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**RESEARCH PAPER**

# Durational aspects of tautosyllabic vowel nasalization in (Brazilian) Portuguese: An airflow investigation

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This study investigates coarticulatory effects caused by the following consonant – either a stop or a fricative – on the duration of the oral and the nasalized portion of the nasal vowel and the nasal murmur in sequences within Portuguese words like *tensa* [ˈtẽsɐ] 'tense' versus *tenta* [ˈtẽtɐ] '(s/he) tries.' The results replicate previous observations that duration adjustments affect the vowel's nasalized portion, as is the case for languages in which the speaker intends nasalization. The second hypothesis is that adjustments in duration as a function of the following onset do not affect the nasalization duration, but only the timing of a nasal gesture relatively constant in duration. Results show that irrespective of the following consonant ([s] or [t]), nasalization remains constant in duration. However, a shorter nasal murmur or a more extended postnasal consonantal oral portion does not follow more extended vowel nasalization. As the entire VNC sequence increases on an individual basis, so does the nasalization. Still, increasing nasalization comes at a cost for the duration of the oral part of the vowel irrespective of [s, t]. These results are compatible with that speaking rate influences coordination timing between the beginning of the vowel and the beginning of nasalization.

**Keywords:** phonetics; experimental phonology; Brazilian Portuguese; vowel nasality

## 1. Introduction

There is a longstanding proposal that the historical change leading to the development of nasal vowels may involve a stage where the lowered velum is coarticulated with the vowel configuration, which is then interpreted by the listeners as part of the vowel articulation (see Ohala 1981 and references therein). Beddor (2009), along with Cohn (1993), argues that this is the case in American English. It is not the case in Spanish (Solé 1992) or Hungarian (Gósy, Beke & Vago 2010), where nasalization appears to be an unintended result of the vocal tract configuration. Suppose we assume as a working hypothesis that nasal vowels come diachronically from a VN sequence through a ṼN stage (VN > ṼN > Ṽ), at least in Romance languages (Sampson 1999). In that case, it is reasonable to ask if there still are traces of a ṼN stage in the language before we conclude that it has arrived at a final Ṽ stage. In this study, we aim at exploring for Brazilian Portuguese some hypotheses that arise from co-articulatory approaches to regressive nasalization. We replicate two previous studies (Beddor 2009; Solé & Ohala 1991) on English and Spanish co-articulatory vowel nasalization and see the extent to which their results are compatible with Portuguese data.

In Portuguese, there are two types of vowel nasality. On the one hand, the vowel in the nucleus of an open stressed syllable assimilates the nasality of a following nasal onset (e.g., in *cena* [ˈsẽna] 'scene'). The language also shows minimal pairs distinguished only by a nasal vowel, which are the focus of this study (**Table 1**; for further examples see the Appendix). In an over a century-long history of publications, some scholars interpreted Portuguese nasal vowels as underlyingly nasal /Ṽ/, a straightforward way of interpreting minimal pairs, as in **Table 1**. A second, more accepted interpretation considers that nasal vowels result from tautosyllabic nasalization. A phonetically nasal vowel stands as an underlying sequence of a vowel followed by either a nasal consonant /VN/ or a nasal glide /VṼ/, in which case the opposition is not due to two different segments, but to two syllabic structures (for comprehensive reviews, see Mateus & Andrade 2000: 20–23; Pimenta 2019a: Ch. 2; Shaw 1986: Ch. 2; Wetzels 1997).

However, the literature on Portuguese nasal vowels – more than a hundred works in Rothe-Neves and Reis (2012) – did not relate the production of nasal vowel with co-articulatory approaches to regressive or "anticipatory" nasalization (Beddor 2007; 2009; Bell-Berti & Harris 1981; Bell-Berti & Krakow 1991; Boyce, Krakow & Bell-Berti 1991; Busà 2003, 2007; Solé 1992, 1995). Moraes (1997) and only incidentally Raposo de Medeiros (2012) are noticeable exceptions.

In fact, Portuguese nasal vowels do not resemble those of French (Delvaux, Demolin, Harmegnies & Soquet 2008) or White Afrikaans (Coetzee 2018), in which nasal airflow begins with or shortly after the beginning of the vowel. Acoustic evidence shows that in Portuguese a nasal vowel is not entirely nasal (Jesus 2002; Moraes & Wetzels 1992; Seara 2000; Sousa 1994), an observation that goes back to Menzerath (1936: 242): "The Portuguese nasal 'vowel' consists of three parts, a non-nasal, a nasal, and a consonantal part". Authors refer to this last consonantal part as "nasal consonant" (e.g., Moraes & Wetzels 1992), "nasal appendix," (e.g., Desmeules-Trudel & Brunelle 2018; Raposo de Medeiros, D'Imperio & Espesser 2008), "nasal coda" (e.g., Raposo de Medeiros 2011; 2012), "nasal tail" (Lovatto, Amelot, Crevier-Buchman, Basset & Vaissière 2007) or "an excrescent nasal coda" (Shosted 2011), depending on how they interpret this sound. As in Sousa (1994), we refer to it as "nasal murmur", defined by Fujimura (1962: 1865) as "the sound produced with a complete closure at a point in the oral cavity, and with an appreciable amount of coupling of the nasal passages to the vocal tract".

As to the facts, speakers may hear a nasal offglide before stops (*campo* [ˈkɐ̃ᵐpʊ ~ ˈkɐ̃pʊ] 'field'; *dente* [ˈdẽⁿtʃɪ ~ ˈdẽtʃɪ] 'tooth'; *canguru* [kɐ̃ᵑguˈɾu ~ kɐ̃guˈɾu] 'kangaroo'), where it agrees in place with the subsequent consonant in forms that alternate with Ṽ-forms without any consonant (Cagliari 1974: 148; Cagliari 1981: 85). A nasal consonant may also be produced as an unreleased nasal closure in word-final position, where it agrees with the preceding vowel (e.g., *sim* [sĩɲ̚] 'yes'; *som* [sõŋ̚] 'sound'; but *sã* [sɐ̃] 'healthy'). The available data on the articulation of word-final nasal vowels do not support the

**Table 1:** Minimal pairs examples of contrasting nasal versus oral vowels in stressed position.

| | | | |
|---|---|---|---|
| [ĩ] | *sinto* | [ˈsĩtʊ] | 'I feel' |
| | *sito* | [ˈsitʊ] | 'located' |
| [ẽ] | *senda* | [ˈsẽdɐ] | 'path' |
| | *seda* | [ˈsedɐ] | 'silk' |
| [ɐ̃] | *canso* | [ˈkɐ̃sʊ] | 'I get tired' |
| | *caço* | [ˈkasʊ] | 'I hunt' |
| [õ] | *conto* | [ˈkõtʊ] | 'tale' |
| | *coto* | [ˈkotʊ] | 'stub' |
| [ũ] | *mundo* | [ˈmũdʊ] | 'world' |
| | *mudo* | [ˈmudʊ] | 'mute' |

occurrence of nasal monophthongs with no accompanying nasal consonant except for [ɐ̃]. As put forth by Cagliari (1977: 33): "I have investigated the pronunciation of speakers of different dialects of Brazil, Portugal, and Mozambique, and I have not come across this phenomenon in any of my informants." More recently, Shosted (2011) investigated with electropalatograhic data the presence of a complete oral occlusion in VN sequences in word-final position followed by a word beginning in [a]–the low vowel provided a context that demands tongue lowering. Shosted concluded that "the raised tongue dorsum is responsible for the articulation" after [ĩ] (limitations of the artificial palate may have precluded registration after the more posterior vowels), and that "the duration of the occlusion supports the possibility that it is not merely transitory but may be used to cue the phonemic nasal distinction among some vowels." (Shosted 2011: 1837).

The standard interpretation (e.g., Moraes & Wetzels 1992; Wetzels 1997) considers the nasal murmur as a manifestation of the underlying N from a hypothesized VN sequence that emerges as a nasal vowel. In this case, a consonant results from spreading the consonant's Place node at the following onset onto the underspecified N in coda position, in just another case of a nasal consonant that assimilates in place of articulation to the following consonant. Some problems remain, however, when it comes to interpreting the phonetic facts according to the standard view directly. First, one finds an intrusive consonant almost exclusively before stops (Lovatto et al. 2007; Moraes & Wetzels 1992; Raposo de Medeiros 2008; Rothe-Neves & Valentim 2012), a fact that requires restricting the rule to [–cont] C. Moreover, the emergence of an intrusive consonant depends on speaker and speech velocity; careful speech typically prevents the consonant. A more challenging fact in formalizing the Brazilian Portuguese nasal vowels is the time course of tautosyllabic vowel nasalization. A theoretical interpretation that posits nasalization before phonetic implementation is hard to reconcile with the observed three-part "vowel" (VṼN). There is no reason for the phonological process to be still underway while speech sounds are produced.

A more natural interpretation was offered by Albano (1999) cast in terms of Articulatory Phonology. According to it, an intrusive consonant emerges because of the misalignment of the otherwise superimposed gestures of velic lowering and oral opening (see, e.g., Browman & Goldstein, 1995: 186 for the representation of the gestural score for *pawn*). If velic lowering aligns perfectly to oral opening, speakers hear a nasal vowel; if, however, the gestures are misaligned, this will result in an interval of time during which the velopharyngeal port is still open, and the oral cavity is already closed for the next consonant when speakers tend to hear a nasal consonant. Such an interpretation goes back to Ohala (1974) and the physiological motivation for the origin of an epenthetic stop between a nasal and the following obstruent. Ohala discusses data from a nasograph and takes the nasal airflow traces as "a rough indication to the degree of velic opening" (p. 357) during two utterances of the word *Samson*. Ohala shows that when the release of the labial closure of the nasal consonant occurs at the same time as the closure of the velum, the uttered word is unchanged. However, when the speaker closes the velum before the labial release, one hears *Sampson* with an epenthetic stop. "This process is actually a partial denasalisation of the nasal consonant in the environment of the following obstruent and is parallel to (but the reverse of) assimilatory nasalization" (Ohala 1974: 358). So, Albano (1999) offers an account as to why the nasal murmur depends on speaker and speech velocity, as well as for the three-part "vowel" (VṼN): "The presence or not of an 'intrusive' nasal depends on the greater or lesser overlap between the consonant gesture to follow and the vowel and velic gestures, which [the overlap] is not required in the lexicon and may vary according to the prosodic, segmental, or even pragmatic context." (Albano 1999: 31). In other words, a nasal murmur emerges because of coarticulation. All subsequent works in a gestural-phonological framework agree that it is in coda position based on that the velum gesture is sequential (or asynchronous) to the oral gesture (Meireles, Goldstein, Blaylock & Narayanan 2015; Oliveira & Teixeira 2007; Raposo de Medeiros 2011; 2012).

In this study, we aim specifically to investigate the duration of the nasalized portion of the nasal vowel and the nasal murmur in sequences within words like *tensa* [ˈtẽsɐ] 'tense' versus *tenta* [ˈtẽtɐ] '(s/he) tries'. According to Beddor (2009), longer vowel nasalization is due not to an increase in nasalization per se, but because of the early onset of a nasal gesture relatively constant in size.[1] Beddor investigates vowel nasalization when the vowel suffers duration adjustments caused by the following consonant in pairs like '*send-sent*.' As we already know, vowels are shorter when the following consonant is voiceless than a voiced stop or when it is a stop versus a fricative (Delattre 1962). Although vowels adjust their duration as caused by the following consonant, Beddor (and other authors she cites) observed that the nasalization does not. The idea of a "roughly constant-sized nasal gesture across VNC contexts" (Beddor 2009: 789)–which we call here the "Constant N Hypothesis" for simplicity–and some of its consequences have been developed to a greater extent in Beddor (2007; 2009) and, more recently, in Beddor, Coetzee, Styler, McGowan and Boland (2018). It is important to recall three observable consequences of the Constant N Hypothesis, which we intend to test. First, N remains a constant gesture in the nasalization of the preceding vowel (Beddor 2009: 788). Second, because of the Constant N Hypothesis, more extended vowel nasalization corresponds to a shorter nasal consonant. Finally, extended vowel nasalization corresponds to a more extended postnasal consonantal oral portion (Beddor 2009: 791).

This study begins with a more general question before investigating the observable consequences of the Constant N Hypothesis. We aimed to explore the prediction from Solé and Ohala (1991), according to which it is the onset of the following nasal consonant that triggers purely mechanical regressive nasalization. "If the vowel is targeted as nasalized, and consequently nasalization is higher-level, nasalization is expected to vary." (Solé & Ohala 1991: 110). Consequently, the hypothesis is that duration adjustments affect the vowel's nasalized portion if the speaker targets nasalization. So, the study begins with the question as to whether the oral portion of the nasal vowel is under duration-adjusting effects caused by the following consonant–either a stop or a fricative.

The studies cited in this section all share the view that researchers may discretize the speech stream to operationalize and observe the construct "nasalization", a fundamental assumption akin to the phonetic alphabet principles. There are, however, reasons to believe this may not be enough to understand how speech articulation occurs. Nasalization, for that matter, appears to involve more than only velopharyngeal port opening (e.g., Carignan, Shosted, Fu, Liang & Sutton 2015; Demolin, Delvaux, Metens & Soquet 2003; Shosted 2015). Notwithstanding the above, to replicate those studies in Portuguese and make our results comparable, it is helpful to proceed in the same fundamental way.

A second note of caution is that the studies cited differ in how to measure the beginning and end of those portions precisely, a topic we will deal more closely with within the next section on Methods. In this study, we refer to the nasalized part of the vowel and the nasal murmur as resulting from what previous studies consider to be the nasal consonant. So,

[1] The term gesture is referred to in this article as used in Albano (1999) and Beddor (2009). For the experiment we describe in this study, it is not relevant whether gestures are phonological units. A reviewer pointed out that it would be clearer to use "constant in duration" instead of "constant in size," mainly since this study deals with airflow. We welcome the suggestion, but the reader should bear in mind that we always refer to "constant in size" whenever quoting Beddor's own words.

"nasalization" is taken to mean the portions where we registered positive nasal airflow and voicing.

## 2. Methods

### 2.1. Participants

Five female Brazilian Portuguese native speakers were recorded in the Phonetics Lab at FALE-UFMG. All speakers were between the ages of 22 and 26 and were born and raised in Southeastern Brazil.

### 2.2. Corpus

The corpus consisted of 15 words with the sequence C1V(N)C2, where V = /e/, N = /n/ and C2 = /t d s/ (**Table 2**). The anterior closed-mid vowel was used because it is the one with the least observed vocalic quality effects on nasalization (Moll & Daniloff 1971), and therefore other authors used it in comparable studies (Beddor 2009; Cohn 1990; Huffman 1990). Similarly, alveolar consonants were used to control for place of articulation. The different consonants serve as experimental manipulation to evaluate the effects of stricture ([t] versus [s]) and voicing ([t] versus [d]). The words were read aloud in the carrier phrase Digo __ claramente [ˈdʒigʊ ___ˌklaɾaˈmẽtʃɪ] "I say ___ clearly.".

### 2.3. Obtaining data

We recorded speech signal, electroglottography, oral, and nasal airflows simultaneously using an EVA2 station (SQLab; Teston, Ghio, & Galindo 1999). Nasal airflow (sampling frequency of 6250 Hz, range of 0 to 0.5 $dm^3/s$) was registered through rubber tubes vertically adjusted to the participants' nostrils. A soft silicone rubber mask allowed for oral airflow registration (sampling frequency of 6250 Hz, range of 0 to 2 $dm^3/s$), without hindering articulatory movements (**Figure 1**). We used the built-in filter described in Ghio and Teston (2004: 57). The equipment's built-in microphone positioned in front of the participant's mouth recorded the speech signal (sampling frequency of 25 kHz, 16 bits). Two electrodes were placed on the wings of the thyroid cartilage to allow for proper capturing of the electroglottography signal.

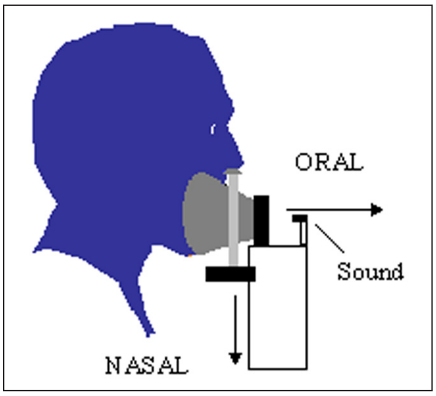


**Figure 1:** Subject position to record acoustic and aerodynamic data with the EVA. Source: SQLab (http://www.sqlab.fr/evaSensFR.htm).

Each participant saw each word on a computer screen, in random order, with the help of the Corpus Viewer (Laboratoire Parole et Langage – LPL, Aix-en-Provence, France). The instructions were clear that the participants should first read each word silently, and then say it out loud once the screen turned blank. Data analyses proceeded with Phonedit (LPL) software. The original sound files were manually marked for the cases of interest. We did not mark any recorded material that resulted from mispronunciations or misreadings, poor adjustment of the equipment, unclear audio recording, or diphthongized pronunciations because they are not a typical dialectal feature for the region.[2] **Table 2** shows the recorded tokens per subject in the analyzed data. The three words with [d] were the more affected: *Leda* and *lenda* were recorded for L1 only, while L2 did not have *seda* on record.

**Table 2:** Repetitions by participant and word in the corpus (<n> orthographically indicates nasality on the previous vowel).

| Following C | Corpus | | Participant | | | | |
|---|---|---|---|---|---|---|---|
| | | | B | I | J | L1 | L2 |
| [d] | *Leda* | (proper name) | 0 | 0 | 0 | 3 | 0 |
| | *lenda* | 'legend' | 0 | 0 | 0 | 3 | 0 |
| | *senda* | 'path' | 3 | 3 | 3 | 3 | 0 |
| [t] | *teta* | 'udder' | 3 | 3 | 3 | 3 | 3 |
| | *benta* | 'blessed' fem | 3 | 3 | 4 | 3 | 3 |
| | *penta* | from Greek, 'fifth' | 3 | 3 | 2 | 3 | 3 |
| | *tenta* | '(s/he) tries' | 7 | 6 | 6 | 6 | 6 |
| | *senta* | 'sit down' | 3 | 3 | 3 | 3 | 3 |
| [s] | *desço* | 'I go down' | 3 | 3 | 3 | 3 | 3 |
| | *teço* | 'I weave' | 3 | 3 | 3 | 3 | 3 |
| | *bença* | 'bless' | 3 | 3 | 3 | 3 | 3 |
| | *denso* | 'dense' masc | 3 | 2 | 3 | 3 | 3 |
| | *pensa* | '(s/he) thinks' | 3 | 3 | 3 | 3 | 3 |
| | *tensa* | 'tense' fem | 3 | 3 | 3 | 3 | 3 |
| | *tenso* | 'tense' masc | 3 | 2 | 3 | 4 | 3 |
| | | Total | 43 | 40 | 42 | 49 | 39 |

Phonetic analysis preceded manual data segmentation, that is, the interpretation of the information provided by the recordings. As the duration of articulatory activity for vowel nasalization is usually longer than the acoustic duration of the vowel (Basset, Amelot, Vaissière & Roubeau 2001), the time measurements were such as to combine information from all sources, as shown in **Figure 2**. Thus, a vowel corresponds to the period when the acoustic wave presents stability of F2 in the speech signal (Lehiste 1970), positive oral airflow, and vocal fold activity; the period between vowels when, including the part of the vowel to consonant and consonant to vowel transitions, is a consonant; and the period where there are positive nasal airflow and vocal fold vibration corresponds to nasality. The oral portion of the vowel corresponds to the vocalic period until the onset of nasal airflow. The nasalized portion of the vowel begins at the beginning of nasalization until the end of the vowel. The nasal murmur goes from the end of the vowel to the end of voicing in the case of [s, t] – it corresponds to the period when the reduction of oral airflow is compatible with an oral constriction, there are positive nasal airflow and vocal fold vibration. In this study, the "beginning of nasalization" means nasal airflow from zero up. EVA 2 system automatically calibrates for aerodynamic signals before data acquisition. Since the nasal airflow pressure sensors have a noticeably short response time (0.1 ms), and linearity (typical: 0.01%, max.: 0.1%), we did not use any threshold above zero.

[2] In some dialects, nasal [ẽ] may be produced word-internally as a nasal diphthong [ẽȷ̃]. It is not a widespread tendency, not even in São Paulo, where the variant seems to be a Paulistano stereotype for non-native speakers (Oushiro & Mendes 2014).

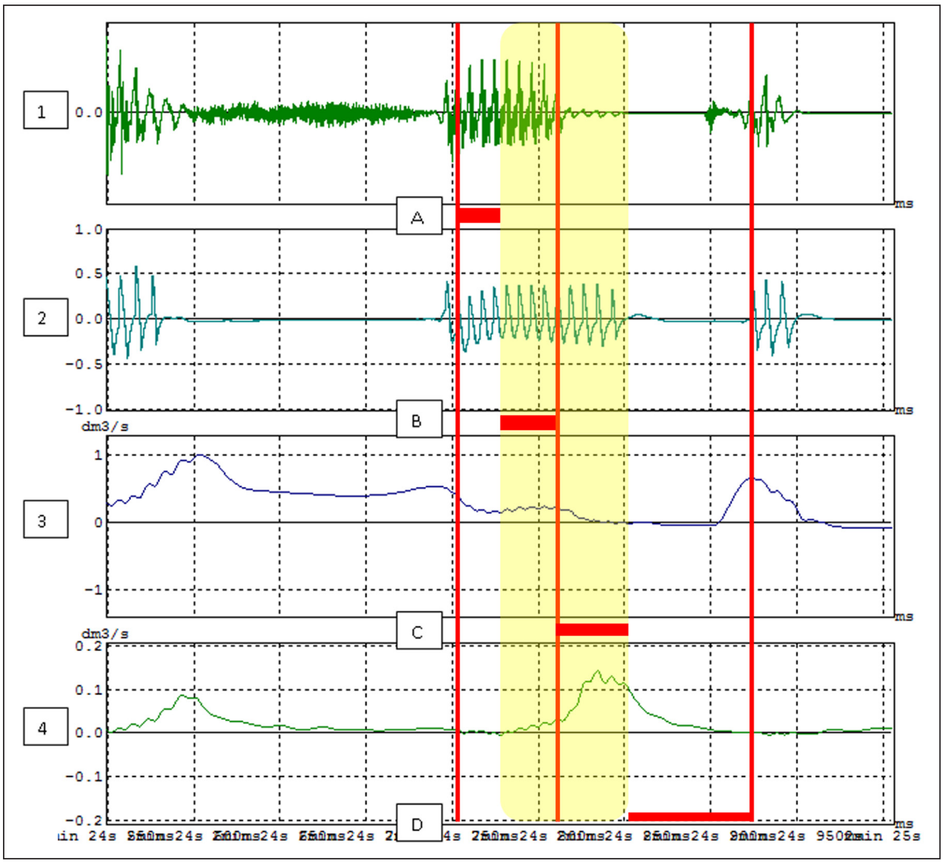


**Figure 2:** Alignment of the four signals used to mark the segments of interest in the word *senta*: (1) speech signal, (2) electroglottogram, (3) oral airflow, (4) nasal airflow. Vertical red lines indicate the beginning and end marking of the vowel and the consonant; the yellow band indicates the marking of the nasalized portion of vowel and consonant. Horizontal red lines indicate **(A)** the oral portion of the vowel, **(B)** the nasalized portion of the vowel, **(C)** nasal murmur, and **(D)** consonant oral portion.

**Figure 2** shows the alignment of the four signals used to mark the segments of interest in the word *senta* [ˈsẽta] 'sit down'. The speech signal (1) shows the fricative noise and the CV transition, after which the first vertical red line marks the beginning of the vowel. Synchronized with the airflows, the electroglottogram (2) provided the means to identify the points of voicing onset and offset. The yellow band indicates the nasalized portion of vowel and consonant: it starts where nasal airflow (4) equals zero and ends shortly after oral airflow (3) crosses zero when there is no more glottal fold vibration or recorded activity in the speech signal. In **Figure 2**, the oral portion of the consonant includes a nasal airflow remnant but no vocal fold vibration and no oral airflow up to the oral closure release. We did not include the nasal airflow remnant in the nasalized portion of the consonant. Although it suggests a velopharyngeal closing movement, here we followed Cohn (1990). We are interested in identifying those portions of the speech stream where we can detect nasal airflow and voicing when there is oral airflow (that is, the nasal portion of a nasal vowel) and when there is no oral airflow (nasal murmur). We then relate those portions with the durations of vowel and consonant. Note that we include in the consonant the oral airflow until the onset of the next vowel.

The duration (ms) for the following measurements were taken:

- Vowel oral portion: from the beginning of the vowel to the onset of nasal airflow;
- Nasalized portion of the vowel: from the onset of nasal airflow to the end of the vowel;

- Nasal murmur (Nasalized portion of the consonant): from the end of the vowel to the offset of nasal airflow and/or voicing;
- Consonant oral portion: the offset of nasal airflow and/or voicing to the end of the consonant.

The sum of the four portions comprises the C(N)V sequence of the target word.

### 2.4. Statistical analysis

For the statistical analyses, we used mixed models that incorporate both fixed effects (those parameters associated with experimental manipulation), and random effects (associated with individual experimental units randomly sampled in the population) (Jaeger 2008; Quené & van den Bergh 2004). Therefore, mixed models consider the correlation of observations within the same experimental unit. Moreover, mixed models can handle unbalanced data; that is, data sets with different amounts of observations for each level or factor.

Except where stated otherwise, we used Context (nasal versus oral) and Following Consonant ([t] versus [s]) as fixed effects–we do not include [d] for the reasons we discuss next. As random effects, an intercept varying by subject proved useful to the models, but not an intercept varying by word. Thus, we only report the models with random effects by subject. The statistical significance of each outcome was estimated by the likelihood ratio test (LR) by comparing the full model, which includes all variables, to a model that omits the evaluated effect.[3]

## 3. Results

### 3.1. Descriptive statistics

After further excluding four outliers, the results of the descriptive analyses (n = 209) are summarized in **Table 3**. **Figure 3** shows the mean durations for the words in the corpus averaged over the five speakers. There is a clear tendency to perform the nasalized portions (in red) at about the same total length when the following consonant is [s] or [t]. When C = [s], the red stretches in the figure appear longer on the vowel side. As is expected from the aerodynamics of speech production, closing the velopharyngeal port is a means to increase the intra-oral pressure and, thus, to produce friction noise. Note,

**Table 3:** Mean duration and standard deviation (in ms) of each portion by context and following consonant.

| Context | C | Tokens | VOP | NPV | Murmur | COP | %NV |
|---|---|---|---|---|---|---|---|
| Oral | [d] | 3 | 159 (6.6) | – | – | 79.3 (3.1) | – |
| | [t] | 15 | 141.8 (18.6) | – | – | 112.3 (35.5) | – |
| | [s] | 30 | 179.1 (16.6) | – | – | 164.5 (32.5) | – |
| Nasal | [d] | 15 | 97.1 (37.45) | 65.3 (52.8) | 89.33 (20.5) | 13.27 (15.3) | 31.4 |
| | [t] | 75 | 82.6 (35.65) | 87.1 (43.4) | 43.3 (17.6) | 82.1 (25.3) | 50.1 |
| | [s] | 71 | 75.5 (29.8) | 129.9 (42.8) | 4.2 (6.7) | 129.2 (25.9) | 62.3 |

Legend: C – Following Consonant; VOP – Vowel Oral Portion; NPV – Nasalized Portion of the Vowel; COP – Consonant Oral Portion; %NV – Nasalized Percent on the Vowel (%) = (NPV/VOP+NPV)*100. Gray area indicates the nasalized portions.

[3] For data analyses and graphics, we used the following packages in R (R Core Team 2019): ggplot2 (Wickham 2016), lme4 (Bates, Maechler, Bolker & Walker 2015), car (Fox & Weisberg 2019), gridExtra (Auguie 2017), psych (Revelle 2018).

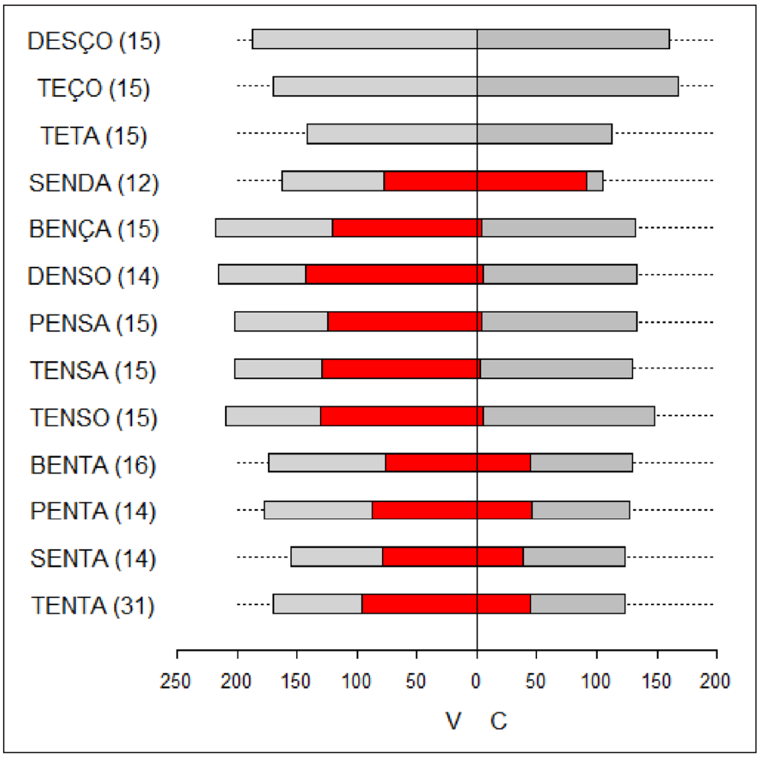


**Figure 3:** Mean duration (ms) of the oral and nasalized (in red) portions of vowels (light grey) and consonants (grey) by word (n of tokens). Zero marks the end of the vowel.

however, that about the same extent of nasalization occurs as before [t]. Statistical tests assess these facts in the following. We omitted vowels produced before [d] in the primary analyses. Those data are biased towards a single participant, as only L1 recorded all words containing [d] (see **Table 2**). At the end of this section, a case study with data by L1 compares the conclusions from the group data to the effect of voicing.

Before proceeding, another fact is perhaps noteworthy. As the total duration of the nasal vowel equals the sum of the oral and nasal portions, the data replicate the known tendency for vowels to last longer before fricatives as compared to those before stops, and for nasal vowels as compared to their oral counterparts. **Table 3** presents the arithmetic mean, which is a descriptive statistic for the group that includes inter-subject variation. A mixed model estimates inter-subject variation and excludes it from the estimate of fixed effects. Thus, the mean represented by the intercept is not confused by the inter-subject variation hidden in the arithmetic mean. **Figure 4** presents the mean estimates (with standard error bars) for vowel duration in nasal versus oral contexts before [s] and [t] that resulted from a mixed model with Consonant and Context as fixed effects and Participant as random effects.[4] In oral context, mean vowel duration resulted 179 (±8.15) ms before [s], and 142 (±8.77) ms before [t]. In nasal context, vowel mean duration before [s] is 205 (±7.78) ms, about 15% longer than in the oral context, and 170 (±7.76) ms before [t] (about 20% longer). Note that "vowel" here excludes the nasal murmur where we do not have oral airflow. So, these duration differences represent an actual lengthening in the vocalic portion of the syllable.

[4] Figure 3 displays the model estimates for visual inspection only. As the total duration is the sum of the oral and the nasalized portions of the vowel and the models next to be presented use those measures to compare with one another, we do not use the model results here for hypothesis testing on vowel duration (we do not assess statistical significance) to preserve probabilistic estimation in the further models.

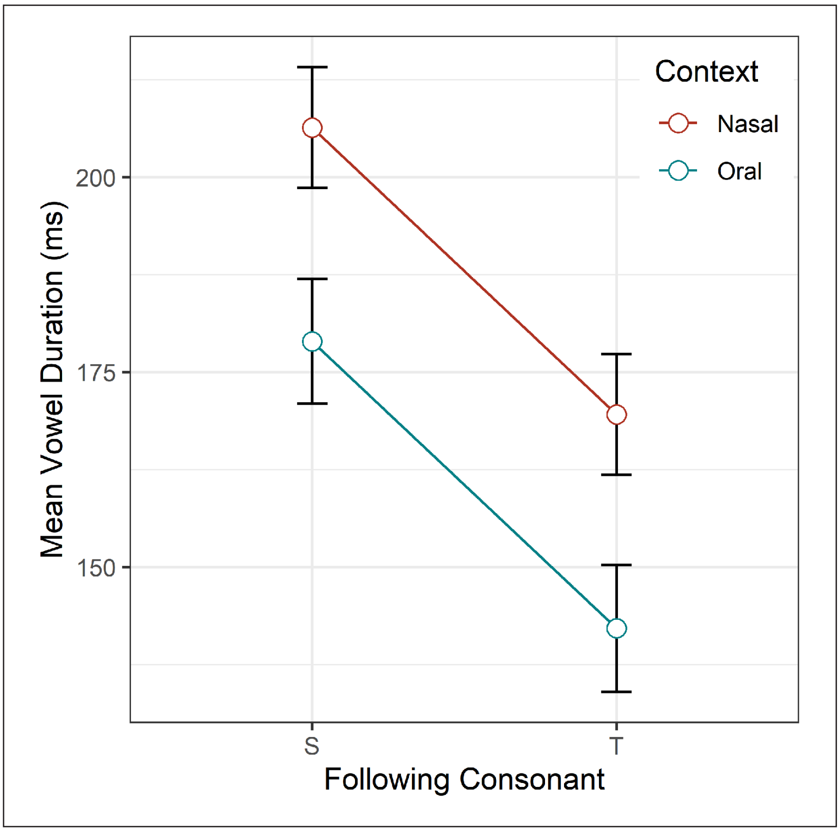


**Figure 4:** Mean vowel duration (ms) estimates in oral versus nasal context before [t] or [s].

### *3.2. Hypotheses testing*

For hypotheses testing, we used only the data in nasal context (n = 146, 75 before [t] and 71 before [s]) because the tests investigate differences in the duration of the effects of nasalization as a function of the following consonant. As already said, for the extent of "nasalization," we take the nasalized portion on the vowel plus the nasal murmur.

#### 3.2.1. Is the oral portion of V constant as the following consonant varies?

Let first recall that according to Solé & Ohala (1991), in the case of phonetic nasalization, the beginning of vowel nasalization is temporally timed to the beginning of the vowel, and not to the beginning of the nasal consonant. The onset of the following nasal consonant triggers the merely co-articulative regressive nasalization and, therefore, this is always dependent on the first. However, according to the authors, when regressive nasalization is phonologized and follows specific language rules, its onset depends on the vowel to be nasalized and no longer on the nasal consonant that is the source of nasalization. Since the speaker's target is the nasalized vowel, duration adjustments affect this portion. Therefore, it would be sensitive to the effects caused by the following consonant–either a stop or a fricative. Recall from **Table 3** that the following onset did promote duration differences in the vowel. In an oral context, the vowel before [t] is 142 ms long, whereas before [s], it lasts for 179 ms (a ratio of 0.79), and the same we observed in nasal vowels: in VNt context, V is 170 ms long, and in VNs context, it is 205 long (a ratio of 0.83). The question here is whether it is the oral or the nasalized portion of the vowel that undergoes adjustment.

**Figure 5** shows the mean duration (ms) of the vowel oral and nasal portions before [s] or [t] by each participant. **Figure 5** is comparable to those of Solé & Ohala (1991: 112). Note that here, too, vowels are, on average, longer before [s] (gray) than before [t] (red

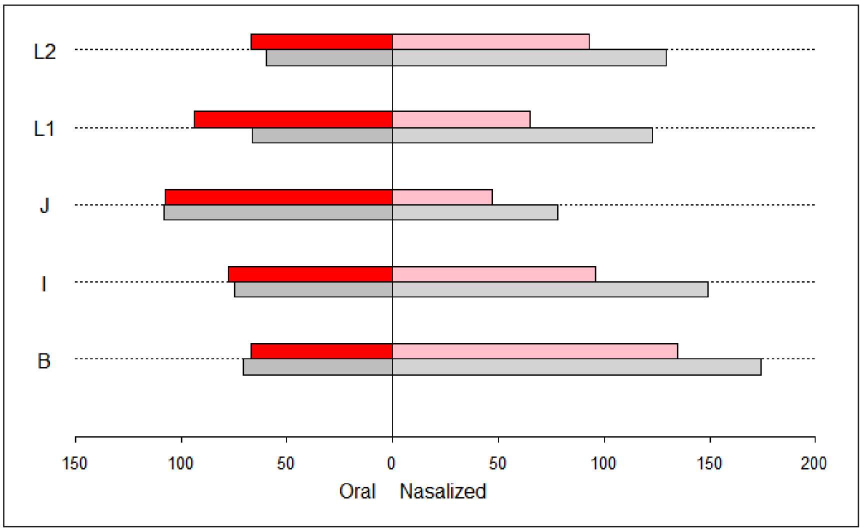


**Figure 5:** Mean duration (ms) of the oral and the nasalized portion of the vowel before [s] (grey/light grey) or [t] (red/pink) by participant. Zero indicates nasal onset.

or pink). So, the same rationale applies, and answering the question "is the oral portion of V constant?" is equivalent to whether vowel oral portion undergoes the duration-adjusting effects of the following consonant. In other words, the question is whether the differences in vowel oral portion as a function of the following consonant are statistically significant.

The resulting model compared the 141 data points of vowel oral portion duration (dependent variable) as a function of C (independent variable), with intercept per subject as a random effect. There was no significant difference ($\beta = 6.97$, t [140] = 1.42, $p > .05$). The mean duration of vowel oral portion is estimated as 75.6 ms (SE = 7.37) when C = [s] and as 82.56 ms (SE = 7.33) when C = [t]. The first hypothesis is that duration adjustments affect the vowel's nasalized portion if the speaker targets nasalization. Results show that the oral portion of the nasal vowel does not undergo duration-adjusting effects as a function of the following onset, as exactly should be the case for languages in which the speaker intends nasalization. The longer vowel before [s] is longer in its nasalized portion.

### 3.2.2. Does nasalization have about the same duration before [s] or [t]?

As shown in **Table 3**, the duration of the nasal murmur plus that of the nasalized portion on the vowel amounts to 134.1 ms before [s], and 130.4 ms before [t]. The 3.7 ms difference is not significant ($\beta = -4.89$, t = –0.9, $p > .05$). The average duration of the nasalized portions before [s] represents well the overall mean ($\beta = 135.29$, t [140] = 8.15, $p < .001$). A model with a random effect term for one intercept per subject was better than another with one intercept only (LR = 97.28, $p < .001$), but not one with Consonant as a factor (LR = 0.82, $p > .05$). The participants' variation was considerable ($\sigma^2 = 1{,}282.6$), typical in a sample of several data points from only five subjects. From the model, the duration of nasalization before [t] can be estimated at 135.29 – 4.89 = 130.4 (same as estimated by the arithmetic mean, **Table 3**), and the small difference of 4.89 ms is not significant. Therefore, the question about the (roughly) constant duration of the nasalization can be answered positively, in favor of Beddor's hypothesis.

### 3.2.3. If the nasalized portion on the vowel increases, does the nasal murmur decrease?

To positively answer the research question, we should find a negative correlation between the nasalized portion on the vowel and the nasal murmur. A negative correlation ($\beta = -0.32$, t [140] = –3.96, $p < .001$) was found only when the effect of the following consonant was not considered (solid line). However, when Consonant is taken into the model (dashed lines), correlation drops to close to zero and is nonsignificant ($\beta = 0.023$, t [139] = –0.41, $p > .05$). Consonant was significant when the model included it as a variable ($\beta = 37.96$, t [139] = 18.05, $p < .001$), so we should consider as two different sets of data those registered before [s] and [t] as to the duration of nasal murmur. In plain English, the conclusion is that if we consider [s] and [t] separately, the nasal murmur does not decrease as vowel nasalization increases. As to the question at hand, this result is only partially compatible with the Constant N Hypothesis. When the consonant is a fricative, nasalization is lengthier on the vowel, but the total duration of the portion in which we recorded nasal airflow is not different if the consonant is a stop versus a fricative. The Constant N Hypothesis predicts such an effect. In this case, one would expect that longer nasalization on the vowel corresponds to more abbreviated nasalization in the consonant. As the average model estimates a negative but non-significant correlation, one cannot say that there is a relationship between the duration of the nasalized portion in the vowel and the duration of the nasalized portion in the consonant.

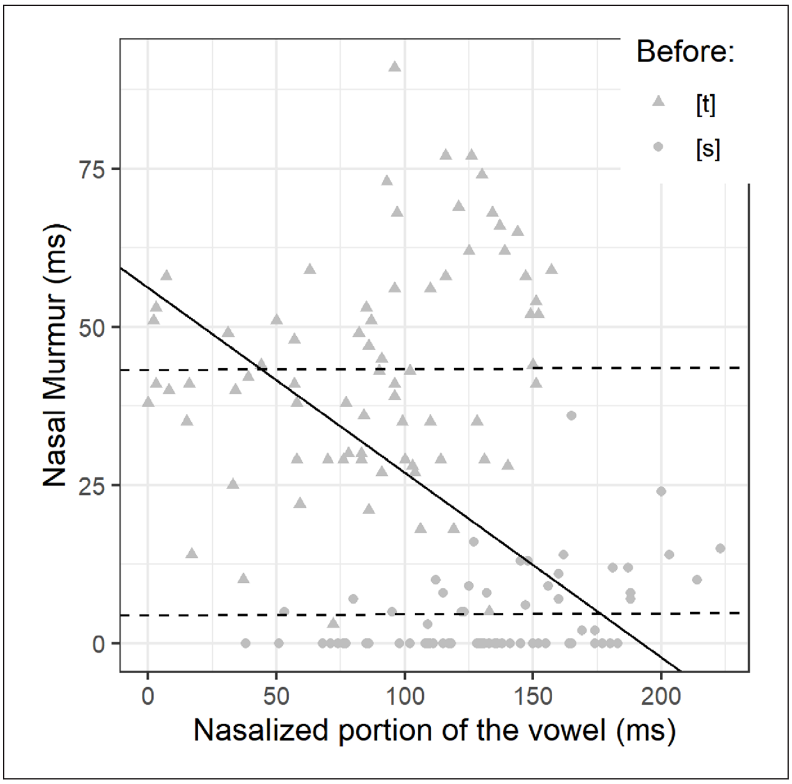


**Figure 6:** Mean duration (ms) of the nasal murmur as a function of the mean duration (ms) of the nasalized portion of the vowel for both consonant contexts (solid line) and by consonant (dashed lines).

This model included the variation due to the participant, with the intercept and the slope randomly varying by subject. **Figure 7** shows the model results, where the red lines represent the results predicted by the model. Note that the red lines are different for each participant, reflecting individual variation to adjust the model prediction better to the pattern of relationship between the two variables. On the other hand, the slope of the red lines does not change for the data before [s] or [t], as this was not different as a function of the following consonant. This result means that the following consonant does not affect the individual pattern of the relationship between the two variables.

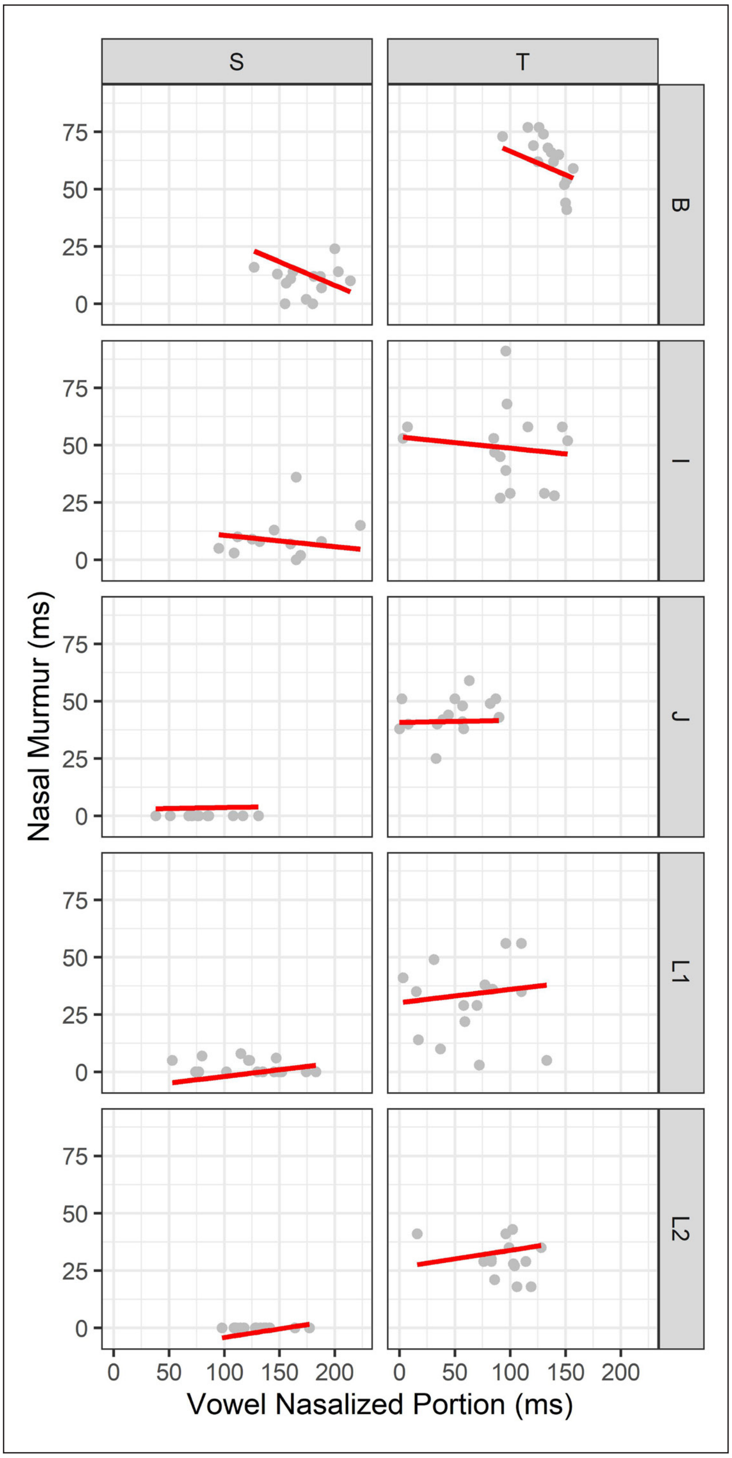


**Figure 7:** Duration of nasal murmur (ms) as a function of the duration of the nasalized portion of the vowel (ms) by participant.

### 3.2.4. When the vowel oral portion decreases, does the consonant oral portion increases?

The last question related to Beddor's Constant N Hypothesis refers to the relationship between the oral portion of the vowel and the oral portion of the consonant. If increasing the nasalized portion of the vowel reduces its oral portion, the oral portion of the consonant should increase if nasalization is constant. However, no straightforward relationship between the vowel oral portion and the consonant oral portion was detected ($\beta = -0.086$, $t\ [140] = -1.04$, $p > .05$). The final model with by-subject intercept fits the data better than a model without random effects ($LR = 37.27$, $p < .001$).

To sum up the results before moving on, the answer was affirmative for two of the study's four questions. First, the mean duration of the oral portion of the vowel is not different if the vowel is before [t] or [s]. Taken together, the duration of the nasalized portion of the nasal vowel and the nasal murmur is approximately constant on average, with no difference caused by the fact that the next consonant is either [t] or [s]. Nonetheless, no change in duration is observed neither in the nasal murmur nor in the consonant oral portion if the vowel's nasal portion increases.

### *3.3. Exploring an alternative explanation*

The first two questions involved verifying systematic differences in the data set due to the following onset's duration-adjusting demands. On the other hand, in a correlation, we consider paired observations, and the data by each participant is highly correlated and representative of her behavior. Individual variability is a result seen in **Figure 7** that seems to be worth exploring. Note that participants B (slope: –0.2) and I (–0.05) negatively correlate the nasalized portion on the vowel and the nasal murmur. Participant J has a slope close to zero (0.009) and participants L1 (0.06) and L2 (0.7), slightly positive slopes. J and L2 (14 and 15 data points, respectively) produced no nasalization on [s]. As the five speakers are women in the same age group and exposed since childhood to speech in the same region, none of these sociolinguistic variables seem relevant. We then move on to investigate whether the evidence suggests the involvement of biomechanical factors on individual variability. We first explore the relationship between vowel length and the murmur's duration. We investigated if the more prolonged is the vowel, the shorter will also be the nasal murmur. The results of a negative correlation may suggest that given enough time for the vowel, the nasalization would perfectly align to it, and no murmur results. However, if other linguistic demands come into play and the mouth closes before the velopharyngeal port's closure, the speaker produces a nasal murmur.

Vowel duration was significantly related to the nasal murmur before [s] ($\tau = 0.34$, $p < .001$) and [t] ($\tau = 0.44$, $p < .001$) if we take all participant's data as a single group in a Kendall's rank correlation test. But this should not be the case if individual differences are at the focus. Mixed models assessed how well vowel duration predicts the nasal murmur separated by consonantal context [t, s]. As we already know, the following onset is a source of variation both on vowel duration and the nasal murmur, so we omitted Following Consonant as a predictive variable. As a result, models that include only the random effects by subject were better than those, not including the individual variability ([t]: LR $= 32$, $p < .001$; [s]: LR $= 26.97$, $p < .001$), but a model that also includes the duration of the vowel as a predictive variable is not better ([t]: LR $= 0.4$, $p > .05$; [s]: LR $= 0.07$, $p > .05$), irrespective of the following consonant. The resulting estimates (**Table 4**) show that nasal murmur depends essentially on the speaker. B has the most

**Table 4:** Mean duration (ms) of the nasal murmur by participant and consonant estimated by a model with intercept and random effects only.

| Participant | Following Onset | |
|---|---|---|
| | [s] | [t] |
| B | 9.78 | 61.4 |
| I | 9.15 | 48.6 |
| J | 0.38 | 43.9 |
| L1 | 2.41 | 31.5 |
| L2 | 0.35 | 31.2 |

extensive nasal murmur before [s] and [t], and L2, the less extensive (in fact, J and L2 did not produce any measurable nasal murmur before [s], and their estimates most certainly result from prediction errors). As expected, the general pattern is that before [s], the nasal murmur is compressed. But the results do not support the hypothesis that a longer vowel would induce velic closure to align with oral closure at the end of the vowel.

Articulation differences in the velopharyngeal port opening are an individual pattern that comes forward here as a variability source. If a participant has a more extended portion in which the velum position allows for nasal airflow, her nasalized portions are longer as compared not only to the other participants but eventually also to her duration measurements related to oral closing and opening movements. We further explore that idea with data on the nasalized portions' duration and the total length of the vowel-nasal-consonant (VNC) sequence for a possible influence of individual differences on articulation. Recall that the total duration of the VNC sequence begins with the vowel and lasts until the vowel starts in the next syllable. This measure refers to the oral airflow and reflects the successive opening and closing movements. B is the participant with the most lengthened total VNC duration and has the most extended nasalized portions. The proportion the nasalized parts take on the VNC sequence is also the largest, as is the nasalized portion on the vowel. On the other hand, J is the "fastest" speaker, with the shortest duration of VNC, nasalized portions, and nasalized portion on the vowel. Nonetheless, the pattern of a direct relationship is not generalized: L2 is the second fastest, but nasalization is longer for her than for L1.

**Table 5:** Mean duration (ms) and nasalized portions (%) to the total duration of the VNC sequence for each participant and averaged over participants.

| Participant | Nasalization | | Total VNC Duration | | Percent Nasalization on VNC | | Nasalized Percent on the Vowel | |
|---|---|---|---|---|---|---|---|---|
| | [s] | [t] | [s] | [t] | [s] | [t] | [s] | [t] |
| B | 184 | 198 | 382 | 323 | 48.4 | 61.5 | 71.1 | 67.3 |
| I | 159 | 145 | 381 | 328 | 41.5 | 44.3 | 66.4 | 55.8 |
| J | 78 | 91 | 295 | 265 | 26.3 | 33.8 | 41.3 | 28.7 |
| L1 | 125 | 95 | 343 | 300 | 36.3 | 31.6 | 64.6 | 40.6 |
| L2 | 130 | 123 | 301 | 259 | 43.1 | 47.7 | 68.1 | 58.3 |
| Mean | 134.1 | 130.4 | 338.8 | 295.1 | 39.0 | 43.8 | 62.3 | 50.1 |

The best mixed-model results for this data included Consonant and total VNC duration as fixed effects, and slope and intercept by subject as random effects. In general, there was a strong relationship between the total VNC duration and the duration of the nasalized portions ($\beta = 0.44$, SE $= 0.14$, t [139] $= 3.14$, $p < .01$), a highly significant result as compared to a null model (LR $= 124.85$, $p < .001$). In **Figure 8**, the red lines are different in slope and intercept by subject, reflecting the differences in the individual pattern of relationship between the two variables. On the other hand, the slope of the red lines does not change for the data before [s] or [t], as there was no difference caused by the following consonant ($\beta = 13.3$, SE $= 6.73$, t [139] $= 1.96$, $p = .05$). The general trend is that all participants show a positive relationship–the longer the total VNC sequence, the longer the nasalized portions–but there are differences as to how is this relationship: it is strong for L1 and very mild for B.

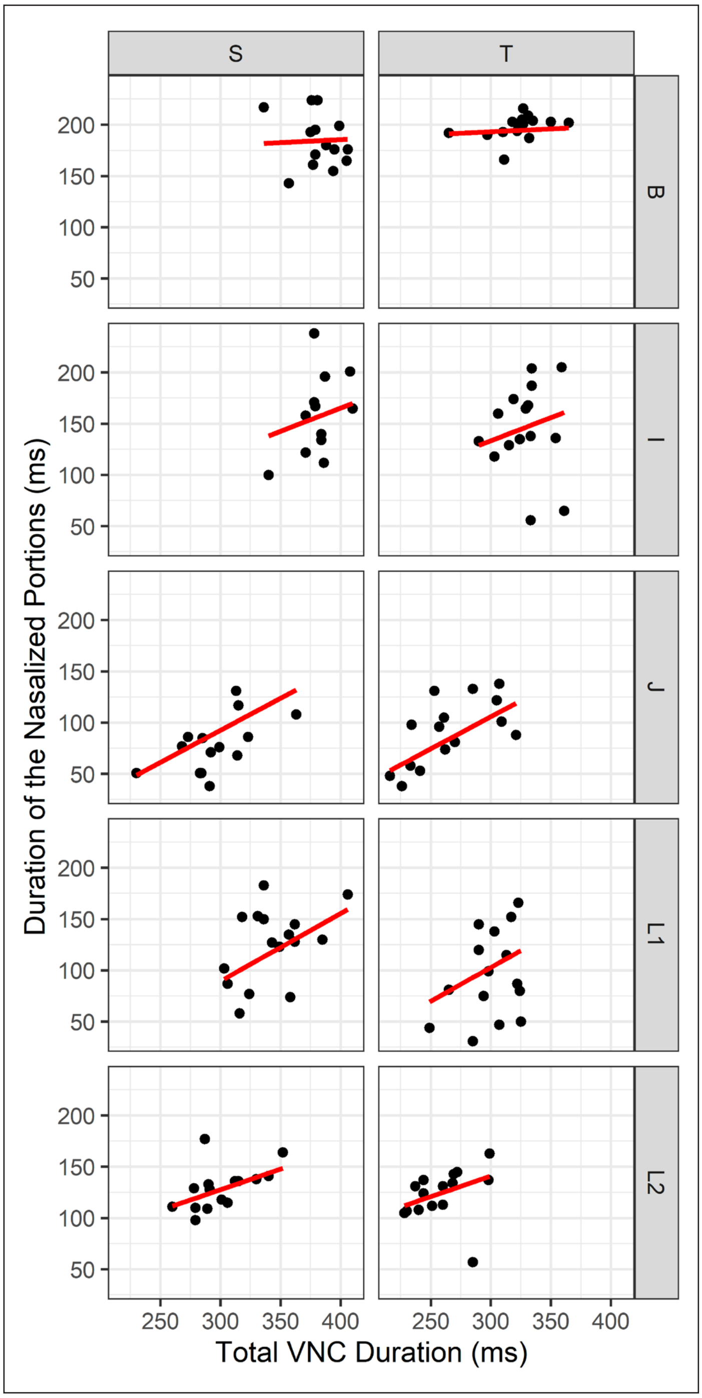


**Figure 8:** Duration of the nasalized portions (ms) as a function of the total VNC duration (ms) by participant and by context. Red lines represent the results predicted by the model.

We have already seen that speakers do make longer vowels before [s], and their vowel nasalized portion is also more extended, but the oral portion of the vowel is not different in duration as compared to the oral portion of the vowel before [t]. We just saw that a longer VNC sequence corresponds to longer nasalized portions. So, an alternative explanation for the lack of relationship between the nasalized portion on the vowel and the nasal murmur is that participants differ as to how they link the "constant N" to the beginning of the vowel as a function of their articulation characteristics, irrespective to what occurs after the vowel. A mixed model to test for this explanation assessed how the oral portions in vowels and consonants are affected by the increase of the duration of the nasalized portions.

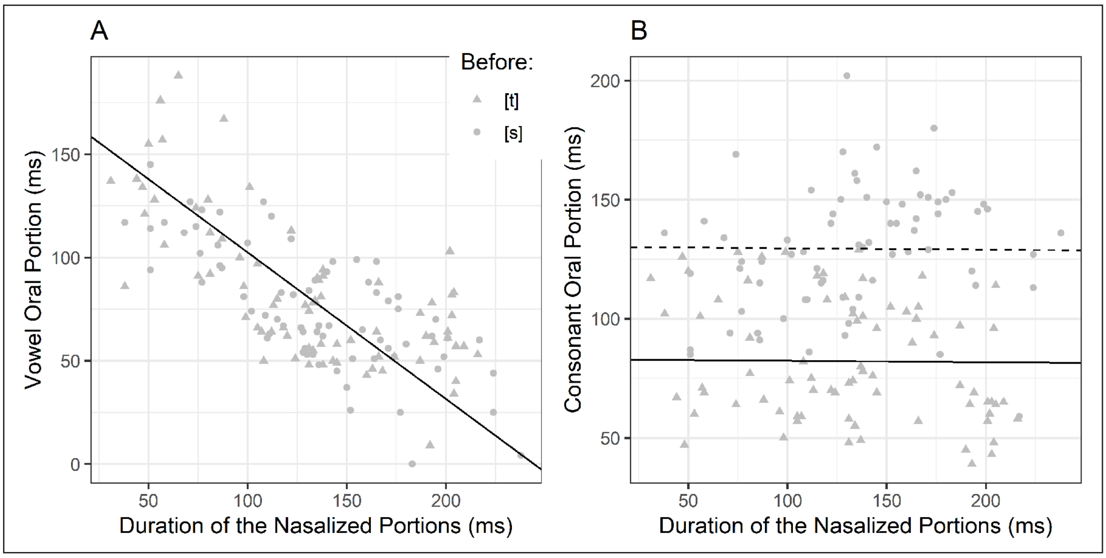


**Figure 9:** Vowel oral portion **(A)** and consonant oral portion **(B)** as a function of the duration of the nasalized portions. Lines represent how the duration of the vowel or consonant oral portion change as a function of the duration of the nasalized portions – in (A), solid line for both [t, s] because there was no difference between contexts; in (B), solid line for [t] and dashed line, for [s].

In **Figure 9A**, as the duration of the nasalized portions increases, the duration of the oral portion in the vowel decreases, a robust relationship ($\beta = -0.71$, SE = 0.045, t [145.91] = –15.78, $p < .001$) no matter the following consonant. As for the consonant oral portion (**Figure 9B**), the effect of nasalization is negligible ($\beta = 0.006$, $p > .05$). The best model estimates for the consonant oral portion result in consonant oral portion before [s] = 129 ($\pm$8.07) ms (t [10.45] = 13.164, $p < .001$), and consonant oral portion before [t] = 82 ($\pm$4.87) ms (t [4.94] = –9.742, $p < .001$). The mean values for the consonant oral portion are represented in (B), solid line for [t] and dashed line for [s]. Note that the consonant oral portion before [s] is on average longer than the average consonant oral portion before [t], as expected by the fact that the fricatives are longer than stops.

We found no effect of consonant on the relationship between the oral portion of the vowel and the duration of the nasalized portions. Nonetheless, irrespective of the following consonant, **Figure 9** shows that the nasalized portions' duration varies by subject and repetition. At an individual basis, increasing the duration of the nasalized portions compresses the oral portion of the vowel. On the other hand, varying the duration of the nasalized portions results in no effect on the consonant, with no influence whatsoever on the duration of the consonant oral portion.

### *3.4. The participant L1*

Before we summarize and discuss the results, we present a case study with data for participant L1 for whom we recorded enough data before [d]. In this experiment, data from one single participant are too sparse to apply inferential statistics adequately (n = 9 [d], 22 [s], 18 [t]). **Table 6** shows the measured portions in L1's data for words with a VNC (nasal) or a VC sequence (oral). Note that the nasal murmur is almost inexistent before [s] and is longer before [d] than [t]. Moreover, the mean duration of each portion is according to the general tendency reported for consonants: the consonant is longer when it is a voiceless stop than a voiced one, but the longest when it is a fricative. As for the vowels, in an oral context, they last longer before fricatives than before stops, and before voiced stops as compared to voiceless stops. The comparison between nasal vowels and their oral counterparts reveals that before [d] vowels in oral context are only

**Table 6:** Mean duration and standard deviation (in ms) of each portion by context and subsequent consonant (Data by Participant L1).

| Context | C | Tokens | VOP | NPV | Murmur | COP |
|---|---|---|---|---|---|---|
| Oral | [d] | 3 | 159 (6.5) | – | – | 79.3 (3.06) |
| | [t] | 3 | 124 (16.5) | – | – | 123.3 (16.4) |
| | [s] | 6 | 166.2 (5.3) | – | – | 175.3 (16.3) |
| Nasal | [d] | 6 | 126.8 (27.9) | 28.7 (24) | 89 (10) | 18.3 (11.9) |
| | [t] | 15 | 93.7 (33.9) | 64.8 (38.6) | 30.5 (17.1) | 111.3 (16.6) |
| | [s] | 16 | 66.5 (37.1) | 122.6 (37.2) | 2.25 (3.1) | 151.9 (22.3) |

Legend: C – Following Consonant; VOP – Vowel Oral Portion; NPV – Nasalized Portion of the Vowel; COP – Consonant Oral Portion. Gray area indicates the nasalized portions.

about 4 ms longer than in nasal context. In comparison, before the voiceless consonants, the nasal vowels are substantially longer: 158 ms before [t] and 189 ms before [s]. Also, the nasalization on the vowel is less extended before [d] (18%) than before [t] (40%) or [s] (65%). On the other hand, as we defined nasal murmur as the stretch with nasal airflow, voicing, and no oral airflow, the voiced portions in the VNC sequence before voiceless consonants comprise about 190 ms – 189 ms before [t] and 191 ms before [s]. So, the lengthening effect we have seen on vowel duration apply here only before voiceless consonants.

As for the question of whether there is a roughly constant N, also for L1 the nasalized portions' duration does not seem to differ as a function of context. Note that before [t], the sum of the nasalized portion of the vowel and the nasal murmur (95 ms) is the lower mean. Nonetheless, it is within the limits of one standard deviation from the other average values–118 ms before [d] and 125 ms before [s]. This is an indication that the differences are nonsignificant and suggests, on average, a constant N.

The pattern in **Figure 10** looks the same as for the group data (**Figure 9**) in respect to the relationship between the duration of the nasalized portions and the oral portions in consonant and vowel, respectively. Although the vowel oral portion lasts longer before [d] than before both voiceless fricative and stop, it shows the same tendency of nasalization increase compressing the vowel oral portion.

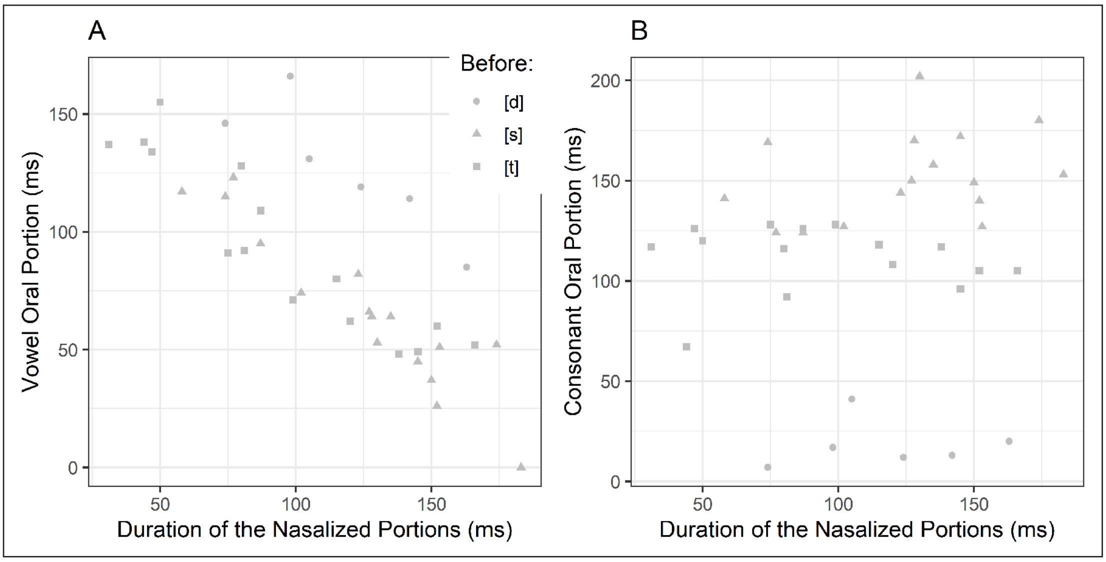


**Figure 10:** Participant L1: Vowel oral portion **(A)** and consonant oral portion **(B)** as a function of the duration of the nasalized portions.

## 4. Discussion and Conclusion

In this study, we replicated several previous findings. We found longer vowels before [s] than [t] in oral as in nasal context. We also found longer vowels before [d] (mean value: 159 ms) than [t] (142 ms) in an oral context but failed in a nasal context (162 ms and 170 ms, respectively) due perhaps to the few data points we were able to collect before [d]. As Delattre (1962) suggested, this difference may be due to physiological mechanisms of speech production. Keating (1999) presents several arguments against physiologically based reasoning because we do not find this difference in some languages, so that the cause may lay in language-related phonetic characteristics. It is important to note that Rothe-Neves & Valentim (2012) only found duration differences in an oral context, not in nasal vowels before [s, t]. In this study, identifying a "vowel" objectively required three parameters (oral airflow, voicing, and formant structure) so that methodological differences between the two studies may be at the source of different results – at least the number and gender of participants, vowel height, and instrumental analyses.

Turning to this study's objectives, we first assessed whether the oral portion of the vowel in the VN sequence suffers the subsequent consonant's duration-adjusting effects. It does not. These results add to Moraes' (1997), supporting the proposed distinction between purely mechanical phonetic sources versus phonologized mechanisms (Solé 2007; see also Solé & Ohala 1991) in Portuguese vowel nasalization. Based on the results, we consider that the vowel's nasal part is the speaker's linguistic target and, thus, regressive nasalization is part of the Portuguese language system.

From the three predictions of the Constant N Hypothesis, we could verify only one. We looked at whether nasalization differs as a function of the following consonant [s, t]. Recall that "nasalization" objectively means here the nasalized portion of the vowel plus the nasal murmur. We noticed no difference in nasalization as a function of the following consonant, so in this respect the Constant N Hypothesis is valid for Portuguese. As well known, fricatives impose aerodynamic restrictions on nasalization to decrease during the consonant drastically. But this does not mean that nasalization should remain constant. It may well disappear entirely instead of regress over the vowel for a longer duration. For instance, this is what happened in Italian, with the systematic loss of nasality in nasal-fricative sequences (Busà 2003; Busà & Ohala 1995). Therefore, the longer nasalized portion on the vowel before [s] comes not only because of the need to increase intraoral pressure but also to preserve the constant nasalization duration.

However, the nasal murmur produced by our Brazilian Portuguese speakers did not behave as a nasal consonant conform to the Constant N Hypothesis. A reduction of the nasal consonant (here, the nasal murmur) is predicted by the Constant N Hypothesis when the vowel nasalized portion increases. We have not observed any significant relationship between one result and the other. Also, there was no negative relationship between the vowel nasal portion and the consonantal oral portion. Here, Ohala and Solé (1991) intuition about linking the nasal onset to the vowel onset was more productive. In this respect, we noticed that when the entire VNC sequence increases on an individual basis, so does the nasalization. Also, increasing nasalization comes at a cost for the duration of the oral part of the vowel irrespective of [s, t]. These results rely on the participants' characteristics: speaking rate influences coordination timing between the beginning of the vowel and the beginning of nasalization.

Taken together, the results of this study seem not entirely compatible with as if Portuguese were at a final Ṽ stage in a diachronic process (VN > ṼN > Ṽ) as supposed by those who conceive of nasal vowels as phonemes. Nasalization on the vowel (the vowel's nasal portion) ranges from about 30–70%, as shown in **Table 5**. It is unclear why the language lexicon distinguishes between oral and nasal vowels, while those are only variably nasal. Also, if nasalization were entirely a property of the vowel, it would seem more coherent to have it adjusted in duration together with the vowel. On the contrary, nasalization is constant in duration while the vowel accommodates in response to the following consonant.

However, our results are not entirely compatible with a ṼN stage either if we consider English as an exemplar language in this stage. Nasalization was constant as it does not adjust to the following [s, t]. But it was variable in respect to the individual differences in articulation, as longer nasalization was related to a longer VNC or else, to slower speakers. Speakers with longer nasalization timed it earlier to the beginning of the vowel, thus producing shorter oral portions of the vowel. The nasal murmur does not relate to vowel duration or the nasalized part of the vowel. All those speech-production characteristics are indicative that they are not a controlled, language-specific process. It seems more like the N of a ṼN stage is already gone.

The alternative of another stage between ṼN and Ṽ is not new. Some authors proposed that Portuguese nasal vowels are underlyingly oral vowels followed by a nasal glide. The proposals diverge as to where the glide belongs in the syllable structure: losing oral closure in coda position (Parkinson 1983; Trigo Ferre 1988) or as a second element in the syllable nucleus (Brandão de Carvalho 1988; Pimenta 2019a, b). In common, they argue that Portuguese uses no more nasal consonants for vowel nasalization based on diachronic facts. For this reason, the discussion is beyond our limits. To further develop the experimental investigation of those proposals into the literature on nasal vowels is a future step.

## Additional file

The additional file for this article can be found as follows:

- **Appendix.** Nasal vowels in Brazilian Portuguese (BP). DOI: https://doi.org/10.5334/jpl.236.s1

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## Competing Interests

The author has no competing interests to declare.

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