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Progressive Vowel Nasalization in Brazilian Portuguese: A Preliminary Analysis

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Abstract: Much of the discussion regarding vowel nasality in Portuguese has revolved around the phonetic and phonological description of the set of contrastive nasal vowels. Although the importance of non-contrastive vowel nasality is well recognized, nasalized vowels have generally received much less attention in the literature. This is especially true in the case of progressive nasalization, which has generally only received passing mention. Previous research, however, has suggested that certain vowels may be strongly affected by progressive nasalization, sometimes even reaching higher levels of nasal energy than found in contrastively nasal vowels. The purpose of this study is to provide a preliminary analysis of progressive nasalization in Brazilian Portuguese (BP), and specifically to answer the following questions: 1) Do high levels of progressive nasalization normally occur in BP in post-nasal, syllable-final tonic vowels (i.e., NV$C)?; 2) Is the level of nasalization conditioned by vowel quality and/or the place of articulation of the preceding nasal consonant?; 3) What are the phonetic differences between nasal and nasalized vowels?; and 4) Is there evidence of variation in progressive nasalization according to extralinguistic variables?

Keywords: Brazilian Portuguese/português brasileiro, phonetics/fonética, phonology/fonologia, progressive nasalization/nasalização progressiva, vowel nasalization/nasalização vocálica

Introduction

Vowel nasalization has played an important role in the history of the Romance languages and is particularly salient in French and Portuguese, the only two descendants of Latin to contain contrastive nasal vowels. Although the diachronic and synchronic characteristics of vowel nasality in French have generally received more attention in the literature (Sampson 1999), Portuguese also presents a wealth of interesting phenomena to be studied.

Portuguese vowels—excluding diphthongs—can be grouped into three general categories when considering nasality:

1. Oral vowels: /i, e, ɛ, a, ɔ, o, u/
   (*quita*, *sede*, *queda*, *cata*, *cota*, *todo*, *escuta*)
2. Nasalized vowels (non-contrastive): [ĩ, ẽ, ɛ̃, ã, ɐ̃, ɔ̃, õ, ũ]
   (*acima*, *quema*, *meta*, *mata*, *cama*, *como*, *moto*, *fuma*)
3. Nasal vowels (contrastive): [ĩ, ẽ, ɐ̃, õ, ũ][1]
   (*quinta*, *tento*, *tanto*, *conto*, *fundo*)

1 Previous research has shown that the distinction between the mid open vowels and the mid closed vowels is nuetralized for Portuguese nasal vowels (Clegg and Fails 1984; Sampson 1999).

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Compared with French, Portuguese nasal vowels present lower levels of nasal energy (Sampson 1999), but even so, nasality is much more significant in Portuguese than in other Romance languages such as Spanish.

Scholarship on vowel nasality in Portuguese has focused on the phonemic status of the nasal vowels. Some researchers propose a separate set of nasal vowel phonemes (e.g., Head 1963; Pontes 1972, qtd. in Fonseca 1984), while others view nasality as a suprasegmental phoneme (e.g., Hall 1943, qtd. in Fonseca 1984), and yet others support a biphonematic approach in which nasal vowels are the result of a V + N sequence (Trager 1943; Reed and Leite 1947; Mattoso Câmara 1953; Morais Barbosa 1961; Mateus 1975, all qtd. in Fonseca 1984) or adopt other theories (e.g., Parkinson 1983). The biphonematic approach has traditionally been the most widely adopted, but a more recent trend has been to apply the principles of articulatory phonology to Portuguese nasal vowels, with insightful results (e.g., Albano 1999; Medeiros 2007; Oliveira and Teixeira 2007). No general consensus has been reached as of yet on the topic.

An in-depth discussion of the debate on the phonemic status of Portuguese nasal vowels is beyond the scope of this article;[2] however, it is important to note that, regardless of whether or not they are considered independent phonemes, Portuguese nasal vowels do contrast with oral vowels at a surface level. This can be seen in pairs such as *caça* ~ *cansa* or *mato* ~ *manto*. These oppositions can occur both word-finally (e.g., *lã* 'wool' ~ *lá* 'over there') and word-internally (e.g., *mansa* 'meek, fem.' ~ *massa* 'mass, dough').

From a phonetic standpoint, nasal vowels in Portuguese show an increase in nasality across production, moving from a more oral to a more nasal state (Lacerda and Head 1962; Sampson 1999). When preceding a stop consonant, these vowels tend to be followed by a brief nasal coda which is homorganic with the stop; however, such segments do not appear with as great a frequency before other types of consonants (Sousa 1994; Sampson 1999; Medeiros 2007), indicating that their presence or absence is primarily the result of coarticulation. Research on European Portuguese (EP) (Galvão 1998) has shown that the high vowels [ĩ] and [ũ] present the highest levels of nasal energy—followed in descending order by [ẽ], [ɐ̃], and [õ]—and that front vowels tend to be more nasal than back vowels. Stressed vowels have been shown to be more nasal than unstressed vowels (Moraes 1997), and nasal vowels tend to have a longer duration than oral vowels (Sousa 1994; Medeiros 2006). Significant work has been dedicated to describing the spectrographic evidence of vowel nasality in Portuguese;[3] however, an analysis of that research is outside the bounds of this study.

Although the literature on the phonetic aspects of Portuguese nasal vowels provides very useful insights into the nature of those vowels, it is important to recognize that the characteristics of nasal vowels can vary across dialects and speakers (Sampson 1999; Azevedo 2005; Lovatto et al. 2007), and that much more research is needed to gain a clearer picture of variation in the characteristics of nasal vowels in Portuguese.

2 For the interested reader, Rothe-Neves and Reis (2012) provides a very useful bibliography.

3 See Sousa (1994) and Seara (2000) for a more in-depth discussion.

In contrast with the case of nasal vowels, significantly less attention has been dedicated to examining Portuguese nasalized vowels, despite their importance in the language's sound system. Any vowel which comes in contact with a nasal consonant can be nasalized to some extent, and it has been shown that nasalized vowels can present levels of nasality similar to their nasal counterparts (e.g., Lacerda and Head 1962; Moraes 1997; Fails 2011). Moraes and Wetzels (1992) note that regressive nasalization occurs most strongly in stressed vowels or in pretonic vowels derived from tonic vowels (e.g., *cano* [kɐ̃nu] → *caninho* [kɐ̃niɲu]), and propose based on their results that nasalized vowels tend to have a briefer duration than both nasal and oral vowels. However, Moraes and Wetzels's results are based on recordings from just two speakers from Rio de Janeiro, and as with the nasal vowels, more research is needed to understand the phonetic characteristics of nasalized vowels.

Variationist studies of Portuguese vowel nasalization are scarce, but there are some indications that, at least in the case of Brazil, higher levels of nasal energy in nasalized vowels are associated with lower levels of education (Tlaskal 1980, qtd. in Sampson 1999), and that differences in contextual nasality are important for understanding variation across speakers and dialects (Shaw 1986; Moraes and Wetzels 1992; Azevedo 2005). Brazilian Portuguese (BP) appears to present higher levels of contextual nasality than does EP, but no data is available regarding other varieties of the language.

Much of the literature discussing nasalized vowels in Portuguese has focused on regressively nasalized vowels (e.g., *c<u>a</u>ma*, *<u>a</u>no*, etc.), leaving any substantial discussion of progressive nasalization to the side.[4] This may be due, in part, to the fact that, in contrast with some regressively nasalized vowels (Moraes 1997), progressively nasalized vowels appear to be the result of purely coarticulatory processes, and do not appear to be perceived as nasal by native speakers. One important reason for this may be that speakers tend to perceive vowel nasality in cases where nasal energy increases across production (Sampson 1999). Thus, progressively nasalized vowels—which show decreasing levels of nasality across production—would not be perceived as nasal, although their levels of nasality may be high. Progressive nasalization does receive passing comments in the literature, but only two studies actually provide any data regarding the phenomenon.

The first of those studies was carried out by Lacerda and Head (1962), in which the authors examined vowel nasality in EP. Lacerda, a native EP speaker, was recorded producing a set of target words placed in carrier sentences. The recordings were made using an instrument (the *pneucromográfico*) that allowed the authors to analyze the levels of nasal

4 For example, see the brief discussions in Lipski (1975), Cagliari (1981), and Medeiros (2007).

and oral energy separately. Results of the study showed what Lacerda and Head term "considerable" levels of progressive nasalization in postnasal tonic and atonic vowels. The nasal energy generally continued for the duration of the vowel, decreasing over time, with some of the vowels presenting a final spike in nasal energy as they ended. Postnasal, tonic vowels tended to be less nasalized than their atonic counterparts, and the levels of nasalization appeared to be comparable between regressively nasalized vowels, progressively nasalized vowels, and fully nasal vowels. The most important difference between nasal and regressively nasalized vowels on one hand and progressively nasalized vowels on the other was that nasal and regressively nasalized vowels increased in nasal energy over their duration while progressively nasalized vowels decreased in their nasal energy.

Although Lacerda and Head's (1962) results provide a useful starting point for understanding progressive nasalization in Portuguese, there are some important limitations to point out. First, the small sample size of one native speaker of EP makes it very difficult to generalize any of the results across other speakers of EP or other varieties of Portuguese. Second, the set of target words only allowed for the analysis of /a, e, o/ in postnasal position, meaning that we have no understanding of how the other vowels behave when preceded by a nasal consonant. Finally, the results are presented in impressionistic terms (e.g., *minimal*, *medium*, or *maximum* are used to describe the level of nasalization), which complicates the interpretation of the data. Lacerda and Head's study does not provide definitive answers about Portuguese progressive nasalization, but it does contribute to an initial understanding of the phenomenon. The authors themselves call for more work to be done to better understand progressive nasalization in Portuguese.

Notwithstanding Lacerda and Head's (1962) remarks on the need for more work on progressive nasalization, the literature over the following decades remained largely silent on the subject. It was not until Fails (2011), almost fifty years Lacerda and Head's study, that any further empirical data was gathered. Fails compared levels of nasalization in Mexican Spanish and BP, and presented evidence that post-nasal, syllable-final tonic vowels (especially the high front vowel /i/) may be strongly affected by progressive nasalization in BP. See, for example, Figure 1, which comes from Fails's study. The image shows that in the production of *mito*—in both Spanish and Portuguese—the nasal energy of the vowel immediately following the nasal consonant remained extremely high, similar to the fully nasal vowels. Unfortunately, as is the case with the previous study, Fails's observations were limited to a single native speaker, and because the primary purpose of his study was not to examine progressive nasalization, it is difficult to draw any conclusions from the few cases that arose in his dataset.

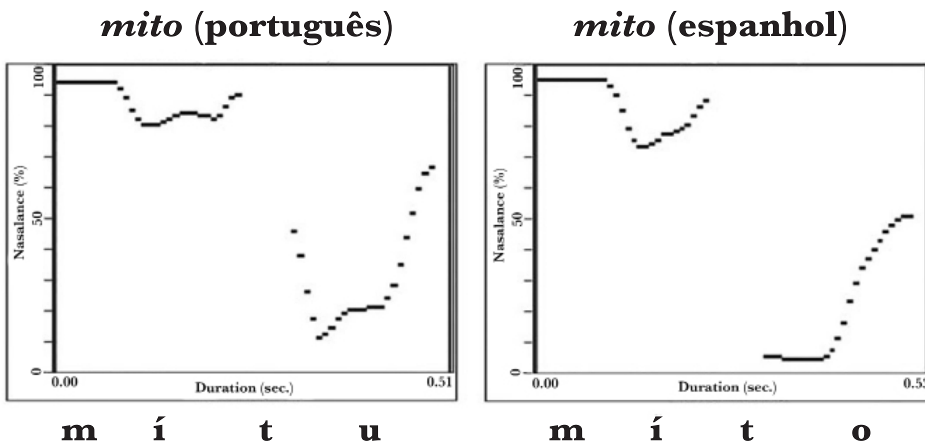

Figure 1. Progressive Nasalization in *mito* (PO) and *mito* (SP) (Fails 2011)

The results presented in Lacerda and Head (1962) and Fails (2011) are not only interesting for the data they provide regarding progressive nasalization in different varieties of Portuguese—they also have potential significance for our understanding of the nature of the Portuguese nasal vowels. Take, for example, the opposition between the words *mito* 'myth' and *minto* 'to lie, 1st per. sing.' Traditional analyses might suggest that the difference between the words lies in the contrast between an oral /i/ in *mito* and a nasal /i/ in *minto* (described as [− nasal] and [+ nasal], respectively); however, the findings of both Lacerda and Head and Fails show that the /i/ of *mito* may present levels of nasal energy similar to those of the nasal /i/ in *minto*, which would mean that a description of [+/− nasal] would not be adequate for describing the difference between the vowels (Sampson 1999). Understanding how such near minimal pairs are differentiated has the potential to shed additional light on the debate surrounding the phonological status of Portuguese nasal vowels as well as on their phonetic description.

Building on the work of Lacerda and Head (1962) and Fails (2011), the purpose of this study is to further explore the role of progressive nasalization in BP and the types of internal and external factors that may influence that process. Specifically, I hope to answer the following questions:

1. Do high levels of progressive nasalization normally occur in BP in post-nasal, syllable-final tonic vowels (i.e., NV$C)?
2. Is the level of nasalization conditioned by vowel quality and/or the place of articulation of the preceding nasal consonant?
3. What are the phonetic differences between nasal and nasalized vowels?
4. Is there evidence of variation in progressive nasalization according to extralinguistic variables?

Methodology

In order to answer these questions, the speech of 19 native BP speakers was analyzed. All participants were between 18–27 years old and were enrolled as degree-seeking students at Brigham Young University (BYU) or as students in BYU's English Language Center. Further demographic information is presented in Table 1.

Table 1. Demographic Description of Sample

	Male	Female	Total
N	10	9	19
Age	22.9	21	22.05
Education			
University	6	5	11
Less than University	4	3	7
Time in United States (Months)	8.4	11.38	9.72
Origin			
São Paulo	3	5	8
Rio de Janeiro	1	2	3
Porto Alegre	1	0	1
Cuiabá	1	0	1
Curitiba	2	0	2
Fortaleza	1	0	1
Brasília	1	1	2

As can be seen in the table, the division between males and females was fairly even in terms of number, level of education, and age, but the female participants tended to have spent a few more months in the United States than the males. The majority of the participants were from São Paulo and Rio de Janeiro (57.89%), and the rest were spread out through the remainder of Brazil, reaching from the Northeast to the far South. Most of the participants had spent less than one year living in the United States.

Participant speech samples were recorded and analyzed using KayPentax's Nasometer.[5] The Nasometer is a special headset which positions a metal plate in between the upper lip and the nose of the wearer. Microphones are positioned on both sides of the metal plate; one captures the acoustic energy coming from the mouth and the other captures the energy coming from the nose. The ratio of nasal to oral energy is captured and transmitted to a computer program which allows for visual and statistical analyses of recordings. An example of the data output can be seen in Figure 2 (as well as in Figure 1), which compares the

5 The Nasometer has also been used by Galvão (1998) and Fails (2011) to study Portuguese vowel nasalization.

words *quita* 'take away, 3rd per. sing.' and *mito* 'myth.' The x-axis represents time and the y-axis represents nasal energy. As there is an increase of nasal energy, the measurement line moves upward. As there is a decrease in nasal energy, the line moves downward. While theoretically a completely nasal consonant would reach a level of 100% nasality, and a completely oral vowel would reach a level of 0% nasality, in practice there are not such absolute results, primarily because, as noted by Fails (2011: 447), some acoustic energy manages to escape through the facial tissues and is picked up by the microphones. Also, research has shown that the velum remains slightly open even during the production of oral vowels, allowing for the presence of nasal energy that normally goes unperceived (Sampson 1999). One benefit of the Nasometer is that it allows for a much more straightforward analysis of nasalization than can be carried out using spectrographic data. Although the Nasometer does present some weaknesses, as will be discussed later, research has shown that it is a valid tool for measuring nasalization (Bae, Kuehn, and Ha 2007).

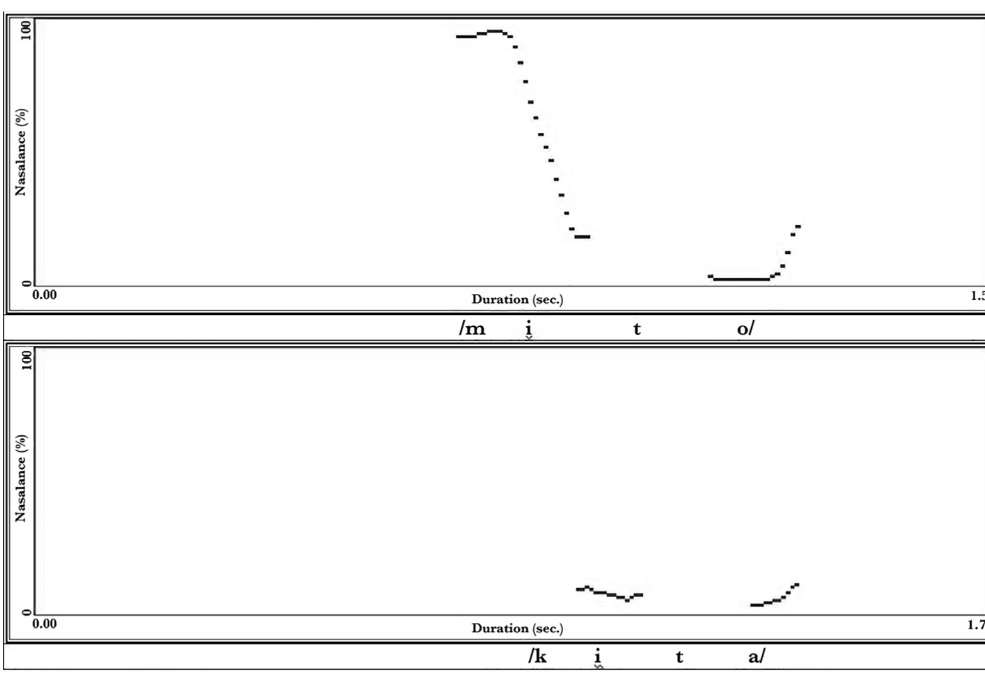

Figure 2. Comparison of *mito* (Top) and *quita* (Bottom)

While wearing the Nasometer, participants were first asked to read a list of words which contained the stressed vowels /a, ɛ, i, ɔ, u/ in between two oral consonants (e.g., *cata*, *queda*, *quita*, etc.). Each participant was then recorded reading a selection of 28 target words which allowed for the production of nearly every vowel[6] preceded by one of the three possible onset nasal consonants, /n, m, ɲ/

6 Because the distinction between the mid open and mid closed vowels is nuetralized for nasal vowels, as previously noted, no distinction between /e/ and /ɛ/ or /o/ and /ɔ/ was used in the selection of the target words.

in the contexts NV$C and NVN$C. Each of those words was recorded separately at conversational speed and with a short delay between recordings to avoid a list effect. Finally, study participants read a set of 20 of the original 28 words, which were organized into near minimal pairs (e.g. *mito* ~ *minto, mato* ~ *manto*). During this stage, participants were asked to differentiate to the degree possible between each of the words in a pair. This was done to see what—if any—characteristics were emphasized in especially careful speech. A total of 58 recordings was created for each participant. The corpus of target words can be seen in Table 2.

Table 2. List of Tokens Read by Study Participants

CV$C

cata, queda, quita, cota, escuta

	NV$C	**NVN$C**
m-	*mato, cometo, mito, moto, mudo*	*manto, cometo, minto, monto, mundo*
n-	*tornado, neto, unido, nodo, desnuda, adivinhado, vinheta*	*tornado, sarneto, unido, nondo, inunda, adivinhando*

Using the Nasometer data, levels of nasalization were compared for oral, nasalized, and nasal vowels. Percentages of nasal energy were measured over the duration of the vowel and at the midpoint. Temporal shifts in nasality were measured by looking at the amount of time the vowel spent decreasing and increasing in nasal energy. Each recording was also examined for evidence of a nasal coda segment between the vowel and the following oral stop. The Nasometer output was also used for measuring vowel duration. Statistical analyses were carried out using the programs STATA and Excel.

Figure 3 presents a labeled Nasometer image which will be useful for understanding some of the terminology used in discussing the results. A brief description of unique terms follows.

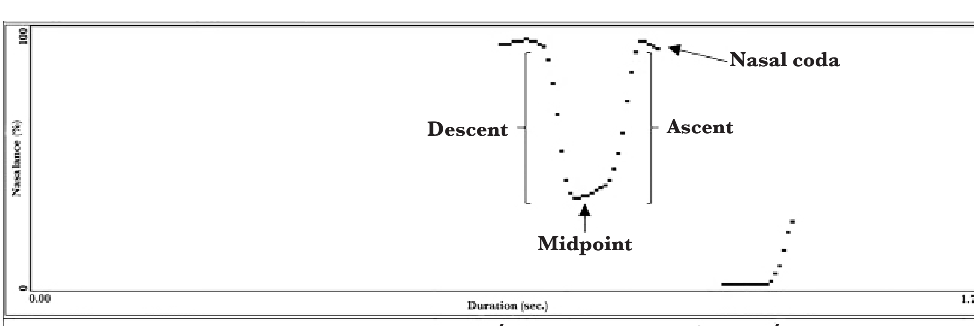

Figure 3. Labeled Nasometer Output for *manto*

Nasal vowel:	For simplicity's sake, I use this term to refer to the stressed vowels found in words like *minto* (i.e., NVN$C).
Nasalized vowel:	Any stressed vowel that has been nasalized as a result of progressive assimilation (i.e., NV$C).
Overall nasality:	The mean of nasal energy across the production of the vowel.
Midpoint nasality:	The percentage of nasal energy at the midpoint of vowel production.
Gradience:	The shifts in nasal energy that occur across the production of the vowel.
Descent:	The drop in nasal energy following the nasal consonant onset.
Ascent:	The rise in nasal energy prior to the following nasal coda and/or oral consonant.

Results

RQ1: Do high levels of progressive nasalization normally occur in BP in post-nasal, syllable-final tonic vowels (i.e., NV$C)?

The data overwhelmingly indicate that progressive nasalization is a categorical occurrence for BP in the context NV$C, but not to the same levels indicated in Fails (2011). See, for example, Table 3, which reports the overall level of nasality as well as steady state and midpoint nasality levels for nasalized and oral vowels. At each measurement point, stressed vowels following a nasal consonant were significantly more nasalized than stressed vowels following an oral consonant ($p < .001$). All of the vowels preceded by a nasal consonant showed evidence of progressive nasalization.

Table 3. Levels of Nasality for Oral and Nasalized Vowels

	Overall	**Midpoint**
Nasalized	45.23%***	42.03%***
Oral	10.31%	8.73%

Note: * = p < .05, ** = p < .01, *** = p < .001

Figure 4 uses 95% confidence intervals to provide another way to look at the statistical difference between the mean nasal energy of oral and nasalized vowels. The circles represent the mean level of nasality at each measurement point, and the bars extending above and below each circle show the expected range of variation. If the range covered by one bar overlaps with that of another bar, it is more likely that the difference between the two could be due to chance and it is therefore not statistically significant. If the ranges do not overlap, the difference is considered to be significant. As can be seen in the figure, there is a wide gap between the nasalized vowels on the left and the oral vowels on the right, indicating a clear statistical difference between the two groups.

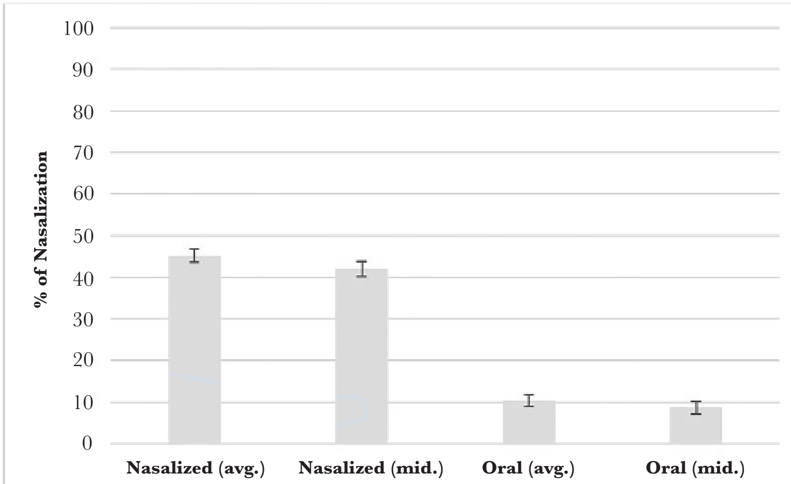

Figure 4. Difference between Nasalized and Oral Vowels (95% CI)

In considering the difference between nasalized and oral vowels, it is also important to look at the factor of gradience, or the temporal shifts in nasality. This concept will be discussed in greater depth when analyzing the difference between nasalized and nasal vowels, but here I would like to point out that the oral vowels showed very little temporal variation in nasality, while the nasalized vowels were generally identifiable by a strong initial level of nasality which sharply dropped before leveling out. This finding supports to some extent the descriptions of Lacerda and Head (1962), although they described a more gradual loss of nasal energy.

RQ2: Is the level of nasalization conditioned by vowel quality and/or the place of articulation of the preceding nasal consonant?

The data clearly indicate a relationship between the level of progressive nasalization and both nasal consonant place of articulation and vowel quality. Table 4 presents an analysis of nasalization by nasal place of articulation. As can be seen in the table, as the place of articulation moves back in the oral cavity—from bilabial to alveolar to palatal—the amount of nasal energy in the following vowel increases. Figure 5 shows that vowels preceded by the palatal nasal consonant /ɲ/ were significantly more nasalized than vowels preceded by the bilabial /m/ or the alveolar /n/.

Table 4. Nasalization by Nasal Consonant Place of Articulation

	m-	**n-**	**ɲ-**
Overall	40.37%	44.43%	51.27%
Mid	38.62%	40.65%	47.18%
Overall r^2	.11		
Mid r^2	.05		

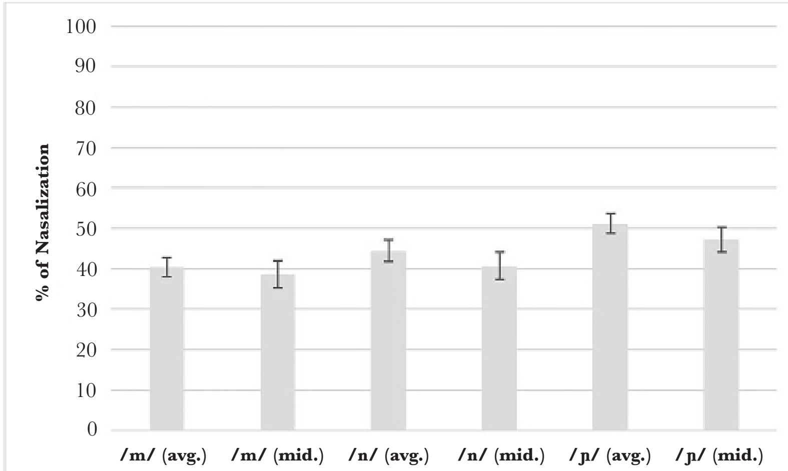

Figure 5. Level of Nasalization by Preceding Consonant (95% CI)

The relationship between vowel quality and level of nasalization was less straightforward. The results presented in Table 5 show that the high front tense vowel /i/ was significantly more nasalized while the mid back vowels /o, ɔ/ were significantly less nasalized than the rest of the vowels. The differences between /a, e, ɛ, u/ were not statistically significant (see Figure 6).[7]

Table 5. Nasalization by Vowel Quality

	a	**e, ɛ**	**i**	**o, ɔ**	**u**
Overall	37.40%	36.26%	47.20%	26.04%	35.01%
Mid	32.92%	36.12%	47.29%	20.40%	31.68%
Overall r^2	.37				
Mid r^2	.41				

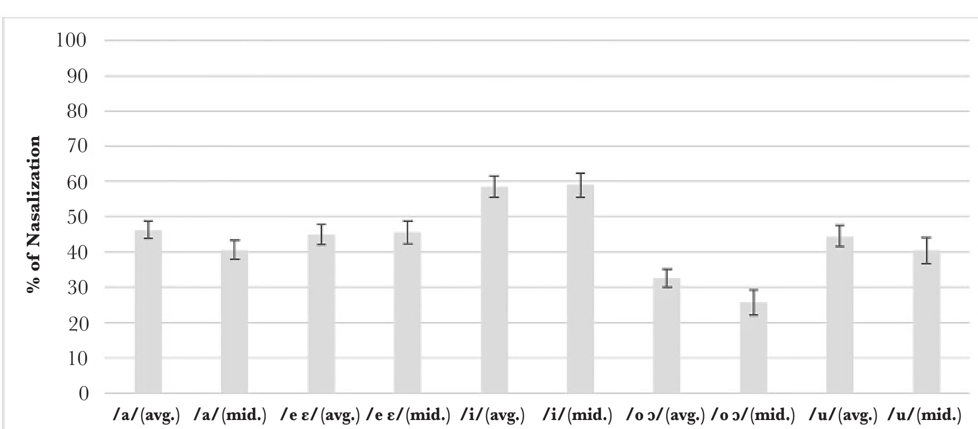

Figure 6. Level of Nasalization by Vowel Quality (95% CI)

7 The R-squared results in Tables 4–5 show that vowel quality (r2 = .37, .41) is a better predictor of the level of progressive nasalization than nasal consonant place of articulation (r2 = .11, .05), though neither of the measurements account for most of the observed variation.

RQ3: What are the phonetic differences between nasal and nasalized vowels?

In order to determine the differences in nasality for each context, I specifically looked at level of nasalization, vowel duration, the presence and duration of nasal codas, and gradience. Tables 6 and 7 present the results of the analysis of level of nasalization and vowel duration. As can be seen in Table 6, nasal vowels presented significantly higher levels of nasal energy than nasalized and oral vowels at every point of measurement. Nasal vowels were also longer than both nasalized and oral vowels, with an average duration of 192 ms as compared to 177 ms for nasalized vowels and 151 ms for oral vowels (see Table 7).

Table 6. Level of Nasalization for Nasal, Nasalized, and Oral Vowels

	Overall	**Midpoint**
Nasalized	45.23%	42.03%
Nasal	72.46%	58.27%
Oral	10.31%	8.73%

Note: The differences in nasality between vowel categories at each point of measurement were significant at p < .001

Table 7. Vowel Duration

	Duration (ms)
Nasalized	177
Nasal	192
Oral	151

Note: The differences in duration between vowel categories were significant at p < .001

In addition to being longer and presenting more nasal energy, nasal vowels also tended to be followed by a nasal coda segment. Out of 229 nasal codas that appeared in the data set, 222 (over 96%) came after nasal vowels. Surprisingly, however, there were some exceptions to this pattern in which nasal codas appeared after a nasalized vowel. Potential explanations for this phenomenon will be discussed in the following section. The nasal codas that appeared after a nasalized vowel were of a significantly shorter duration than those that appeared after nasal vowels (30 ms and 57 ms, respectively).

With regard to gradience, the data showed that nasal vowels in the context NVN$C spent significantly less time losing and gaining nasal energy than did nasalized vowels or oral vowels. Whereas nasalized vowels spent over half of their duration descending in nasality (109 ms out of 177 ms) and less than one fifth of their duration ascending (35 ms out of 177 ms), nasal vowels spent only about a quarter of their duration descending (50 ms out of 192 ms) and close to half of their duration ascending (82 ms out of 192 ms) (see Table 8).

Table 8. Measures of Gradience for Nasal and Nasalized Vowels

	Descent (ms)	Ascent (ms)
Nasalized	109	35
Nasal	50***	82***

Note: The differences in descent and ascent were significant at p < .001

The final stage in examining the distinctions between nasal and progressively nasalized vowels was to look at if/how speakers distinguished between the two when asked to do so as clearly as possible. The only significant changes were in vowel duration and nasal coda duration. Both nasal and nasalized vowels became longer (202 ms and 203 ms, respectively), as might be expected in careful speech, and the nasal coda segments also lengthened to 75 ms.

RQ4: Is there evidence of variation in progressive nasalization according to extralinguistic variables?

In order to answer this question, a multivariate regression was run, which considered the external factors of gender, age, level of education, time in the United States, and origin, as well as the internal factors of vowel quality and nasal consonant place of articulation. The results can be seen in Table 9.

Table 9. Multivariate Regression of Overall Progressive Nasalization

Variables	Coeff.	Std. Err.	p < t	95% Conf. Interval	
Gender	6.48	2.44	**	1.68	11.28
Age	3.00	0.73	***	1.56	4.45
Education	8.63	3.52	*	1.69	15.57
Time in United States	0.04	0.11		−0.19	0.26
Nasal consonant P.O.A.	5.47	0.89	***	3.72	7.22
Vowel quality	−1.69	0.51	**	−2.69	−0.70
Origin: Rio de Janeiro	−5.26	3.50		−12.16	1.64
Origin: Fortaleza	5.81	5.01		−4.06	15.68
Origin: Porto Alegre	−3.72	3.97		−11.55	4.10
Origin: Curitiba	−7.05	2.82	*	−12.60	−1.49
Origin: Cuiabá	−3.95	3.59		−11.03	3.13
Origin: Brasília	−0.63	2.87		−6.28	5.02
Intercept	−40.54				
n	260				
R-squared	0.26				

Note: Demographic information missing for one female participant. Her speech data was included in the overall analysis but was excluded from the analysis of extralinguistic variables. * = p < .05, ** = p < .01, *** = p < .001

As indicated by the $p < t$ values in the table, there was a significant relationship between the levels of overall progressive nasalization and participant age, gender, and education. Older participants produced higher levels of nasal energy than younger participants (3% more nasalization per year increase in age), females produced higher levels of nasalization than males (46.43% and 44.15%, respectively), and those with a university education produced higher levels of nasalization than those without (45.23% v. 44.29%). In the case of participant origin, the only statistically significant relationship appeared in the case of the two speakers from Curitiba, whose nasalized vowels were significantly less nasal than those of the participants from São Paulo (40.23% v. 47.27%). As was previously mentioned, both vowel quality and place of nasal consonant articulation correlated significantly with levels of nasalization.

Discussion

By way of a brief summary, data analyses revealed that:

1. Stressed vowels preceded by a nasal contain significantly more nasal energy than vowels preceded by an oral consonant. However, the level of nasalization is usually less than that found in Fails (2011).
2. The place of articulation of the pre-vocalic nasal consonant does correlate with the level of nasal energy in the vowel—as the place of articulation regresses (bilabial → alveolar → palatal) the vowel becomes more strongly nasalized. Vowels preceded by the palatal nasal /ɲ/ were significantly more nasal than vowels preceded by /m/ or /n/. These results support the comments made by Moraes and Wetzels (1992) regarding the effects of /ɲ/ in cases of regressive nasalization.
3. Vowel quality is also a predictor of the level of nasalization. The vowels /i/ and /o, ɔ/ are, respectively, the most and least susceptible to nasalization, with the other vowels falling in between. Vowel quality is a better predictor of the level of nasal energy than is the nasal consonant place of articulation.
4. There were clear differences between nasal and nasalized vowels. Nasal vowels were significantly more nasal and longer than nasalized vowels, and were normally followed by a nasal coda. Gradience was also shown to be an important distinguishing factor, with nasal vowels spending significantly less time losing nasal energy and significantly more time gaining nasal energy.
5. The extralinguistic factors of age, gender, education, and origin did correlate significantly with levels of progressive nasalization; however, the differences in nasal energy between groups were generally minimal (around 1–2%), and these variables only contribute to explaining a small portion of the observed variation in nasalization (as evidenced by the R-squared value of 0.26).

The reason for the higher levels of nasal energy in the vowel /i/ and in vowels preceded by /ɲ/ is not entirely clear. For Galvão (1998), the levels of nasal energy in /i/ are the result of greater amounts of constriction in the oral cavity for high vowels. Although Moraes and Wetzels (1992) do not give any explanation for the stronger nasalizing effect of /ɲ/, the explanation may lie in the fact that the consonant is a palatal sound, just like /i/. Although all of the nasal stops create a total blockage of the oral cavity, the fact that /ɲ/ creates that blockage nearer the velic opening may play a role in the higher levels of nasality. The low levels of nasal energy in the vowels /o, ɔ/ is likewise unclear, though it is interesting to note that vowels which showed the greatest and least amounts of nasal energy were almost diametrically opposed (high front versus mid back). These results also support the conclusions of Galvão (1998) regarding the nasal energy in EP nasal vowels.

The appearance of nasal coda segments in the context NV$C also needs to be addressed. These codas appeared in a total of 20 cases (just 4% of the time) and always presented a shorter duration than the codas that followed nasal vowels. The source of such segments is unclear. They could simply be the result of the artificial nature and instability of laboratory speech, a misreading of the target word, or a technological failure. Research in the area of articulatory phonology has shown that gestural timing can change with speed of speech (Parrell 2012), and the appearance of nasal codas in the context NV$C could result from gestural instability, with the velum in some cases remaining open throughout vowel production and up to the occlusion gesture for the following oral stop.

Regarding the nasal coda in general, although the presence of a nasal coda was a key to distinguishing between nasal and nasalized vowels in this study, previous research has shown that such segments are generally favored before stop consonants, and are much less likely to appear before other types of consonants (e.g., fricatives such as those found in words like *mansa*, *mancha*) (e.g., Sousa 1994; Medeiros 2007). This strongly indicates that the presence or absence of a surface nasal coda segment cannot be the distinguishing factor between vowels in the contexts NV$C and NVN$C, and that the appearance of any such segment is due to coarticulation. It would be useful for future research to include tokens with a variety of oral consonants to the right of the vowel (e.g., fricatives, liquids, affricates) in order to obtain a better vision of how speakers differentiate between nasal and progressively nasalized vowels in contexts that do not favor the presence of a nasal coda.

The results of the recordings of careful speech also bear mentioning. When speakers were asked to clearly differentiate between nasal and nasalized vowels, the only characteristics that significantly changed were vowel duration and duration of the nasal codas. The lengthening of these segments could be explained simply by a slower rate of speech, as would be expected in careful articulation; however, the lengthening of the nasal coda segments may provide some insight into the presence or absence of a nasal coda at the phonological level. If such a segment were to exist at some underlying level, we might expect speakers to emphasize that element in careful speech, perhaps by modifying its duration. Although speakers significantly lengthened the nasal codas in careful speech (from an average of 56 ms to an average of 73 ms), this result may have been influenced by orthography.

Finally, regarding the influence of extralinguistic factors on progressive nasalization, it is worth observing that the results of this study contradict Tlaskal (1980, as qtd. in Sampson 1999), in that higher levels of nasalization were correlated with the higher level of education. It is also interesting to note that speakers from Porto Alegre and São Paulo presented the strongest levels of progressive nasalization, in contrast with observations made by Moraes and Wetzels (1992) that levels of contextual nasalization generally decreased moving from the north to the south of Brazil. These results may indicate some difference between regressive and progressive nasalization, or they may be an aberration due to the reduced sample size. Despite these contrasts with previous studies, the results presented here should be taken as an indication that more research is needed on the subject of variation in BP vowel nasalization rather than as any sort of definitive conclusion.

Limitations

In considering the results of this study, it is also essential to discuss the limitations which may or may not have played a role in the data. First, the speech samples that were gathered were clearly laboratory speech, and artificial to some extent. Part of this problem is a natural extension of using the Nasometer, which does not lend itself to natural speech situations; however, some methods could be implemented to circumvent this problem. Following Kelm (1989), for example, it would be useful to have speakers read the token words in carrier sentences at varying speeds, thus allowing for an examination of both rapid and careful speech styles. However, a second limitation may be found in the written nature of the tokens themselves. Speakers may have been influenced by the presence of the orthographic *n* in words like *minto, manto, monto*, etc., and in the future it may be useful to explore the use of pictures or other visual stimuli to avoid the influence of orthography.

Another important limitation to this study is the reliance on Nasometer data. While the Nasometer provides a visually simple and appealing method for studying nasalization, it only indicates changing levels of nasal energy in correlation—more or less—with the lowering and raising of the velum, and provides no information about formant movements, which in the literature have been shown to be important for identifying nasality in vowels (e.g., Sousa 1994; Sampson 1999; Seara 2000). I am currently working on a spectrographic analysis of this same dataset using Praat, which I believe will help provide a more detailed answer to the research questions in this article.

Beyond carrying out a more detailed spectrographic analysis, future research should also approach this problem from a perceptual standpoint. Although many of the differences found in this article were statistically significant, statistical significance does not necessarily indicate perceptual importance. Some very interesting perceptual work on BP nasal and nasalized vowels has been carried out by Moraes (2003) and others,[8] and similar techniques could be applied to the problems discussed here. It would be particularly useful to look at how speakers perceptually differentiate between regressively and progressively nasalized vowels.

Finally, the relatively small and homogenous sample group makes it difficult come to any general conclusions regarding variation in progressive nasalization. As noted above, with such a reduced sample size the probability that any trends in the data are due to chance is elevated. Future studies should not only include a larger sample, but should also look to carry out more comparative work. Besides examining differences in nasalization across dialectal regions in Brazil, more work is needed to understand nasalization in other varieties of Portuguese, especially those outside of Brazil and Portugal. Areas of language contact may be especially interesting to study.[9]

Conclusion

This study joins a growing body of work in helping to clear up some of the gaps in our knowledge regarding the phonetic and phonological nature of nasal and nasalized vowels in Portuguese. The results presented here are important in that they provide the first detailed examination of progressive nasalization in BP; however, they also provide a testament to the complex nature of vowel nasality. Perhaps the most useful conclusion that can be made is that nasality is a dynamic and complex phenomenon that needs to be examined from multiple perspectives in order to be accurately understood and described. Further research on Portuguese nasal vowels is needed, not only to answer extant questions specific to Portuguese, but also to understand the place of nasal vowels within the larger framework of the Romance languages.

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8 See, for example, Brito (1975); Stevens, Andrade, and Viana (1987); Seara (2000); and Hajek and Watson (2007).

9 See, for example, Castañeda-Molla (2011) on nasalization along the Brazil-Uruguay border.

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