18 tokens of /a/ for speaker M1 to a low of two tokens of /E/ for speaker F1. For all speakers, /a/ and /i/ occurred in the greatest number of measurable tokens, while each of the other vowels was measured between two and six times. The words used are listed in Table 2.

Table 2. Words used for vowel formant measurements

vowel	word	gloss
i	ti!	sugar cane
	cicci!	fishing line
	ticci!	paper
	i!	comb
	ci!	spear
i…	tii~	tea
	atii~	mute
	ciÏ	cloth (manou)
	ilre	inflate
	≠Ôil!	sun
	cii~	mushroom
I…	tII	flood
	ndII	son
e…	tee	fish (sp.)
	utee!	ashes
e	te!	good
	ndee!	clan
E	tE!	blood
a	ta!	ground
	weta!	age
	potaa	river
	pWalta!	Paita
	koota	egg
a…	taa!	one
	caa!	juice
	taakuŸ	five
	taa~	un
o…	koota	egg
	Ngoo	tree
U…	kUU	start
	UU	fishing net
	vUU	rock
	NgUU	root
U	U!	chest
u…	vuure	speak
u	Ngure	breathe
	ku!	yam

The mean values of the first three formants for each vowel for each of the speakers are shown in Table 3, except for F3 values for the back vowels. These could not be reliably measured, due to background noise and faintness of energy in the higher harmonics.

Table 3. Mean values of first three formants for the vowels of four speakers from Naniouni.

Speaker & vowel	n	F1	F2	F3
F1	n			
i	13	356	2639	3255
I	2	414	2614	3080
e	4	490	2408	3194
E	2	583	2153	2516
a	13	909	1663	3006
o	2	531	1075	
U	5	375	702	
u	3	293	594	
F2				
i	12	339	2573	3369
I	2	380	2613	3097
e	5	421	2300	2962
E	2	461	1944	2886
a	10	719	1651	2927
o	2	540	951	
U	4	410	722	
u	3	357	590	
F3	n			
i	12	308	2648	3277
I	4	382	2564	3104
e	5	408	2314	2932
E	2	560	1972	2813
a	12	755	1663	2895
o	2	554	1118	
U	2	406	752	
u	3	341	682	
M1				
i	16	307	2232	2637
I	2	373	2162	2606
e	6	365	2034	2503
E	3	414	1938	2415
a	18	678	1351	2411
o	2	474	838	
U	4	352	603	
u	3	311	623	

To provide a visual idea of the range of variation of the vowels, all measured tokens of the vowels of the three female speakers are plotted in Figure 2 in an F1 vs. F2 space. A more compact view of these distributions is provided in Figure 3, which plots the mean for each vowel of each speaker and thus equalizes the contribution of each speaker despite the variable numbers of tokens. The ellipses in Figures 2 and 3 are drawn with radii of two standard deviation along the axes of the first two principal components of the distribution. The spacing of the vowels of the male speaker in the F1 vs F2 space is similar to that of the females.

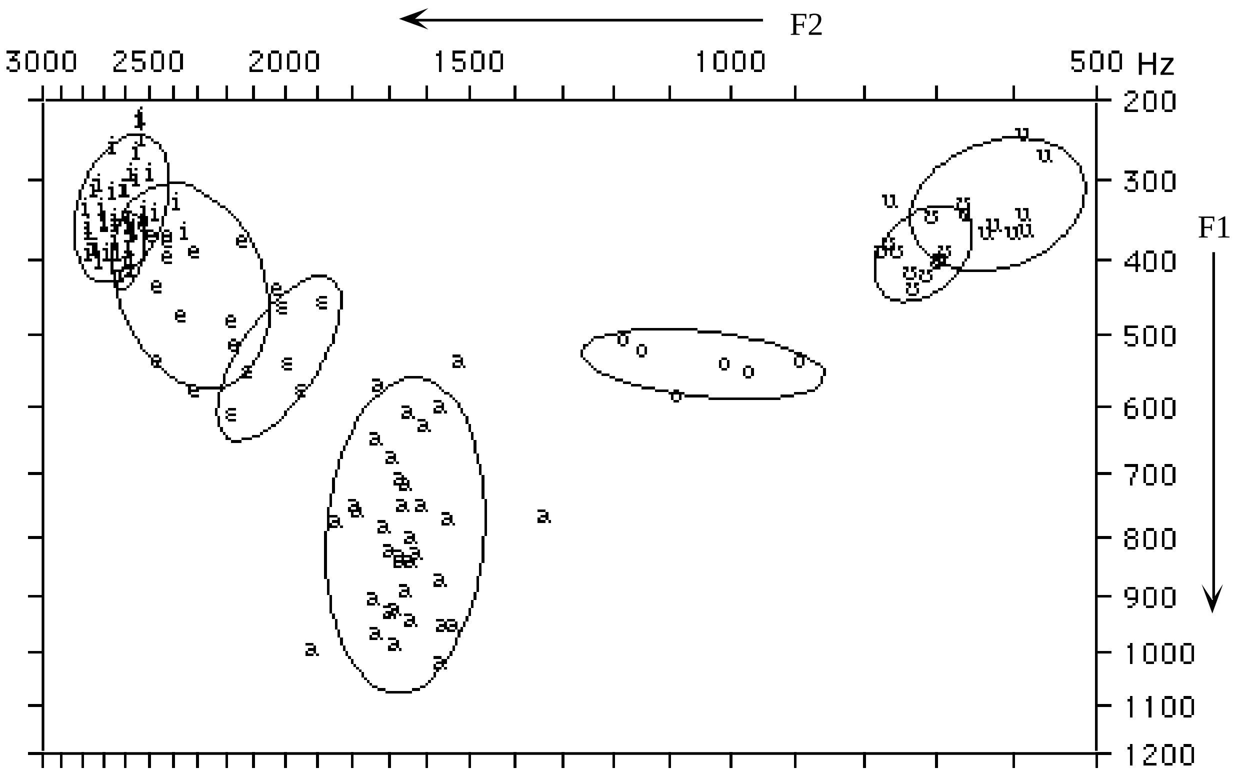


Figure 2. Plot of all measured vowel token from speakers F1, F2, F3 in F1 vs F2 space.

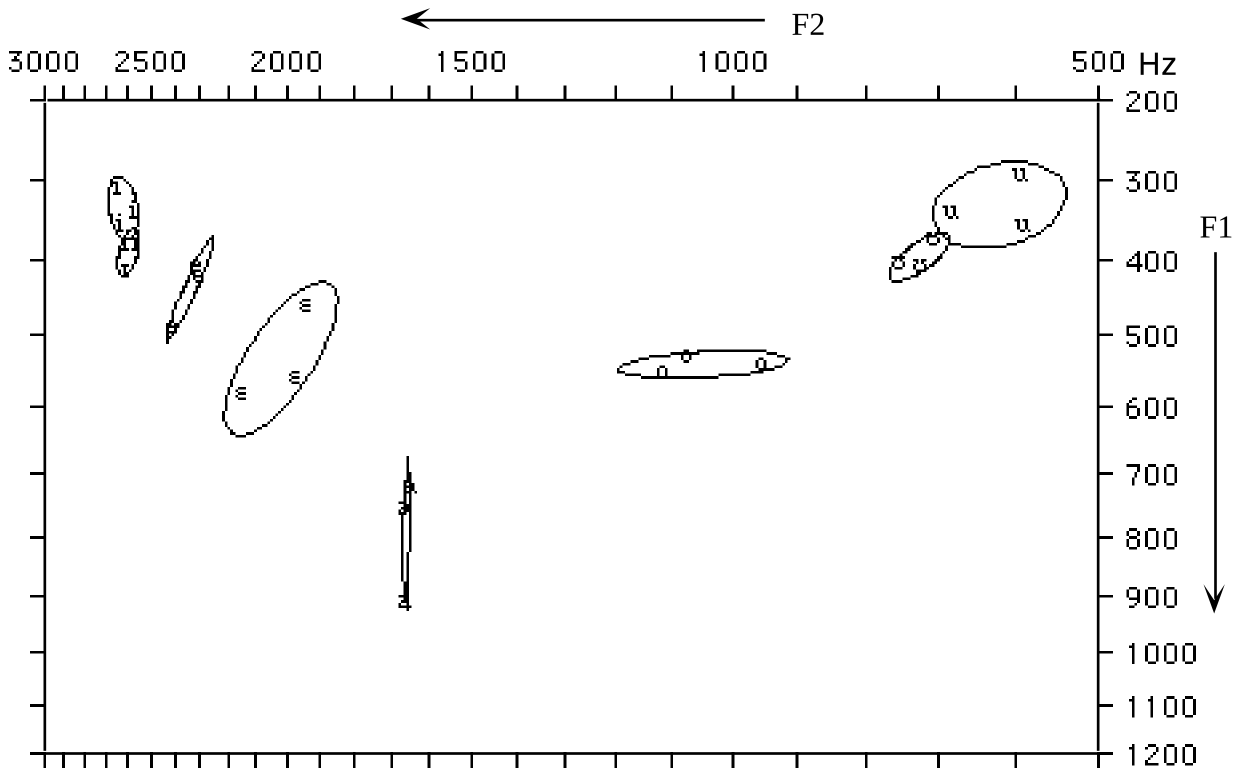


Figure 3. Plot of mean of each vowel for each of speakers F1, F2, F3 in F1 vs F2 space.

Most of the vowels are differentiated well on the basis of the first two formants in both figures, the exception being /I/ in figure 2 which is completely overlapped by the ellipse for /e/ and largely overlapped by the ellipse for /i/. As shown in figure 3, however, the mean F1 and F2 values for /I/ are reasonably well differentiated from both /i/ and /e/, from /i/ mainly in the F1 dimension and from /e/ on the basis of both F1 and F2. As shown in Table 2, /i/ and /I/ are well differentiated by their third formant values, at least for the female speakers; F3 values for /I/ are lower than those for /i/ for all speakers, ranging from 272 Hz lower for speaker F2 to just 31 Hz lower for speaker M1. We interpret this as indicating a more backed articulation for /I/ than for /i/.

As for the suggestion that the short /e/ and /E/ are the short counterparts of the long /IÜ/ and /eÜ/, we have no comment to make on its phonological appropriateness, but our acoustic analysis indicates that the qualities are as represented in Rivierre’s transcription. /eÜ/ and /E/ sound substantially different, as borne out by the formant values, which show that /E/ is more central and lower than /eÜ/. Although /e/ and /IÜ/ sound more similar impressionistically, their formant values are no closer to each other than /IÜ/ is to /iÜ/, a minimal contrast which clearly must rely on a quality difference

2.2. NASALIZED VOWELS. The occurrence of nasalized vowels is to a large degree predictable, since they are confined to environments in which nasal consonants occur, or where they used to occur but have left unique reflexes, as in the case of /V/. (/V/ is the reflex of */N/ before an originally nasalized vowel; it is lost before back vowels, and the nasality of the vowel is also lost.) However, nasalized vowels contrast with oral vowels after voiceless stops, the glide

/w/ and the labiodental fricative /v/. Since only oral vowels follow prenasalized stops and only nasalized vowels occur after nasals, Rivierre observes that oral and nasalized vowels are in complementary distribution after these classes of consonants. This distributional pattern could also be expressed by saying that nasals before oral vowels have an oral release, thus treating the prenasalized stops as variants of the nasals. This is indeed their historical source in this language (Rivierre 1973, Ozanne-Rivierre & Rivierre 1991). Plain nasals occur in Numee where prenasalized stops are found in Ndumbea, as the language names themselves attest.

3. CONSONANTS. Table 4 shows the consonant inventory for Ndumbea, as reported by Rivierre (1973) but generally transcribed using IPA symbols. Consonants such as /f, s, l/ which are found only in a few recent loan-words are not included in this chart. We find the same number of consonants as Rivierre, but aim to add some details of their phonetic characterization. Apart from the absence of /NW/, voiceless and prenasalized plosives and nasals occur symmetrically at the same number of places of articulation. Recall that prenasalized stops and nasals are not found in minimally contrasting positions, given their distribution with respect to vowel nasalization. The prenasalized stops are produced with a nasal portion of varying duration. A few utterance-initial tokens were observed to be produced as a voiced stop without an audible nasal portion. These are nonetheless prevoiced prior to closure release, and are thus distinct from the voiceless stops, which have a short voice onset delay.

Table 4. Consonants of Ndumbea (after Rivierre 1973)

	Bilabial	Labialized bilabial	Labio-dental	Dental	Post-alveolar	Palatal	Velar	Labialized velar
Plosive	p	pW		t1	t¢	c	k	kW
Prenasalized plosive	mb	mbW		nd1	nd¢	≠Ô	Ng	NgW
Nasal	m	mW		n1	n¢	≠	N	
Fricative			v				V	
Approximant						j		w
Tap					|¢			

The two segments listed as fricatives, /v/ and /V/ (Rivierre transcribes this last sound with the symbol /x/ but notes that it is voiced), are often realized as approximants in the speech of our consultants. The approximants /w/ and /j/ are never fricated, however. (For convenience /w/ is placed in the labialized velar column in Table 4). /j/ is very nearly in complementary distribution with /≠/, as it occurs almost always before an oral vowel, whereas /≠/ is followed by a nasalized vowel. The production of /≠/ includes cases where the palatal closure in incomplete, resulting in the pronunciation of [j)].

The places of articulation labeled dental, post-alveolar and palatal (except for the articulation of /j/) can all be considered coronal, that is, they involve the tongue tip and/or blade as the active articulator (Ladefoged and Maddieson 1996). The consonants labeled post-alveolar in Table 3 are generally referred to in previous literature as retroflex, but this is an ambiguous term which covers a range of degrees and modes of retracting the point of closure in a coronal consonant. Post-alveolar place is indicated here by a subscript dot in preference to using the IPA symbols for retroflex consonants. The stop consonants labeled palatal are produced further forward in the mouth than prototypical palatal consonants (as exemplified in Hungarian, for example). There is no doubt that these Ndumbea consonants are appropriately classed as coronal. The characteristics of this three way coronal distinction are discussed in more detail with respect to the voiceless stops in the next section.

The post-alveolar tap /|¢varies with a post-alveolar approximant /®¢ with the tap articulation predominating in the data set collected. In a minority of cases, this sound appeared to have been realized as an alveolar tap /|/; there were also a few tokens containing an alveolar trill, involving two or three contacts between the tongue and the roof of the mouth. A following nasalized vowel typically spreads its nasality to an adjacent /|¢with the result being either a nasalized tap, an extremely short nasal stop or a short nasalized approximant. The vowel preceding this nasal segment may also be nasalized. A spectrogram illustrating two of these variants in the word ***ca|¢a)|¢e)*** 'to run' is shown in figure 4. (Recall the suggestion that the first vowel in cases such as this might be regarded as solely a transitional element between the initial stop and the tap.) /|¢and /n¢are largely in complementary distribution, conditioned by the nasality of the following vowel and position in the word. They do not contrast in word-medial position and /|¢does not occur initially in a word, although is very common medially and does begin some common suffixal morphemes.

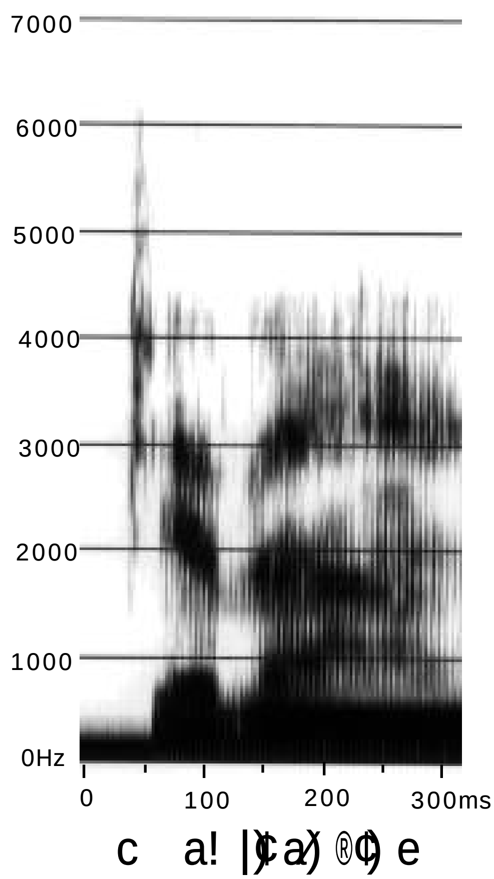


Figure 4. Spectrogram illustrating two variants of nasalized /|¢ a nasal tap and a nasalized approximant, as spoken by Speaker F1.

4. THE CORONAL CONTRAST. As mentioned above, Ndumbea is one of a comparatively small number of languages in the world which contrasts three coronal stops, i.e. stops involving contact between the tip or the blade of the tongue and tectum, or roof of the mouth. According to Rivierre, the contrast is one between an apical dental, a retroflex and a prepalatal stop, which may be followed by a period of frication following the release.

4.1 PALATOGRAPHY. As part of our analysis, palatograms were made of the three voiceless coronal stops as produced by two of the three Ndumbea speakers. Illustrative examples of the near-minimal triplet ***t1a*** 'reef' ***t¢*** 'ground' and ***cah*** 'juice' as produced by speaker F1 are shown in Figure 5. The palatograms of the other speaker show very similar articulations.

t1a t a! cah

Figure 5. Palatograms of the three voiceless coronal stops of Ndumbea before /a/.

As is clear from the palatography, the contact for the dental stop is against the upper teeth and the front of the alveolar ridge. The contact is not particularly broad in the sagittal plane. Although we do not have any linguagrams to show the point of contact on the tongue directly, the palatogram for the dental stop is suggestive of an apical (or perhaps "apico-laminal" in Dart's (1998) terminology) contact between the tongue and roof of the mouth. As for the post-alveolar, its contact area is a little narrower and is markedly farther back in the mouth than that of the dental, at the back of and just behind the alveolar ridge. It does not involve any contact on the front teeth. This might also be characterized as apical.

As in Iaai, another New Caledonian language (Maddieson and Anderson 1994), the contact area for this post-alveolar in Ndumbea is not as far back on the palate as the retroflex stops in Dravidian languages such as Tamil, Telugu (Ladefoged and Bhaskararao 1983) and Toda (Shalev, Ladefoged and Bhaskararao 1994) or the apical retroflex in the Australian language, Eastern Arrernte (Butcher, in progress, cited in Ladefoged and Maddieson 1996). In fact, although the Ndumbea post-alveolar can be classed as a type of retroflex it more closely resembles the apical alveolar stop than the retroflex of Eastern Arrernte.

The third coronal has a very broad contact that extends a little further forward than the post-alveolar, and extends substantially further back. It is without any doubt a laminal articulation, and could be more precisely described as a laminal post-alveolar rather than as a palatal. We retain the less cumbersome term 'palatal' for convenience, but it should be remembered that it is being used in a special sense.

4.2. ACOUSTIC ANALYSES. Spectrograms of the three voiceless coronal stops in the triplet ***t1a*** 'reef', ***t a!*** 'ground' and ***cah*** 'juice', as produced by speaker F1 are shown in figure 6. As the spectrograms show, the stops differ in the amplitude, duration and spectral composition of their release portions. In order to describe the acoustic properties which differentiate them, as well as to draw further inferences about their articulation, a battery of acoustic analyses was performed on the three voiceless coronal stops. These analyses include the spectra of the bursts, burst amplitudes, formant transitions upon release of the stop, and durations of the closure and the noisy period following release. Closure duration and formant transitions were not examined for the palatal series for two reasons. First, the palatal stop in intervocalic position was typically characterized by an incomplete oral closure which made measurement of closure duration difficult. Secondly, the transitions are quite clearly distinct by inspection alone, with a higher origin for F2 than is seen with the other two classes of coronals.

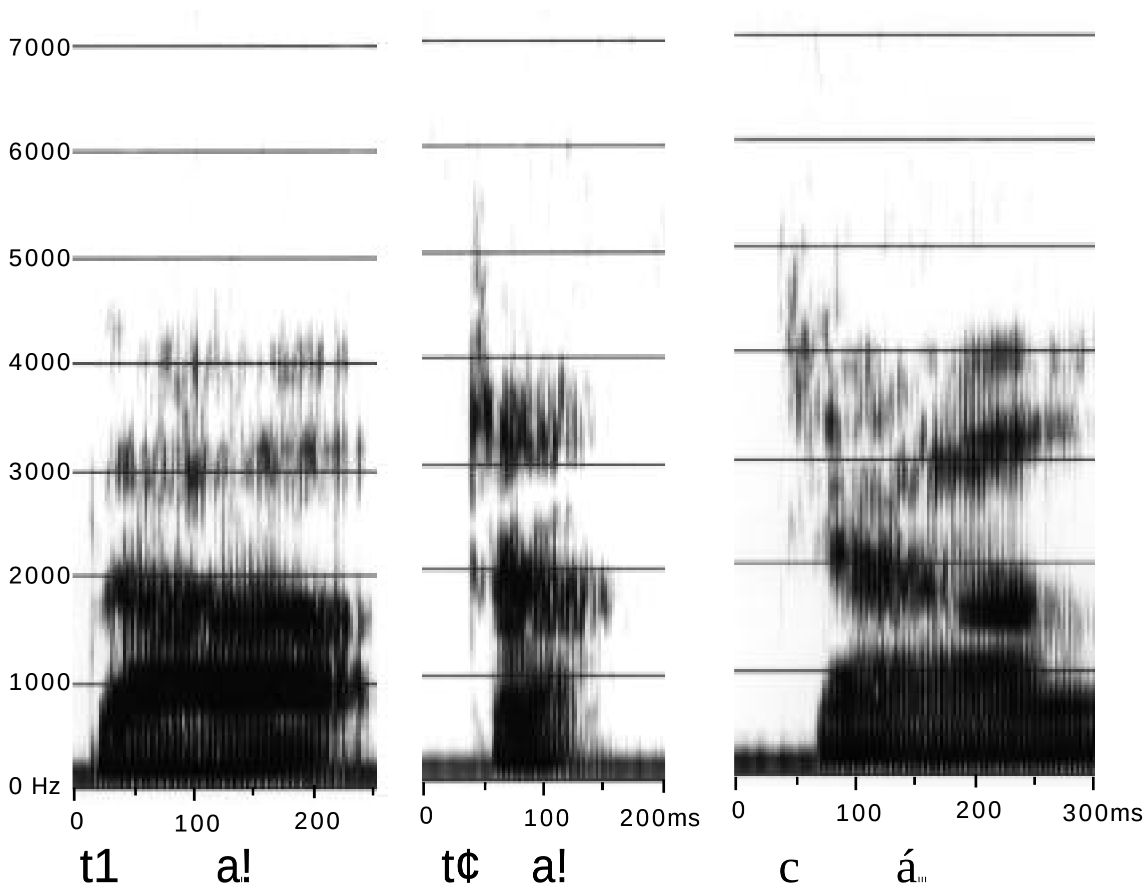


Figure 6. Spectrograms of words illustrating the three voiceless coronal stops of Ndumbea, as spoken by Speaker F1.

4.2.1. BURST SPECTRA. Using the Kay Computerized Speech Lab system, tokens were sampled at 20 kHz to capture the spectral properties of the burst from 0 to 10 kHz. A 256 point (12.8 ms) window was centered around the burst transient and the FFT spectrum of this window calculated. A short window was chosen since the dental stop has a short VOT and it was desirable to remain consistent in methodology for all three coronal stops. A longer window would have incorporated voiced pitch periods dominated by the formants of the vowel following the dental stop, thereby failing to represent the spectral properties of the burst itself. The words examined are listed in Table 5. Table 6 shows the number of tokens measured for each speaker by place of articulation and the following vowel. Limitations on the material recorded means that the data are not balanced across any of the three factors of consonant place, vowel context and speaker. This restricts the analysis that can be performed.

To compare the burst spectra of the different consonants, amplitude values for each point in the FFT spectrum from all tokens of a given CV sequence for a given speaker were averaged together to produce a mean spectrum. Figure 7 shows the mean burst spectra for /t1/, /t¢/ and /c/ in word initial position before /a/ and before /i/ from the four speakers from whom measurements in both vowel contexts were taken (Speaker F3 had no measurable tokens containing a palatal stop before /a/). The spectral displays show the frequency range from 1000-8000 Hz plotted on a logarithmic scale, thus focusing on the spectral range of greatest importance to the human listener and approximating the frequency scaling of the auditory system.

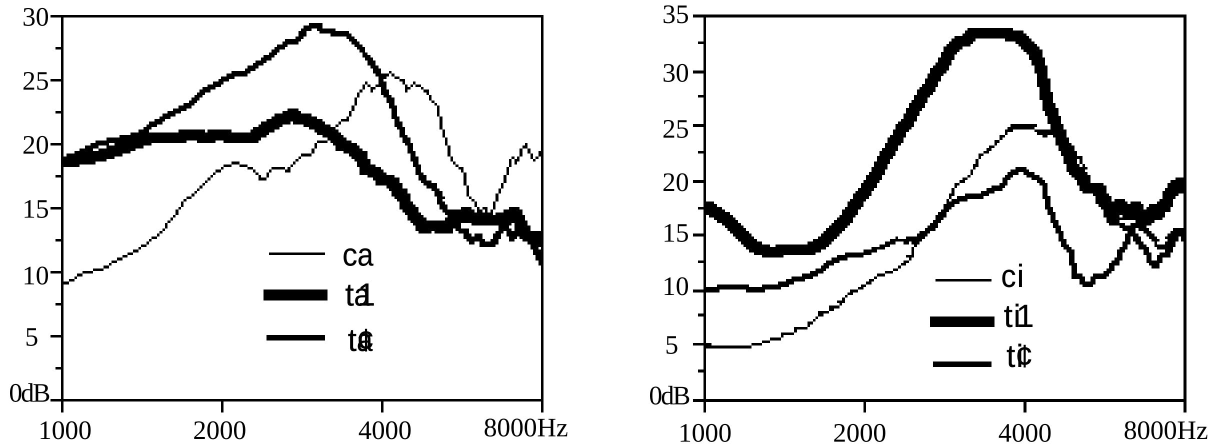
Table 5: List of words used to measure word-initial burst spectra of voiceless coronal stops.

Dental		**Post-alveolar**		**Palatal**	
Before /a/					
t1a!	'chicken'	t¢a	'ground, dirt'	caa	'juice'
t1a1a	'reef'	t¢aut¢i~	'trousers'	ca(|a)	'run'
t1a1a~	'one'				
Before /i/					
t1i1	'blood'	t¢i¢	'tea'	cici!	'fishing line'
t1i1	'sugar cane'			ci!	'spear'
t1i1ci!	'paper'			cii~	'mushroom'
t1i1	'kidney'			cil	'cloth ("manou")'
t1i1~	'mute'				

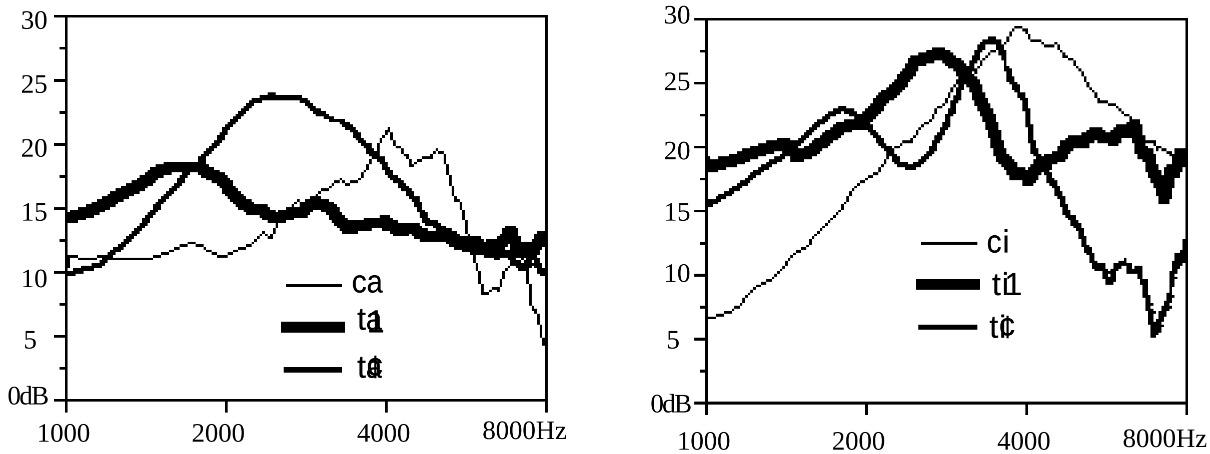
Table 6: Number of measured burst tokens by speaker, place of articulation and following vowel.

	Speaker F1	F2	F3	M1	M2	F4
Before /a/						
t1	3	4	2	2	6	5
t¢	3	2	2	2	4	4
c	1	1	0	2	4	2
Before /i/						
t1	3	1	3	3	0	0
t¢	1	1	1	1	0	0
c	5	4	5	5	0	0

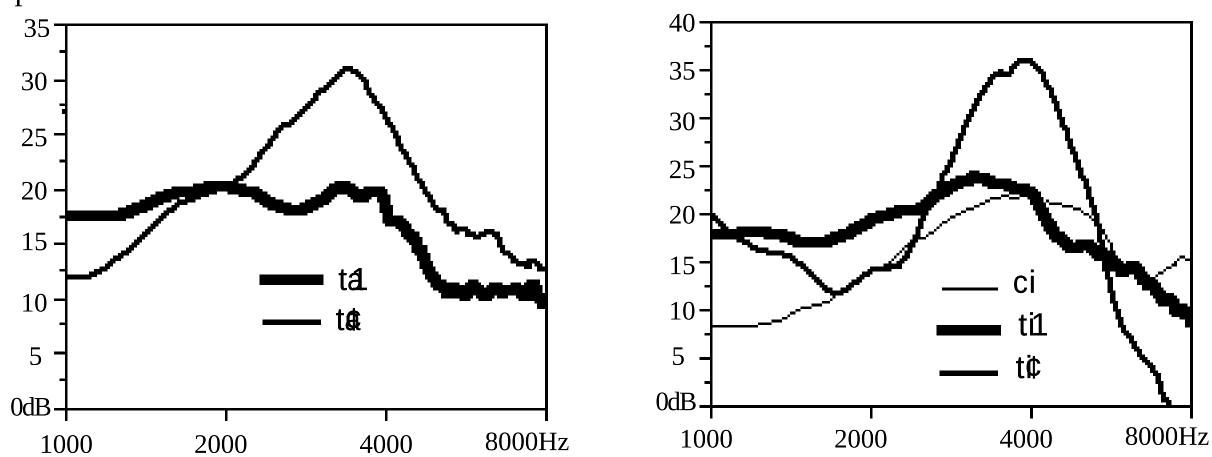
Speaker F1



Speaker F2



Speaker F3



Speaker M1

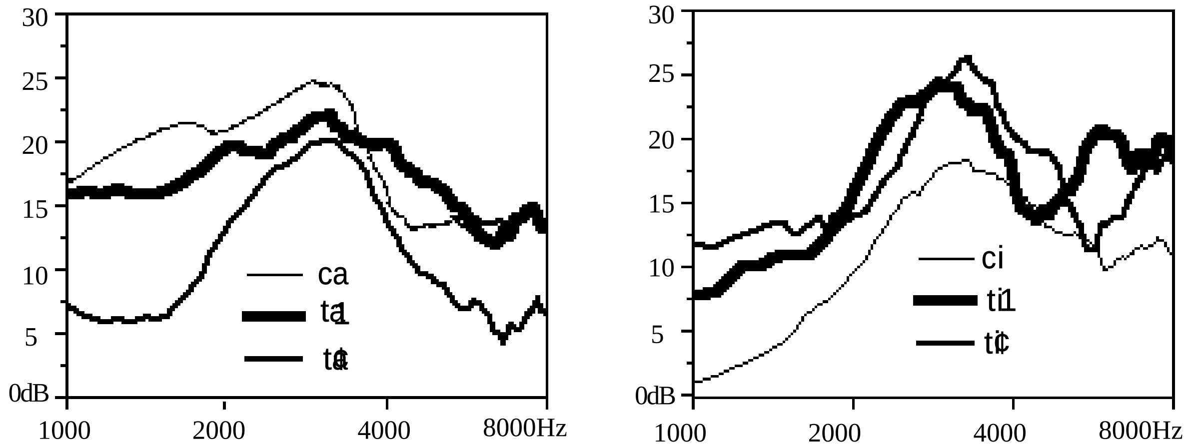


Figure 7. Mean burst spectra of word-initial voiceless coronal stops before /a(ː)/ and /i(ː)/ from the four speakers from Naniouni.

Spectra of the voiceless coronal stop bursts from the second group of speakers from Unia, are shown in Figure 8. This figure shows only the context before /a/, but includes the burst spectrum of the dental and post-alveolar stops intervocalically in the minimal pair /wet a1/ 'age' (6 tokens) versus /wet a¢/ 'enemy' (3 tokens) as produced by speaker M2

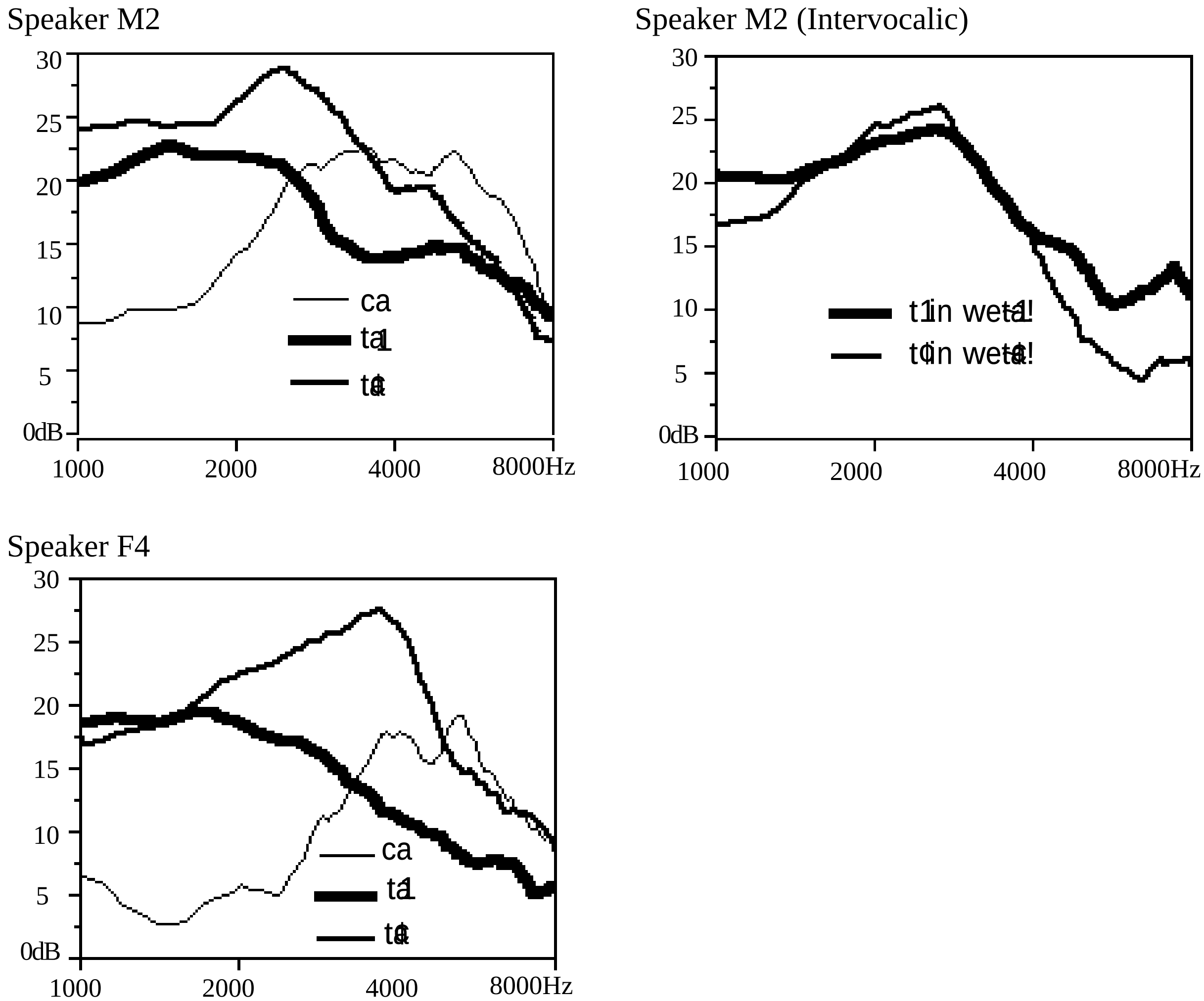


Figure 8. Mean burst spectra of word-initial voiceless coronal stops before /a(ː)/ from the two speakers from Unia, and intervocalic /t̪/ and /t̠/ from speaker M2.

There are many detailed differences in such spectra, but major properties can be described in terms of three parameters, overall spectral slope, relative degree of flatness (also called ‘diffuseness’), and the relative frequencies and bandwidths of principal spectral peaks. For these spectra, overall slope is not usually a good descriptor. However, this measure has usually been used to characterize only that part of the spectrum below 5 kHz (e.g. by Stevens and Blumstein 1978). Within this range it is not unusual to see a generally rising or falling trend. The other parameters distinguish the consonant categories well. The spectra for the dentals, shown by the boldest lines in the figure panels, are generally flatter than those of the other coronals. A more peaked spectrum occurs before /i(ː)/, particularly for speakers M1, F1 and F2. In this environment the peak for the dental is lower in frequency and broader in bandwidth than is seen with /t̠/ or /c/. Except for the three cases of M1, F1 and F2 before /i(ː)/, the overall spectral shape for /t̪/ can be described as falling. The post-alveolar stop burst, shown by the intermediate thickness line in the figures, typically has the most peaked spectrum of the three coronals. There is generally a relatively narrow bandwidth spectral peak between 3000 and 4000 Hz. The palatal stops, represented by the thin lines, are also less flat than the dental, being characterized by a peak above 4000 Hz for the female speakers, and having the lowest relative amplitudes in the lower part of the spectrum.

Some individual differences stand out in this data. Speaker M1 has a similar frequency for the spectral peak of both the post-alveolar and palatal stops, but the post-alveolar peak is narrower. Speaker F1 appears to show a greater degree of coarticulation before /i“‥‘/ than other speakers, since the spectral shapes of all three coronals are rather similar in this environment. In particular, there is a strong spectral peak in the region of the second and third formants of the following vowel for the dental burst. The comparison of intervocalic dental and post-alveolar stops of speaker M2, on the right of Figure 8, also seem to show the influence of a front vowel environment, in this case a preceding one, on the dental spectrum.

4.2.2 NOISY POST-RELEASE INTERVAL (VOICE ONSET TIME). The coronals are also differentiated by the amplitude and duration of the interval of noise following the release of the closure. The duration of this noisy period was measured from the moment of the release of the stop to the onset of the first formant of the following vowel. (This is essentially the same measurement as voice onset time, but we wish to clarify that the interval concerned may contain portions of both affrication and aspiration noise). Measurements were taken from the same tokens used for the burst spectra for all six speakers. Results for each speaker separately are shown in figure 9. The coronals were measured before /i/ and /a/ for the speakers from Naniouni but only before /a/ for the two speakers from Unia. For speaker M2 a word-medial comparison of /t/1and /t/¢is included.

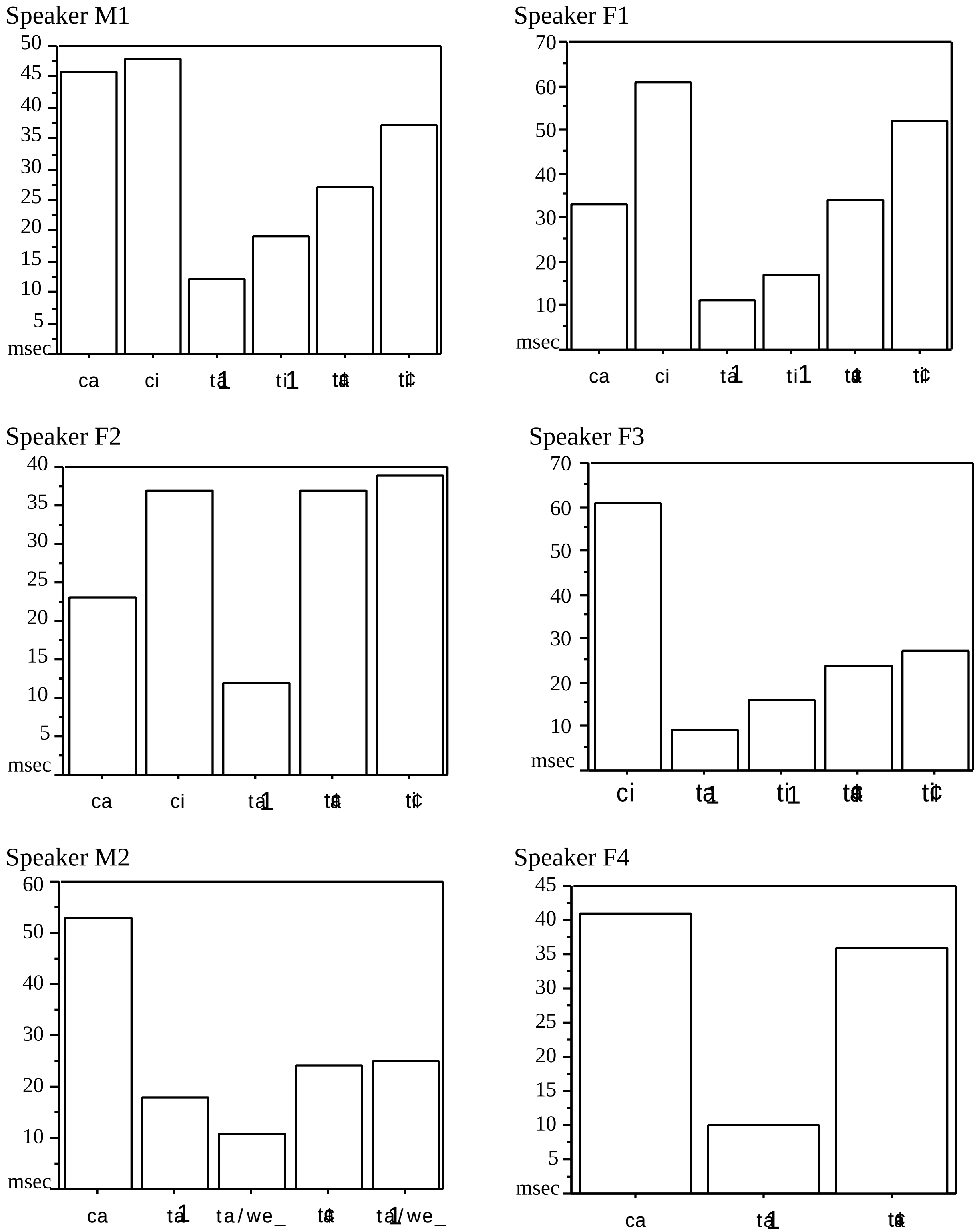


Figure 9. Histograms showing mean duration of the noisy post-release interval from six speakers.

The histograms in figure 9 suggest two principal findings. The three coronals appear to be differentiated by the duration of the noisy interval, and these durations are affected by the quality of the following vowel. The palatal and post-alveolar stops both have longer durations than the dental, which has a markedly shorter noisy interval. A tendency for the palatal to be longer than the post-alveolar is also apparent. Noise duration is longer before /i“‘/ than before /a“‘/ for every comparison that can be made. Speaker F2 has an anomalously short duration of the frication period for the palatal stop, resulting in it having a shorter duration than the post-alveolar in her case.

In order to test the effects of vowel quality and place of articulation, a two factor ANOVA was performed. Because of gaps in the data set, this meant splitting the analysis into two parts. Post-alveolars and palatals were examined for speakers M1, F1 and F2 as a group, with vowel quality as a second independent variable. Results showed no significant effect of place of articulation on duration of the noisy period (F(1, 8) = .436, p = .5276). Nor did vowel quality have a significant effect, although results revealed a trend toward significance (F(1, 8) = 4.933, p = .0571). In order to test whether the failure of the effect of place of articulation on the noise duration to reach significance was due to the aberrant values of speaker F2, the test was redone using only speakers F1 and M1. Once again, neither place of articulation (F(1, 4) = .2.359, p = .1993) nor vowel quality (F(1, 4) = 5.497, p = .0790) had a significant effect on the duration of the noisy post-release period.

Dentals and post-alveolars were compared grouping together speakers M1, F1 and F3. For the dental and post-alveolar set there was a significant effect of place on noise duration (F(1, 9) = 7.039, p = .0263); the noise duration following the post-alveolar was significantly longer than following the dental. The effect of vowel quality was again insignificant (F(1, 9) = .189, p = .6737). From these two analyses we may conclude that the dental is significantly shorter than both the post-alveolar and the palatal in the duration of the following noise.

4.2.3. BURST AMPLITUDE. Burst amplitudes of the three coronals in Ndumbea were examined using the same tokens. In order to normalize for variation in overall speech amplitude and recording conditions, measurements of the peak burst amplitude were made relative to the peak amplitude of the following vowel. All measurements were taken from a smooth RMS energy curve using 5 ms windows calculated continuously through each token. The peak amplitude of the burst was subtracted from the peak amplitude of the vowel. Taking the difference of the two amplitude values resulted in a greater scatter of values and, hence, better differentiation of the stops, than is obtained by dividing the vowel amplitude by the burst amplitude. The results of the burst amplitude analysis are presented in Figure 10. A higher value indicates a burst with lower relative amplitude.

The general pattern is for the palatal to have the weakest release burst — i.e. the largest vowel-burst difference. The dental and post-alveolar release bursts are more intense, with some tendency for the post-alveolar to be stronger than the dental. This result therefore seems to be dividing the stops according to their degree of laminality. In general, the bursts of all three coronals have greater relative intensity in comparison with a following /i/ than with a following /a/, as is expected given that /i/ generally has less intensity than /a/.

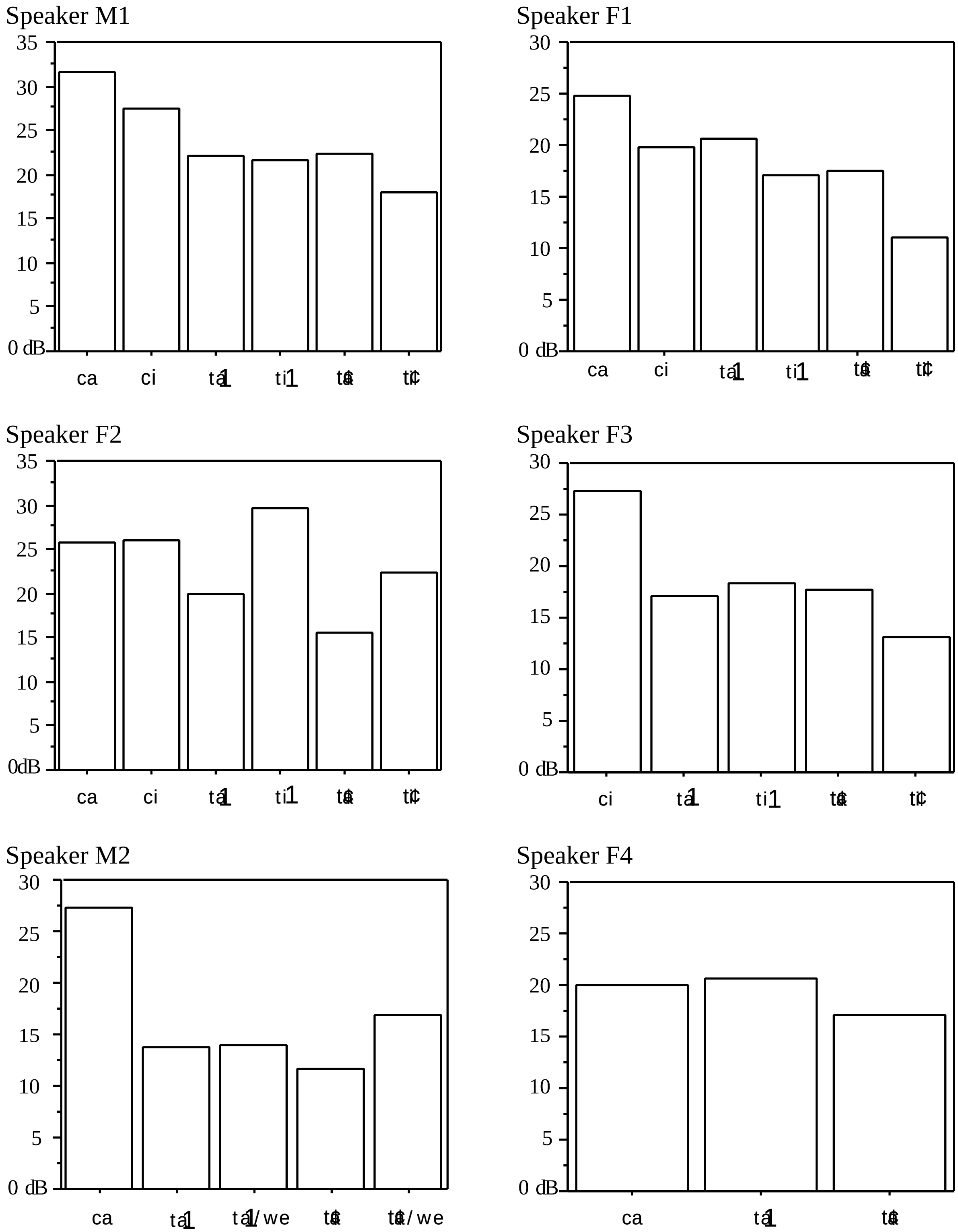


Figure 10. Histograms showing differences between peak burst amplitude for the three voiceless coronal stops and peak amplitude in the following vowel.

4.2.4. FORMANT TRANSITIONS. The onset F2 and F3 values of /a(ː)/ were measured to compare the formant transitions after word-initial voiceless dental and post-alveolar stops only. (Transitional onsets are obviously distinct after /c/.) Onset transitions were obtained from a 14-coefficient LPC analysis calculated over a 20 ms window beginning 10 ms following the release. The choice of this time-point represents a reasonable compromise between the moments at which clear formant structure begins following these two categories of consonants. In some problematic cases, an FFT power spectrum was consulted to resolve F3 where the LPC analysis failed. Speaker M1 was not analyzed due to the presence of noisy excitation in the F2-F3 region which made formants impossible to resolve at the vowel onset.

Because there are only a few words in the data set containing short /a/ after a dental and none containing long /aː/ after a post-alveolar, the effect of the preceding consonant is confounded with a potential effect of vowel length on the formants of the vowel, which might affect the onset transitions measured (/a/ is the most variable vowel in Figure 2). For this reason, separate analyses were performed to tease apart the effect of vowel duration and place of articulation of the preceding consonant on formant values. A set of words containing long and short /a/ after dentals only was examined to test the effect of vowel duration alone. This data set contained one long/short pair from each of five speakers. Formants were measured at two points: at the mid-point of the vowel (as discussed in section 2), and at the vowel onset. F2 and F3 values for long and short vowels at either the onset or the mid-point of the vowel generally differed relatively little from each other, as Table 7 shows. None of these differences is statistically significant, but the number of data points is small. There is, however, some indication that F2 may be typically higher in short /a/ than in long /aː/.

Table 7: Formant values for long and short /a/ at onset and middle of the vowel (after dentals).

	Onset		**Mid-point**	
	F2	F3	F2	F3
Short	1797	2936	1671	2981
Long	1764	2938	1602	2879

The effect of the preceding consonant on formant values was examined over a set of 30 tokens balanced for speakers and place of articulation (15 following the dental, 15 following the post-alveolar). Only tokens in which the consonant was word-initial were chosen in order to exclude the possibility of coarticulation with a preceding vowel. Because of the limitations on the data set noted earlier, all 15 post-alveolar tokens contained short vowels, while 13 of the 15 dental tokens contained long vowels. The mean onset F2 was higher following the post-alveolar than after the dental, 1921 Hz to 1753 Hz, a difference of 168 Hz. In an analysis of variance, the effect of the preceding consonant on the second formant was found to be highly significant ($F(1, 28) = 14.912$, $p = .0006$). The effect of place of the preceding consonant on F3 was not significant ($F(1, 28) = .0082$, $p = .986$).

An analysis of variance in which *length* was the relevant factor confirmed that the place of the preceding consonant had a larger effect on onset F2 values than the duration of the vowel did. A further analysis of 34 tokens with equal numbers of long and short vowels, balanced by speakers but not by place was conducted (the set contained 17 long vowels, all after dentals and 17 short vowels, 12 after post-alveolars and 5 after dentals). This showed a difference of only 122 Hz in the F2 mean for short vowels vs. long vowels (1867 Hz vs 1745 Hz), and a lower level of significance for the comparison. Because the difference was smaller when the data set was sorted by vowel duration than by preceding consonant, one may conclude that the effect of the preceding consonant is at least greater than that of vowel duration if in fact both are present.

4.2.5. CLOSURE DURATION. In our data few comparisons are available for the stops in intervocalic positions, hence little information can be given about closure duration. However, the duration of the closure was measured for the voiceless dental and post-alveolar stops in intervocalic position in the minimal pair /wet1a/ (8 tokens) versus /wet¢a/ (6 tokens) as spoken by speakers M2 and F4. Of the 14 tokens measured only two came from speaker F4, one example containing a dental and one with a post-alveolar. The measurement began with the cessation of F2 of /e/ and ended at the release of the stop closure. The mean duration for the post-alveolar was 154 ms while the mean for the dental was only 115 ms. A one factor ANOVA computed over a balanced set of 6 dental and 6 post-alveolar tokens showed this difference to be statistically significant ($F(1, 10) = 6.530$, $p = .0286$), but the limited number of tokens means that this result should be treated with caution.

4.3. DISCUSSION OF THE CORONAL CONTRAST. The three voiceless coronal stops of Ndumbea are quite easily differentiated in both the articulatory and acoustic domains. The dental is articulated further forward than the other two. The palatal is laminal in opposition to the other two. The dental has a short period of noise after its release, whereas the other two have longer and more intense noise. The spectra of these noisy periods show that the palatal has the highest frequency concentration of energy, and the post-alveolar has the narrowest bandwidth of noise. The onset of F2 is highest after the palatal, and significantly higher after the post-alveolar than after the dental. Closure duration appears longer for post-alveolar than for dental stops.

In many languages, dental consonants are typically laminal, e.g. in Toda (Shalev et al. 1994), and Dahalo (Maddieson et al. 1993), and they are often accompanied by considerable noisiness or affrication on their release, although this is not the case for Dahalo. Retroflex or post-alveolar stops often have a short post-release noise period, as in Tiwi and Arrernte (Anderson and Maddieson 1994, Ladefoged and Maddieson 1996), and this has sometimes been explained as a consequence of their apical articulation. The tongue-tip can move rapidly and the tongue body is lower in the mouth than for a laminal. This creates a short frication duration since the aperture increases rapidly. However, Ndumbea reverses this pattern. Although the post-alveolar is apical, it has a noisy release.

The Ndumbea post-alveolar stops shows some other unexpected features. First, F3 values immediately following the post-alveolar do not differ consistently from F3 values after the dental. Post-alveolar consonants are often associated with lowered F3 values in transition from an adjacent vowel (Stevens and Blumstein 1975, Jongman, Blumstein and Lahiri 1985).. Furthermore, F2 values for the post-alveolar are higher than those for the dental. Retroflex consonants often have shorter closure durations than other coronals, but not in Ndumbea. These formant measures suggest that there is no significant sublingual cavity in Ndumbea post-alveolars, and that the tongue body and/or the jaw may be higher for post-alveolars than for dentals.

We may posit that the dental/post-alveolar contrast in Ndumbea crucially involves not only a place of articulation difference but also use of a more forceful articulatory contact for the post-alveolar. This is inferred from our duration measurements, and may in turn account for some of the acoustic properties, such as the apparently slower release and higher F2 for the post-alveolar. Further, the post-alveolar is not produced in Ndumbea with the quasi-ballistic forward moving gesture that is seen in languages with more retracted retroflex consonants. These observations reinforce the point that, despite many overall similarities in pattern, languages nevertheless demonstrate many variations in the relationship between broad articulatory categories and the acoustic patterns produced.

5. PRENASALIZED STOPS. As with many Austronesian languages Ndumbea has a series of voiced prenasalized stops. Given the sequential complexity of this segment type, the temporal patterns associated with them are of particular interest. The duration of the two main acoustic components of the prenasalized stops in word-initial position was measured in a subset of words balanced across the speaker groups as well as the available recordings allowed. The nasal portion was taken to be from the onset of detectable voicing to the point where a diminution of amplitude and simplification of the waveform shape suggest that nasal airflow has terminated. The oral portion is from this point until the burst transient indicating the release of the oral closure. These points were determined by examining an expanded waveform display in conjunction with a spectrogram using the CSL or Macquirer software, and verified by listening to fragments of the waveform. Figure 11 shows a sample of such a waveform with the points marked. Time is shown in milliseconds.

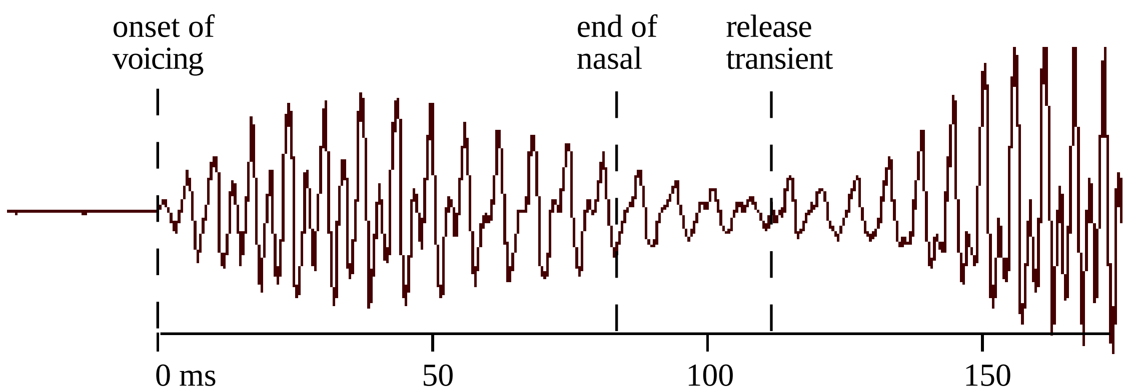


Figure 11. Waveform of the beginning of the word /ndɖu/ 'island' spoken by speaker F2 illustrating determination of nasal and oral components of a prenasalized stop.

The mean durations of the nasal and oral portions in the tokens measured are displayed by place of articulation in Figure 12, and listed in Table 8. Following a trend concerning stop closure durations which is commonly found across languages, the bilabials are longest and the velars shortest (this is the only pairwise comparison among these durations which reaches statistical significance). The greater duration of the bilabials is the result of both a longer nasal and a longer oral part. The duration of all three coronals is not greatly different from that of the velars.

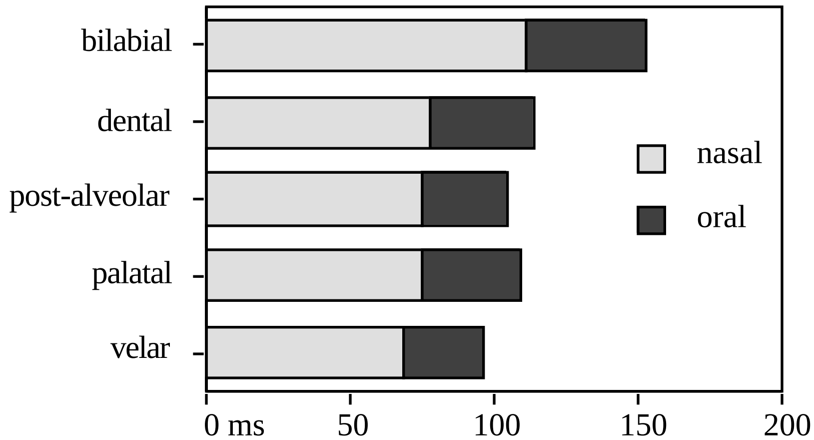


Figure 12. Mean durations of nasal and oral components of prenasalized stops by place of articulation.

Table 8. Duration of components and total duration of prenasalized stops by place

place	**n**	**nasal duration**	**oral closure**	**total duration**
bilabial	15	111.7	41.8	153.5
dental	13	78.4	36.2	114.5
post-alveolar	13	75.4	29.3	104.7
palatal	7	75.3	34.4	109.7
velar	8	69.0	27.9	96.9
Mean across places		**81.9**	**33.9**	**115.9**

As Table 8 indicates, a ‘typical’ duration pattern for these initial prenasalized stops is about 75 ms of nasal followed by about 30 ms of purely oral closure, giving a total audible segment duration of about 105 ms. This duration was compared with that of word-initial plain nasals, measured in a comparable fashion from voicing onset to the point of release into the following vowel. The results are given in Table 9 by place of articulation.

Table 9. Duration of nasals by place.

place	**n**	**nasal duration**
bilabial	9	76.9
dental	9	126.1
post-alveolar	7	130.9
palatal	13	135.2
velar	7	124.0
Mean across places		**118.6**

As the means across places in Tables 8 and 9 show prenasalized stops and nasals have extremely comparable overall durations, 116 vs 119 milliseconds. This is because the nasal component of the stops is (weakly) significantly shorter than the duration of plain nasals when these sets of means are compared ($F(1, 8) = 7.903$, $p = .0228$). However, the behavior of the bilabials appears anomalous. In the selected data measured, plain bilabial nasals have almost half the total duration of the prenasalized stops, and the nasals are markedly shorter than just the duration of the nasal portion of the bilabial prenasalized stops. If both bilabial means are omitted from the comparison and only coronal and velar durations are compared, the plain nasals are significantly longer than the prenasalized stops (F (1, 6) = 24.912, p = .0025), having a mean of 129.0 ms to 106.5. The surprisingly short duration obtained for the bilabial nasals may be due to the choice of a disyllabic word with a short initial syllable, /makaa/ 'house', as the main representative of this category. There are many interactions between factors such as vowel context, word structure, tonal patterns and lexical frequency (not to mention pragmatic effects such as order in a group of speakers, reaction to being asked to repeat a word, etc) which affect consonant durations, and these could not be controlled for in this comparison, as the wordlist in Table 10 demonstrates. However, it is very clear that the sequential complexity of prenasalized stops does not result in their being longer in duration than a less complex class of consonants in Ndumbea.

Table 10. List of words from which the duration of prenasalized and oral stops were measured.

Place of articulation	**Prenasalized stop**	**Nasal**
Bilabial	mbee 'fish'	makaa 'house'
	mboo 'moon'	mo)) 'shy' (Unya)
Dental	nd11U 'mangrove tree'	nee 'taro'
	ndee 'son'	
Postalveolar	nd¢u 'island'	n¢a 'language'
	nd¢u 'knife'	
Palatal	≠Ôil 'sun'	≠aa 'mother'
	≠ÔU!boat	≠e!'thorn'
Velar	Ngoo 'plant, tree'	Na(|¢) 'do, work'
	NgUU 'root'	

A broadly similar situation, that prenasalized stops have comparable duration to simple consonants, has been found in Fijian (Maddieson 1990). This is different from certain Bantu languages in which the nasal part of a prenasalized stop has separate moraic status, such as Sukuma (Maddieson and Ladefoged 1993) and Runyambo (Hubbard 1995). In both of these languages, prenasalized stops are substantially longer than plain nasals, for example.

As a final note on prenasalized stops, it is worth noting that the distinction among the three coronals is reflected in similar differences in formant transitions and post-burst noise duration as was observed for the voiceless stops. Representative tokens of the dental and post-alveolar stops which show the longer noisy interval after release for the post-alveolar are illustrated by the spectrograms in Figure 13.

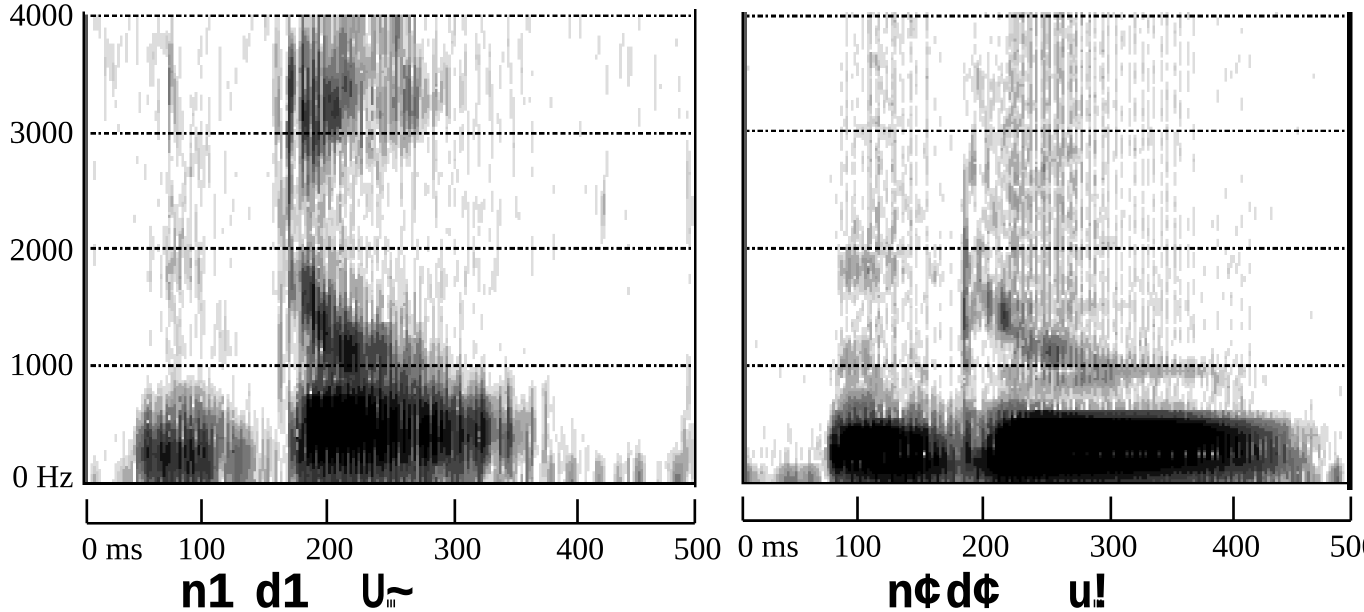


Figure 13. Representative tokens of the dental and post-alveolar prenasalized stops in the words /n̪d̪ʊ̃/‘mangrove tree’ and /n̠d̠u/ ‘island’

6. **SUMMARY.** In summary, our work on the phonetics of Ndumbea has shown the following. The eight vowel qualities of Ndumbea are for the most part well differentiated on the basis of mean F1 and F2 values, although individual tokens of /ɪ/ show considerable overlap with both /i/ and /e/. The third formant distinguishes /i/ from /ɪ/. The three places in the coronal area at which stops are produced can be easily distinguished by both their articulatory and acoustic properties. However, the way that these properties are related to each other provides further evidence that there are no simple language-independent associations between acoustic realization and the basic place of articulation for a class of consonants. Finally, prenasalized stops are broadly comparable in duration to simple nasal consonants.

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