THE AERODYNAMICS OF VOWEL NASALITY AND NASALIZATION IN BRAZILIAN PORTUGUESE[1]

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ABSTRACT

Brazilian Portuguese (BP) is thought to possess contrastive nasal vowels that are different from contextually nasalized vowels in its phonological system. Aerodynamic data (nasal and oral airflow) of 11 native speakers show that interspeaker variability is important in this language with regard to the nasal airflow ratio of tautosyllabic nasal vowels (TNVs; *campo* [kɐ̃^(m)pʊ] 'field') and heterosyllabic nasalized vowels (HNVs; *cama* [kamɐ] or [kɐ̃mɐ] 'bed'). This shows that TNVs are not thoroughly differentiated from HNVs in production throughout the whole duration of the vowels, and speaker-specific variability is important, thus suggesting that vowel nasality has not reached a fully contrastive status in this language. Stage of assimilation of nasality on the vowel in the evolution of the phonological system is suggested as the explanation for the observed differences between HNV and TNV and the apparently ambiguous status of vowel nasality in BP.

Keywords: Vowel nasality, aerodynamics, Brazilian Portuguese, speaker variability.

1. INTRODUCTION

The phonological status of nasal and nasalized vowels in Brazilian Portuguese (BP) has often been a topic of interest to phonologists and phoneticians as these vowels are often extensively nasalized ([1]; [10]; [12]; [14]; [16]; [17]), but language-internal evidence (e.g. minimal pairs) for a phonological contrast between contrastive tautosyllabic nasal vowels (TNVs; *campo* [kɐ̃^(m)pʊ] 'field') and coarticulated heterosyllabic nasalized vowels (HNVs; *cama* [kamɐ] or [kɐ̃mɐ] 'bed') is not revealing. Also, the fact that Portuguese TNVs are "unpacked" in loanwords ([11]) or during some morpho-phonological processes ([17]) supports the view that these vowels are in fact formed by an oral vowel followed by a nasal consonant/element, and that vowel nasality is not totally integrated to the vowel at the phonological level (in a broad sense).

Another argument in favour of the hypothesis that nasal vowels are underlyingly formed by two elements is that they are often assumed to possess longer durations than oral vowels, as the former are historically formed by a merged sequence of an oral vowel and a nasal consonant (e.g. in Romance languages, see [16]), and have retained their two time units (for a review on BP, see [15]). Hence, according to several analyses ([14]; [15]; [16]), BP nasal vowels (TNVs) possess two time units, and are longer than oral vowels (HNVs or non-nasalized oral vowels) that possess only one time unit.

As stated in Sampson [16] (who recognizes the existence of phonological nasal vowels in Portuguese), it is very likely that TNVs in BP have emerged (or have been *phonologized*; see [2], [3], [8] for more precise accounts of the sources of phonologization) from the merging of an oral vowel and a nasal consonant through the evolution of the phonological system. Diachronically, the oral vowels were at first coarticulatorily nasalized, and speakers further exaggerated this coarticulatory property until it became part of the language's phonological system. Hence, the phonetic properties of phonological nasal vowels (e.g. nasal airflow) should be similar across speakers in order to maintain a consistent and constant contrast with oral vowels in the language.

Studying BP nasal(ized) vowels is also complicated by the fact that they are realized differently across dialects, that mid-vowels /ẽ/ and /õ/ are sometimes realized as diphthongs (e.g. in Southeastern dialects), and that the emergence of a nasal *coda* (a consonant-like nasal sound between the vowel and following stop consonant that is homorganic to the following consonant) is variable concerning its context of occurrence and duration ([14]; [17]). Partly due to these difficulties of investigation, authors have not yet reached consensus on the phonological status of vowel nasality in this language, and no experiment has investigated the aerodynamics of these vowel types with a substantial number of participants. The following experiment taps into this particular problem.

One approach to the phonology of vowel nasality, by Cohn [5], has argued that there is a phonetic difference between phonological nasal vowels (here TNVs in BP) and coarticulated nasalized vowels (here HNVs in BP), because they are the results of different types of implementation rules ([13]), either phonological or phonetic. For example, Cohn [5] shows that phonological nasal vowels (as in French *daim* [dɛ̃] 'deer' or in English for some contexts – e.g. *sent* [sɛ̃$^{(n)}$t]) display a plateau-like pattern of nasal airflow, and that coarticulated nasalized vowels (in other contexts of English – e.g. *den* realized [dɛn] or [dɛ̃n] with the vowel being partially nasalized) display cline-like patterns of nasal airflow. Thus, analyzing the nasal airflow patterns of different types of nasal(ized) vowels enables one to infer the phonological status of vowel nasality, and shed light on the problem of interest in BP.

The following experiment investigates the nasal airflow of TNVs, HNVs and oral (non-nasalized) vowels in BP in order to determine if there exist consistent differences between these vowel types, if the expected plateau or cline patterns of nasal airflow (depending on the vowel type) are present in the productions of native speakers' nasal(ized) vowels, and to what the potential differences between the vowel types are due.

2. METHODS

2.1. Participants

Eleven native speakers of Southeastern BP (states of São Paulo, Paraná, Rio de Janeiro, and Minas Gerais) took part in the study. Nine participants had been living in Ottawa (ON, Canada) for less than one year, one for seven years, and one for nine years. They were aged between 23 and 48 years old, had university or *ensino superior completo* (equivalent to university) levels of education. All participants had been exposed to English as their second language, and some participants self-reported levels of spoken proficiency in Spanish and/or French (the latter language possesses phonological nasal vowels that may have a perhaps limited influence on the productions in the participants' native language; observing the data of the concerned participants did not suggest interference from French in their productions). The participants were financially compensated for their participation in the study.

2.2. Procedure for data collection

After obtaining informed consent from the participants, they were comfortably installed in front of the EVA2 system setup ([7]) for measurement of nasal and oral airflow and were given the instructions for the experiment. They were asked to read over 90 randomized sentences of BP twice, presented on a computer screen, containing the words with the target TNVs, HNVs, and oral vowels (/ɐ̃, ẽ, õ/ and nasalized or oral /a, e-ɛ, o-ɔ/), speaking into a flexible silicone mask for oral airflow measurement, and with two flexible rubber tubes at the entrance of their nostrils for nasal airflow measurement. All vowels were stressed and followed by a voiceless stop in the word or sentence. Note that high vowels (TNV /ĩ, ũ/, and HNV and oral /i, u/) were not included as target segments as /ũ/ restrains the velum lowering due to its articulation height and backness; the tongue may come in contact with the lowered velum during its production. /ĩ, i/ were also excluded for consistency and comparability reasons with regards to height of articulation. Oral and nasal airflow (sampling frequency of 6250 Hz, range of 0 to 2dm^3/s and 0.5dm^3/s respectively) as well as voice signal (sampling frequency of 25 kHz, 16 bits) were simultaneously recorded.

2.3. Segmentation and data preparation

Each target vowel was hand-segmented in Praat (version 5.3.62; [4]) based on the acoustic characteristics of the target vowels (waveform periodicity, formant structure, change in waveform shape, auditory confirmation). The nasal coda of TNVs was not included in the vowel interval as it is thought to be the overlap of a (perhaps) vocalic characteristic on the closure of the following stop consonant ([14]). The textgrid was labelled with the target word label as well as other information. 1882 target vowels were obtained for analysis.

A Praat script (retrieved from [9]) was used for extracting duration values of the acoustically defined vowel intervals for each participant. The data was then appended with each participant's code, imported into R ([6]) for analysis, and merged into one data frame for extracting averages and standard deviations.

Another Praat script (originally written by Dr. Marc Brunelle and modified by the author) was used for airflow data extraction, relying on the boundaries of the acoustically defined vowels and saving the oral and nasal airflow values at every 5% of the vowel duration from vowel onset until 50% of duration after vowel offset (total of 31 measurement points) in a text file. The script also enabled to encode some information in the data frame for further analysis (participant label, textgrid labels, etc.)

The data was then imported into R and appended with more information for analysis (e.g. vowel type – TNV, HNV, oral). Nasal airflow ratio was also calculated with the following equation (after replacing the obtained negative values by 0 as these are not thought to be linguistically relevant, but due to physiological constraints – e.g. muscle/tissue recoil – or setup calibration) in order to normalize for potential speaker-specific differences in airflow (i.e. differences in speakers' vocal tracts):

$$(1) \qquad \frac{\text{Nasal airflow value}}{\text{Nasal airflow value + Oral airflow value}}$$

Nasal airflow ratio will be presented in section 3 along with the raw nasal airflow values when pertinent. Graphing was made using splines in the R package *ggplot2*.

3. RESULTS

Table 1 presents the averaged duration values for each vowel type. Contrary to what is expected, oral vowels are longer, on average, than TNVs. The qualitative observation of the duration values per word, per vowel quality, and per participant did not reveal any particular tendency with regard to the average duration of the different vowel types (only tendencies regarding the speaker-specific speech rates were observable). Let us also recall that the nasal murmur of TNVs was not included as part of the vowel for reasons that were given earlier, which may have an influence on the presented results.

Table 1: Average duration values for each vowel type (in ms – standard deviations are given between parentheses).

Vowel type	Duration
TNV	140 (47.7)
HNV	133.5 (40.6)
Oral	144.9 (46.7)

Figure 1 shows the average values of nasal airflow ratio and nasal airflow by vowel type through time across all participants in the study. TNV nasal airflow ratio and nasal airflow values diverge (on average) from HNVs starting at around 50% of their normalized duration until after vowel offset (to the right of the vertical grey dashed line). Oral vowels seem to display minimal nasal airflow values across their duration. Note that the nasal airflow ratio of oral vowels rises after vowel offset, which is possibly due to a major decrease in oral airflow as the vowel is followed by a stop consonant. It is also worth noting that nasal airflow ratio value and raw nasal airflow values seem to behave in similar ways, which further justifies the use of nasal airflow ratios to study the aerodynamics of nasal(ized) vowels.

Figure 1: Averaged nasal airflow ratio (top graph) and nasal airflow values (bottom graph) across participants for each vowel type.

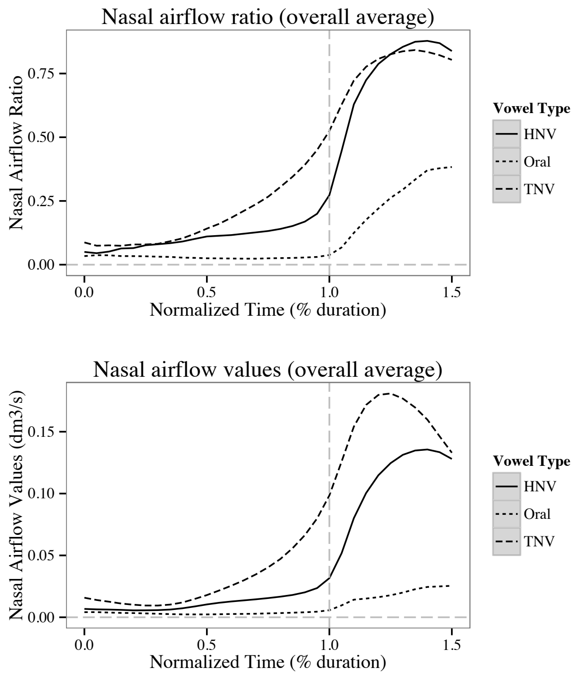

Figure 2: Different patterns of nasal airflow ratio in BP from three individual speakers.

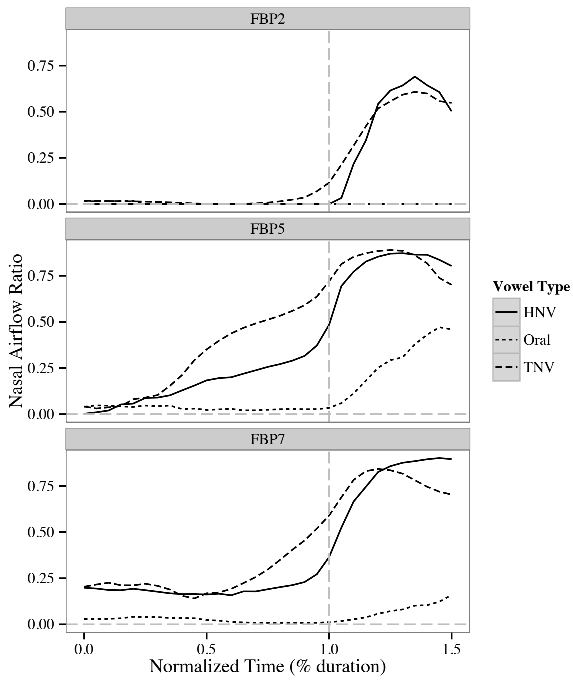

Figure 2 shows the patterns of nasal airflow ratio for three participants in the study. These are considered representative of tendencies observed across participants. Also note that in order to classify the participants depending on their pattern of nasal airflow, observation of the raw airflow values was necessary.

Participant FBP2 (upper panel in Fig. 2) displays minimal airflow ratio for HNVs and oral vowels throughout the duration of the intervals, and an increase in nasal airflow ratio of TNVs starting at around 80% of the intervals' duration. Nasal airflow ratio starts increasing after vowel offset for HNVs. That is, TNVs are nasalized late, while HNVs are not nasalized (as oral vowels). This is observed for five participants in the study.

The second pattern of nasal airflow ratio (3 participants), observed on FBP5's data (middle panel in Fig. 2), shows a cline of nasal airflow ratio for both TNVs and HNVs, with a steeper increasing curve for TNVs between 30% and 50% of duration. Nasal airflow ratio continues to increase after vowel offset for both vowel types. Oral vowels display minimal nasal airflow ratio throughout their duration, which increases after vowel offset (several factors may explain this phenomenon, e.g. decrease in oral airflow and ratio calculation, air leakage from the velopharyngeal port, etc.). Hence, TNVs and HNVs are nasalized throughout their duration, perhaps more for TNVs than HNVs.

The third (lower) panel in Fig. 2 shows another observed pattern of nasal airflow ratio where a plateau is present for the first part of the TNVs and HNVs (3 participants). Nasal airflow ratio starts to increase after 50% of duration for TNVs, and after 80% for HNVs. The characteristic property of this pattern is the presence of a plateau for at least part of the duration of the vowels, which means that nasalization begins early in the interval.

Overall, speaker-specific variability seems to characterize the aerodynamics of TNVs and HNVs in BP. Despite the classification that was proposed, most participants displayed individual characteristics of nasal airflow ratio and this is hypothesized to play a role in determining the status of vowel nasality in BP, as explained in the following section.

4. DISCUSSION AND CONCLUSION

The duration results that were presented in the preceding section show that oral vowels were longer, on average, than TNVs (around 5 ms), which goes against the "two-time-units" explanation. This suggests that stressed oral and nasal vowels are not differentiated with regards to duration in BP, and that nasal vowels do not necessarily possess two time units as suggested in previous literature.

Concerning the aerodynamic data, a cline-like pattern of nasal airflow can be generally observed for TNVs and HNVs in BP, which in turn suggests that both vowel types are the result of a phonetic rule of nasalization in this language, according to Cohn [5]. Consequently, TNVs are not considered phonological in BP from this point of view. The analysis proposed by Mattoso Camâra Jr. [10] (that TNVs are underlyingly formed by a sequence of an oral vowel followed by a nasal consonant) finds support in the collected data.

Moreover, it has often been said that the production of TNVs in BP is variable across phonological contexts and speakers ([14], [17]), and this is confirmed by the presented results with a substantial number of participants. Without completely excluding the possibility that TNVs are contrastive in BP, their variability across participants suggests that the opposition between TNVs and HNVs is not always robust (e.g. patterns 1 and 3). As suggested in [2], speaker variability is central to the initiation of sound change (from a coarticulation rule to a speaker-controlled rule). This suggests that the phonologization of vowel nasality in BP has been initiated, starting from the exaggeration of a phonetic property and the variability across speakers, but has not reached a fully contrastive status for all speakers.

Consequently, it is suggested that TNVs are on their way to becoming phonological in BP as (1) most authors recognize the existence of extensive nasalization in certain contexts, (2) individual speaker variability is important, but there remain differences between TNVs and HNVs in BP, and (3) *phonologization* theories predict the occurrence of an intermediate stage (exaggeration of the phonetic property [8] or important speaker variability [2]) for the establishment of a contrast, which seems to fit the collected data. Differences between TNVs and HNVs may then emerge from the nearly contrastive status of vowel nasality in BP.

This is presented as a tentative hypothesis in order to reunite the theories on the status of nasal and nasalized vowels in Portuguese, meaning that TNVs are neither phonetic nor phonological, but at a stage of evolution where they are in between. Namely, variability is still important and present, but they possess several common characteristics with vowels that are the result of phonological rules of nasalization (e.g. in certain contexts in English, or French nasal vowels; see [5]).

Finally, as suggested by the problems in investigating vowel nasality in BP underlined in previous literature and the results of the current experiment, the status of vowel nasality in BP cannot be considered other than ambiguous. Taking into account the possibility that these vowels are in an intermediate stage of evolution towards becoming phonological appears to be a reasonable solution to the problem.

7. REFERENCES

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