

## Phonetic evidence for contextual underspecification of nasality in A'ingae

Vowels are often nasalized before nasal consonants. Cohn (1993a) argued that contextually nasalized vowels in [VN] are unspecified for nasality in American English, and are only phonetically nasalized through gradient anticipation of the following nasal. In contrast, Solé (1995) argued that contextual nasalization is so extensive in English [VN] that nasalized vowels must be phonologically [+NASAL]. This disagreement reflects a broader problem: how do we determine the phonological specification of segments with phonetically intermediate values?

We contribute to this debate with data from A'ingae, a language spoken in the Ecuadorian and Colombian Amazon. A'ingae has a /V  $\tilde{V}$ / contrast, along with left-to-right, phonological nasal spreading. We present aerodynamic data showing that A'ingae also has extensive, but nonetheless partial nasalization in [VN, V<sup>N</sup>D]. This partial nasalization is phonetically distinct from contrastive / $\tilde{V}$ /, and from nasal vowels derived by phonological spreading. From token to token, vowels in [VN, V<sup>N</sup>D] range from fully nasal, to partly nasal, to essentially oral. We argue that these results are inconsistent with treating partially nasalized vowels as [+NASAL], or as specified for 'weak' or 'late' nasalization. Instead, we suggest that partial nasalization in A'ingae reflects surface underspecification.

## 1 Cross-linguistic patterns of contextual nasality

This paper investigates vowel nasality in A'ingae, an Indigenous language of the Ecuadorian and Colombian Amazon. We claim that surface forms in A'ingae may contain vowels which are either nasal, oral, or unspecified for nasality (= [ $\emptyset$ NASAL]). To contextualize this claim, we first discuss some cross-linguistic facts about the phonetics and phonology of nasal (and nasalized) vowels.

In a survey of 224 languages, Hajek (2013) reports that 26% have contrastively nasal vowels, as in San Martín Peras Mixtec [k<sup>w</sup>áà] 'blind' vs. [k<sup>w</sup>ââ] 'yellow' (Eischens & Hedding 2024). Nasal vowels are also commonly produced by assimilation to neighboring nasal sounds (1).<sup>1</sup>

- (1) Local nasal assimilation in Bengali: /V/ → [ $\tilde{V}$ ] / \_\_\_\_ N  
(Indo-Aryan, primarily Bangladesh and India; Lahiri & Marslen-Wilson 1991)
- [pak] 'cooking' vs. [pāk] 'slime'
  - /pa-ʃ/ → [paʃ] 'you (familiar) get'
  - /pa-n/ → [pān] 'you (honorific) get'

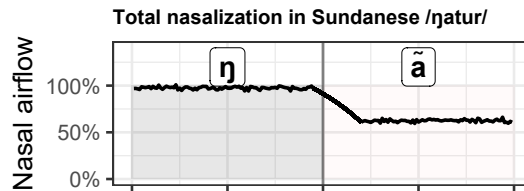
Contextual vowel nasalization may neutralize phonemic contrasts, as in Bengali (1), but can also be purely allophonic and non-neutralizing, as in Sundanese (2).

- (2) Unbounded L → R nasal spreading in Sundanese (spreading domain underlined)  
(Austronesian, primarily Java, Indonesia; Robins 1957, 1953, Cohn 1993a,b, and references there)
- /ŋ-ala/ → [ŋāla] 'take (ACT.TR)'
  - /ŋ-pihak/ → [mīhāk] 'take sides (ACT.TR)'
  - /ŋ-saur/ → [nāūr] 'say (ACT.TR)'
  - /-al-, ŋ-saur/ → [n-āl-āūr] 'say.PL (ACT.TR)' (opaque V nasalization, cf. (2b,d))

<sup>1</sup>We use the symbol 'V' for vowels (often oral vowels specifically), ' $\tilde{V}$ ' for nasal vowels, 'N' for simple nasal stops like [n, m, etc.], and '<sup>N</sup>D' for prenasalized stops and affricates like [n<sup>d</sup>, m<sup>b</sup>, n<sup>d</sup>z, etc.]. Slash brackets '/ /' indicate underlying forms, square brackets '[' ]' surface forms. Abbreviations are defined in the appendix.

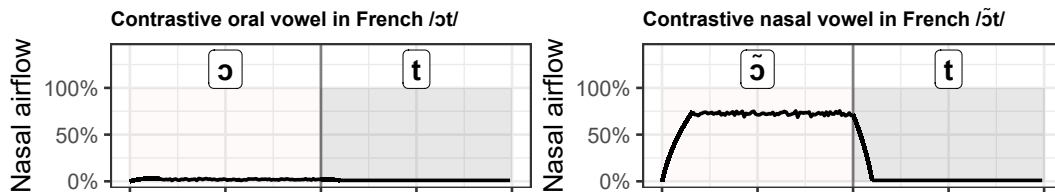
Despite being non-neutralizing, nasal spreading in Sundanese has the hallmarks of a phonological process. First, nasality can spread over a potentially unbounded distance (2a-c): it continues, left-to-right, until it encounters a consonant other than [h ?]. Second, nasal spreading can be rendered opaque by infixation (2c,d), leading to the impression that nasal spreading has overapplied. Both of these properties imply that nasal spreading is part of the phonology: it is not just local, phonetic coarticulation for nasality (see e.g. McCollum 2019, Eischens 2022).

Contextual nasalization in Sundanese is also PHONETICALLY COMPLETE: nasalized vowels are strongly nasalized throughout. Fig. 1 reproduces a nasal airflow trace from Cohn (1990, 1993a,b), which shows that /a/ is fully nasalized to [ã] after /ŋ/ (see also Robins 1957). The fact that nasal airflow is lower for [ã] than for [ŋ] follows from aerodynamic principles: all airflow is nasal in [ŋ], while airflow is divided between the oral and nasal channels in [ã].



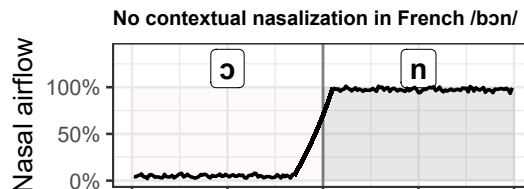
**Figure 1:** Nasal airflow trace for Sundanese [ŋã] from [ŋatur] ‘arrange’ (Cohn 1993a:57).

Allophonically nasalized vowels in Sundanese are phonetically similar to contrastive nasal vowels in other languages. For example, nasal vowels are contrastive in European French (e.g. *beau* /bɔ/ ‘beautiful’ vs. *bon* /bɔ̃/ ‘good’) and also produced with substantial nasal airflow (Fig. 2, right).



**Figure 2:** Nasal airflow traces for European French /ɔt/ from /bɔt/ ‘boot’ (left) and /ɔ̃t/ from /bɔ̃te/ ‘goodness’ (right) (Cohn 1993a:51-2).

European French is also a language in which vowels are typically realized as *oral* when preceding nasal consonants, rather than nasal (Fig. 3, Delvaux et al. 2008, Dow 2020).<sup>2</sup> Note the slight increase in nasal airflow at the end of the vowel: this is plausibly a brief coarticulatory effect, reflecting the articulatory transition from an oral vowel to a nasal consonant.

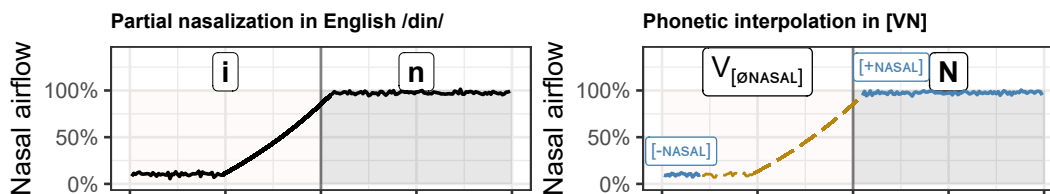


**Figure 3:** Nasal airflow trace for [ɔn] from European French [bɔn] ‘good’ (Cohn 1993a:51-2).

<sup>2</sup>High vowels, which do not contrast for nasality in French, tend to be realized with more contextual nasalization (e.g. Rochet & Rochet 1991, Spears 2006, Delvaux et al. 2008, Desmeules-Trudel & Brunelle 2018, Dow 2020).

## 1.1 Partial nasalization in [VN]

In some languages, vowels may be only PARTIALLY NASALIZED when adjacent to nasal sounds (Fig. 4). In partial nasalization, a vowel is nasalized under the influence of an adjacent nasal, but nasal airflow is (i) only significant for part of the vowel, and (ii) is greater in duration and/or magnitude than what would otherwise be expected for a mechanical transition between oral and nasal sounds. Compare e.g. American English (Fig. 4) to European French (Fig. 3).



**Figure 4:** Left: Nasal airflow trace for [in] in English *dean* [dīn] (Cohn 1993a:60). Right: partial nasality as phonetic interpolation. Solid lines indicate regions with specified targets for [NASAL], broken line indicates interpolation between targets. Initial [-NASAL] reflects preceding context.

Partial nasalization is widespread in [VN] sequences in American English, as documented by Cohn (1990, 1993a), Solé (1995, 2007), Beddor et al. (2018), Zellou (2022), and many others.<sup>3</sup>

The phonological interpretation of partial nasalization has been a matter of debate. Cohn (1990, 1993a) argued that partially nasalized vowels in American English [VN] sequences are *UNDERSPECIFIED* for nasality: they lack any value or target for [NASAL] whatsoever. Underspecified vowels in [VN] may still be *phonetically* nasalized through *INTERPOLATION*. Specifically, Cohn (1990, 1993a) proposed that vowels in [VN] may show a cline-like pattern of increasing nasality simply because they intervene between a [-NASAL] and a [+NASAL] target.

Interpolation for nasality is schematized in Fig. 4 (right). Nasality begins low, reflecting the [-NASAL] specification of the preceding context. Nasality then rises gradually, peaking at the following nasal stop, which is [+NASAL]. This cline-like increase in nasality is possible precisely because the vowel itself does not have a target for [NASAL] — it ‘doesn’t care’ about nasal airflow, or the position of the velum. Partial nasalization is thus conceptualized as a transition between phonetic targets which are separated by a targetless region.

Solé (1992, 1995) offers a different perspective on vowel nasalization in American English. First, Solé observes that nasalization in [VN] often begins much earlier in the vowel than necessary to anticipate the following nasal consonant. Second, the timing of nasalization during the vowel is correlated with duration: the *proportion* of the vowel which is nasalized remains roughly constant across changes in duration or speech rate (Solé 2007). Third, Solé (1992, 1995) shows that some [VN] tokens are nasalized throughout their entire duration.

These observations are surprising if vowel nasalization in [VN] reflects a transition from oral to nasal targets, over a targetless vowel. Instead, speakers of American English appear to be *intentionally producing* more nasalization than necessary on vowels in [VN]. For that reason, Solé proposes that pre-nasal vowels in [VN] are phonologically [+NASAL], rather than underspecified for nasality (see also Pouplier et al. 2024).<sup>4</sup>

<sup>3</sup>Nasalization is stronger in [VN] sequences in which the nasal stop is a coda consonant. Stress also plays a role in determining the extent of nasalization in American English [VN]. See e.g. Krakow (1999), Byrd et al. (2009), Krämer (2017), and Bellavance et al. (2024) for discussion.

<sup>4</sup>Zellou (2022) reports that only 38% of the American English speakers in her study showed the timing patterns

Partially nasalized vowels in English do not phonetically resemble [+NASAL] vowels in European French (Figs. 2, 4). To account for this fact, Solé (1995) proposes that the feature [+NASAL] may be implemented differently when contrastive (as in French) than when allophonic. However, this fails to explain why vowels are fully nasalized in Sundanese, since [+NASAL] is purely allophonic, and not contrastive, on vowels in that language (see also Krämer 2017).

In sum, the featural specification of partially nasalized vowels is largely unresolved. Here, we explore this issue with an analysis of nasality in A'ingae, an Indigenous language spoken in the western Amazon. Like French, A'ingae has contrastive vowel nasality (3a,b). Like Sundanese, A'ingae has a phonological process of left-to-right nasal spreading (3c). And like English, we show that A'ingae has extensive partial nasalization of vowels in /VN/ sequences (3d), as well as in /V<sup>N</sup>D/ sequences (3e).<sup>5</sup>

(3) Vowel nasality in A'ingae

- |    |                                    |                 |   |
|----|------------------------------------|-----------------|---|
| a. | <i>athe</i> ['a.t <sup>h</sup> e]  | 'saw'           | (contrastive oral /V/)                              |
| b. | <i>anthe</i> ['ã.t <sup>h</sup> e] | 'stopped, left' | (contrastive nasal / $\tilde{V}$ /)                 |
| c. | <i>na'en</i> /naʔe/ → ['nã.ʔẽ]     | 'river'         | (L → R nasal spreading)                             |
| d. | <i>ana</i> ['ã.nã]                 | 'slept'         | (partially nasalized [ $\tilde{V}$ N])              |
| e. | <i>ande</i> ['ã. <sup>n</sup> de]  | 'land'          | (partially nasalized [ $\tilde{V}$ <sup>N</sup> D]) |

This convergence of properties is useful, because it allows us to phonetically compare vowels in /VN, V<sup>N</sup>D/ sequences to phonologically oral and nasal vowels *within a single language*. We find that pre-nasal vowels in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] are phonetically distinct from (i) underlying [+NASAL] vowels, (ii) phonologically derived [+NASAL] vowels, and (iii) underlying oral vowels. Phonetically, vowels in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] range from fully nasal to fully oral, with many intermediate, partly nasal tokens. We conclude that, on the surface, vowels in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] are unspecified for nasality in A'ingae.

## 2 Language background

A'ingae is a linguistic isolate spoken in what is now northern Ecuador and southern Colombia. The term *a'i* (literally '(civilized) person') is used to refer to members of the ethnic group which traditionally speaks this language. The A'ingae language and A'i people are also commonly referred to as *Cofán* or *Kofán*, a term of uncertain origin.

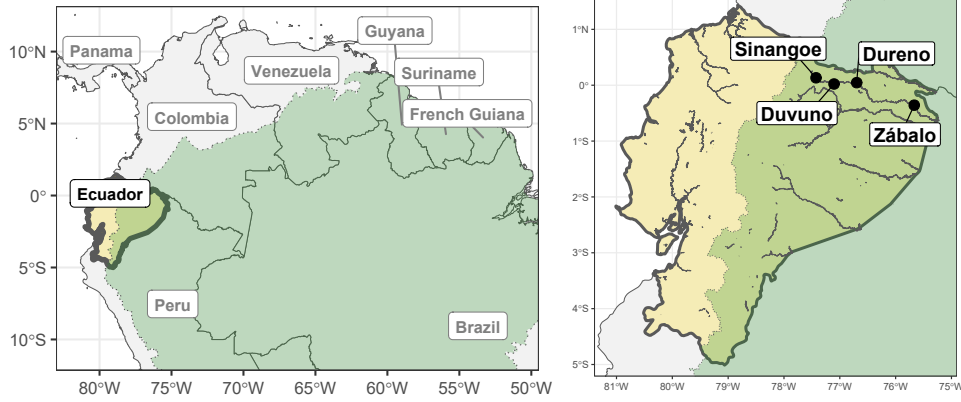
A'ingae is spoken in communities along two main rivers and their tributaries: the Aguarico River in Sucumbíos province in Ecuador; and the San Miguel River, which forms the border between Ecuador and Colombia in this region. This geographic context, along with 4 major Ecuadorian A'i communities, is shown in Fig. 5 (Sinangoe being farthest upriver). A'ingae is spoken in 9 additional communities in Ecuador, as well as several communities in Colombia. A small amount of dialect variation has been noted for A'ingae: for example, Borman (1976) identifies some lexical items which are attested in Colombian A'ingae, but not in Ecuador. However, no significant phonological differences have so far been identified across varieties of A'ingae.

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that Solé (1992, 1995, 2007) reports for American English. This highlights the fact that there may be considerable inter-speaker (and inter-dialectal) variation with respect to nasality in [VN] sequences, and in other contexts (see also Cohn 1990:2-3, Delvaux et al. 2012, Beddor et al. 2018, Bongiovanni 2021, Pouplier et al. 2024).

<sup>5</sup>As there is no widely used diacritic for partial nasalization, we transcribe partially nasalized vowels in forms like (3d,e) with the normal IPA diacritic for nasality, [ $\tilde{V}$ ]. It should be borne in mind that vowels transcribed as [ $\tilde{V}$ ] in surface forms may not be fully nasalized, especially in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] contexts.





**Figure 5:** Ecuador (left), and 4 major A’i towns along the Aguarico River in the Ecuadorian Amazon (right). Green region overlapping eastern Ecuador is Amazon basin. Map data from `rnaturalearth` R package, [data.humdata.org/dataset/hotosm\\_ecu\\_waterways](https://data.humdata.org/dataset/hotosm_ecu_waterways) (CC by 4.0 license, [creativecommons.org/licenses/by/4.0/](https://creativecommons.org/licenses/by/4.0/)), and [github.com/gamamo/AmazonBasinLimits](https://github.com/gamamo/AmazonBasinLimits).

A’ingae has approximately 1500 speakers (although a robust census is lacking). In several communities (Zábalo, Chandia Na’en), the language remains entirely vital, being used in nearly all aspects of day-to-day life by community members of all ages. However, an ethnolinguistic vitality assessment by Pomilia (2025) finds a more mixed picture in other communities. While A’ingae is still acquired by most children in all A’i communities, Spanish may have begun to displace A’ingae in certain social contexts, especially in Duvuno, and to a lesser extent Sinangoe (Fig. 5). Overall, Pomilia (2025) finds the language to be relatively vital, though with some cause for long-term concern; especially so, given ongoing challenges to A’i territorial sovereignty posed by oil and other extractive industries, and the processes of colonization they have facilitated (see Cepek 2018). For summaries of prior research on the language, along with text and multimedia collections, see Dąbkowski (2021a, 2024) and the [REDACTED] project website.

The work we report on comes from a long-term language documentation and revitalization project, called the [REDACTED]. This project is a collaboration between academic linguists, A’i community linguists, and A’i educators and scholars from adjacent fields. Each of these groups are represented in the co-authorship team: [REDACTED]. The research questions we explore here were motivated by the scientific interests of the research team, as well as by a desire to better understand nasality in A’ingae to inform ongoing orthography standardization and pedagogy projects. In addition to academic-facing outputs, our findings have been presented to A’i members of the [REDACTED], as well as broader A’i audiences, including a meeting in July 2024 bringing together all educators working in Ecuadorian A’i communities as well as other interested parties, including educators from Colombia and officials from Secretaría de Educación Intercultural Bilingüe y la Etnoeducación [Secretary of Intercultural Bilingual Education and Ethnoeducation] (SEIBE).

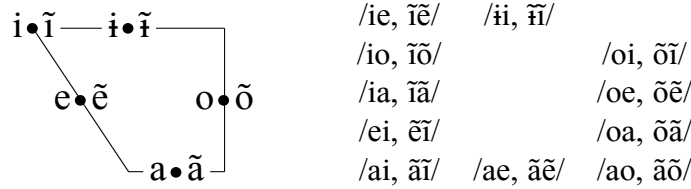
### 3 Phonology of nasal segments in A’ingae

In this section we outline the phonology of nasal vowels and consonants in A’ingae. For general information on the phonology of A’ingae, see Repetti-Ludlow et al. (2020), Fischer & Hengeveld (2023), Dąbkowski (2024), Sanker & AnderBois (2024) and references there. The A’ingae data we present in this paper is taken from those sources, two dictionaries (Borman 1976, ALDP ms), as well as our own extensive original fieldwork on the language, and the introspective judgments of

two native speaker co-authors ([REDACTED]).

### 3.1 Contrastive vowel nasality

Nasality is contrastive on vowels in A’ingae, as evidenced by (near-)minimal pairs like *ji* [hi] ‘came’ vs. *hin* [hĩ] ‘existed’, or *uti* [oti] ‘hammered’ vs. *untin* [õti] ‘gadfly’. The phonemic vowel inventory is provided in Fig. 6.<sup>6</sup>



**Figure 6:** Phonemic vowel inventory of A’ingae. Inventory of diphthongs from Dąbkowski (2024); cf. Repetti-Ludlow et al. (2020), Fischer & Hengeveld (2023), Sanker & AnderBois (2024).

### 3.2 Prenasalized stops

The phonemic consonants of A’ingae include both simple nasal stops /N/ and prenasalized stops /<sup>N</sup>D/ (Tab. 1). Prenasalized stops and affricates /<sup>N</sup>D/ are unitary segments in A’ingae, not clusters (see e.g. Riehl 2008, Riehl & Cohn 2011, Gouskova & Stanton 2021). First, prenasalized stops /<sup>N</sup>D/ are ‘non-separable’. Prenasalized stops in A’ingae consist of a nasal interval [N] followed by a voiced stop interval [D]. However, voiced stops do not otherwise occur in the language. Hence, prenasalized /<sup>N</sup>D/ cannot be analyzed as a cluster of two independently occurring consonants.

	Bilabial	Labio-dental	Alveolar	Post-alveolar	Palatal	Velar	Glottal
<b>Stops</b>	p p <sup>h</sup>		t t <sup>h</sup>			k k <sup>h</sup>	ʔ
<b>Prenasalized stops</b>	<sup>m</sup> b		<sup>n</sup> d			<sup>ŋ</sup> g	
<b>Affricates</b>			ts ts <sup>h</sup>	tʃ tʃ <sup>h</sup>			
<b>Prenasalized affricates</b>			<sup>n</sup> dʒ	<sup>n</sup> dʒ̃			
<b>Fricatives</b>		f	s	ʃ			h
<b>Nasals</b>	m		n		ɲ		
<b>Glides and rhotics</b>		ʋ	r		j	ɰ	

**Table 1:** Phonemic consonant inventory of A’ingae (Repetti-Ludlow et al. 2020, Fischer & Hengeveld 2023, Dąbkowski 2024, Sanker & AnderBois 2024).

Second, consonant clusters do not generally occur in native A’ingae words. Syllable structure is maximally [CV]; the only potential coda is /ʔ/ (e.g. *kan’chu* [kãʔ.tʃo] ‘binoculars, scope’), which can be analyzed as a prosodic feature instead (see Dąbkowski 2024). Syllable phonotactics thus argue against treating prenasalized /<sup>N</sup>D/ as a cluster. Word-initial prenasalized stops, as in *giyaen* [<sup>ŋ</sup>gi.jãẽ] ‘cleaned’, are especially bad candidates for clusters due to their sonority contour.

In many Amazonian languages, prenasalized stops are allophones of either nasal consonants or oral stops (e.g. Stanton 2018, Lapierre 2023, Sanker & AnderBois 2024 and references there). This does not appear to be the case in A’ingae; see Dąbkowski (2024:13), Sanker & AnderBois (2024).

<sup>6</sup>The phonetic realization of phonemic /o õ/ ranges from [o õ]/[ɔ ɔ̃] to [u ü]/[ʊ ü̃] in A’ingae. For the sake of consistency, we transcribe phonemic /o õ/ as a mid-back vowel throughout.

### 3.3 Nasal harmony

A'ingae has a pervasive process of left-to-right (progressive) nasal harmony. Nasality spreads rightward from nasal vowels (4)-(5). Laryngeal consonants [ʔ h] are transparent for nasal spreading (4a), (5a), and seem phonetically nasalized (Walker & Pullum 1999). Spreading across morpheme boundaries is blocked by non-laryngeal obstruents (4b) and the tap [ɾ] (though only one suffix, /-ri/ NOM, begins with [ɾ]). We indicate the domain of nasal spreading with underlining.<sup>7</sup>

(4) Nasal spreading from [ĩ] in A'ingae: across morpheme boundaries

- a. Laryngeal transparency across morpheme boundaries  
*ja'je* /ha-ʔhe/ → [ʔhaʔ.he] 'go-IPFV'  
*tsun'jen* /tsō-ʔhe/ → [ʔtsōʔ.hẽ] 'do-IPFV'
- b. Blocking by non-laryngeals across morpheme boundaries  
*jen'chu* /hẽ-ʔtʃo/ → [ʔhẽʔ.tʃo] 'a sound (sounded-NMLZ)'

Inside roots, fricatives and plain (unaspirated) stops and affricates tend to pattern as transparent for nasal harmony (5b). Spreading inside roots is blocked by aspirated stops and affricates (5c). There are no alternations within roots, so 'spreading' is diagnosed by static co-occurrence patterns; see Dąbkowski (2024), Sanker & AnderBois (2024) for details.

(5) Nasal spreading from [ĩ] in A'ingae: inside roots

- a. Laryngeal transparency inside roots  
*ûnjîn* /ĩhi/ → [ʔĩ.hĩ] 'rain'  
*in'jan* /ĩʔha/ → [ʔĩʔ.hã] 'think, want'
- b. Transparency of fricatives, plain stops and plain affricates inside roots  
*panshan* /pãʃa/ → [ʔpã.ʃã] 'passed'  
*unken* /ũke/ → [ʔũ.kẽ] 'goddaughter'
- c. Blocking by aspirated stops and affricates inside roots  
*kankhe* /kãk<sup>h</sup>e/ → [ʔkã.k<sup>h</sup>e] 'town, city'  
*sinthû* /sĩt<sup>h</sup>ĩ/ → [ʔsĩ.t<sup>h</sup>ĩ] 'bit'

Nasal harmony triggers alternations between glides and nasals. In native A'ingae words, the glides /v j/ and tap /ɾ/ never follow a nasal vowel. When /v j/ are placed after a nasal vowel through suffixation, they become nasal stops (6b), (7b). Harmony feeds glide nasalization (6c), (7c).<sup>8</sup>

<sup>7</sup>We use the terms 'spreading' and 'harmony' in a purely descriptive sense. We take no stance on whether these patterns are best analyzed with literal feature spreading, as in autosegmental phonology (Piggott & Van der Hulst 1997, Walker 2003), or with other devices such as agreement-by-correspondence (e.g. Rose & Walker 2004) or gestural blending (e.g. Smith 2018).

We reserve the term 'coarticulation' to refer to strictly phonetic processes involved in co-producing neighboring segments in physical time and space. Since we assume that phonetic processes may be language-specific (e.g. Keating 1984, Kingston & Diehl 1994), 'coarticulation' in this sense may be either intended (i.e. controlled), or mechanical (i.e. unavoidable), depending on the process.

<sup>8</sup>The velar glide /ɰ/ only occurs root-medially, and only after oral vowels. As such, /ɰ/ does not participate in alternations related to nasality. The velar nasal [ŋ] does not occur in A'ingae, which suggests that /ɰ/ never undergoes nasalization. The tap /ɾ/ is opaque to harmony, and does not undergo alternations related to nasality.

- (6) Glide nasalization after nasal vowels: /j/ → [ɲ]
- shakaye* /ʃaka-je/ → [ʃa.<sup>h</sup>ka.je] ‘lack-INF’
  - kañe* /kã-je/ → [ˈkã.ɲɛ̃] ‘look-INF’
  - chavuen’jeña* /tʃava-ẽ-ʔhe-ja/ → [tʃa.<sup>h</sup>ũẽɛ̃.ɲẽ.<sup>h</sup>ɲã] ‘buy-CAUS-IPFV-VER’
- (7) Glide nasalization after nasal vowels: /v/ → [m]
- thesive* /t<sup>h</sup>esi = ve/ → [t<sup>h</sup>e.si.ve] ‘jaguar=ACC2’
  - sin’ma* /sĩ-ʔva/ → [ˈsĩ-ʔ.mã] ‘bruise (lit. black-CLF:AREA)’
  - kun’sime* /kũʔsi = ve/ → [ˈkũʔ.sĩ.mẽ] ‘woolly.monkey=ACC2’

The triggers for nasal harmony include both nasal vowels (6)-(7) and the simple nasal stops /m n ɲ/. Vowels following nasal stops are always, exceptionlessly nasal. That this is so can be shown by the fact that vowels following nasal consonants are themselves triggers for harmony (8b).

- (8) Nasal spreading from [N] in A’ingae
- nae’sû* /naeʔ-si/ → [ˈnãẽɛ̃.ɲi] ‘fish (river-ATTR)’
  - semañe* /sema-je/ → [sẽ.mã.ɲẽ] ‘work-INF’

Left-to-right nasal harmony is a phonological process in A’ingae. First, it neutralizes the contrast between glides and homorganic nasal stops, as in (6b,c), (7b,c) and (8b). It is phonetically possible, in principle, to nasalize glides without changing their manner, /j v/ → [ɲ ʋ] etc. (Cohn 1993b). The fact that harmony changes the manner of articulation of glides, as well as their nasality, supports the claim that it is a phonological process, not just phonetic coarticulation for nasality.

Second, harmony spreads nasality over a potentially unbounded distance (6c), (7c). This too is characteristic of a phonologically-controlled harmony process (e.g. McCollum 2019). Third, inside roots, harmony can spread nasality through plain stops and fricatives (e.g. *anchan* /ãtʃa/ → [ˈã.tʃã] ‘mosquito’), even though such segments are both oral and phonetically antagonistic to nasality (see also Walker 2000, Shosted 2006, Smith 2018).

Nasal vowels produced by phonological harmony provide an important comparison for the nasality of vowels *preceding* [N, <sup>N</sup>D], to which we now turn.

### 3.4 Pre-nasal vowels

Although vowel nasalization is contrastive in A’ingae, /V <sup>h</sup>V/ contrasts are suspended before simple nasals [N] and prenasalized stops [<sup>N</sup>D]: there are no hypothetical minimal pairs like [ˈa.mĩ] vs. [ˈã.mĩ], or [ˈa.<sup>h</sup>gi] vs. [ˈã.<sup>h</sup>gi]. In other words, the /V <sup>h</sup>V/ contrast is neutralized before [N, <sup>N</sup>D]. However, the surface *result* of neutralization in this context is not obvious. Impressionistically, there is some degree of nasalization on vowels preceding [N, <sup>N</sup>D], e.g. words like *fuñu* [ˈfũ.ɲũ] ‘skirt’ and *kimbi* [ˈkĩ.<sup>m</sup>bi] ‘got tired’ have audible nasality on the initial, stressed vowel. Nasalization before [N, <sup>N</sup>D] is also clear when comparing morpho-syntactically related forms like those in (9):

- (9) a. *thesi* [t<sup>h</sup>e.sĩ] ‘jaguar’ vs. *thesinga* [t<sup>h</sup>e.sĩ = <sup>h</sup>ga] ‘to the jaguar’  
b. *patû* [ˈpa.tĩ] ‘rock’ vs. *patûma* [ˈpa.tĩ = mã] ‘rock=ACC’

At the same time, nasality on vowels before [N, <sup>N</sup>D] sounds weaker than nasality on contrastively nasal vowels in words like *kanse* /ˈkã.se/ ‘lived’. Indeed, native speaker judgments of nasality suggest that vowels preceding [N, <sup>N</sup>D] may not be fully nasalized.

We have worked closely with (other) A’ingae speakers to codify their orthography, and produce community-oriented materials such as dictionaries and story collections. In general, A’ingae speakers have clear judgments of vowel nasality, particularly in stressed syllables. This is not surprising, given that vowel nasality is contrastive. However, many of our A’i collaborators and consultants have expressed the intuition that vowels preceding [N, <sup>N</sup>D] are not fully nasal. Instead, vowels in this context are often described as ‘only half-nasal’. In some cases, speakers are simply unsure as to the nasality of vowels preceding [N, <sup>N</sup>D], or may disagree when given a binary choice between oral and nasal options. These judgments suggest that the neutralization of /V <sup>~</sup>V/ contrasts before [N, <sup>N</sup>D] may produce something other than a fully nasal vowel.<sup>9</sup>

There is thus a question as to whether nasality on vowels preceding [N, <sup>N</sup>D] is complete (i.e. categorical) or partial (i.e. phonetically gradient). If nasalization before [N, <sup>N</sup>D] is categorical, then it is reasonable to analyze it as part of the abstract, symbolic phonology of A’ingae. If nasalization before [N, <sup>N</sup>D] is instead partial, it may be better understood as reflecting a gradient phonetic process, such as coarticulation for nasality between the vowel and a following [N] or [<sup>N</sup>D].

To our knowledge, there is no *phonological* evidence that sheds light on the [NASAL] specification of vowels preceding [N, <sup>N</sup>D]. Unlike nasal harmony (section 3.3), anticipatory nasalization before [N, <sup>N</sup>D] is strictly local. It does not spread through laryngeals (10a), nor does it trigger glide ~ nasal stop alternations (10b).

(10) Anticipatory nasalization is strictly local

- a. *ijima* /ihi = ma/ → [i.hĩ.mã], \*[ĩ.hĩ.mã] ‘armadillo=ACC’
- b. *indiyembi* /i<sup>n</sup>di-je-<sup>m</sup>bi/ → [ĩ.<sup>n</sup>di.jẽ.<sup>m</sup>bi], \*[ĩ.<sup>n</sup>dĩ.jẽ.<sup>m</sup>bi] ‘grab-PASS-NEG’

These properties are consistent with treating anticipatory nasalization in [<sup>~</sup>VN, <sup>~</sup>V<sup>N</sup>D] as either a phonetic or phonological process.

Phonetic phenomena, such as coarticulation, should not feed or bleed phonological rules. This follows from the assumption that in speech production, the phonetics interprets the output of the phonology, and so cannot ‘look backward’ to affect the application of phonological processes (see Eischens 2022, Bennett et al. 2023 for discussion and references). Indeed, anticipatory nasalization does not feed or bleed any known phonological process in A’ingae, nor is it blocked by any kind of phonotactic requirement (see e.g. Dąbkowski 2024). The lack of feeding and bleeding interactions certainly makes sense if anticipatory nasalization is a physical, phonetic process of coarticulation. Alternatively, anticipatory nasalization could be a phonological rule which just happens, by chance, not to interact with other rules or constraints in the phonology of the language.

The punchline is that we cannot assess the phonological vs. phonetic character of anticipatory nasalization in A’ingae based on phonological patterning. The available evidence is compatible with treating vowels in [<sup>~</sup>VN, <sup>~</sup>V<sup>N</sup>D] as either [+NASAL], [-NASAL], or unspecified [Ø<sub>NASAL</sub>].

Given the lack of clear phonological evidence, in the remainder of the paper we turn to a phonetic study of vowel nasality in A’ingae. We will argue that vowels in [<sup>~</sup>VN, <sup>~</sup>V<sup>N</sup>D] contexts are phonetically distinct from [-NASAL] vowels, underlying [+NASAL] vowels, and phonologically derived [+NASAL] vowels. We conclude that underspecification for nasality, [Ø<sub>NASAL</sub>], best characterizes

<sup>9</sup>The perception of ‘weaker’ nasality in [<sup>~</sup>VN, <sup>~</sup>V<sup>N</sup>D] could be a context effect: vowels are generally perceived as less nasal when adjacent to a nasal consonant (e.g. Beddor & Krakow 1999, Fowler & Brown 2000, Zellou 2017). However, this does not explain why vowels in [NV] are consistently identified as fully nasal by A’ingae speakers, at least in our informal experience. See Jeong (2012), Rysling (2017) for related discussion.

the phonetics and phonology of vowels preceding [N, <sup>N</sup>D] in A’ingae.

## 4 Aerodynamic study

In the remainder of the paper we present a phonetic study of vowel nasality across several contexts, comparing pre-nasal [ṼN, Ṽ<sup>N</sup>D] with underlying, contrastively oral /V/ and nasal /Ṽ/ as well as phonologically derived post-nasal /NV/ → [ÑṼ]. This section outlines the study. Section 5 presents the results, and section 6 argues that our findings are most consistent with treating vowels preceding [N, <sup>N</sup>D] as phonologically and phonetically unspecified for nasality, [Ø<sub>NASAL</sub>].

### 4.1 Items

The items in our study consisted primarily of bisyllabic roots like those in Tab. 2. These roots were chosen to compare nasality on stressed vowels in four conditions: underlying oral /V/; underlying nasal /Ṽ/; phonologically derived post-nasal /NV/ → [ÑṼ]; and pre-nasal [ṼN, Ṽ<sup>N</sup>D]. Since these vowels are in monomorphemic roots, they are all non-alternating (i.e. phonologically invariant), because their context never changes. We included a relatively large number of items in the [ṼN, Ṽ<sup>N</sup>D] conditions, since these are the conditions of primary interest.

Item shape	Description	Example	# of items
[‘CV.CV]	Contrastive oral /V/	<i>tufa</i> [‘t <u>o</u> .fa] ‘lizard’	21
[‘C <sup>Ṽ</sup> .CV]	Contrastive nasal /Ṽ/	<i>finfin</i> [‘f <u>ĩ</u> .f <u>ĩ</u> ] ‘fanned one’s self’	9
[‘NV.CV]	Nasal [Ṽ] derived by L → R harmony (section 3.3)	<i>masha</i> [‘m <u>ã</u> .ʃa] ‘heron’	7
[‘C <sup>Ṽ</sup> .ÑV]	Vowel preceding [N]	<i>china</i> [‘tʃ <u>ĩ</u> .n <u>ã</u> ] ‘daughter-in-law’	15
[‘C <sup>Ṽ</sup> . <sup>N</sup> DV]	Vowel preceding [ <sup>N</sup> D]	<i>thumbû</i> [‘tʰ <u>õ</u> . <sup>m</sup> b <u>ĩ</u> ] ‘grasshopper’	18

**Table 2:** Sample items for each condition in the aerodynamic study. C = oral consonant, N = nasal stop, <sup>N</sup>D = prenasalized stop. Stressed target vowels are underlined.

Our study also included some morphologically complex words like *khakenga* [‘k<sup>h</sup>a.k<sup>h</sup>ẽ = <sup>ŋ</sup>ga] ‘to the leaf’. These items were included to gather information about contextual nasalization across morpheme boundaries. However, we found it difficult to accurately measure nasality on unstressed, root-final vowels, which are often quite reduced in A’ingae. As such, in complex words like *khakenga* [‘k<sup>h</sup>a.k<sup>h</sup>ẽ = <sup>ŋ</sup>ga], we only consider the nasality of the stressed vowel.

To summarize, the vowels analyzed here were always stressed; were typically root- and word-initial; and typically in the penultimate syllable. Less commonly, they were antepenultimate in morphologically complex words (on stress in A’ingae, see Dąbkowski 2021b, 2024).

Participants sometimes produced tokens which were different from what had been prompted, but which nonetheless fell into one of the conditions of interest of this study (e.g. producing *pûsh-esûnga* [pĩ.ʃe-sĩ = <sup>ŋ</sup>ga] ‘to the woman’ instead of the intended *pûshenga* [‘pĩ.ʃẽ = <sup>ŋ</sup>ga] ‘to the wife’). The stressed vowels in such items were included in our data as long as they could be accurately transcribed and annotated.

Vowels preceding glottal stop [ʔ] or [h] were excluded from analysis, because of the difficulty involved in segmenting and analyzing vowels in these contexts (e.g. *cha’nditshi* [‘tʃã?.<sup>n</sup>di-ts<sup>h</sup>i] ‘cold’, *nuhan* [‘nõ.hã] ‘thorn’, etc.). Items with diphthongs (whether oral or nasal) were similarly excluded

to keep vowel measurements as comparable across items as possible.

Together, the preceding factors account for the uneven distribution of items across conditions in Tab. 2. A full list of items analyzed in this study is provided in the appendix.

Vowel height can affect the amount of nasal airflow in nasal vowels, for both articulatory and aerodynamic reasons (e.g. Bell-Berti 1993, Hajek 1997, Young et al. 2001, Gick et al. 2012:129-36, Kunay et al. 2022). We therefore tried to vary vowel quality, and particularly vowel height, for the stressed vowels in each condition. We also tried to vary the place and manner of the flanking consonants, in order to minimize any idiosyncratic influences on nasal airflow in the vowel (e.g. Bellavance et al. 2024). Some of the items in the /V/, / $\tilde{V}$ /, and [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] conditions lacked an initial consonant, e.g. *ansin* [ˈã.sĩ] ‘salt’. Our ability to fully vary these factors was limited by (i) the number of items in each condition, which was chosen in part to keep recording sessions to a reasonable length; and (ii) a desire to use items consisting of relatively familiar bisyllabic roots, so as to minimize the difficulty of the task.

## 4.2 Participants

37 Participants were recruited via word of mouth in Zábalo and Lago Agrio, Ecuador (Fig. 5). All participants were native speakers of A’ingae who use the language as their primary means of daily communication with friends and family. The analysis consists of data from 15 speakers (7 male, 8 female; ages 19-63, mean = 38.4, median = 29, *SD* = 14). Thirteen participants lived in Zábalo at the time of recording, and 2 lived in Dureno (Fig. 5). All were born in either Zábalo or Dureno. We halted data annotation at 15 speakers because that was deemed to be a sufficient amount of data.

## 4.3 Data collection

### 4.3.1 Recordings

Oral and nasal air pressure recordings were made with two Glottal Enterprises (GE) PT-2E pressure transducers, mounted on a GE oro-nasal mask. The GE oro-nasal mask has separate oral and nasal chambers, which allows oral and nasal air pressure to be recorded more-or-less independently.<sup>10</sup> The oral pressure transducer was mounted directly on the mask, and the nasal pressure transducer was mounted on a GE DRTH-1 mask handle connected to the mask.

The air pressure transducers were connected to a GE MS-110 pressure transducer unit with a GE BFC-2 cable. The GE MS-110 pressure transducer unit was connected to a computer via USB cable. The oral and nasal air pressure recordings were made at 11,025 Hz using Audacity. Modulation was turned off on both channels on the GE MS-110 pressure transducer unit.

Simultaneous audio recordings were made with an Audio-Technica AT831b cardioid condenser lavalier microphone and Zoom H5 solid-state portable recorder, at a 48 kHz sampling rate with 24 bit quantization. Our procedure for transcribing, segmenting, and annotating these recordings is described in more detail in the appendix.

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<sup>10</sup>Recordings made with dual-chamber masks will often show small amounts of oral air pressure even in entirely nasal sounds (e.g. [m]), and small amounts of nasal air pressure even in entirely oral sounds (e.g. [v]) (Kochetov 2020; see e.g. Figs. 7, 8 for examples). This reflects the fact that the pressure transducers used for recording are mounted on the same mask, and so any physical vibration of that mask caused by oral airflow may register slightly in the nasal pressure transducer, and vice-versa. We also cannot rule out some degree of leakage between the oral and nasal chambers. Phonologically oral sounds may be produced with small amounts of nasal airflow, which can additionally result in some amount of nasal pressure signal during oral sounds (e.g. Bell-Berti 1993).



### 4.3.2 Item presentation and recording procedure

Items were presented on a laptop screen, using a Python script which randomized the order of presentation for each session. Items were presented in A'ingae orthography in a large font, with a Spanish translation in smaller font below. Some participants preferred to use the contemporary (as of 2023) A'ingae orthography, while others preferred to use the older orthography found in sources like Borman (1976). The norms for writing vowel nasality are the same in both systems.

Participants were asked to repeat each item six times: twice without the oro-nasal air pressure mask in place; twice with the mask in place, speaking at a normal rate; and twice with the mask in place, speaking at a faster rate. The goal of manipulating speech rate was to elicit vowels of varying durations, so that we could investigate whether the proportion of the vowel which is nasalized in  $[\tilde{V}N, \tilde{V}^ND]$  correlates (or not) with vowel duration (Solé 1992, 1995, 2007 and section 1.1). Participants sometimes repeated target items more often than requested, particularly at the beginning of each session as participants became accustomed to the recording setup. Any extra repetitions produced with the mask in place were included in our analysis (section 5). The mask-off repetitions were recorded to have clear audio of each item as a backup for analysis in case the airflow equipment or data was compromised; those audio recordings are not analyzed here.

During the recording session each participant held the mask by the handle, and raised it to their face as needed for recording. Participants were asked to place the mask gently but firmly on their face, forming a seal between their skin and the silicon ridge separating the oral and nasal chambers.

Participants completed an IRB-approved consent form in Spanish before participating. The contents of the consent form were first discussed in Spanish, and were then further discussed and clarified in A'ingae with the help of co-author [REDACTED]. Participants typically arrived at recording sessions in family groups: the consent form, recording process, and project goals were generally discussed among these groups before any family members began their participation.

Once recording began, sessions typically lasted 15-25 minutes. Participants were paid \$15 US for enrolling in the study. All recordings took place in July 2023.

## 4.4 Measurement and normalization of intensity and nasalance

A Praat script was used to extract intensity contours for the oral and nasal channels separately, using the `To Intensity` function, with the pitch floor set to 200 Hz, the time step set to one quarter of the effective window length (the default), and no mean subtraction. These intensity contours were then read into R (R Development Core Team 2025), and normalized to the range [0,1] for each speaker and channel separately.

The dependent measure of this study was `NASALANCE` (11), defined as the proportion of the total, combined oral and nasal intensity signals belonging to the nasal channel during each vowel.

- (11)    a.     $A_x$  = intensity of channel X  
         b.     $Nasalance = A_{nasal} / (A_{nasal} + A_{oral})$

Nasalance is a useful measure because it relativizes nasal air pressure to the sum total of air pressure in both the oral and nasal channels, expressed as a percentage. This helps control for the fact that *raw* nasal air pressure can be affected by changes to the overall volume of air leaving the vocal tract (e.g. when speaking loudly vs. quietly). Nasalance minimizes this confound. Additionally, it has been argued that the timecourse of nasalance is well-correlated with the timecourse of velar port opening (Siriwardena et al. 2024), though the initial phase of velum lowering can occur without

significant acoustic effects (Bell-Berti 1993).

Nasalance values are dependent on both oral and nasal air pressure. Because of this, nasalance can vary as a function of vowel quality, in particular height. High vowels have a narrower oral constriction than low vowels, and thus tend to have less oral airflow. Nasal high vowels also tend to have more nasal airflow than nasal low vowels, because their narrow constrictions increase oral impedance, forcing more air through the nasal tract. As a consequence, even when overall airflow is held constant, high vowels will have higher nasalance values than low vowels (e.g. Hajek 1997, Young et al. 2001). In our statistical analysis, we try to factor out the effect of vowel quality on nasalance measurements.

To compute nasalance, the normalized intensity values produced in R were first exported to files in Praat’s .Intensity format (following Stewart & Kohlberger 2017). Separate R and Praat scripts were used to compute nasalance at 17 equidistant, time-normalized steps for each vowel. Each step corresponds to the average nasalance in a window with duration equal to  $\frac{1}{17}$  of the duration of the vowel. These nasalance values were then imported into R for statistical analysis. Intensity values in dB (a logarithmic scale) were converted to Pascal (a linear scale) prior to processing. Nasalance was set to N/A for any point with nasal air pressure below 1% of that speaker’s maximum nasal air pressure. In the discussion that follows, we will sometimes use the terms ‘nasalance’ and ‘nasality’ interchangeably when discussing our phonetic results.

Overall, we analyzed 3772 target vowels across conditions. The average number of observations per participant was 251 (range = [237, 260],  $SD = 5.5$ ), including all items and repetitions. The average number of observations per item type (Tab. 2), per participant, was 50.3 (median 56) (range = [28, 72],  $SD = 15.7$ ). The width of this range reflects the fact that we had more items in the crucial  $[\tilde{V}N, \tilde{V}^ND]$  conditions than in other conditions. A breakdown of total observations per item type is provided in Table A1 in the appendix, along with a full list of items.

## 5 Results

In exploring our results, we first describe qualitative patterns based on individual tokens (section 5.1). We then statistically compare nasalance trajectories across conditions by means of generalized additive mixed models (GAMMs; section 5.2). Lastly, we fit sigmoid functions to individual nasalance trajectories to analyze the timing of nasality in  $[\tilde{V}N, \tilde{V}^ND]$  sequences (section 5.3).

### 5.1 Qualitative patterns

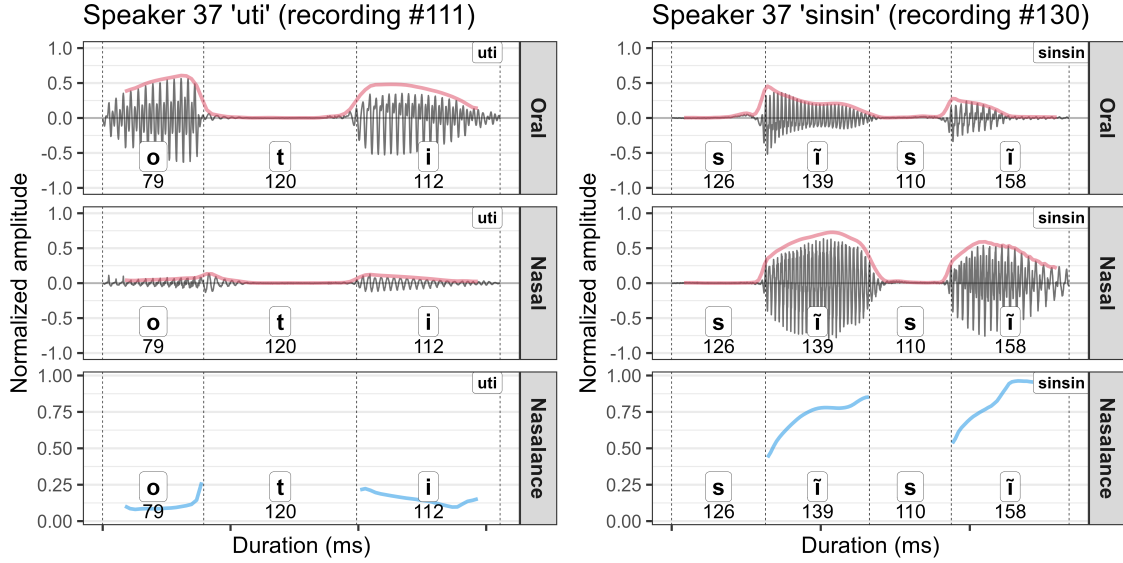
In general, surface oral vowels were produced with little to no nasal air pressure, and relatively low nasalance (Fig. 7, left).<sup>11</sup> Y-axis limits for nasalance reflect the range of nasalance values for that speaker. All plots were drawn with the ggplot2 package in R (Wickham 2016).

Underlying, contrastive nasal vowels are generally produced with high levels of nasal airflow, and correspondingly, high nasalance (Fig. 7, right). Nasalance is typically high throughout the entire vowel, though is often slightly depressed at the beginning of the vowel, presumably due to coarticulation with the preceding consonant, which was always oral (see also sections 5.2, 5.3, 6.1).

Phonologically derived nasal vowels in  $[N\tilde{V}]$  resemble underlying nasal vowels  $/\tilde{V}/$ : they are

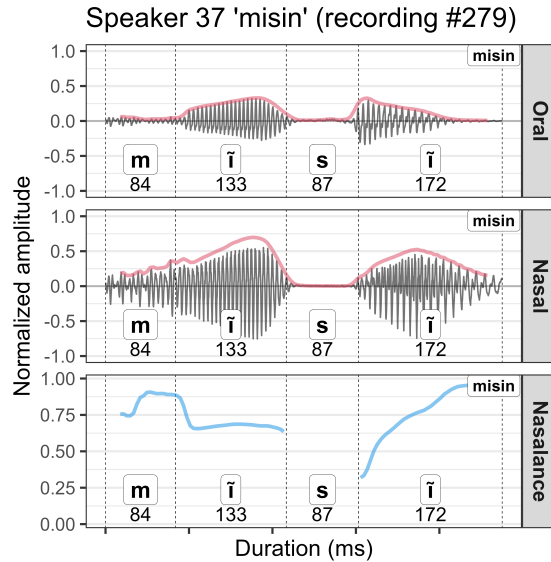
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<sup>11</sup>We omit nasalance measures on obstruents in our plots because the low levels of overall air pressure during obstruents can lead to wild fluctuations in nasalance, which is misleading and visually distracting. Oral air pressure is low for fricatives in our data because of the 11,025 Hz sampling rate of the GE MS-110 pressure transducer unit, which cannot record higher-frequency noise components; see e.g. Fig. 7.



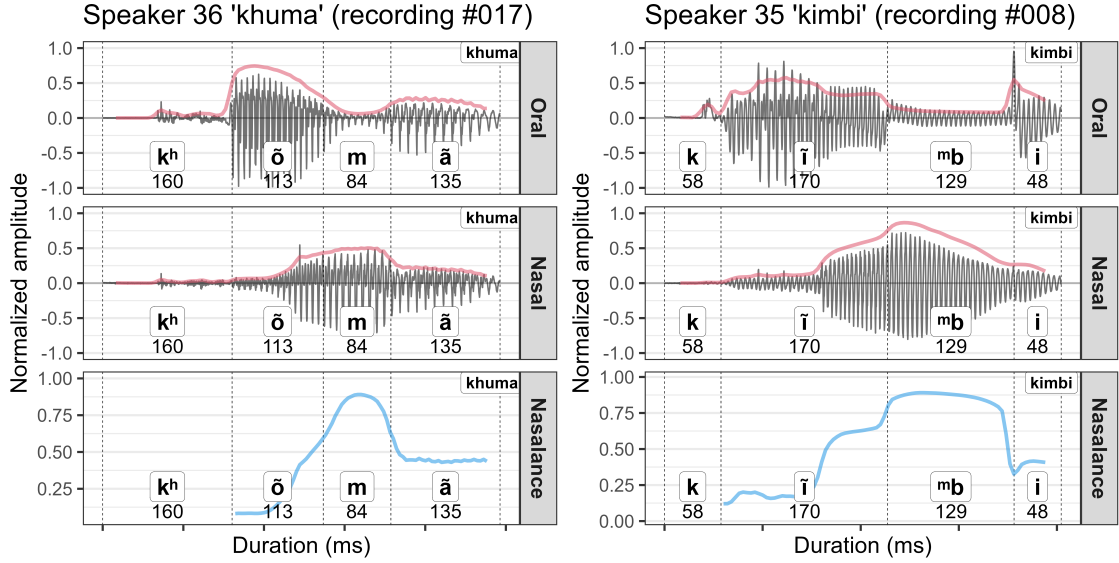
**Figure 7:** Sample token of a contrastive oral vowel /V/, *uti* [ʰo.ti] ‘hammered’ (left); and a contrastive nasal vowel /Ṽ/, *sinsin* [ʰsĩ.sĩ] ‘louse’ (right). Top panel shows oral air pressure and intensity, middle panel nasal air pressure and intensity, bottom panel nasalance (section 4.4).

strongly nasalized throughout their entire duration, though nasalance sometimes dips at the juncture between the nasalized vowel and the following consonant, which was always oral (Fig. 8).



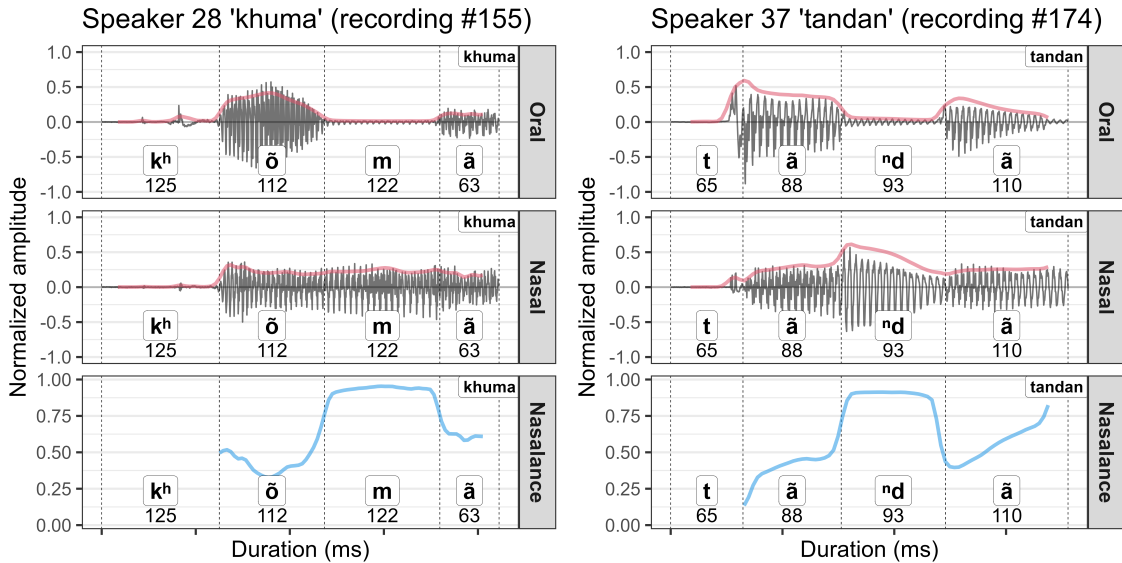
**Figure 8:** Sample token of a derived nasal vowel /NV/ → [NṼ], *misin* /misi/ → [ʰmĩ.sĩ] ‘worm’.

For vowels preceding [N, <sup>N</sup>D], we find patterns of variation, reminiscent of anticipatory nasalization in English (section 1). First, vowels preceding [N, <sup>N</sup>D] often show partial nasalization (Fig. 9): nasalance is low for roughly the initial ¼-½ of the vowel, then sharply increases, remaining relatively high until the onset following [N] or [<sup>N</sup>D].



**Figure 9:** Sample token of a vowel with partial nasalization preceding [N], *khuma* /k<sup>h</sup>oma/ → [k<sup>h</sup>õ.mã] ‘chile’ (left) and preceding [N<sup>D</sup>], *kimbi* /ki<sup>m</sup>bi/ → [kĩ.<sup>m</sup>bi] ‘tired’ (right).

Vowels may also show consistent, and relatively high levels of nasality preceding [N, N<sup>D</sup>], rather than a cline-like increase (Fig. 10).

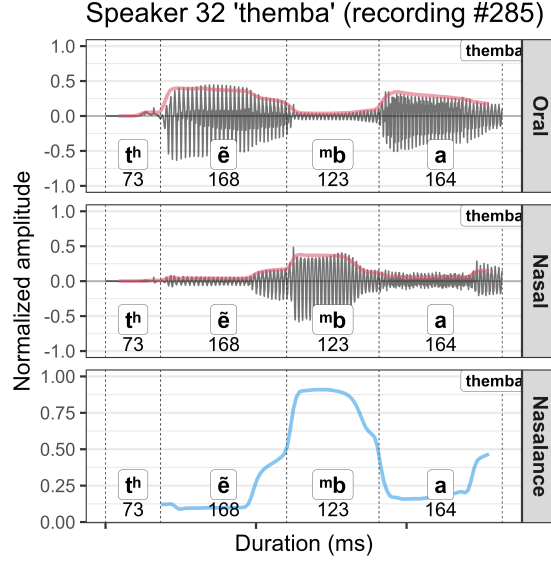


**Figure 10:** Sample token of a vowel with full nasalization preceding [N], *khuma* /k<sup>h</sup>oma/ → [k<sup>h</sup>õ.mã] ‘chile’ (left) and preceding [N<sup>D</sup>], *tandan* /ta<sup>n</sup>dã/ → [tã.<sup>n</sup>dã] ‘tied’ (right).

Lastly, some vowels preceding [N, N<sup>D</sup>] are essentially oral for most of their duration (Fig. 11)

## 5.2 Statistical analysis using GAMMs

We modeled nasalance trajectories using a generalized additive mixed model (GAMM), following Winter & Wieling (2016), Sóskuthy (2017, 2021), Baayen et al. (2017), Wieling (2018) and Baayen



**Figure 11:** Sample token of a pre-nasal vowel with prolonged orality, *themba* [t<sup>h</sup>e<sup>m</sup>ba] ‘branch’.

& Linke (2021). GAMMs were fit using the `bam()` function in the `mgcv` package (Wood 2017).<sup>12</sup>

The dependent measure was vowel nasalance. Our goal was to model nasalance trajectories over time for vowels in each of our key experimental conditions: contrastive oral /V/; contrastive / $\tilde{V}$ /; phonologically derived /NV/  $\rightarrow$  [N $\tilde{V}$ ]; and pre-nasal [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D]. Here, we focus on the fixed-effects structure of the model; see the appendix for additional details of model fitting, including random effects.

Our fixed effects included a difference smooth for NASALITY CLASS, comparing nasalance across timesteps for contrastive oral /V/, contrastive / $\tilde{V}$ /, phonologically derived /NV/  $\rightarrow$  [N $\tilde{V}$ ], and [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D]. Following Sóskuthy (2017), we also included a reference smooth for TIMESTEP, and a parametric term for NASALITY CLASS. All smooths used thin plate regression splines as the basis type (Wood 2003), with knots set at  $k = 17$  (the maximum possible, given 17 timesteps).

We treated [ $\tilde{V}$ N] and [ $\tilde{V}$ <sup>N</sup>D] as separate levels of NASALITY CLASS. This was to allow for the possibility that nasalance patterns might be different in [ $\tilde{V}$ N] and [ $\tilde{V}$ <sup>N</sup>D]. Our results nonetheless suggest that nasalance patterns are comparable for [ $\tilde{V}$ N] and [ $\tilde{V}$ <sup>N</sup>D].

The GAMM included parametric fixed-effects for several control predictors. First, vowel height is known to affect nasality, for both articulatory and aerodynamic reasons (sections 4.1, 4.4). This motivates the inclusion of a control predictor for V QUALITY in our models, with levels /a e i o ɨ/. The manner of articulation of the consonant in a [C $\tilde{V}$ ] sequence can also affect vowel nasalization (e.g. Bellavance et al. 2024). To control for this possibility, we included PRECEDING C as a parametric fixed-effect. The levels for this control predictor were FRICATIVE, PLOSIVE, PRENASALIZED<sup>N</sup>D, and # (= word-initial vowel). In the [N $\tilde{V}$ ] condition, the preceding consonant was always nasal: for vowels in this condition, the value for PRECEDING C was specified as the value of the *following* consonant instead (which was always an oral fricative or plosive).

We also included a smooth term for V DURATION (again using thin plate regression splines, knots set to  $k = 9$ ). This was motivated by prior observations that vowel nasality may vary with speech rate and/or vowel duration (e.g. Solé 2007). We explore the potential effect of duration on

<sup>12</sup>The `mgcv::bam()` function excludes tokens with missing values. Before fitting a GAMM, missing nasalance values were supplied using the `downup` imputation method of `tidyr::fill()` (Wickham et al. 2024).

vowel nasality in more detail in section 5.2.2.

NASALITY CLASS was treatment coded as an ordered factor with / $\tilde{V}$ / as the reference level. V QUALITY and PRECEDING C were also treatment coded, with reference levels [a] and # (= word-initial vowel) respectively. V DURATION and TIMESTEP were mean-centered.

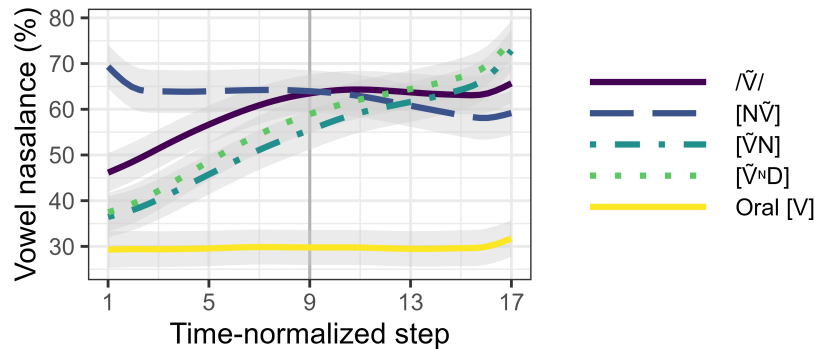
The model structure is summarized in Table 3. Since V QUALITY and PRECEDING C are included primarily as controls, we omit detailed discussion of those predictors, and do not provide model estimates for their individual levels in Table 3.

NASALANCE (%)  $\sim$  NASALITY CLASS + V QUALITY + PRECEDING C +  
s(DURATION, BS="TP", K=9) + s(TIMESTEP, BS="TP", K=17) + s(TIMESTEP, BY = NASALITY CLASS, BS="TP", K=17) +  
s(WORD, BS="RE") + s(TIMESTEP, SPEAKER, BS="FS", M=1)

PARAMETRIC TERMS	ESTIMATE	SE	<i>t</i>	<i>p</i>
(INTERCEPT)	59.94	2.04	29.33	< .001*
<b>NASALITY CLASS</b> (REFERENCE = / $\tilde{V}$ /)				< .001*
/NV/ $\rightarrow$ [N $\tilde{V}$ ]	2.84	1.78	1.60	.11
[ $\tilde{V}$ N]	-5.89	1.54	-3.83	< .001*
[ $\tilde{V}^N$ D]	-3.28	1.50	-2.19	< .05*
ORAL [V]	-30.22	1.53	-19.73	< .001*
<b>PRECEDING C</b>				< .001*
<b>V QUALITY</b>				< .05*
SMOOTH TERMS	EDF	REF. DF	F	<i>p</i>
s(TIMESTEP) (MEAN-CENTERED)	13.79	14.38	40.74	< .001*
s(TIMESTEP, BY = NASALITY CLASS)				
/NV/ $\rightarrow$ [N $\tilde{V}$ ]	14.79	15.73	228.82	< .001*
[ $\tilde{V}$ N]	14.03	15.34	121.50	< .001*
[ $\tilde{V}^N$ D]	13.64	15.11	121.12	< .001*
ORAL [V]	11.09	13.31	154.13	< .001*
s(DURATION) (MEAN-CENTERED)	4.19	5.21	6.43	< .001*

**Table 3:** Fixed-effects estimates for GAMM, fit to vowel nasalance at 17 time-normalized steps.

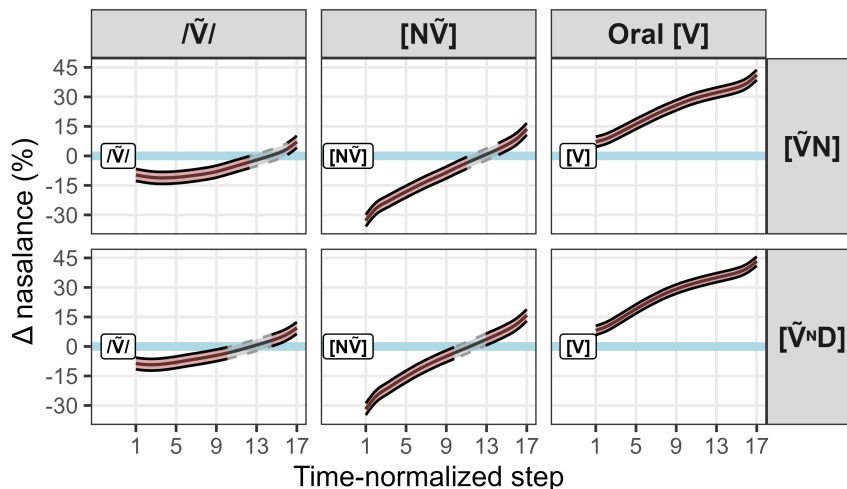
Fig. 12 shows the nasalance trajectories that the GAM model predicts for each segmental condition. These predicted trajectories are marginal effects, i.e. they are generalized over all other factors in the model (V QUALITY, PRECEDING C, V DURATION, and the random effects).



**Figure 12:** Model predictions for vowel nasalance by nasality class. Gray bands indicate confidence intervals around predicted values. Produced with `tidygam::predict_gam()` (Coretta 2024).

Underlying nasal / $\tilde{V}$ / shows high levels of nasality throughout the vowel in Fig. 12, apart from an initial rise which likely reflects coarticulatory influence from preceding oral consonants (see sections 5.3.1, 6.1 for more on [C $\tilde{V}$ ] coarticulation). Derived nasal vowels /NV/  $\rightarrow$  [N $\tilde{V}$ ] are consistently nasal throughout, with a slight initial drop in nasality reflecting the transition from the preceding nasal consonant. Oral vowels display low, unchanging nasality across their durations. Most importantly, vowels preceding [N,  $^N$ D] show a cline-like pattern of partial nasalization, beginning low, and rising gradually toward the following nasal consonant.

Fig. 13 shows difference smooths comparing pre-nasal [ $\tilde{V}$ N,  $\tilde{V}^N$ D] to the other conditions in our study (contrastive nasal / $\tilde{V}$ /, phonologically derived /NV/  $\rightarrow$  [N $\tilde{V}$ ], and contrastive oral /V/).



**Figure 13:** Difference smooths comparing nasalance across conditions. Positive values indicate greater estimated nasalance for [ $\tilde{V}$ N] or [ $\tilde{V}^N$ D] (rows) relative to comparison category (columns); negative values indicate greater estimated nasalance for comparison category. Red regions with solid outlines correspond to significant differences between compared conditions; grey regions with dashed outlines indicate the lack of a significant difference. Produced with `tidygam::get_difference()` (Coretta 2024).

As implied by Fig. 12, pre-nasal [ $\tilde{V}$ N,  $\tilde{V}^N$ D] have lower nasality than contrastive nasal / $\tilde{V}$ / up to somewhere around step 10-12 ( $\approx$  60-70% of the vowel’s duration). At the tail end of their trajectories, pre-nasal [ $\tilde{V}$ N,  $\tilde{V}^N$ D] have higher nasality than contrastive nasal / $\tilde{V}$ /, reflecting a transition into the following nasal consonant for [ $\tilde{V}$ N,  $\tilde{V}^N$ D].

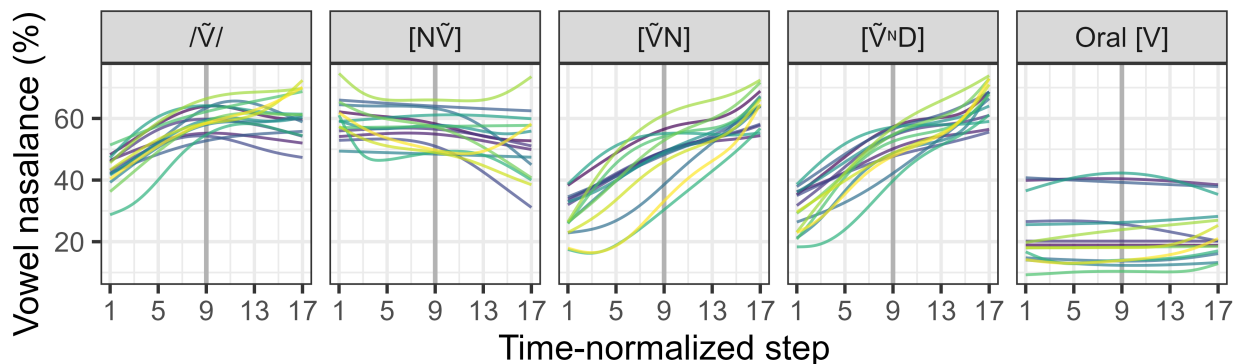
The same pattern holds for pre-nasal [ $\tilde{V}$ N,  $\tilde{V}^N$ D] compared to phonologically derived /NV/  $\rightarrow$  [N $\tilde{V}$ ], though the magnitude of the difference in nasality is larger. This reflects the fact that derived /NV/  $\rightarrow$  [N $\tilde{V}$ ] begins with a nasal consonant, and so has the highest initial nasality of all vowel types in our study (Fig. 12).

Finally, pre-nasal [ $\tilde{V}$ N,  $\tilde{V}^N$ D] have higher nasality than contrastive oral /V/ at all time points, with the size of the difference growing substantially over time as nasality increases in [ $\tilde{V}$ N,  $\tilde{V}^N$ D].

### 5.2.1 Nasalance patterns by speaker

Fig. 14 shows smoothed nasalance trajectories for each condition, grouped by speaker. These smooths were fit over the raw data, rather than our model predictions; the by-speaker predictions of our model are comparable.





**Figure 14:** GAM smoothed nasalance traces over raw nasalance, by speaker and nasality class.

While the trajectories in Fig. 14 are not identical across speakers, they are generally quite similar, and clearly reflect the overall trends plotted in Figs. 12, 13.<sup>13</sup>

We conclude that the population-level patterns reported in our statistical analysis are broadly representative of how individual A’ingae speakers realize vowels across these contexts. We return to speaker-level patterns in section 5.3.5.

### 5.2.2 Effects of speech rate and vowel duration

Our speech rate manipulation (slow vs. fast productions) affected vowel duration as expected. The mean vowel duration for slow repetitions (154ms) was longer than the mean vowel duration for fast repetitions (124ms), according to a *t*-test ( $p < .001$ ). The [2.5%, 97.5%] data range for duration was [84, 224]ms, mean = 139ms, median = 132ms,  $SD = 46$ ms.

To assess the potential effect of vowel duration on nasality, we added two fixed effects to the model described above: a smooth allowing the effect of duration to vary by timestep (=  $s(\text{Timestep}, \text{Duration}, \text{BS} = \text{“TP”}, \kappa = 17)$ ), and a smooth allowing the effect of duration at each timestep to vary depending on the condition (=  $s(\text{Timestep}, \text{Duration}, \text{BY} = \text{Condition}, \text{BS} = \text{“TP”}, \kappa = 17)$ ).<sup>14</sup>

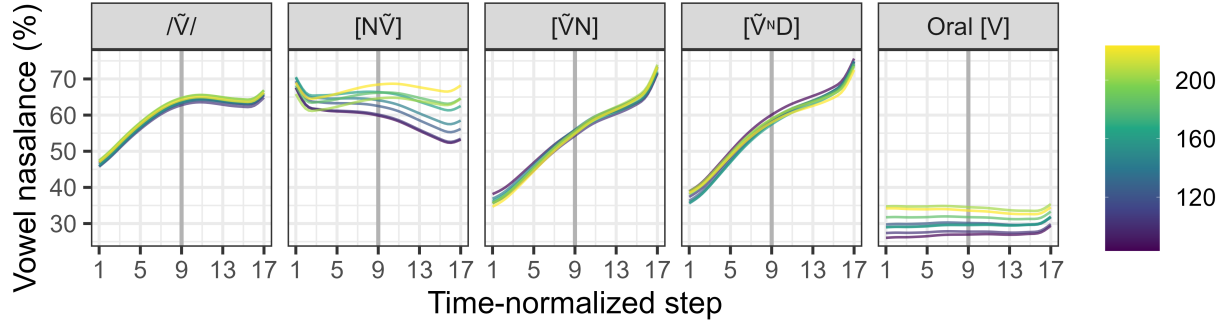
Fig. 15 shows how duration modulates — or mostly, fails to modulate — nasalance within each level of NASALITY CLASS. It is evident from Fig. 15 that vowel duration has essentially no predicted effect on the nasalance contours for contrastive nasal /Ń/, or pre-nasal [ŃN, ŃND].

At shorter durations, the nasalance contour for /NV/ → [NŃ] declines more strongly. We interpret this as an effect of coarticulation with the following oral consonant: a fixed amount of local coarticulation at the [Ń-C] transition in [NŃ.C] will have a greater *proportional* effect on shorter vowels. However, we do not know why the same effect is absent for contrastive /Ń/, as these vowels are also followed by oral consonants. Oral vowels slightly increase in nasality at longer durations.

These results hold even when (i) duration is replaced with a categorical predictor for REQUESTED SPEECH RATE (fast vs. slow), or (ii) REQUESTED SPEECH RATE is included alongside the duration-related predictors described above. In both cases, the nasalance contours that our GAM model

<sup>13</sup>We speculate that inter-speaker differences in nasalance values for baseline oral vowels /V/ in Fig. 14 owe to anatomical variation, possibly related to gender and/or age. See e.g. Rochet et al. (1998), Young et al. (2001), Okalidou et al. (2011), Zellou (2022:28). It may also be that some speakers had greater leakage between the oral and nasal chambers of the air pressure mask than others.

<sup>14</sup>These duration-related fixed effects were not included in the initial GAMM because their addition increases concavity above recommended levels. The results presented in Figs. 12, 13 are essentially unchanged when these duration-related predictors are included in the model. See the appendix for more discussion.



**Figure 15:** Model predictions for nasalance, as a function of vowel duration and nasality class. Lines correspond to 20ms increments in the range [84, 224]ms, the [2.5%, 97.5%] range for duration in our data. Confidence intervals omitted for readability. Produced with `tidygam::predict_gam()` (Coretta 2024).

predicts for  $[\tilde{V}N, \tilde{V}^ND]$  are essentially insensitive to changes in vowel duration and/or speech rate, as in Fig. 15. (We omit plots demonstrating this finding for reasons of space.)

### 5.2.3 Discussion of GAMM results

These results align with our qualitative observation that pre-nasal vowels in  $[\tilde{V}N, \tilde{V}^ND]$  are often produced with nasalization that is *partial* (increasing over time) when compared to contrastive  $/\tilde{V}/$  or derived  $/N\tilde{V}/ \rightarrow [N\tilde{V}]$ . Importantly, partial nasalization in  $[\tilde{V}N, \tilde{V}^ND]$  does not appear to be conditioned by vowel duration or speech rate.

Our GAMM analysis confirms that vowels in  $[\tilde{V}N, \tilde{V}^ND]$  are phonetically distinct from both contrastive  $[+NASAL]$  vowels  $/\tilde{V}/$  and allophonic  $[+NASAL]$  vowels  $/N\tilde{V}/ \rightarrow [N\tilde{V}]$ . Pre-nasal vowels in  $[\tilde{V}N, \tilde{V}^ND]$  are also phonetically distinct from  $[-NASAL]$  oral vowels  $/V/$ . This three-way phonetic distinction between  $[+NASAL]$  vowels,  $[-NASAL]$  vowels, and  $[\tilde{V}N, \tilde{V}^ND]$  motivates our claim that vowels in  $[\tilde{V}N, \tilde{V}^ND]$  contexts are phonetically and phonologically unspecified for nasality.

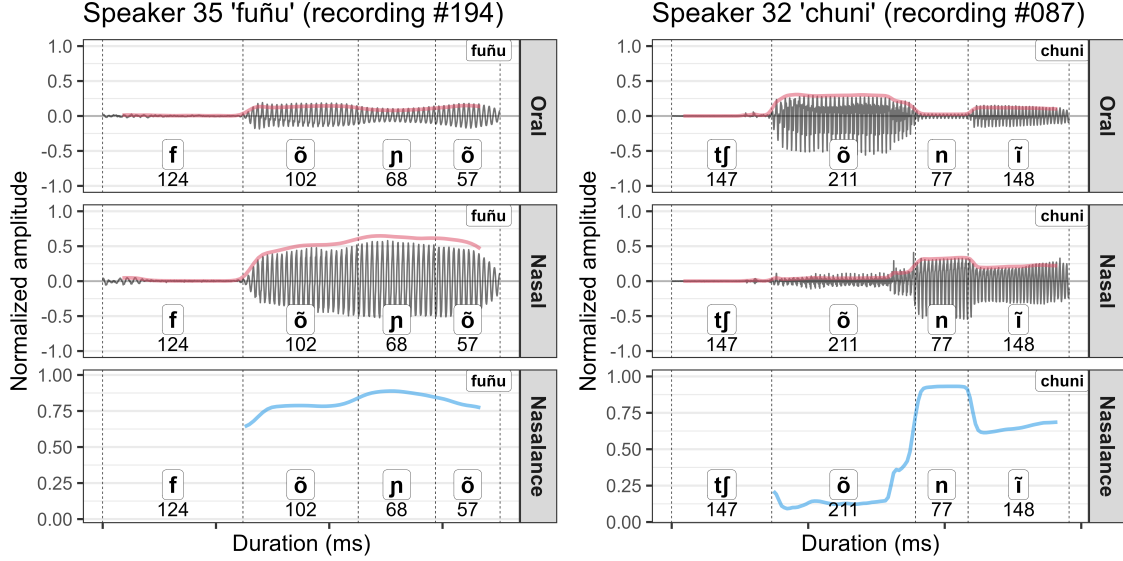
In the following section we build on these results by showing that the timing of nasality in  $[\tilde{V}N, \tilde{V}^ND]$  is highly variable, consistent with the qualitative patterns in section 5.1, and with a formal analysis based on nasal underspecification.

## 5.3 The timecourse of nasality in $[\tilde{V}N, \tilde{V}^ND]$

As observed in section 5.1, vowels in  $[\tilde{V}N, \tilde{V}^ND]$  in A’ingae seem to vary from fully nasal, to partially nasal, to mostly oral. We illustrate this variation in Fig. 16 (see also Figs. 9, 10, 11, etc.).

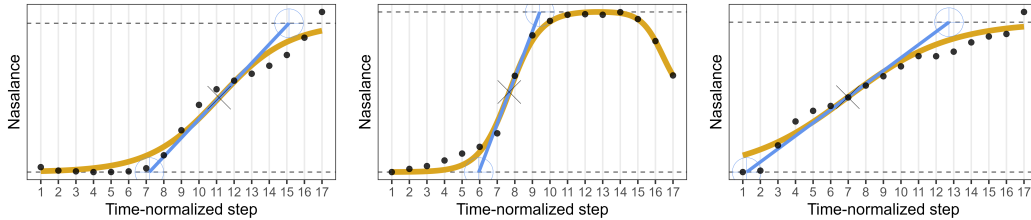
To better understand how nasality is realized on vowels in  $[\tilde{V}N, \tilde{V}^ND]$  in A’ingae, in this section we analyze the timecourse of vowel nasality in  $[\tilde{V}N, \tilde{V}^ND]$  in quantitative terms. To do this, we used the `sicegar` package in R (Caglar et al. 2018) to fit sigmoidal (‘s’-shaped) curves to measurements of nasality over time (a method borrowed from Pouplier et al. 2024). The shape of these curves can then be used to estimate when nasality begins to rise (if at all) during any particular token.

The `sicegar` package attempts to classify whether time-varying data shows a pattern of change which resembles a sigmoidal curve. A sigmoidal (‘s’-shaped) curve typically begins with a relatively flat set of values, which at some point steadily increases until reaching a maximum value (Fig. 17, left panel). The `sicegar` package can also classify tokens as having a double-sigmoidal curve, consisting of a sigmoidal rise followed by a sigmoidal fall (Fig. 17, center panel). Note that `sicegar` will fit ‘sigmoids’ which are close to linear (Fig. 17, right panel): these are sigmoids with



**Figure 16:** Sample tokens of pre-nasal vowels with early nasality, *fuñu* /fopõ/ ‘skirt’ (left), and prolonged orality, *chuni* /tʃoni/ ‘nutria’ (right).

a low value for the slope parameter  $k$  in the logistic function  $y = \frac{Max(y)}{1+e^{-k(x-m)}}$ , which is the basis of the sigmoids fit by *sicegar* (see Caglar et al. 2018 for additional details).



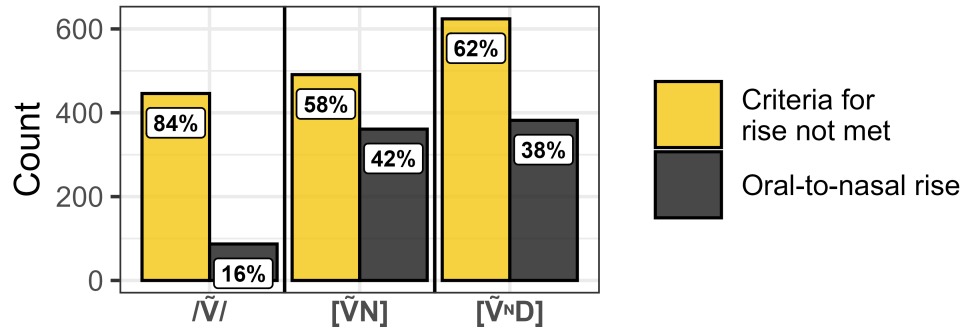
**Figure 17:** Sample sigmoidal (left), double sigmoidal (center), and quasi-linear (right) fits. Black dots indicate original measurements of nasalance. Blue lines are tangent to sigmoidal curve at midpoint of rise, marked with X. Estimated start time of rise is marked with bullseye intersecting minimum value of data; estimated end time is marked with bullseye intersecting maximum of curve.

The timing of a nasalance rise can be estimated by drawing a line tangent to the midpoint of the rising portion of the sigmoidal curve (Fig. 17). The intersection of this tangent with the line marking the minimum value of the input data provides an estimate of the start time of the rise. The intersection of this tangent with the line marking the maximum value in the sigmoidal curve provides an estimate of the end time of the rise.

Several parameter settings affect how the `fitAndCategorize()` function in *sicegar* detects rises, and how stringent it is about model fit for any given curve. We chose fairly strict parameter settings which were intended to report a rise only for vowels which truly had an oral-to-nasal transition, and not just any kind of increase in nasalance (e.g. a change from nasal to more strongly nasal). Our results are thus conservative, and may undercount the number of tokens which show a significant increase in nasality during the vowel. Details on the parameter settings used here are provided in the appendix. We manually classified oral vowels [V], and allophonically nasalized vowels produced by harmony /NV/ → [ÑV], as not having an oral-to-nasal rise (Figs. 12, 14).

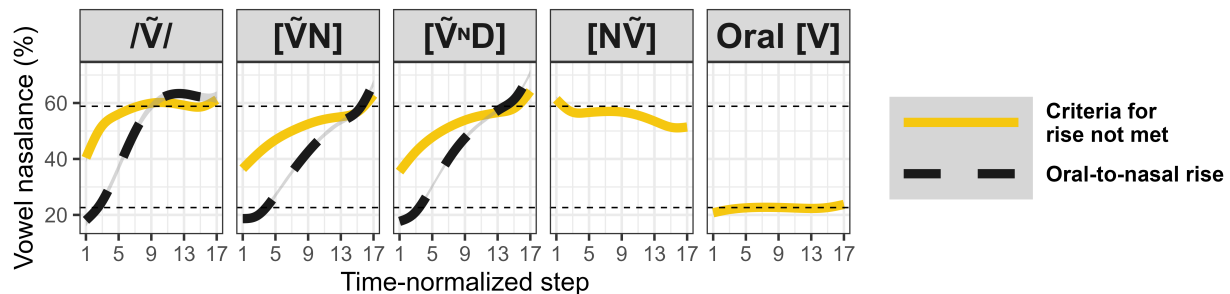
### 5.3.1 Overall trends for oral-to-nasal transitions

Fig. 18 shows the number of tokens classified as having an oral-to-nasal rise in three conditions: contrastive  $/\tilde{V}/$ ,  $[\tilde{V}N]$ , and  $[\tilde{V}^ND]$ . As expected, oral-to-nasal rises are far more common for  $[\tilde{V}N]$ ,  $[\tilde{V}^ND]$  (about 40% of tokens) than for contrastive  $/\tilde{V}/$  (about 15% of tokens).



**Figure 18:** Barplot of nasalance traces classified as sigmoidal (black) vs. non-sigmoidal (yellow) with sicegar package in R, by condition. Percentages are within-condition.

Oral-to-nasal rises seem more gradual for  $[\tilde{V}N]$ ,  $[\tilde{V}^ND]$  compared to contrastive  $/\tilde{V}/$  (Fig. 19, dashed black lines). Peak nasality also occurs later in  $[\tilde{V}N]$ ,  $[\tilde{V}^ND]$  than in  $/\tilde{V}/$ . Even for tokens which are identified as *lacking* an oral-to-nasal rise, the achievement of peak nasality is later in  $[\tilde{V}N]$ ,  $[\tilde{V}^ND]$  than in  $/\tilde{V}/$  (Fig. 19, solid yellow lines). These timing differences are consistent with our GAMM results (Figs. 12, 13). In general, contrastive nasal vowels  $/\tilde{V}/$  seem to be fully nasalized by vowel midpoint or earlier, while full nasality in  $[\tilde{V}N]$ ,  $[\tilde{V}^ND]$  occurs later (see also Huffman 1989).



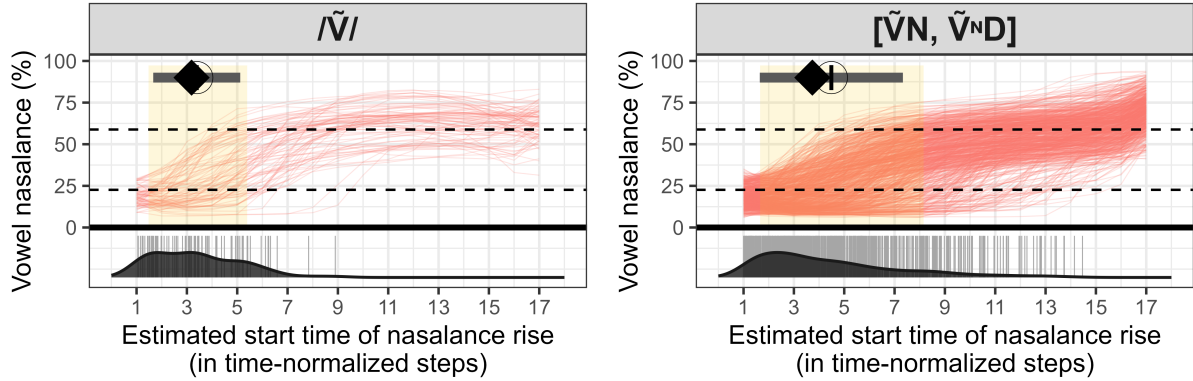
**Figure 19:** GAM-smoothed nasalance contours for tokens identified as having vs. lacking an oral-to-nasal rise, by condition. Dashed horizontal lines show mean nasalance for contrastively oral (lower) and nasal vowels  $/\tilde{V}/$  (upper), taken across steps 6-12.

The presence of an oral-to-nasal rise does not appear to be tied to vowel duration. For contrastive  $/\tilde{V}/$ ,  $[\tilde{V}N]$ , and  $[\tilde{V}^ND]$ ,  $t$ -tests find no significant differences in duration between vowels identified as having vs. lacking an oral-to-nasal rise ( $p > .085$  in all cases, largest mean difference = 6ms). These patterns are consistent with our finding above that duration is not a significant predictor of nasalance trajectories (section 5.2.2).

### 5.3.2 Start times of oral-to-nasal transitions

Fig. 20 shows the distribution of rise times for vowels identified as having an oral-to-nasal transition in  $/\tilde{V}/$  and  $[\tilde{V}N]$ ,  $[\tilde{V}^ND]$ . Almost all rises for  $/\tilde{V}/$  begin before step 7, while there are many tokens of

$[\tilde{V}N, \tilde{V}^ND]$  with rises that begin later than step 7.



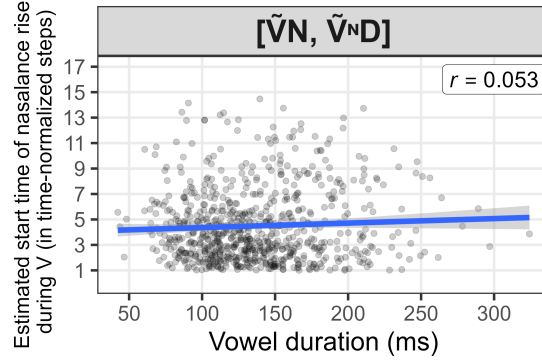
**Figure 20:** Start times for oral-to-nasal rises in  $/\tilde{V}/$  and  $[\tilde{V}N, \tilde{V}^ND]$ , in normalized time. Top of each figure (above 0 line): Individual nasalance traces shown in red. Dashed black lines mark mean nasalance for contrastive oral  $/V/$  and nasal  $/\tilde{V}/$  vowels (Fig. 19). Bottom of each figure (below 0 line): Vertical gray lines show estimated rise times for individual tracings. Density plot shows overall distribution. Shaded yellow regions cover middle 75% of rise times, [12.5%, 87.5%]. Open circles indicate means, diamonds medians, and grey horizontal bars  $\pm 1$  standard deviations from the mean.

For  $[\tilde{V}N, \tilde{V}^ND]$ , most oral-to-nasal rises begin between time steps 2 and 8, i.e. in the first  $\approx 45\%$  of the vowel. There is a clump of values between steps 1-3, in the first  $\approx 15\text{-}20\%$  of the vowel. There is also a very long tail of estimated rise times, extending past the 14th time step ( $\approx 85\%$  of the vowel).

It seems clear that nasality occurs relatively late in  $[\tilde{V}N, \tilde{V}^ND]$  when compared to contrastive  $/\tilde{V}/$ . Although there are some contrastive  $/\tilde{V}/$  tokens which begin with low levels of nasality, they are infrequent: the vast majority of  $/\tilde{V}/$  tokens begin with moderate-to-strong nasality (Figs. 18, 19). Even for those tokens of contrastive  $/\tilde{V}/$  which do begin with low nasality, nasality increases early in the vowel. This is not the case for  $[\tilde{V}N, \tilde{V}^ND]$ , which includes many tokens that have prolonged oral stretches before increasing in nasality (Figs. 19, 20).

We interpret the brief nasalance rises at the beginning of contrastive nasal  $/\tilde{V}/$  as primarily reflecting coarticulation with the preceding oral consonant (e.g. Delvaux et al. 2008:592-5, Bellavance et al. 2024; see also Desmeules-Trudel & Brunelle 2018). In any event, it is clear that the timing of nasality is quite different in  $[\tilde{V}N, \tilde{V}^ND]$  than in  $/\tilde{V}/$ . Further, the source of these timing differences is not the preceding consonant, which was always either oral or prenasalized for both  $[\tilde{V}N, \tilde{V}^ND]$  and  $/\tilde{V}/$ . Nor can these timing differences be attributed to the influence of vowel height, because vowel height was varied in both conditions (e.g. Kunay et al. 2022).

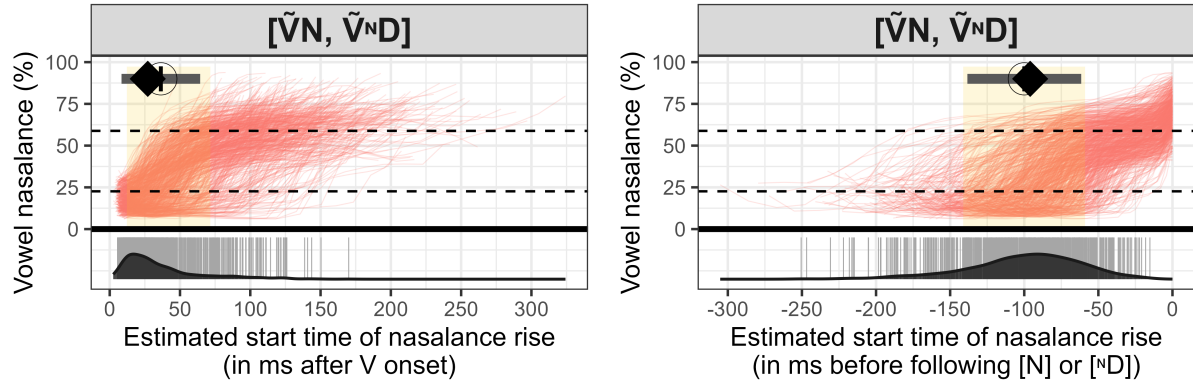
In what follows, we focus our discussion on the results for  $[\tilde{V}N, \tilde{V}^ND]$ . There appears to be no correlation between vowel duration and estimated rise time in  $[\tilde{V}N, \tilde{V}^ND]$ . Across vowel durations, rise times can be found which span essentially all timesteps (Fig. 21).



**Figure 21:** No correlation between V duration and start of oral-to-nasal rise (in time-normalized steps).

It seems that nasality may begin to rise at essentially any point during the vowel in  $[\tilde{V}N, \tilde{V}^ND]$ . While there is a bias toward early rises, late rises are also quite common, even across changes in speech rate and duration.

Similar variability can also be observed if we consider rise times in physical ms, rather than normalized time (Fig. 22). Although oral-to-nasal rises *tend* to occur in the first  $\approx 70$ ms after vowel onset, and/or around 150 to 50ms before vowel offset, there is a wide distribution of rise times in each case. (The mean vowel duration in our data is 139ms,  $SD = 46$ ms, median = 132ms.)



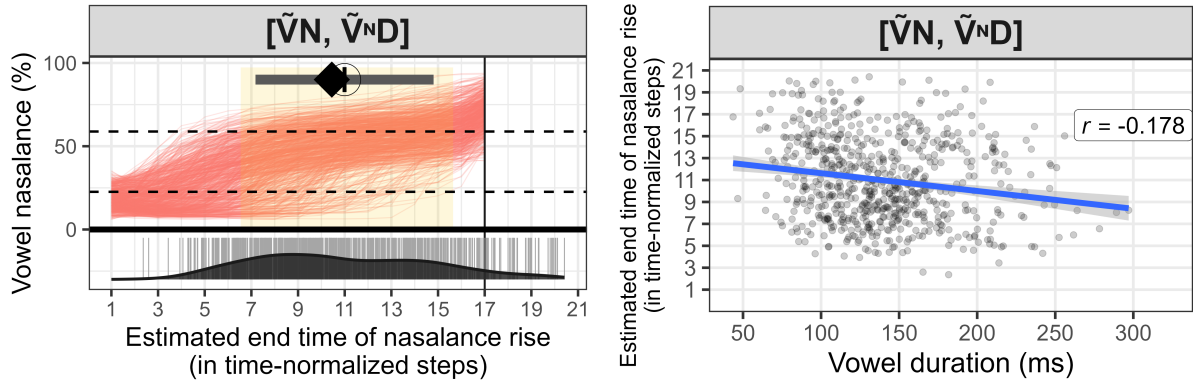
**Figure 22:** Start times for oral-to-nasal rises in  $[\tilde{V}N, \tilde{V}^ND]$ , in ms after vowel onset (left) and before vowel offset (right). See Fig. 20 for more details.

Poupier et al. (2024) estimate that “25 ms [is] needed minimally to arrive at peak [velar] opening” for a nasal stop. The majority (73%) of oral-to-nasal rises for  $[\tilde{V}N, \tilde{V}^ND]$  begin more than 75ms before the following nasal consonant (Fig. 22, right panel). Though it is hard to pin down what a truly minimal amount of coarticulation for nasality would be in a  $[VN]$  or  $[V^ND]$  sequence, it is clear that the onset of nasality in  $[\tilde{V}N, \tilde{V}^ND]$  in our data typically exceeds any plausible threshold for mechanical coarticulation with the following  $[N]$  or  $[^ND]$ .

### 5.3.3 End times of oral-to-nasal transitions

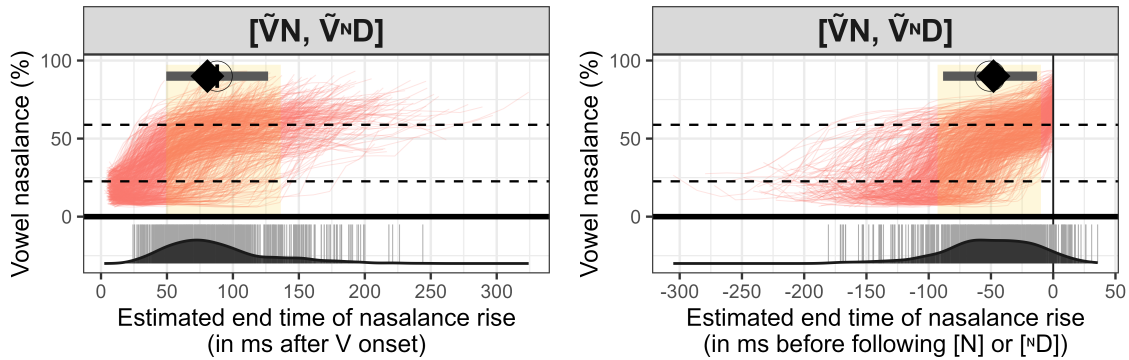
The same patterns of variability can be observed for the estimated *end* points of the nasalance rises in  $[\tilde{V}N, \tilde{V}^ND]$  (Fig. 17). First, the estimated end points span the entire range of time-normalized steps, with little evidence of clustering around any particular value (Fig. 23). And again, there is no apparent correlation between vowel duration and the end point of the rise.





**Figure 23:** End times for oral-to-nasal rises in  $[\tilde{V}N, \tilde{V}^ND]$ , in normalized time (left), and correlated with V duration (right). Estimated end points larger than 17 imply that nasalance reaches a peak *after* vowel offset.

In physical ms, the same patterns hold (Fig. 24). The end of a nasalance rise in  $[\tilde{V}N, \tilde{V}^ND]$  does not lag the beginning or end of the vowel by any consistent amount of time.



**Figure 24:** End times for oral-to-nasal rises in  $[\tilde{V}N, \tilde{V}^ND]$ , in ms after vowel onset (left) and before vowel offset (right) (see Fig. 20 for more details). Estimated end points larger than 0 in right panel imply that nasalance reaches a peak *after* vowel offset.

### 5.3.4 Interim summary of timing patterns for nasality in pre-nasal $[\tilde{V}N, \tilde{V}^ND]$

The timecourse of nasality in  $[\tilde{V}N, \tilde{V}^ND]$  sequences in A'ingae is quite variable. The onset of nasality may occur at essentially any point; the same is true for the achievement of peak nasality. Vowels in  $[\tilde{V}N, \tilde{V}^ND]$  may be fully nasalized, nasalized fairly early, or nasalized quite late. While certain outcomes are more common than others, all of these outcomes are robustly attested in our data. Variation in the time course of nasalization appears to be unrelated to vowel duration.

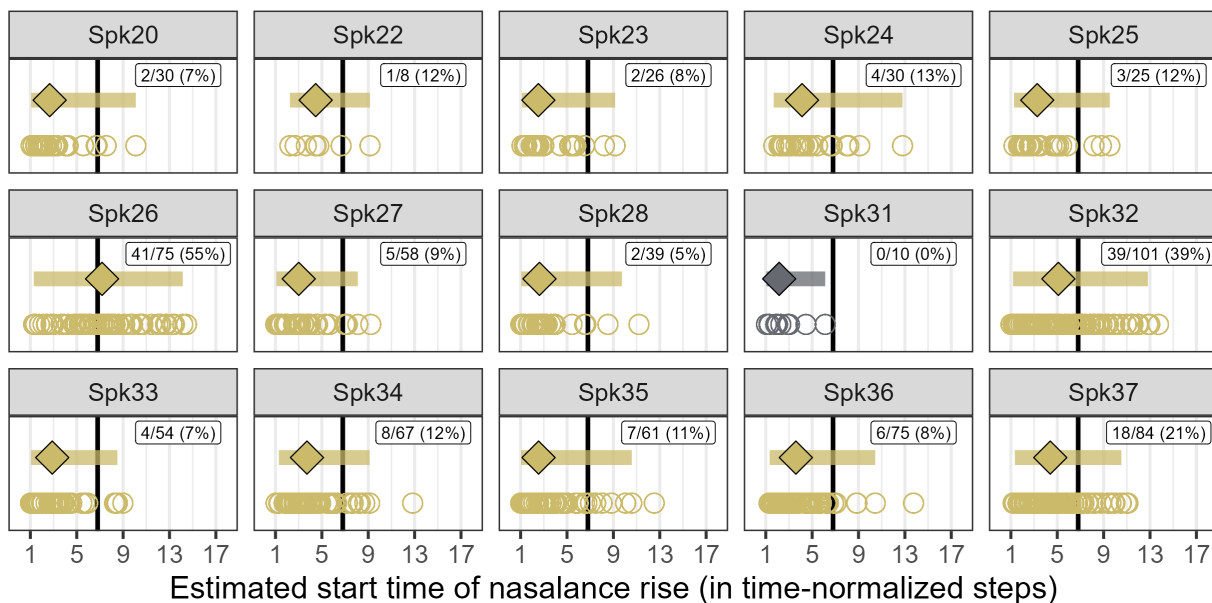
### 5.3.5 Speaker-level timing patterns for pre-nasal $[\tilde{V}N, \tilde{V}^ND]$

In this section we explore timing patterns for nasality in  $[\tilde{V}N, \tilde{V}^ND]$  at the level of individual speakers (see also Beddor et al. 2018, Zellou 2022). Caution must be taken in interpreting speaker-level data, because the amount of data we have for each speaker is limited (= 118-129 tokens of  $[\tilde{V}N, \tilde{V}^ND]$  per speaker). There is a risk that spurious patterns might occur in a particular speaker's dataset, as an artifact of data sparsity in our modestly-sized samples. Still, we believe we have enough data to claim that individual speakers show approximately the same patterns of timing vari-



ability reported in aggregate in section 5.3.2.

Fig. 25 shows the start points for oral-to-nasal transitions in  $[\tilde{V}N, \tilde{V}^ND]$ , grouped by speaker.



**Figure 25:** Start times for oral-to-nasal transitions in  $[\tilde{V}N, \tilde{V}^ND]$  by speaker (time-normalized). Diamonds indicate median values, horizontal bands [2.5%, 97.5%] data range. Open circles mark start times for individual observations. Vertical black line marks 40% of time-normalized vowel duration. Boxed numbers tally  $[\tilde{V}N, \tilde{V}^ND]$  tokens classified as having late rises for each speaker, and associated percentage of that speaker’s total oral-to-nasal rises.

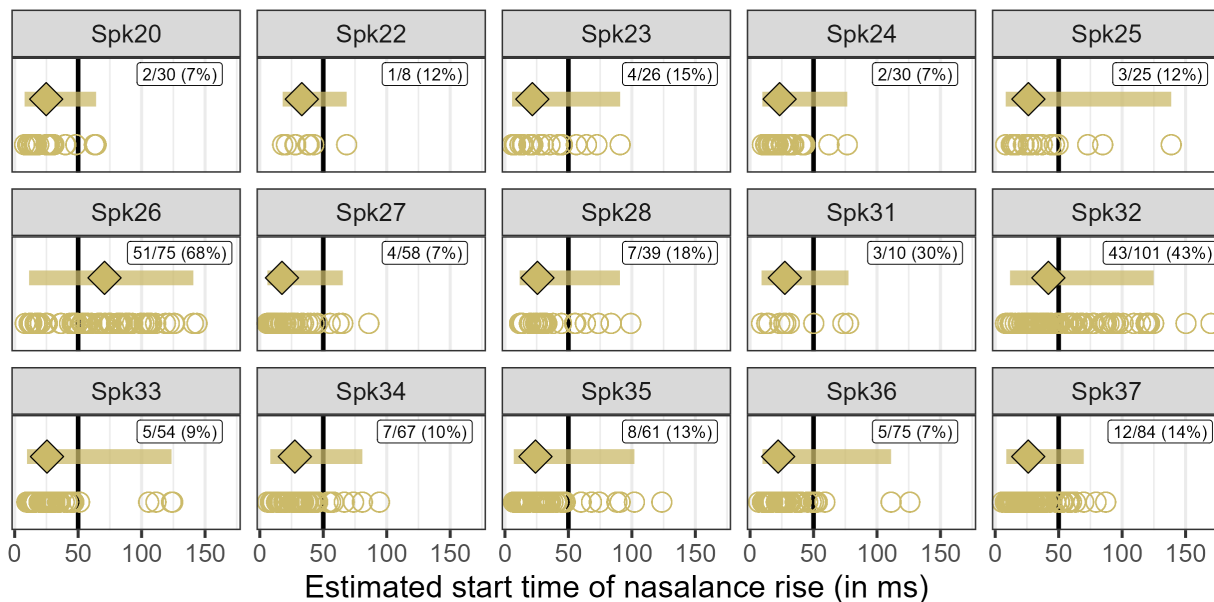
If the [2.5%, 97.5%] data range for a given speaker extended past 40% of time-normalized vowel duration (= step 6.8) we classified that speaker as having at least *some*  $[\tilde{V}N, \tilde{V}^ND]$  tokens with significantly delayed nasality. Otherwise, we classified that speaker as having only early rises in nasality in  $[\tilde{V}N, \tilde{V}^ND]$ .

The 40% threshold was chosen somewhat arbitrarily as reflecting a fairly late onset of vowel nasality. Since the data points in Fig. 25 correspond to the estimated *onset* of an oral-nasal transition, rather than the achievement of significant nasality, we believe this is a reasonably stringent criterion for counting as a vowel with ‘late’ nasality (see Figs. 19-24).

By this criterion, 14/15 of our speakers had at least some  $[\tilde{V}N, \tilde{V}^ND]$  tokens with significantly delayed nasality. For 3 speakers (26, 32, and 37), late rises were very common, constituting 21-55% of all oral-nasal transitions. For 5 speakers (22, 24, 25, 34, 35), late rises were a minority pattern, but nonetheless corresponded to at least 10% of each speaker’s oral-nasal transitions. For the remaining speakers, late rises constituted 0-10% of the total.

The same patterns are evident in physical ms, as shown in Fig. 26. We set a somewhat arbitrary threshold of 50ms as the criterion for a ‘late’ onset of vowel nasality (= 38% of the 132ms median vowel duration for  $[\tilde{V}N, \tilde{V}^ND]$  in our study). By this criterion, all speakers in our study had at least some late rises (though the proportion varies, as with the time-normalized data in Fig. 25). And again, these rise times indicate the *onset* of vowel nasality, rather than the ultimate achievement of target nasality later in the vowel.

We conclude that variability in the timing of nasality in  $[\tilde{V}N, \tilde{V}^ND]$  is not an artifact of pooling



**Figure 26:** Start times for oral-to-nasal transitions in  $[\tilde{V}N, \tilde{V}^ND]$  by speaker (in ms). Criterion for ‘late’ rise: start time  $\geq 50$ ms. See Fig. 25 for more details.

across speakers with different, stable timing patterns. The same timing variability seen in macro, across speakers, can also be seen in micro, at the level of individual speakers. Similarly, timing variability is not an artifact of time-normalization, as the same variability is evident in physical ms.

## 6 Formal analysis: contextual underspecification of nasality

Phonologically, there is no contrast between oral  $/V/$  and nasal  $/\tilde{V}/$  preceding  $[N, {}^ND]$ , even though vowel nasality is otherwise robustly contrastive in A’ingae. In other words, the  $/V \tilde{V}/$  contrast is contextually neutralized before  $[N, {}^ND]$ . But are these vowels neutralized to  $[+NASAL]$ , to  $[-NASAL]$ , or to  $[\emptyset_{NASAL}]$ ?

There are no phonological facts known to us which clearly speak to the  $[NASAL]$  specification of vowels preceding  $[N, {}^ND]$  (section 3.4). But phonetically, vowels preceding  $[N, {}^ND]$  are distinct from (i) underlying oral vowels  $/V/$ , (ii) underlying nasal vowels  $/\tilde{V}/$ , and (iii) phonologically derived nasal vowels produced by left-to-right spreading,  $/NV/ \rightarrow [N\tilde{V}]$ . In particular, the onset of nasality varies in  $[\tilde{V}N, \tilde{V}^ND]$  between early, delayed, or very late. These timing patterns correspond to fully nasal, partially nasal, and essentially oral realizations of the vowel in  $[\tilde{V}N, \tilde{V}^ND]$ .

These phonetic facts are consistent with our claim that vowels in  $[\tilde{V}N, \tilde{V}^ND]$  sequences are *underspecified* for nasality in A’ingae: they do not have a nasal specification or target of their own. Underspecification for nasality then produces the three-way, surface phonetic distinction between oral  $[V]$  ( $= [-NASAL]$ ), nasal  $[\tilde{V}]$  ( $= [+NASAL]$ ), and pre-nasal  $[\tilde{V}N, \tilde{V}^ND]$  ( $= [\emptyset_{NASAL}]$ ) that we observe in our data.<sup>15</sup>

We propose that contextual underspecification is the result of a process like (12): vowels are predictably underspecified for nasality ( $= [\emptyset_{NASAL}]$ ) when preceding nasal consonants of any kind ( $= \{N, {}^ND\}$ ). This is true whether the vowels in question are taken to be underlyingly oral  $/V/$  or

<sup>15</sup>To produce a three-way distinction in nasality by means of underspecification,  $[\pm NASAL]$  must be binary rather than unary/privative. See also Cohn (1993b), Trigo (1993) and references there.

underlyingly nasal / $\tilde{V}$ /.<sup>16</sup> Rule (11) is neutralizing, because it collapses oral /V/ and nasal / $\tilde{V}$ / vowels into a single surface output, underspecified  $V_{[\emptyset_{\text{NASAL}}]}$ . Rule (11) thus accounts for the lack of an oral /V/ vs. nasal / $\tilde{V}$ / contrast preceding [N, <sup>N</sup>D] in A’ingae.

(12) Neutralization of /V  $\tilde{V}$ / contrast through contextual underspecification

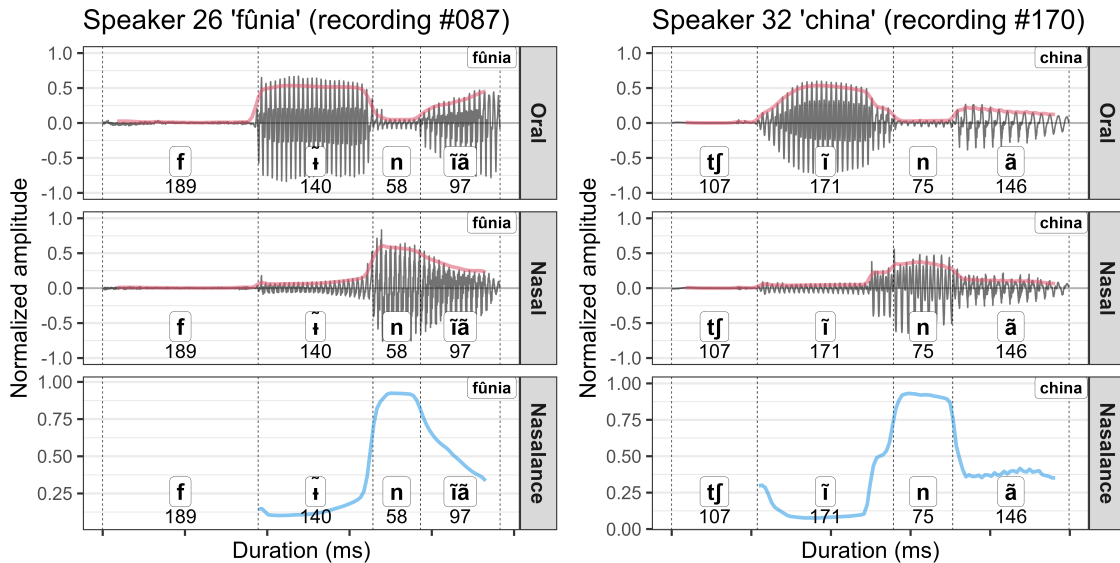
$$/V, \tilde{V}/ \rightarrow [\emptyset_{\text{NASAL}}] / \_\_\{N, {}^N D\}$$

In the following sections we consider alternative analyses of these facts, arguing in favor of the simple underspecification analysis in (12).

## 6.1 Against [+NASAL] with coarticulation

Given the significant nasalization on many vowels preceding [N, <sup>N</sup>D], the question arises as to whether such vowels could be treated as [+NASAL] rather than underspecified [ $\emptyset_{\text{NASAL}}$ ], following Solé’s (1995) proposal for anticipatory nasalization in American English (section 1.1).

An obvious challenge for this approach comes from partial nasalization. In many tokens in our data, vowels in [ $\tilde{V}N$ ,  $\tilde{V}{}^ND$ ] begin with very low nasal air pressure, growing more nasal over time (e.g. Fig. 27). Partial nasalization is *not* characteristic of underlying nasal vowels / $\tilde{V}$ / or nasal vowels derived by left-to-right spreading in [ $N\tilde{V}$ ] in A’ingae. If vowels preceding [N, <sup>N</sup>D] are [+NASAL], it is unclear why they do not have the phonetic characteristics of contrastive / $\tilde{V}$ / or phonologically derived [ $N\tilde{V}$ ].



**Figure 27:** Sample tokens of mostly oral vowels in [ $\tilde{V}N$ ], *fûnia* /f̥ɰ̃ɰia/ → [ʰf̥ɰ̃ɰiã] ‘round’ (left), and *china* /tʃ̥ina/ → [tʃ̥iã.nã] ‘daughter-in-law’ (right).

Partial nasalization in [ $\tilde{V}N$ ,  $\tilde{V}{}^ND$ ] cannot be attributed to coarticulation with the preceding oral consonant (e.g. *pindu* [p̥i.<sup>n</sup>du] ‘hawk’). First, partial nasalization in [ $C\tilde{V}N$ ,  $C\tilde{V}{}^ND$ ] is more extreme than the local coarticulatory effects observed in contrastive / $C\tilde{V}$ / (e.g. *fɪnfin* [ʰf̥i.f̥i] ‘fanned one’s

<sup>16</sup>Rule (12) should apply equally to morpheme-internal /VN,  $V{}^ND$ / sequences and cross-morpheme /V-N,  $V{}^N$ - $V{}^ND$ / sequences. The data in this paper bear only on morpheme-internal /VN,  $V{}^ND$ /; we leave the phonetics of cross-morpheme /V-N,  $V{}^N$ - $V{}^ND$ / for future research, but retain the strong version of rule (12) for the time being. See section 6.4.2 for some suggestive evidence regarding nasalization across morpheme boundaries.

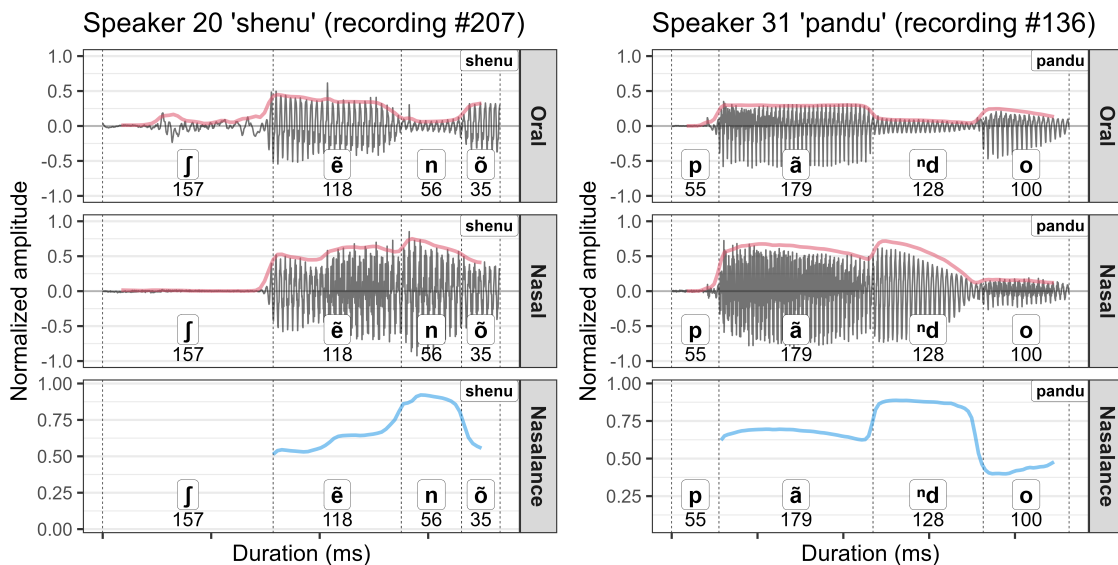
self’). Nasality can occur quite late in the vowel in  $[\tilde{V}N, \tilde{V}^ND]$  (Figs. 11, 16, 27, etc.). Nasality begins much earlier in contrastive  $/\tilde{V}/$ , even when slightly delayed by coarticulation (Figs. 7, 12, 19, etc.). Second, partial nasalization is far more frequent for  $[\tilde{V}N, \tilde{V}^ND]$  than for contrastive  $/\tilde{V}/$  (Fig. 18), despite the fact that the preceding consonants are comparable in both conditions.

We conclude that coarticulation with a preceding oral consonant is not sufficient to explain partial nasalization in  $[C\tilde{V}N, C\tilde{V}^ND]$ , particularly in tokens with a very late onset of nasality like Fig. 27. It follows that treating vowels in  $[C\tilde{V}N, C\tilde{V}^ND]$  as  $[+NASAL]$  does not provide an account of their phonetic differences from contrastive  $/\tilde{V}/$  and phonologically derived  $/NV/ \rightarrow [N\tilde{V}]$ .

## 6.2 Against $[-NASAL]$ with coarticulation

Alternatively, it might be possible to treat vowels preceding  $[N, ^ND]$  as phonologically  $[-NASAL]$ . This would straightforwardly distinguish those vowels from contrastive  $/\tilde{V}/$  and derived  $/NV/ \rightarrow [N\tilde{V}]$ , which are unambiguously  $[+NASAL]$ . Partial nasalization could then be attributed to local phonetic coarticulation for nasality with the following  $[N, ^ND]$  (see also Pouplier et al. 2024).

A challenge for this analysis comes from the fact that many tokens of  $[\tilde{V}N, \tilde{V}^ND]$  in our data are *fully* nasalized, even at fairly long durations (e.g. Fig. 28). This is surprising if those vowels are  $[-NASAL]$ , given that  $[-NASAL]$  vowels in languages like French show only limited coarticulation with a following nasal consonant (section 1).<sup>17</sup>



**Figure 28:** A mostly oral token and a mostly nasal token of  $[\tilde{V}N]$ ,  $f\tilde{u}nia /f\tilde{u}nia/ \rightarrow [f\tilde{u}.n\tilde{u}]$  ‘round’.

In our view, nasalization is too extensive in vowels preceding  $[N, ^ND]$  to plausibly reflect an active specification for an oral (=  $[-NASAL]$ ) target. We believe this is true even in theories of the phonetics-phonology interface which only require a loose correspondence between phonological

<sup>17</sup>Pouplier et al. (2024) report that nasalization can occur early in  $/V \# IVN/$  sequences in European French. However, such ‘early’ nasalization appears to be comparatively weak, about half as intense as anticipatory nasalization in English  $/VN/$ . Early nasalization in A’ingae  $[\tilde{V}N, \tilde{V}^ND]$  is often comparable to contrastive  $/\tilde{V}/$ , and hence does not resemble the weaker coarticulatory nasality that Pouplier et al. (2024) report for French. For work which reports limited nasal coarticulation in French  $/VN/$ , see Cohn (1990), Rochet & Rochet (1991), Spears (2006), Delvaux et al. (2008), Proctor et al. (2013), Desmeules-Trudel & Brunelle (2018), Dow (2020), Zellou & Chitoran (2023) and references there.

features and phonetic events. For example, Huffman (1989) proposes that phonologically [-NASAL] vowels are only required to be oral in the vicinity of the vowel midpoint. This allows some wiggle-room for nasal coarticulation with neighboring nasal consonants. However, in our data, vowels preceding [N, <sup>N</sup>D] are often substantially nasalized at vowel midpoint; this is true for both fully and partially nasalized tokens (e.g. Figs. 9, 10, etc.). This is incompatible with [-NASAL], even in the relatively permissive framework laid out by Huffman (1989) (see also Cohn 1990). We conclude that treating vowels preceding [N, <sup>N</sup>D] as [-NASAL] is untenable on phonetic grounds.

### 6.3 Against multivalued [NASAL]

We have so far assumed that [NASAL] is a binary feature, with two values ([+NASAL] and [-NASAL]), and the possibility of underspecification ([ØNASAL]). It has also been proposed that features may be multivalued, with three or more values along a scale (see e.g. Gnanadesikan 1997, Lionnet 2017, McCollum 2019, Sande & Oakley 2023 for references and discussion).

For the sake of simplicity, we consider a theory with a three-valued [NASAL] feature: oral [-NASAL], nasal [+NASAL], and intermediate, weakly nasal [≈NASAL]. Could vowels preceding [N, <sup>N</sup>D] bear this latter, intermediate [≈NASAL] value?<sup>18</sup>

There is both typological and language-internal evidence against this approach. Typologically, no language is reported to make a three-way contrast in vowel nasality (Ladefoged & Maddieson 1996:135). Adopting a multivalued [+/-/≈NASAL] feature incorrectly predicts that such a contrast should be possible (e.g. Hall 2007).<sup>19</sup>

Furthermore, there are no cases known to us in which a putative intermediate value for [NASAL] shows the behavior of a bona fide phonological feature, such as spreading or assimilation. Indeed, A'ingae-internal evidence against this approach comes from the interaction between vowels and simple nasal stops [N]. Nasal stops are uncontroversially [+NASAL], particularly since they spread the feature [+NASAL] to the following vowel, /NV/ → [N<sup>̃</sup>V] (section 3). So if vowels preceding nasal stops [N<sup>̃</sup>V] are [≈NASAL], where do they acquire that feature specification from? It cannot be via spreading from the following nasal [N], because nasal stops are fully [+NASAL], not weakly [≈NASAL]. But treating vowel nasalization in [N<sup>̃</sup>V] as the result of something *other* than spreading misses a clear generalization about the source of nasality in [N<sup>̃</sup>V].

An intermediate [≈NASAL] specification also fails to explain why vowels preceding [N, <sup>N</sup>D] are often strongly nasalized in our data (e.g. Fig. 28). The feature [≈NASAL] should correlate with *consistent* weak nasality, but what we find is a range of variation from partially to completely nasalized vowels, as well as vowels that are mostly oral. Such variability is more naturally accommodated by contextual underspecification [ØNASAL] than by a specified, but weak [≈NASAL] target.

While we have couched our critique here in terms of a ternary [+/-/≈NASAL] feature, we believe the same basic arguments (particularly, the last one) also apply to more sophisticated theories using multivalued features, including theories which use continuous, numerically-specified feature values like [0.4 NASAL] (e.g. Lionnet 2017, McCollum 2019 and references there).

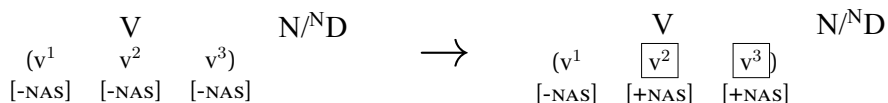
<sup>18</sup>A three-way contrast in nasality could also be produced using two binary features, e.g. [±NASAL] and [±ORAL].

<sup>19</sup>Three-way contrasts in vowel nasality have been reported for varieties of Chinantec and Chatino, both Oto-Manguean languages. It is possible to analyze these contrasts as a distinction between oral /V/, nasal /Ñ/, and oral-nasal diphthongs /ṼÑ/ (Ladefoged & Maddieson 1996:299-300, Merrifield & Edmondson 1999), or between oral /V/, nasal /Ñ/, and nasal /Ñ/ followed by a nasal coda /ŋ/. See Chávez-Peón (2014) for details and further references.

## 6.4 Against sub-segmental spreading

### 6.4.1 Sub-segmental spreading in Q theory

It has been proposed that information about the internal, temporal structure of segments is present in phonological representations. For example, in Q theory, segments are discretized into three semi-independent sub-units: roughly, the onset, center, and offset of those segments (Shih & Inkelas 2018, Lapierre 2023 and references there). Each of these three sub-segmental units can be specified for different feature values. With this type of representation, it becomes possible to generate SUB-SEGMENTAL SPREADING: the [+NASAL] feature associated with [N] or [N<sup>D</sup>] can spread leftward to some, but not all of the sub-segmental units associated with the preceding vowel (Fig. 29). This produces a phonological representation with an oral-to-nasal transition inside a single segment — in other words, partial nasalization.



**Figure 29:** Partial nasalization in Q theory

Q-theoretic representations are thus capable of representing partial vowel nasalization as a kind of oral-to-nasal contour segment or diphthong (as is also possible in Autosegmental Phonology; Sagey 1986, Jardine et al. 2021).

To the extent that Q-theoretic representations like Fig. 29 make predictions about the timecourse of phonetic nasality, they predict that the *proportion* of the vowel which is nasalized should be relatively consistent across tokens. Q theory may also predict that velum lowering should be roughly synchronous with some articulatory landmark in the vowel, given that sub-segmental units in Q theory have been explicitly (though only approximately) equated with major gestural landmarks like ONSET, PLATEAU, and RELEASE (e.g. Lapierre 2023 and references there).<sup>20</sup>

The timing results discussed in section 5.3 argue against the claim that partial nasality reflects sub-segmental spreading of a [+NASAL] feature (section 6.4). The proportion of the vowel which is nasalized in [VN̄, VN̄<sup>D</sup>] is highly variable. Further, we find a wide and continuous distribution of start and end times for the nasalance rise in [VN̄, VN̄<sup>D</sup>], which do not appear to cluster around any particular landmark (Figs. 20-24). While there is a tendency for nasality to begin early in the vowel in [VN̄, VN̄<sup>D</sup>], this is by no means an ironclad rule.

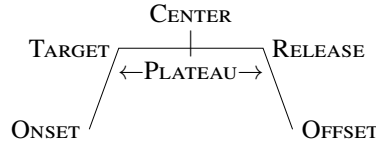
If the extent of sub-segmental spreading of [+NASAL] is variable, optionally targeting either 1, 2, or 3 of the preceding sub-segments (Fig. 29), we should find a multimodal distribution of start or end times. But again, we find a broad distribution of start and end times instead.

### 6.4.2 Sub-segmental spreading in Articulatory Phonology

Partial nasalization can also be modeled with the abstract gestural representations of Articulatory Phonology (e.g. Browman & Goldstein 1986, 1989, Gafos 2002, Smith 2018 and references there). In Articulatory Phonology, segments are decomposed into their component articulatory gestures.

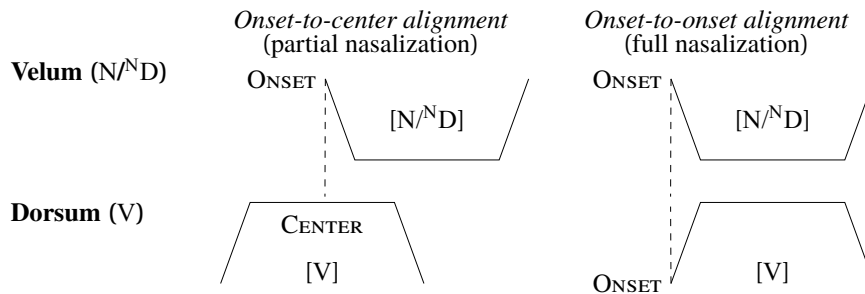
<sup>20</sup>Since Q-theoretic representations are abstract and phonological, one could object that they make no predictions at all about the timecourse of phonetic nasality inside segments. In that case, we know of no evidence that bears on the plausibility of a Q-theory approach to this data: the phonological evidence alone simply does not shed enough light on the matter (section 3.4). See e.g. Lapierre (2023) for work which explicitly links the number of [+NASAL] sub-segmental units in Q theory to the proportion of a segment which is phonetically realized as nasal.

These gestures are represented abstractly in the phonology itself. This allows for phonological representations which include information about the timecourse of articulator movements. Conventionally, the timecourse of an articulatory gesture (e.g. velum lowering) is expressed with an open trapezoid, as in Fig. 30.



**Figure 30:** Major gestural landmarks in Articulatory Phonology

Gestures belonging to neighboring segments may overlap with each other, depending on how they are coordinated. Overlap between gestures can be represented by fixing the relative timing of their respective articulatory landmarks (Fig. 30). Fig. 31 shows how gestural representations could be used to specify partial or total nasalization of vowels preceding [N] or [N<sup>D</sup>]. Essentially, the velar lowering gesture associated with [N] or [N<sup>D</sup>] extends and/or shifts leftward to generate significant overlap with the preceding vowel, thereby nasalizing it. Since overlap can be partial, nasalization can be too.



**Figure 31:** Gestural timing patterns for anticipatory nasalization. Gestural trapezoid for velum position is inverted to emphasize lowering of the velum for nasalization.

Gestural representations like those in Fig. 31 predict that the timing of velum lowering should be relatively stable with respect to some landmark in the vowel's articulation (e.g. Solé 1995, Krakow 1999, Byrd et al. 2009, etc.). But again, our results are at odds with the claim that nasality in [ṼN, Ṽ<sup>N</sup>D] is tightly bound to any particular landmark in the pre-nasal vowel.

Many pre-nasal vowels are fully nasalized, or nasalized quite early, somewhere near the [CV] transition in [C̃VN, C̃V<sup>N</sup>D]. This implies that nasality is synchronized with the release of the oral consonant in [C̃VN, C̃V<sup>N</sup>D] (that is, with the acoustic onset of the vowel). But as is clear from the long, right tail in Figs. 20 and 22 (left), the association between C release and the onset of nasality is, at best, quite loose. Instead of a discrete, unimodal pattern, we find a broad and essentially continuous distribution for the timing of nasalization, albeit with a tendency toward earlier onset times.

Relatedly, the timing of nasality in [ṼN, Ṽ<sup>N</sup>D] is *different* from the timing pattern seen for contrastive /Ṽ/. It has been argued that the onset of velum lowering in contrastively nasal vowels is coordinated with consonant release in [C̃V] in both European and Brazilian Portuguese (Meireles et al. 2015, Cunha et al. 2021; see also Proctor et al. 2013:578 on European French). Our timing results for contrastive /Ṽ/ seem consistent with that assumption (Figs. 18, 19). But the timing of



nasality is different in [C $\tilde{V}$ N, C $\tilde{V}$ <sup>N</sup>D] when compared to /C $\tilde{V}$ /. This difference also suggests that nasality is *not* tightly coordinated with consonant release in [C $\tilde{V}$ N, C $\tilde{V}$ <sup>N</sup>D].

It may be possible to produce these results in Articulatory Phonology with the use of PHASE WINDOWS (Byrd 1996) (see also Keating 1990, Zsiga 2000). Byrd (1996) proposes that timing relationships between articulatory gestures may be relatively tight (narrow phase window) or relatively loose (wide phase window; see also the related notion of ‘coupling strength’, e.g. Mücke et al. 2020). If we assume that (i) the onset of nasality is timed relative to oral C release in [C $\tilde{V}$ N, C $\tilde{V}$ <sup>N</sup>D], and (ii) that this timing relation is relatively loose, then wide, continuous timing distributions like those in Figs. 20-22 are likely to result.

However, assuming a wide phase window for the timing of nasality in [C $\tilde{V}$ N, C $\tilde{V}$ <sup>N</sup>D] is tantamount to underspecification, stated over the time domain. It also expresses the basic intuition that vowels in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] are more or less ‘indifferent’ to the time course of nasality in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D]. For that reason, we do not view the phase window approach as a competing analysis of our data: instead, it is an alternative means of expressing the same essential claim that vowels in [ $\tilde{V}$ N,  $\tilde{V}$ <sup>N</sup>D] are relatively free to vary in their nasality because they do not have a robust specification for the timing and/or magnitude of velum opening.

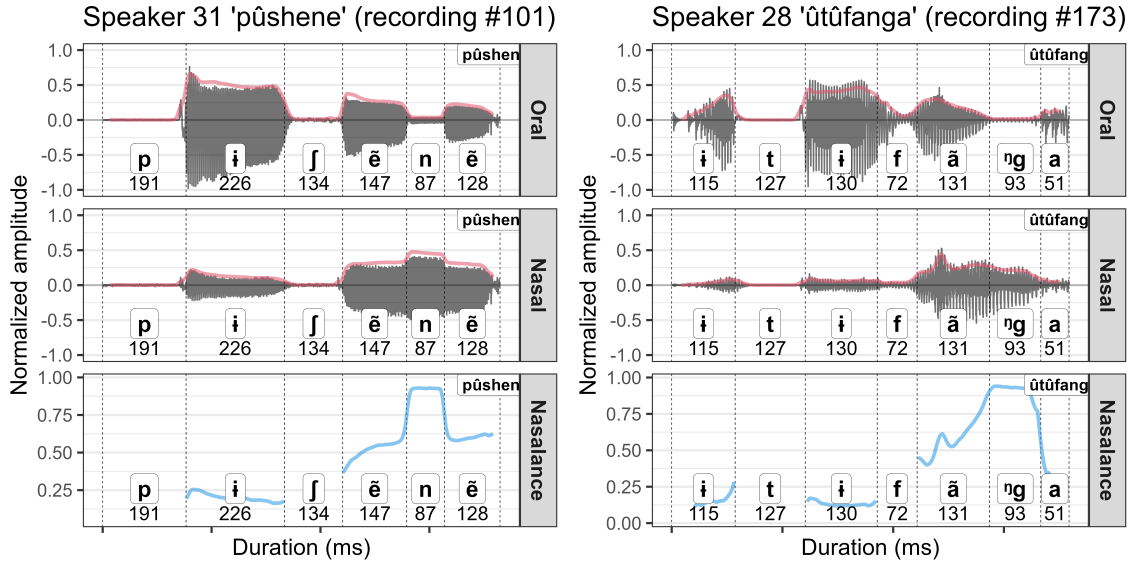
To be sure, we are not claiming that wide phase windows are *equivalent* to underspecification for [Ø<sub>NASAL</sub>]. These conceptual tools are embedded in very different theories, and so cannot be straightforwardly equated. But at a higher level of abstraction, they share the the property of relative ‘indifference’ suggested by our results.

Contemporary work in Articulatory Phonology often dispenses with both phase windows and landmark-to-landmark coordination (see Hall 2017 for an overview; but cf. Shaw 2022 and references there). Instead, coordination between gestures is specified to be either *in-phase* (simultaneous initiation) or *anti-phase* (sequential initiation). Gestures in syllable onsets are specified for in-phase timing, i.e. for simultaneity between oral and velar gestures in onset nasals in [NV] (Krakow 1999). All else being equal, velum lowering in [V.NV] should initiate with the nasal consonant itself, and nasalization of the preceding vowel should be fairly minimal.

However, the precise timing of in-phase gestures can be perturbed through competition with other gestural specifications. Of particular interest here is Byrd et al.’s (2009) finding that in American English, the velar gesture of the nasal in [<sup>1</sup>V.NV] appears to be ‘attracted’ to the stressed vowel, such that velar lowering occurs earlier in [<sup>1</sup>V.NV] than in [V.<sup>1</sup>NV]. This effect could be responsible for the significant anticipatory nasalization found in our study, given that the pre-nasal vowels we investigated were always stressed [<sup>1</sup> $\tilde{V}$ .NV] or [<sup>1</sup> $\tilde{V}$ .<sup>N</sup>DV].

This analysis appears to make the wrong predictions about anticipatory nasalization in *unstressed* vowels in A’ingae. Although we have not provided a quantitative analysis of nasality in unstressed vowels, our data does include many examples of unstressed vowels which are strongly nasalized before [N, <sup>N</sup>D], even when relatively long in duration (Fig. 32).

The attraction of velum lowering to a preceding stressed vowel does not, by itself, explain the significant nasalization of *unstressed* pre-nasal vowels in [V.NV] or [V.<sup>N</sup>DV] in examples like Fig. 32. Of course, more work is needed to confirm this tentative result. Assuming the nasalization of unstressed pre-nasal vowels is systematic in A’ingae — as it appears to be, both impressionistically and in our initial data here — it would support our claim that anticipatory nasalization is produced by underspecification of [<sub>NASAL</sub>], rather than by stress-sensitive coarticulation. While more intricate patterns of gestural coordination in [ $\tilde{V}$ .NV], [ $\tilde{V}$ .<sup>N</sup>DV] may be able to produce these results, we leave a fuller evaluation of such possibilities to future work.



**Figure 32:** Anticipatory nasalization for phonetically long, unstressed pre-nasal vowels. Left: *pûshene* /*pi̯e*=*ne*/ → [*pi̯i̯.ẽ̯.nẽ̯*] ‘about the wife’. Right: *ûtûfanga* /*it̪ifa*=*ŋga*/ → [*i̯.t̪i̯.fã̯.ŋga*] ‘to the corner’.

In any case, the mechanism responsible for partial nasalization in [ $\tilde{V}N$ ,  $\tilde{V}^ND$ ] in A’ingae must, to some extent, be specific to this particular language. Anticipatory nasalization is frequent and extensive in [ $VNV$ ] sequences in A’ingae. But in Spanish, Italian, Greek, and several languages of Australia, among others, anticipatory nasalization in [ $VNV$ ] appears to be much more limited (e.g. Solé 1995, 2007, Diakoumakou 2004, Delvaux et al. 2008:596, Stoakes et al. 2020 and work cited there). The active control of anticipatory nasalization in / $VNV$ / is further underscored by the fact that nasalization in / $VN$ / appears to vary across speakers and dialects of the same language (e.g. Delvaux et al. 2012, Beddor et al. 2018, Bongiovanni 2021, Zellou 2022).

Lastly, it bears mentioning that gestural dynamics like the above do not themselves account for the fact that oral vs. nasal / $V \tilde{V}$ / contrasts are suspended before [ $N$ ,  $^ND$ ] in A’ingae. Some kind of neutralizing rule or process, like our rule (12), is still required to implement this generalization.

## 7 Discussion

On the basis of phonetic and phonological evidence, we have argued that partially nasalized vowels in A’ingae should be analyzed as phonologically unspecified for nasality, [ $\emptyset_{NASAL}$ ]. Key to our argumentation is the fact that A’ingae has *both* contrastive [ $+NASAL$ ] vowels and phonologically derived [ $+NASAL$ ] vowels produced by harmony, alongside [ $-NASAL$ ] oral vowels. This allows us to compare partially nasalized vowels to vowels that are unambiguously [ $+NASAL$ ] and [ $-NASAL$ ], while also controlling for the possibility that underlying and derived instances of [ $+NASAL$ ] might be produced with different patterns of phonetic nasality (Solé 1995 and section 1.1).

To date, partial nasality has only been examined in languages which do not allow for this full range of comparisons. As such, it has not been possible to definitively conclude whether partially nasalized vowels are [ $+NASAL$ ], [ $-NASAL$ ], or [ $\emptyset_{NASAL}$ ] in those languages. The phonological structure of A’ingae resolves this ambiguity, and does so in favor of Cohn’s (1990) proposal that partial nasalization may reflect phonological underspecification for nasality.

## 7.1 The phonetics of [Ø<sub>NASAL</sub>]

We have said very little about how vowels lacking a specification for nasality, [Ø<sub>NASAL</sub>], are mapped to speech production targets. We concur with Solé (1995) that the many cases of full nasalization on [ṼN, Ṽ<sup>N</sup>D] in our data are at odds with a naive target interpolation model which simply implements a gradual transition between [-<sub>NASAL</sub>] and [+<sub>NASAL</sub>] targets over an intervening, underspecified span (section 1.1). More sophisticated models of interpolation are of course conceivable, and might suffice (see e.g. Liberman & Pierrehumbert 1984 for discussion). It is also possible that phonetic mechanisms *other* than interpolation are called for here (e.g. phase windows, section 6.4). Lastly, whatever mechanisms are responsible for the phonetics of [Ø<sub>NASAL</sub>] vowels, those mechanisms could either be universal, or to some extent specific to A'ingae (e.g. Keating 1984, Kingston & Diehl 1994, Zsiga 2000, etc.). We leave a more detailed exploration of these issues to future work. What is clear, however, is that nasalization in [ṼN, Ṽ<sup>N</sup>D] is more extensive than simple, mechanical coarticulation for nasality — it must be under speaker control in some sense (e.g. Solé 1992, 1995, 2007).

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