The Internal Structure of Nasal-Stop Sequences: Evidence from Austronesian

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1 Introduction

The phonological and phonetic structure of nasal-stop sequences has elicited much attention. Yet, less is known about the internal timing of nasal-stop sequences than often assumed. This includes clusters, both nasal voiced-stop clusters (ND) and nasal voiceless-stop clusters (NT); and unary cases, most commonly prenasalized stops (^{N}D) but also so-called postploded nasals (N^{D}).[1] The latter are cases that have been described as being in some sense the mirror image of prenasalized stops, where the segment is taken to be primarily nasal, but with an oral release. (*Nasal-stop sequence,* or *NC sequence,* is used here to refer to both unary and cluster cases.)

Based on impressionistic phonological descriptions, we would expect the phonetic timing relationships schematized in Figure 1. First, in terms of overall duration, prenasalized stops (a) and postploded nasals (b) are expected to have roughly the overall duration of a single segment and nasal-stop clusters (c & d) should be longer, in line with the duration of other clusters in the language (Riehl 2008). In terms of relative duration of the nasal and oral components, in the case of prenasalized stops (a), the nasal component is expected to be quite brief, taking up just the beginning of the total duration. While in the case of postploded nasals (b), the converse is expected, with the nasal closure taking up the majority of the total duration and only a brief period of oral closure. In the case of nasal voiced-stop and nasal voiceless-stop clusters (c & d), the total duration is expected to be roughly evenly divided between the nasal component and oral component for both cases.

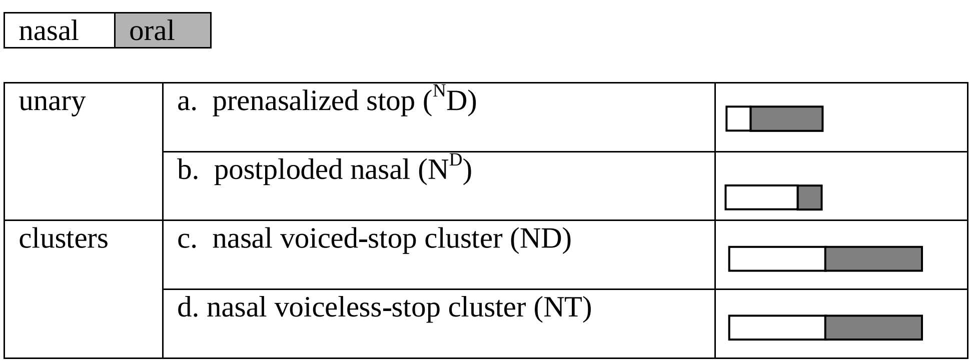

Figure 1: Expected phonetic timing relationships of nasal and oral components of NC sequences.

Phonetic data addressing the realization of these phonological types is quite limited, but the available data suggest quite different realizations than expected. In a cross-linguistic study of nasals and nasalization in English, French, and Sundanese, Cohn (1990) observed a systematic asymmetry in the relative timing of the nasal and oral portions in nasal voiceless-stop vs. nasal voiced-stop clusters: For the NT cases, the nasal and oral components each take up about half of

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[1] For the sake of convenience we refer to "postploded nasals" as N^{D}. However, as we shall see below in the cases under discussion here, these are arguably clusters and this abbreviation will prove less than perspicuous.

the total duration, as expected; while in the ND cases, the sequence is nasal for all but a very brief period. While others have since noted a similar asymmetry, no full account has been offered. As far as unary cases, claims have been made about there being different types based on relative timing of the nasal and oral portions. First, do the prenasalized stops exhibit the expected pattern? Second, in the case of postploded nasals, are they indeed the mirror image of prenasalized stops? Are they actually unary segments or clusters? Finally are they a phonologically distinct type of NC sequence? The goal of this paper is to bring to bear a more extensive body of phonetic data in order to better understand the phonological structure and phonetic realization of this range of nasal-stop sequences. We present data from six Austronesian languages to investigate these questions. The Austronesian language family is known for its rich array of nasal-stop sequences, including nasal-obstruent clusters and cases of both prenasalized stops and what have been described as postploded nasals.

In §2, we present some background on the question of prenasalized stops vs. nasal-stop clusters, reviewing relevant results from Riehl (2008) and in §3, the methodology of the present study. In §4, we investigate the asymmetry between the voiced and voiceless NCs and in §5 & §6, we consider the phonological status and phonetic realization of postploded nasals. We will see that to address each of these points the central issue is timing. This includes total duration, the relative timing of the nasal and oral components, and finally what we call microtiming, that is, the structure of the transition from nasal to oral and the nature of the oral component.

2 Background

A priori, we would expect differences in overall timing (total duration) between unary nasal-stop segments and nasal-stop clusters, where in the unary case, the duration should be comparable to other segment types (e.g., plain nasals and voiced stops) and in the cluster case comparable to other clusters. However, claims have been made in the literature suggesting that this difference in phonological structure between unary segments (e.g., prenasalized stops) and nasal-stop clusters is not systematically realized in the phonetics. For example, Downing (2005:183) states "There is no consistent phonetic contrast, like a durational distinction, between prenasalized stops and NC clusters." (See also Browman and Goldstein 1986, Maddieson and Ladefoged 1993.)

Riehl (2008) addresses this question through a systematic phonological and phonetic investigation of four Austronesian languages containing different sorts of nasal-stop sequences. Contra the claims in the literature, Riehl finds strong support for the conclusion that there is a systematic difference in overall timing between unary cases (^{N}D) and clusters (ND) whereby ND is substantially longer than ^{N}D. She concludes that the best way to assess this difference is by looking at a ratio of the duration of a plain nasal to the duration of an NC sequence (nasal + oral): N:NC. This is illustrated in Figure 2 for medial NCs where the ratios are close to 1 for the unary cases and significantly greater than 1 (minimum of 1.5 on the average) for the cluster cases.

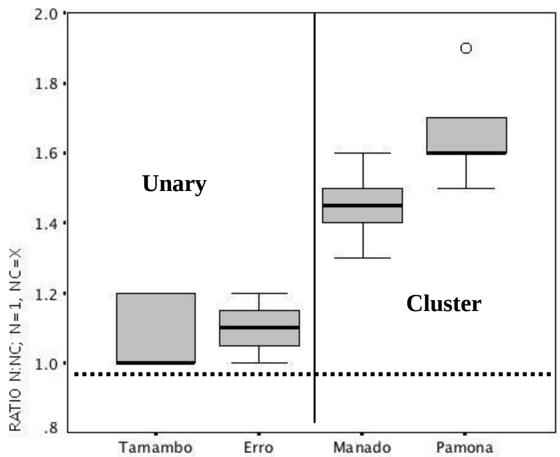

Figure 2: Total duration ratios of alveolar /n/ to /ⁿd, nd/ in two languages with unary segments and two with clusters, in medial position; averages across five speakers of Tamambo, four of Erromangan, six of Pamona and Manado Malay; ten repetitions per speaker. The duration of the plain nasal is /n/=1. (Adapted from Riehl 2008: 266.)

This systematic difference in the unary vs. cluster cases holds for the four languages under investigation. It holds for all speakers, across different word positions and places of articulations. It is also consistent with prior observations in the literature for those cases where the phonological structure of the NCs is not debatable (e.g., the prenasalized stops of Ndumbea, Gordon and Maddieson 1999, and the clusters of English, Vatikiotis-Bateson 1994).

In light of these robust conclusions, we might wonder why there have been contradictory conclusions in the literature. First is the question of how the comparisons are made. Many past studies compared absolute durations both across languages and speakers resulting in misleading conclusions. In fact, the only valid comparisons across languages and speakers are relative measures such as ratios. In addition, in many past studies NCs were compared to the duration of plain voiceless stops rather than plain nasals, which is also misleading as there are added differences in voicing and aspiration. Second, there is a need for sufficient data, both in terms of multiple repetitions and multiple speakers. Many past studies make use of only one or two speakers or repetitions, which may be problematic, especially since, as we will see below in §6, some speakers exhibit considerable variability, and there are also subtle, but systematic, difference between speakers. Finally, as discussed below, putative cases of one type or the other need to be reevaluated in light of certain questionable phonological assumptions.

In addition to the observations about overall timing, Riehl also makes some typological observations about possible phonological contrasts that are important to our discussion. Based upon a cross-linguistic survey of NCs, Riehl proposes a classification of occurring and non-occurring patterns. She finds two clear gaps. First, no language has unary ^{N}T.[2] Second, no language exhibits a contrast within morphemes between ^{N}D and ND, unless the language independently has a singleton-geminate contrast (e.g., Sinhala). Such cases arguably show a singleton-geminate contrast in the nasal-stop sequences, rather than a contrast between ^{N}D and ND per se. These two gaps account for the fact that languages have, at most, a two-way contrast: ND vs. NT or ^{N}D vs. NT.

We turn now to the methodology of the present study.

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[2] Although claims of ^{N}T have been made in the literature, Riehl (2008) argues that these cases are better analyzed as clusters and that there is no clear evidence that unary ^{N}T occurs in any language.

3 Methodology

We present acoustic and nasal airflow data for six Austronesian languages, which between them are described to exemplify four nasal-stop sequence types: ^{N}D, N^{D}, ND, and NT, as summarized in Table 1.

Language	Nasal voiced-stop sequence			Nasal voiceless-stop sequence	# of speakers	# of repetitions
	^{N}D	N^{D}	ND	NT		
Tamambo	√				5	10
Erromangan	√			√	4	10
Acehnese		√		√	1	5 x 2
Sundanese		√		√	2	5 x 2
Pamona			√	√	6	10
Manado Malay			√	√	6	10

Table 1: NC-types in each language studied, with number of speakers and repetitions analyzed.

The data presented here are an extension of Riehl's (2008) study. Data from the four languages investigated there are supplemented by a study in progress of Acehnese[3] and preliminary Sundanese data from Cohn (1990). Tamambo and Erromangan (Oceanic languages of Vanuatu) are described as having prenasalized stops. Acehnese and Sundanese (West Austronesian languages of Indonesia) are described as having postploded nasals. Pamona and Manado Malay (also West Austronesian languages of Indonesia) are described as having nasal voiced-stop clusters. In addition, in each of these languages except for Tamambo, the nasal voiced-stop sequences contrast with nasal voiceless-stop clusters.

The data consist of target words with nasal-stop sequences,[4] in minimal or near-minimal sets with corresponding plain nasals and stops, recorded in appropriate frame sentences. The target words reported on here and the frame sentences for each of the languages are presented in Appendix A. These patterns were investigated in both initial and medial position (where possible depending on the phonotactics of the language) and for all major places of articulation.

For all of the languages except Sundanese, acoustic recordings were made with a Marantz PMD 670 digital recorder and Shure SM10A microphone. Labeling was done in Pratt based upon waveforms and spectrograms. Nasal and oral airflow recordings were made with a Scicon MacQuirer (except for Acehnese for which the Glottal Enterprises Airflow system model MS-100A2 was used and Sundanese for which the earlier hardware-based Glottal Enterprises Airflow system was used.) Although airflow data were consulted for comparison and are used here for illustration, the results reported in the graphs are based on the acoustic data, given the considerably larger amount of useable data.

Since there are no initial NC's in Sundanese and only marginally so in Manado Malay, it is only in medial position that these cases can be compared across all of the languages. Thus, we focus primarily on medial position. The results across place of articulation are quite consistent, with a few small qualifications (see Riehl 2008 for discussion); due to space limitations, we focus here on the coronals. We are now ready to turn to the question of relative timing of the nasal and

[3] We report here on data from one speaker of Acehnese and are in the process of collecting data for additional speakers.

[4] We limit ourselves here to a discussion of nasal-stop sequences, since these are the canonical types of nasal-oral sequences; see Riehl (2008) for discussion of nasal-affricate cases.

oral portions of nasal-stop sequences and consider in particular the question of the asymmetry between nasal voiceless-stop and nasal voiced-stop sequences.

4 Relative Timing

A priori, we would expect the nasal and oral components of nasal-stop clusters, whether voiceless or voiced, to take up roughly half of the combined duration, which should be comparable to the total duration of other clusters in the language. Instead Cohn (1990) observed a systematic asymmetry in the relative timing of the nasal and oral components: For the NT cases, the nasal and oral components each take up about half of the total duration, as expected; while in the ND cases, the sequence is nasal for all but a very brief period. This asymmetry is illustrated in Figure 3 for English, French, and Sundanese, where (filtered) nasal airflow is presented for one representative token of both ND and NT for the three languages.

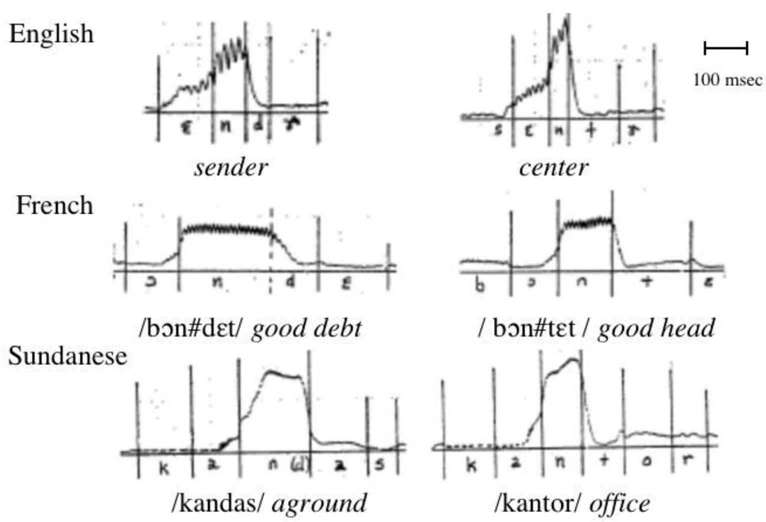


Figure 3: Filtered nasal airflow for one representative token of ND (left) and NT (right) for English, French, and Sundanese.

For English, it is widely assumed that the NC sequences are clusters. In French, the NC sequences occur only across morpheme boundaries. In Sundanese, the NC sequences are also clusters, although the NDs in Sundanese have been described as postplosed nasals (a point to which we return below in §5). In all three cases, this asymmetry is systematic and pervasive. While others have since noted a similar asymmetry (e.g., Beddor pc, Ohala and Ohala 1991, Hayes and Stivers 2000, Riehl 2008, and others), no full account has been offered.

We turn to the results of the relative timing of the nasal and oral components in §4.1, considering not only the nasal cluster cases, but also the unary cases. We outline a possible account of the observed asymmetry between ^{N}D/ N^{D}/ND and NT cases in §4.2. We conclude this section with a brief discussion of the realization of plain nasals vs. NC sequences in §4.3.

4.1 Results – Relative Timing of Nasal and Oral Components

The results for the relative timing of the four nasal-stop sequence types—^{N}D, N^{D}, ND, and NT—are presented in Figure 4.

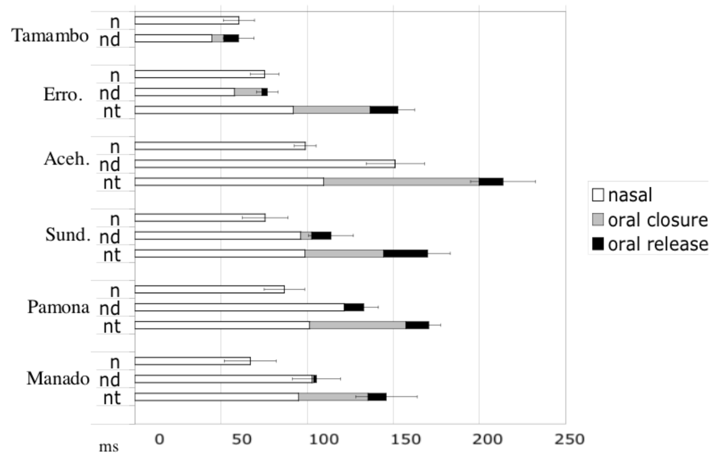


Figure 4: Average duration of N, ᴺD/ Nᴰ/ND, NT from one representative speaker of each language, ten repetitions. Error bars reflect one standard deviation of total duration.

In Figure 4, we present average durations of the nasal and oral components of N, ᴺD /Nᴰ/ND, and NT for one representative speaker of each language (except Tamambo, which does not have NT). The two languages with canonical unary NDs, Tamambo and Erromangan, are presented on the top; the two languages described as having postploded nasals, Acehnese and Sundanese, are in the middle; and the two languages with nasal voiced-stop sequences, Pamona and Manado Malay, are on the right. The observations above about overall timing of unary NCs vs. clusters can also be observed in this figure: The ᴺDs in both Tamambo and Erromangan are about the length of the plain nasal, while in Pamona and Manado Malay the ND clusters are significantly longer than the plain nasals. The question of where Acehnese and Sundanese fit in in terms of overall timing will be taken up below in §5.

Our focus at this point is the relative timing of the nasal and oral components. For the nasal component, this includes any portion that shows nasality. For the oral component, this includes both the oral closure and the oral release, if present. As can been seen here, for all NT cases, there is an oral closure, while for the ND cases, only a very brief oral closure and/or brief oral release, if any, are observed, a point that we return to below in §6.

In terms of relative timing, we see in the five languages where ᴺD, Nᴰ, or ND contrast with NT that the relative timing of the nasal and oral components is systematically different between the voiced and voiceless cases. The relative timing of the nasal and oral portions is roughly as expected for NT, a significant nasal component (roughly the first half of the total duration) followed by a significant oral component (roughly the second half of the total duration), the latter including both an oral closure and release. In all of the nasal voiced-stop cases, however, the nasal component comprises all but the final portion of the combined duration, with only a very brief oral portion (an average of 0-18 ms across speakers), regardless of whether unary or cluster. Thus, the difference in overall duration between the unary and cluster cases lies primarily in the duration of the nasal component.

The ND pattern is at odds with the standard transcriptions of both the prenasalized stops and the clusters. In the case of clusters the transcription suggests that there are significant periods of both nasal and oral closures. In the case of the prenasalized stops, the transcription suggests that the nasal component is quite brief followed by a predominantly oral phase, and yet we see just the opposite, a predominantly nasal phase followed by only a brief oral component. This leaves us with two questions: 1) Why is there an asymmetry between NT and ND? This is the topic of §4.2, and 2) If unary NCs described as prenasalized are more accurately transcribed as Nᴰ, what then are postploded nasals? This is the topic of §5 & 6.

4.2 The ND – NT Asymmetry

The observed asymmetry between ND and NT cases is striking. Based on our own data, our reading of the literature, and personal communications from other researchers, we know of no counterexamples to this observed asymmetry.[5] In summary, we compare the expected patterns with the observed patterns in Figure 6.

nasal	oral

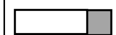
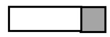
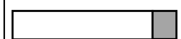
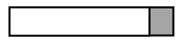
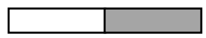
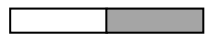
		A. expected	B. observed	C. languages
ND	a. prenasalized stop (^{N}D)			Erromangan Tamambo
	b. postploded nasal (N^{D})			Acehnese Sundanese
	c. nasal voiced-stop cluster (ND)			Manado Malay Pamona
NT	d. nasal voiceless-stop cluster (NT)			All except for Tamambo

Figure 5: Expected and observed phonetic timing relationships.

In terms of relative timing, not only the differences between ND and NT in each language, but also the similarities of ^{N}D, N^{D} and ND across languages require an account. We conclude that the explanations lie in the phonetics, not the phonology, since there is strong phonetic consistency across languages independent of phonological structure.

First, why should the NT case be different from the ND cases? The phonological difference between these cases is that in the ND cases, only the nasality changes, but in the NT case, both nasality and voicing change. To accomplish this phonetically, NT requires an abrupt change from nasal to oral and a clear oral closure, given the precise timing needed to change both voicing and nasality. Ohala and Ohala (1991:213) observe: "[The perceptual] requirements [for voiced stops] are still met even with velic leakage during the first part of the stop.... However, voiceless stops have less tolerance for such leakage because any nasal sound—voiced or voiceless—would undercut either their stop or their voiceless character."

Less obvious is why the ND cases are *necessarily* the way they are. The fact that there *can* be nasality through much of what would be assumed to be oral would follow from the strong propensity for nasality to persevere, combined with the lack of perceptual importance of the nasal murmur itself (Hertz p.c.). However, this does not explain why there is such strong consistency across languages. The systematicity suggests that not only *can* nasality be tolerated in such cases, it is, for some reason, strongly preferred. We believe that the explanation lies in the aerodynamic requirements of obstruent vs. sonorant voicing. As is well known, while vocal cord vibration is the default for sonorants, including nasals, active measures are required to maintain voicing during obstruents (Halle and Stevens 1971). Once spontaneous voicing is underway, it would require active readjustments to switch to obstruent voicing, that is, voicing of an oral voiced stop. The evidence from microtiming is basically consistent with this point, to be discussed in more detail in §6.

[5] It is also noteworthy that a similar asymmetry is observed for nasal vowels followed by voiced or voiceless stops. In French, Cohn (1990) observes an asymmetry between ṼD and ṼT cases, e.g., *bonde* /bõd/, 'plug' vs. *tonte* /tõt/ 'sheep sheering'. Such an asymmetry is also seen in Yoruba (Huffman 1990).

4.3 Plain Nasals vs. NC Sequences

The very brief oral component of the ND cases raises the question of the nature of the phonetic realization of contrast between plain nasals and NC sequences, especially in those cases where both are voiced and the durations are comparable, i.e. in the prenasalized stop cases, exemplified in the present study by Erromangan and Tamambo. What are the phonetic cues marking this contrast? While NTs are clearly distinguished by a voiceless oral closure, the difference between the ND cases and plain nasals can be quite subtle acoustically (we delve into the finer acoustic details of the oral portions below in §6). However a striking difference between the plain nasals and all NCs is the presence or absence of nasality on the following vowel. In all of the languages under investigation, following plain nasals, there is strong perseverant vowel nasalization for the full duration of the vowel. This is part of the widely cited case of long distance nasal spread, whereby a string of vowels or laryngeals may be nasalized following a nasal consonant, observed in these and other Austronesian languages (see Cohn 1990 for discussion of nasal spread in Sundanese and Cohn 1993 for a survey of such cases). In contrast, following NDs and NTs, the vowel is completely oral, quite crisply so. This difference is illustrated for Tamambo and Manado Malay with nasal airflow traces shown in Figure 6.

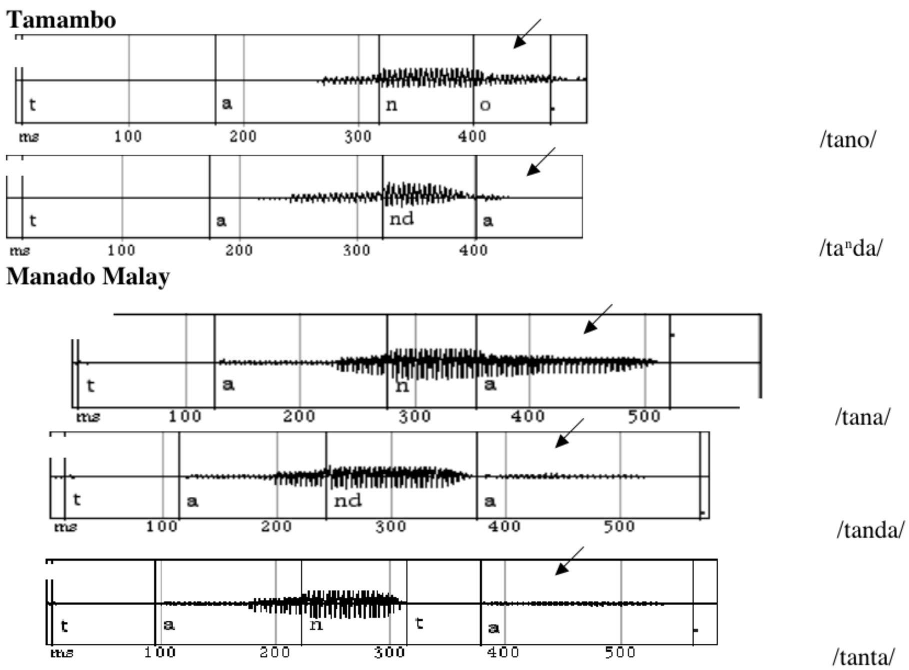


Figure 6: Nasal airflow data from Tamambo and Manado Malay, illustrating differences in nasal airflow in vowels following plain nasals and NC sequences.

These observations suggest that a perceptually salient cue or even the most salient cue to whether the consonant is a plain nasal or NC sequence is whether the following vowel is nasalized. Describing Sundanese, Robins (1957: 91) states that “In such cases [nasal voiced-stop clusters] absence of nasality in the vowel following the plosive or affricate was found to be a more readily noticeable mark of the nasal+voiced consonant sequence as distinct from a single intervocalic nasal consonant.”

Experimental support for the salience and critical importance of the perseverant nasalization on the following vowel in the plain nasal case comes from Beddor and Onsuwan’s (2003) study of the perception of the prenasalized stops of Ikalanga. They manipulated both the duration of the oral closure portion of an ^{N}C (in which acoustically the nasal component takes up most of the total duration, consistent with our findings for similar cases) and the extent of perseverant nasalization on the following vowel. They found "In contrast, at least for these stimuli, the variation in coarticulatory vowel nasalization was both *necessary and sufficient* for listeners to differentiate /m/ and /^{m}b/" (Beddor and Onsuwan 2003:409). The nonsalience of the duration of the oral closure and critical role of the vowel nasalization suggest at least part of the explanation of the very limited set of possible contrasts between nasals and partially nasal cases observed by Riehl (2008).

In summary then, NTs are characterized by a robust nasal component followed by a robust oral component — both closure and release —and a following oral vowel, while NDs — whether unary or clusters — are characterized by a robust nasal component, a very brief oral component, and a fully oral following vowel. We turn now to the question of postploded nasals, considering their phonological status and overall durational properties in §5 and their finer phonetic characteristics in §6.

5 Phonological Status of Postploded Nasals

A number of descriptions in the literature suggest that Acehnese and Sundanese and other Western Austronesian languages of Indonesia share the property of having a series of unusual nasal stops described as "funny", "postploded", "poststopped", or "orally released" nasals (Durie 1985, Blust 1997, Maddieson and Ladefoged 1993, Long and Maddieson 1993, Ladefoged and Maddieson 1996). The wording used in these descriptions suggests that these segment-types are in effect the mirror-image of prenasalized stops, with a nasal closure and oral release (under the assumption that prenasalized stops have a more substantial oral portion). Maddieson and Ladefoged (1993: 280–284) discuss two different kinds of "poststopped nasals." The first type, cases where orally released nasals are allophones of plain nasals, has been described for some dialects of Chinese (e.g., Chan and Ren 1987).[6] Maddieson and Ladefoged draw a distinction between these cases that appear to involve questions of oral and nasal coarticulation and those cases described in Acehnese and Rejang where these segment-types are in contrast with "ordinary" nasals. We focus here on the Acehnese type, where these entities are in contrast with both plain nasals and plain voiced stops. In addition it has been suggested by Catford (1977) and Durie (1985) that in the case of Acehnese, these so-called "funny" nasals differ from plain nasals in the degree of nasality during the nasal consonant itself, suggesting an otherwise unattested type of phonological contrast.

These segment-types have elicited considerable interest due both to Catford's claim and the goal of characterizing the typology of partially nasal segment types. We are in a position to take a closer look at both this segment-type and these claims, with data from Acehnese and Sundanese. In this section we address the question: What are the phonological entities in contrast and what are the relevant dimensions? To answer this question we consider phonological patterning and overall phonetic timing. This leads us to an investigation of the finer phonetic characteristics in §6, where we consider what differences, if any, there are between postploded nasals and the other ND-types, and whether there is evidence that they constitute a distinct category of NC sequence.

Thus the first question to consider is whether the NDs of Acehnese and Sundanese are in fact unary segments. Although such a characterization is often implied in the descriptions, we need to examine the phonological evidence to see if this is indeed the case. In the case of Sundanese, there is really no evidence to suggest that the NDs are anything but clusters, beyond the labels

[6] In addition, there are cases of "partially oralized" nasals described in Karitiana (Storto 1999) and related languages that appear to be allophones of plain voiced stops.

used to describe these entities in some of the secondary sources. The distribution of NDs completely parallels that of NTs. There are only medial nasal-stop sequences. Robins (1957: FN 1), despite often being cited as providing evidence that these are a special segment-type, is very clear about this: "Within a word, *intervocalic sequences* of nasal consonant followed immediately by a homorganic voiced plosive or affricate are frequently pronounced with a very light articulation of the non-nasal consonant (i.e. mb [mᵇ], ŋg [ŋᵍ], nd [nᵈ], ndʒ [nᵈʒ]. . .)." [Emphasis added.] Thus what may be special is not the phonological structure of these sequences, but rather their phonetic realization.

The situation in Acehnese is a bit more complex. Durie (1985) analyzes them as unary. This treatment is picked up by Long and Maddieson (1993), Blust (1997), and others.[7] Durie's main motivations for the proposed unary analysis stem from phonotactic arguments and the general goal of offering a phonemic analysis of nasalization. Indeed he offers a careful discussion of this point comparing several possible analyses including both unary and cluster characterizations of the "funny" nasals (p. 23). However, our interpretation of the phonotactic evidence leads us to the opposite conclusion, that the NDs are best treated as clusters. As observed by Durie, it is a difficult to provide a strictly phonemic analysis of Acehnese, as there are a very small number of forms that challenge otherwise general phonotactic patterns. The close parallels between phonotactic patterns observed for ND and NT suggest a unified treatment of these cases, as clusters, in line with the later analysis assumed by Daud and Durie (1999:6–7).

The situation in Acehnese is reminiscent of the situation in Pamona, where NCs occur word initially but are quite limited in their distribution, in contrast, for example, to the unary cases in Tamambo and Erromangan, where initial ^{N}Ds are abundant. In addition, as will be seen below, the durational properties for initial and medial NCs in Pamona support a unified treatment of these cases, and Riehl (2008) argues that the NCs, while clearly tautosyllabic, are nevertheless clusters. More generally, Riehl questions a widely held assumption that NCs occurring word initially (and hence non-ambiguously in syllable-initial position) are necessarily unary, since otherwise such clusters would violate sonority sequencing principles. Adisasmito-Smith's (2003) analysis of Javanese also provides support for tautosyllabic clusters.

Let's return to the duration results to see if they provide support one way or the other in terms of the structure of the NDs in Acehnese and Sundanese. We present an expanded version of Figure 2 here as Figure 7, incorporating the N:NC ratios for Acehnese and Sundanese, as well as initial results for the other languages, where available (initial on left, medial on right).

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[7] Long and Maddieson (1993) describe four consonant series for Acehnese, plain stops, plain nasals, orally-released nasals (the *NDs* under discussion here) and also nasal + stop. This final case, at least in the example given, *mandum* 'all' is a case of a nasal + stop across a morpheme boundary, *man* 'all' + *dum* 'much, many' in contrast to the word-internal medial case.

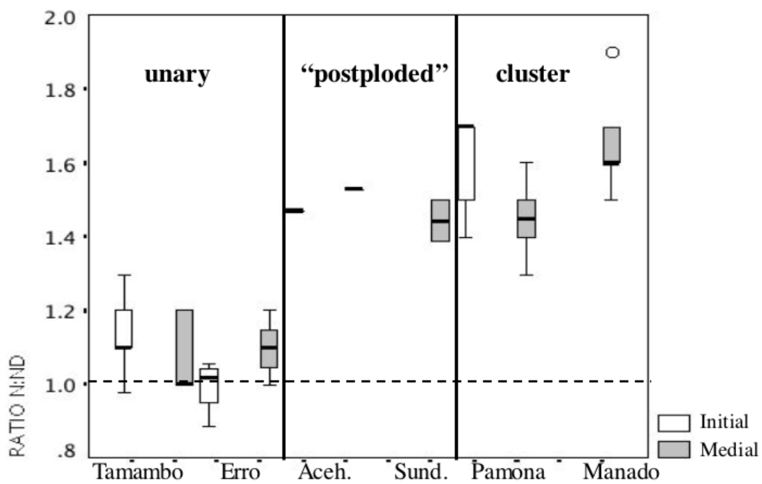


Figure 7: N:ND total duration ratios in initial and medial position for six languages.

In both Sundanese and Acehnese, the ratios are significantly greater than 1, similar to the patterns observed in the cluster cases, Manado Malay and Pamona. The results for Acehnese are also consistent with Durie's (1985:15) finding that "The initial funny nasals are characterized acoustically by a longer duration than the initial plain nasals." Taken together with the phonotactic evidence, we conclude that these are phonologically clusters in both languages. Comparing initial to medial position, for the unary NDs in Tamambo and Erromangan, both the initial and medial cases are consistent in showing durational patterns similar to simple nasals; Acehnese is similar to Pamona in having limited initial NDs (and NTs), which, like the medial cases, exhibit durations substantially greater than plain nasals, as expected for clusters, while Sundanese is like Manado Malay in lacking initial NCs.

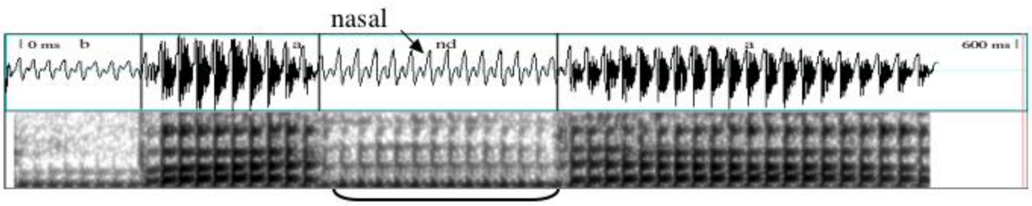
In sum then, the phonological and phonetic evidence converge supporting the conclusion that the NCs of both Acehnese and Sundanese are structurally clusters. These sequences contrast with plain nasals both in their overall duration and the crisp transition to a fully oral following vowel. They contrast with the NTs in maintaining voicing throughout.

Since in both Sundanese and Acehnese we have concluded that the NDs are clusters, the question at hand is not whether these so-called "postploded" nasals are distinct from prenasalized stops; they differ from the prenasalized stops of Tamambo and Erromangan in the same ways that Pamona and Manado Malay do. Rather, are they really different from the ND clusters of Pamona and Manado Malay? Is there something special about their phonetic realization and the oft-cited observation that they are somehow phonetically merged? In other words, is there evidence that they constitute a distinct category of NC sequences?

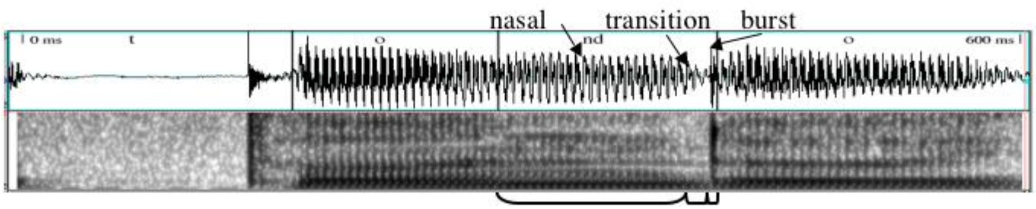
6 Postploded Nasals?

In this section, we consider the question of whether there are systematic differences in the finer details of the nasal to oral transition and the oral component that could be the source of the impressionistic characterization of postploded nasals as distinct from prenasalized stops and nasal voiced-stop clusters. In looking at the finer details of the final portion of these entities, we have attempted to identify three periods: a. the transition from nasal to oral (where intensity of the nasal is decreasing), b. an oral closure (which we would expect to be voiced, but in some cases is devoiced), and c. an oral burst. These three phases fall within a very brief window (an average of 1 to 41 ms. across the speakers). It is important to remember that all of these cases share the property of having a fully oral vowel, crisply oral from the very beginning of vowel. Consider the three labeled tokens in Figure 8.

Achenese /banda/



Pamona /tondo/



Erromangan /na^{n}dup/

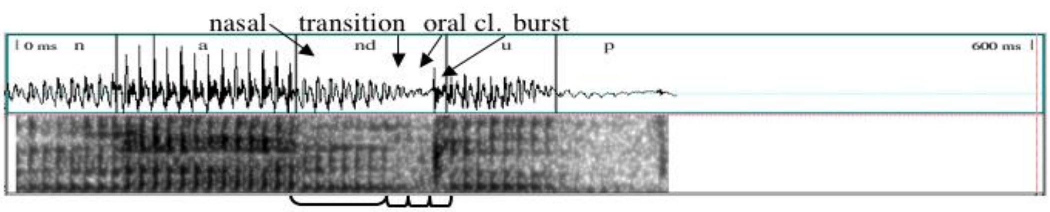


Figure 8: Spectrograms of ND sequences in three languages, with ND parts labeled.

In the Acehnese token, the entire duration of the ND is comprised of a steady nasal, with no notable transition where the intensity decreases, and no oral portion. In the Pamona token, a steady nasal extends for most of the total duration, with a brief transition at the end where the nasal drops in intensity, followed by an oral burst. In the Erromangan token, the steady nasal portion ends in a longer transition of decreasing amplitude and is followed by a possible oral closure and finally a clear burst.

In reporting these results, we note that drawing a boundary between the nasal-to-oral transition and the oral closure proved particularly difficult, so the internal timing of the oral component is only approximate, nevertheless the results allow us to make a number of observations.

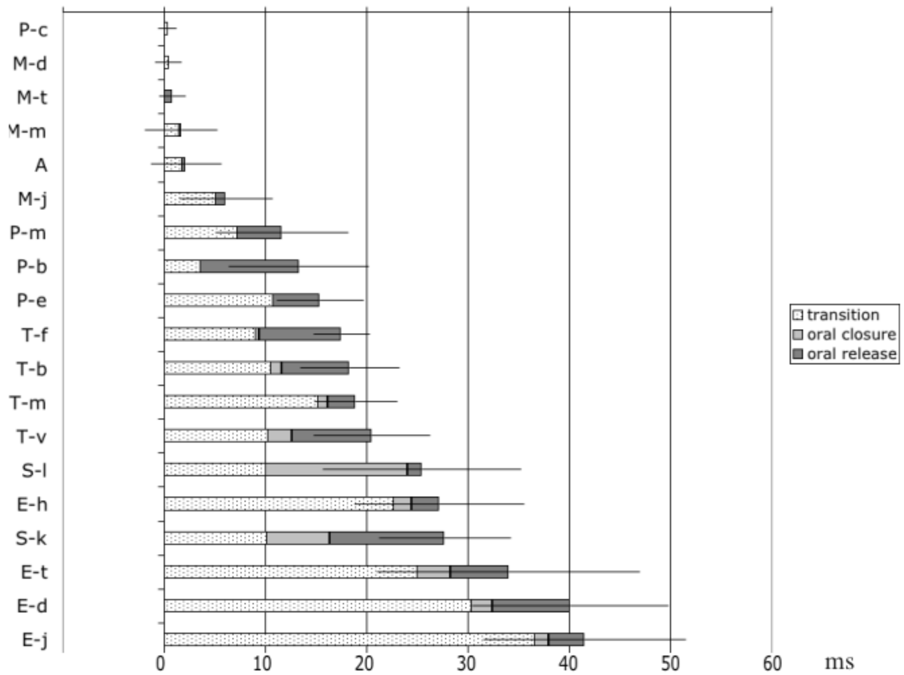


Figure 9: Microtiming data from 1-4 speakers of each language (P=Pamona, M=Manado Malay, A=Acehnese, T=Tamambo, S=Sundanese, E=Erromangan; each followed by speaker identification letter) including nasal transition, oral closure, and oral release. Error bars indicate one standard deviation of the total duration.

In Figure 9, we show the finer details of the duration of the nasal to oral transition, the oral closure and the oral burst to see whether there are systematic differences. These are laid out by total duration of these three phases from shortest to longest. There is a continuum from the shortest to longest, but are there any subgroups? Roughly speaking, there are three types: 1) cases with almost no oral component (one speaker of Pamona, all four speakers of Manado Malay and the one speaker of Acehnese); 2) cases with a clear oral burst and either a brief nasal transition or a brief oral period (three speakers of Pamona and all four speakers of Tamambo), and 3) cases of a clear nasal to oral transition or oral closure followed by a clear oral release (both speakers of Sundanese and all four speakers of Erromangan). These differences are largely consistent within each language, with the exception of Pamona where one speaker is different from the other three. However, these three types do not capture the differences between the impressionistic grouping of the ND types. The two unary cases show either the second or third pattern, the two clear cluster cases show either the first or second pattern and the two putative postploded nasal cases show the first pattern in one case and the third in the other.

It is important to realize that the magnitude of these differences are quite small and the variation seen between speakers is in some cases greater than the variation seen between languages. For example the difference between PamonaC and the other three is greater than the difference seen between Tamambo and Sundanese. Also, the amount of intra-speaker variation differs. As indicated by the standard deviation of the total duration of the final portion, some speakers have a very small range, and others a really large range, greater than the magnitude of the average differences. Overall the very short total durations show very small ranges and the longer total durations show greater variation, but there are also individual differences in this regard, e.g., TamamboV and TamamboF. It is possible that some of the differences stem from different phonetic strategies for realizing the same goal, that is, a crisply oral following vowel. It seems that in certain cases this is achieved by having an oral burst. In order to achieve this, aerodynamic adjustments need to be made by the end of the closure phase to build up pressure for an oral release. In such cases the transition from nasal to oral during the closure can be quite subtle and quite slow. In other cases, the transition from nasal to oral is quite rapid, similar to the change seen in the NT cases where both nasality and voicing change simultaneously. In such cases there is often a very brief oral closure that may or may not be followed by an audible burst. While further investigation of these strategies is needed, the nature of the observed differences in microtiming suggest that these are the results of different strategies of implementation, not the realization of objects of contrast.

Other phonetic attributes also do not appear to correlate with the different ND-types. Maddieson and Ladefoged (1993) suggest that the high intensity bursts seen in the phonetic N^Ds in the Zhongshang dialect of Chinese (based on Chan and Ren's 1987 data) may be a more general characteristic of this ND-type, given that such bursts are not found in the prenasalized stop data they considered. However, Chan and Ren did not observe these bursts in the phonetic N^Ds of the Kaiping dialect, indicating that this particular type of burst in the Zhongshang dialect simply reflects one of the various strategies available for achieving a following oral vowel and is not more broadly characteristic of a particular ND-type. Another property attributed to so-called post-stopped nasals by both Catford as well as Maddieson and Ladefoged in Acehnese is a lesser amount of nasal airflow and pressure during the duration of the ND versus a plain nasal. However, as already discussed, the NDs in this case appear to be typical clusters. While the degree of nasality may indeed differ between plain nasals and ND sequences in general (and more aerodynamic data is sorely needed to establish these facts), this does not offer evidence that the Acehnese and Sundanese NDs are unique segment-types or even atypical of NDs in general.

We conclude that the cases under investigation here that have been described as having postploded nasals are not structurally distinct from those cases that have been described as having ND clusters. This leads us to wonder whether all the cases at hand are of the same type, but that the special property of being postploded had been overlooked for Manado Malay and Pamona. A brief look at comparable data for English nasal-stop clusters highlights that this is not the case. In Figure 10, we present microtiming data for two speakers of English against the backdrop of the microtiming differences seen in Figure 9.

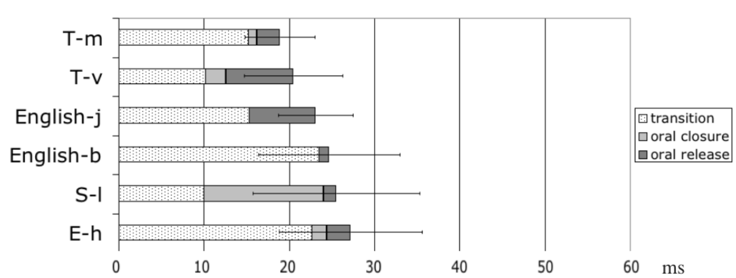


Figure 10. Microtiming data for two speakers of English, as positioned alongside speakers of other languages (preceding and following two) from Figure 9.

The results for these two speakers of English (consistent with Cohn's 1990 observations for English as well as Vatikiotis-Bateson's 1984 data for overall timing and relative nasal and oral timing for these clusters) fall in the second and third types, amongst the unary cases. These results suggest that the kind of microtiming differences observed here, while systematic for some speakers and perhaps some languages (although we predict that if we looked at many more speakers for additional languages, the picture would become less, rather than more, clear), cannot be the basis of a difference in phonological type. This leads us to the more general question of what is phonologically relevant and how the phonological structure is implemented phonetically.

Our results, coupled with insight into ^{N}D perception by Beddor and Onsuwan (2003), suggest that the critical property shared by all the NC cases is a crisply oral following vowel. For the NT case, where change in not only nasal to oral is required but also from voiced to voiceless, a voiceless closure is always present. The combined simultaneous requirements of a change in nasality and in voicing impose very different phonetic requirements. In contrast to the NT case, only the shortest of oral closures are observed in any of the ND cases, consistent with Beddor and Onsuwan's observation that duration of the oral closure does not appear to be a salient property.

7 Conclusions

In conclusion, our findings reaffirm that there is a systematic difference between unary and cluster nasal voiced-stop sequences (not predicted to occur in a single language unless there is independently a single-geminate contrast), realized in terms of the ratio of simple nasal to NC. They highlight the systematic phonetic differences in the relative timing of nasal and oral components of nasal voiced vs. voiceless sequences. They suggest that there might be multiple phonetic strategies for realizing the most salient perceptual difference between simple nasals and nasal-stop sequences, that is nasality or crisp orality on the following vowel. Our findings are summarized in the following Table 2:

		N	**^{N}D**	**ND**	**NT**
Phonological properties	[nasal]	nasal	nasal/oral	nasal/oral	nasal/oral
	[voice]	voiced	voiced	voiced	voiced/ voiceless
	Units	unary	unary	cluster	cluster
Phonetic realization	Timing	short	short	long	long
	Targets	nasal	crisply oral V	crisply oral V	oral closure, tight N/O and V/-V transition

Table 2: Phonological structure and phonetic requirements of nasal – oral contrasts.

As seen above, all of the NC-types differ crucially from plain nasals in having both nasal and oral specifications, realized as a following oral vowel, with NT clusters additionally requiring a clear voiceless oral closure in order to be distinguished from the voiced cases. The two voiced sequence-types differ from one another only in their unary or cluster status—manifested in a total duration difference, not in nasality or voicing, resulting in their lack of contrast except in languages with phonemic length. The characterization in Table 2 further captures the lack of other phonological NC-types. Given only the above three dimensions in the phonology, finer distinctions in the phonetic implementation of the features are not relevant.

Past descriptions of NC sequences, such as those of postploded nasals, when viewed in the light of the data in this paper, lead us to sound a cautionary note. Just because we can measure some property of the phonetics does not mean that it can or does indicate a phonological contrast. The details of the phonetic implementation of the perceptual goals have been assumed to be the goals in and of themselves, rather than the means of realizing the goals (e.g., the difference in rate of airflow during an NC may reflect different means of achieving a following oral vowel but not be indicative of different phonological entities). Further work is clearly needed, in particular aerodynamic and perceptual studies, to better understand the roles of voicing and nasality in NC sequences to answer these questions.

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Language	**Target words**	**Frame sentence**
Tamambo	/ta**n**o/ 'garden' /ta**n**^{d}a/ 'to look up'	/ku hare _____ tovona/ 'I write ____ today'
Erromangan	/na**n**i/ 'goat' /na**n**^{d}up/ 'bead tree' /na**nt**ip/ 'banyan root'	/nalau amaŋku _____ ire/ 'The baby says ___ now'
Pamona	/to**n**o/ 'to knock head' /to**nd**o/ 'next to' /to**nt**o/ 'to empty out'	/mantoʔo ______ dʒa seʔi/ 'Just say ____ now'
Manado Malay	/ta**n**a/ 'earth' /ta**nd**a/ 'sign' /ta**nt**a/ 'aunt'	/tʃumu dʒo _____ skarang/ 'Just say ____ now'
Acehnese	/ba**n**eng/ 't.o. turtle' /ba**n**da/ 'a seaport city' /ba**nt**a/ 'younger generation' /ba**nt**eng/ 'bouncing' /ta**n**oh/ 'land' /ta**nd**a/ 'sign, mark'	/lɔn pike ___ barɔᵊ/ 'I thought ___ yesterday'
Sundanese	/ka**n**a/ 'for the purpose' /ka**nd**as/ 'aground, ashore' /ka**nt**or/ 'office' /si**n**ar/ 'ray of light' /si**nd**ir/ 'sneer' /si**nt**ir/ 'twirl a coin'	/tulis _____ ɟəlas/ 'Write ___ clearly'

Appendix A: Target words and frame sentences.