INTERSPEECH 2017
August 20–24, 2017, Stockholm, Sweden

Perception and acoustics of vowel nasality in Brazilian Portuguese

Luciana Marques[1], *Rebecca Scarborough*[1]

[1]University of Colorado at Boulder, USA
luciana.marques@colorado.edu, rebecca.scarborough@colorado.edu

Abstract

This study explores the relationship between identification, degree of nasality and vowel quality in oral, nasal and nasalized vowels in Brazilian Portuguese. Despite common belief that the language possesses contrastive nasal vowels, literature examination shows that nasal vowels may be followed by a nasal resonance, while nasalized vowels must be followed by a nasal consonant. It is argued that the nasal resonance may be the remains of a consonant that nasalizes the vowel, making nasal vowels simply coarticulatorily nasalized (e.g. [1]). If so, vowel nasality should not be more informative for the perception of a word containing a nasal vowel than for a word containing a nasalized vowel, as nasality is attributed to coarticulation. To test this hypothesis, randomized stimuli containing the first syllable of words with oral, nasal and nasalized vowels were presented to BP listeners who had to identify the stimuli original word. Preliminary results demonstrate that accuracy decreased for nasal and nasalized stimuli. A comparison between patterns of response to measured degrees of vowel acoustic nasality and formant values demonstrate that vowel quality differences may play a more relevant role in word identification than type of nasality in a vowel.

Index terms: vowel perception, vowel nasality, acoustic nasality

1. Introduction

While it is commonly accepted that Portuguese has contrastive nasal vowels, an examination of the relevant phonetic and phonological literature shows different positions on the matter. Phonetically, nasal vowels can be followed by a nasal resonance, called nasal appendix [2]. This nasal appendix may be the remnant of a historical nasal consonant that nasalizes the vowel [1]. If that is the case, then nasal vowels may actually be coarticulatorily nasalized, just like the nasalized vowels that occur before full nasal consonants in Portuguese, as products of an allophonic rule of vowel nasalization. Regardless of phonemic status, though, it is agreed that both nasal and nasalized vowels are heavily nasalized, with similar degrees of velopharyngeal opening [3] and nasal airflow, though perhaps with differences towards the end in degree of nasality [2].

A novel approach to the question of the contrastive status of these vowels lies in assessing how listeners of Brazilian Portuguese perceive and interpret vowel nasality. It is known that listeners use segmental phonetic features as cues for speech perception. In terms of feature contrastiveness, it is known that if a given feature is not contrastive in a language, it will likely be used to either anticipate an upcoming segment or be perceptually factored out due to rules of coarticulation, for example. Contrastive features will not be useful to anticipate an upcoming segment and will not be factored out as product of coarticulation (e.g. [4, 5]). In terms of identification, a contrastive feature should always map into words containing the contrastive feature.

In Brazilian Portuguese, perceptual evidence suggests that vowel nasality is contrastive, but not without reserve. Moraes [3] shows that splicing a nasalized vowel in an oral context yields the percept of a word containing a nasal vowel, but mostly for the low vowel. Brito [6] reported that a nasal vowel was only perceived as such at about 52% of the time in isolation contexts, with non-low vowels yielding lower ratings than the low vowel. The author attributes this difference to changes in vowel quality when the low vowel is nasal. The same vowel quality effect is reported by Seara [7], who found that manipulated mid-front vowels were not perceived as nasal, likely due to the diphthongization that this vowel undergoes when nasal. Thus, it seems that vowel nasality and vowel quality *both* influence the perception of nasality in Brazilian Portuguese, but it is hard to differentiate the nature of these influences and how they bear on the issue of the phonological status of nasal vowels in the language. This is especially true for non-low vowels, where previous formant analysis [8, 9] shows small to no differences between oral, nasal and nasalized vowels.

The present study explores the factors influencing the perception of vowel nasality in Brazilian Portuguese by relating patterns of vowel identification with patterns of vowel nasality and vowel quality. To this end, a word identification experiment was conducted with partial-word stimuli containing oral, nasal and nasalized vowels. Analyses of acoustic vowel nasality and vowel formants were also performed to examine the relation between patterns of word identification and vowel nasality and formant profiles.

2. Word identification experiment

The identification task consisted in presenting the first syllable of words containing oral, nasal and nasalized vowels to Brazilian Portuguese speakers who had to identify the original word. Considering phonemic nasal vowels, two questions emerge: Can BP listeners accurately distinguish these vowels from oral and nasalized vowels? And if so, what is this distinction based on – nasality only, or is there something else? In other words, we ask what it is about nasal vowels that make them distinctive.

Monosyllabic stimuli were presented randomly to 43 participants at UNICAMP, São Paulo, Brazil. The stimuli were generated from 30 words (10 with oral vowels, 10 with nasal vowels, 10 with nasalized vowels) recorded by two native speakers. The original words were all disyllabic, but only the first syllable through the end of the first vowel was used for the stimuli, as illustrated in Table 1. Upon hearing a stimulus, participants had to press the key corresponding to the word they thought the stimulus came from. On the computer screen, three choices were presented: words with

http://dx.doi.org/10.21437/Interspeech.2017-570

oral, nasal and nasalized vowels of the same vowel quality.

Table 1: *Word template and cut stimulus. V≈ means nasal vowel; V~ means nasalized vowel.*

Word	Stimulus
CV.CV	CV
CV≈.CV	CV≈
CV~.NV	CV~

2.1. Results

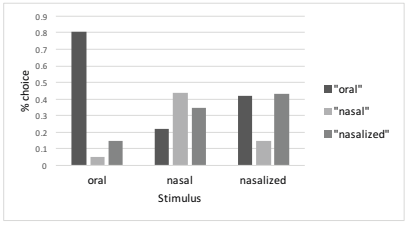

Figure 1. *Responses by stimulus vowel nasality.*

Listeners identified the oral words accurately (80%); however, accuracy decreased substantially when the stimulus was either nasal or nasalized. This finding is supported by a logistic mixed-effects model of accuracy, with vowel nasality and quality as factors (nasal est. = -3.6694, $p < 0.005$; nasalized est. = -2.5175, $p < 0.005$). Participants correctly identified nasal vowel word for nasal stimuli 43%, and nasalized vowel word for nasalized stimuli also 43% of the time. Patterns of mistakes show that nasal vowels can be confused with nasalized vowels (35% nasalized word answer for nasal stimuli), while the latter are mostly confused with oral vowels (42% oral word answer for nasalized stimuli).

An analysis of possible factors contributing to this pattern of confusion suggests a possible role for vowel quality role, given the differences across vowels, as presented in figure 2.

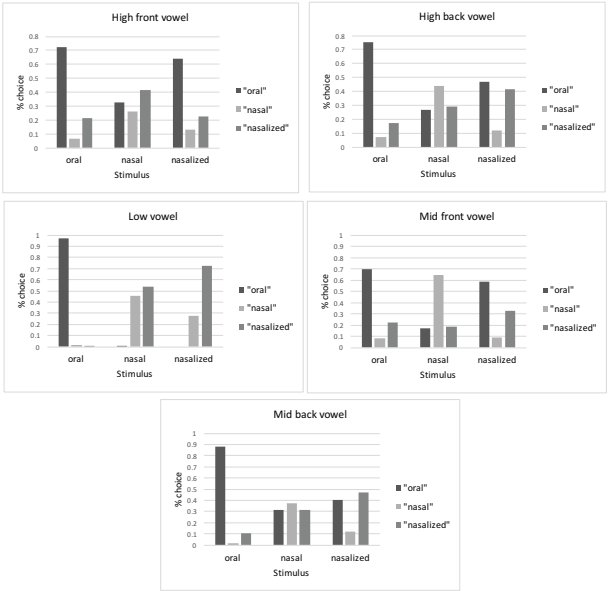

Figure 2. *Patterns of word identification, by vowel.*

The low vowel response pattern shows the nasal vowel is often identified as the nasalized one (53% of the time vs. 45% accurate nasal word answers), but not the reverse, i.e., nasalized vowels are not identified as nasal. For the mid-front vowel, the nasal vowel is accurately identified most of the time (65%), but the response patterns shows nasalized and oral vowel confusion, with 59% of nasalized stimuli being identified as oral, but not the reverse. The mid-back vowel response pattern shows the nasal vowel is confused with both the oral and the nasalized vowel, so that answers were close to chance level (31%, 37% and 31% oral, nasal and nasalized word responses, respectively); the nasalized vowel was often confused with the oral vowel (41% oral and 47% nasalized word responses, respectively).

Like the mid vowels, the high front nasalized vowel is confused with the oral vowel (65%), but not the reverse. Unlike the mid front, however, the high nasal vowel is confused with the oral *and* the nasalized vowels, yielding responses higher than the correct one (33%, 26% and 41% for oral, nasal and nasalized words, respectively). The high back nasalized vowel is also misidentified as oral (47% vs. 41% correct identification as nasalized). The nasal vowel, however, yielded the second most correct responses (44%), a pattern unlike any other vowel quality examined. These identification patterns are summarized in Table 2.

Table 2. *Patterns of confusion for nasal and nasalized vowels divided by vowel quality.*

Vowel	Nasality	Confusion
a	V≈	nasal or nasalized
	V~	nasalized or nasal
e	V≈	no confusion
	V~	nasalized or oral
i	V≈	nasalized or oral
	V~	nasalized or oral
o	V≈	nasal, nasalized or oral
	V~	nasalized or oral
u	V≈	no confusion
	V~	nasalized or oral

All the non-low nasalized vowels were, to different degrees, confused with the oral vowel, as expected since nasality in a nasalized vowel should not be inherent. For the nasal vowels, however, the low, mid back and high front nasal vowels were confused with the nasalized vowels; the high back and the mid front were not. These patterns of response have led us to consider that each vowel quality either has a specific pattern of nasality, or there are vowel-specific, formant properties that listeners attended to when identifying words. We examine these possibilities in the following sections.

3. Acoustic nasality and formants

Nasality is examined through two related acoustic correlates: A1-P0 and A1-P1 [10], calculated as the difference between the amplitude of the first formant spectral peak, A1, and the amplitude of a nasal peak, P0 (around 250 Hz) or P1 (around 950Hz). With velopharyngeal coupling, A1 amplitude decreases and P0 and P1 amplitudes increase. Thus, the more nasalized a vowel is, the smaller the difference between these peaks (A1-P0 or A1-P1). A1-P0 is used for non-high vowels, where A1 and P0 are distinct; A1-P1 is used for high vowels where A1 would be at a similar frequency as P0.

A1-P0 and A1-P1 were automatically measured at 8 different time points in the vowels of 10 oral, 10 nasal, 10

nasalized words produced by 6 native BP speakers. The different time points showed how nasality unfolded over time. Time points 7-9 were averaged and used in separate linear mixed models, one for each vowel category, with A1-P0 or A1-P1 as dependent variables, vowel nasality as independent variables, and speaker as random variable. Formant values, F1 and F2, were automatically measured in the middle of each vowel in the same words. Separate linear mixed models with F1 or F2 as dependent variables, vowel nasality as independent variables, and speaker as random variable were fit, one for each vowel quality. Nasality and formant values analysis results are presented by vowel quality.

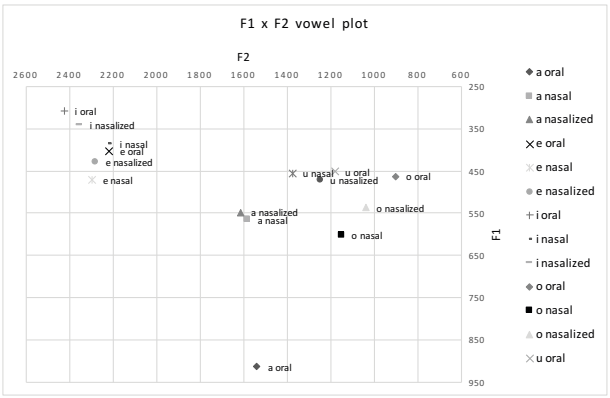

Figure 3. *F1xF2 scatterplot for all vowels.*

3.1. Low vowels

Figure 4 shows the low vowels' A1-P0 nasality profiles (note that greater nasality is indicated by lower A1-P0). The arrows represent the direction in which acoustic nasality increases. There is a notable difference between the oral (triangles) and the non-oral low vowels, with greater A1-P0 for the oral vowels (17 dB A1-P0) than for the other two categories (6 dB A1-P0 for nasal and 9 dB A1-P0 for nasalized), indicating that they are comparatively less nasal (nasal $t(36) = -5.186$, $p < 0.005$; nasalized $t(36) = -4.273$, $p < 0.005$). The nasal and nasalized vowels are not statistically different from each other ($t(36) = 1.543$, $p = 0.1323$).

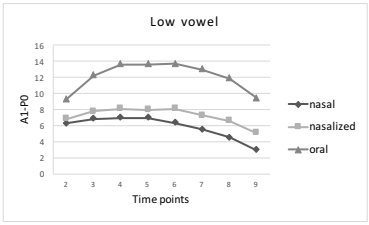

Figure 4. *A1-P0 profiles for the low vowel.*

Nasal and the nasalized vowels formant values are very close to each other, but quite distant from the oral low vowel, in terms of F1, so that the nasal and nasalized vowels are not statistically different from one another ($t(36) = -0.687$, $p = 0.497$), but are from the oral vowel ($t(36) = -14.01$, $p < 0.005$; $t(36) = .14.69$, $p < 0.005$, for the nasal and nasalized vowel, respectively). Both nasality profiles and formant values are consistent with the identification patterns found, in that the nasal vowel yielded both nasal and nasalized responses, while the oral vowel yielded only oral responses. However, neither nasality profiles nor formant values explain why the nasal vowel is confused with the oral vowel.

3.2. Mid front vowels

Figure 5 shows the mid vowels A1-P0 nasality profiles. The mid-front oral vowels were again less nasal (10 dB A1-P0) than the nasal (3 dB A1-P0) and the nasalized (7 dB A1-P0) vowels ($t(36) = -5.975$, $p < 0.005$ and $t(36) = -3.188$, $p < 0.005$, respectively), but for these vowels, the nasal and nasalized vowels also differ from each other ($t(36) = 2.943$, $p < 0.05$).

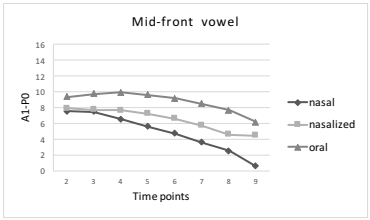

Figure 5. *A1-P0 profiles for the mid front vowels.*

In terms of formants, the mid-front vowels show a bigger difference in F1 between the nasal and the other two vowels (oral $t(34) = -3.773$, $p < 0.005$; nasalized $t(34) = -2.309$, $p < 0.05$), while oral and nasalized vowels are not statistically different from each other ($t(34) = 1.585$, $p = 0.123$). So, while the nasality pattern does not reflect the identification patterns response, this pattern does parallel differences in vowel quality, more specifically F1.

3.3. High front vowels

Figure 6 shows the high front vowels A1-P1 nasality profiles. The high front oral, nasal and nasalized vowels have endpoint average A1-P1 values of 45dB, 32 dB and 37dB, respectively. (A1-P1 values are not directly comparable to A1-P0 values due to inherent amplitude differences related to spectral tilt.) The differences among all three vowels are significant, oral from nasal and nasalized ($t(36) = -6.708$, $p < 0.005$; $t(36) = -3.656$, $p < 0.005$) and nasal from nasalized ($t(36) = 3.053$, $p < 0.005$). Given these differences, we would have expected more accurate responses than actually observed for these vowels.

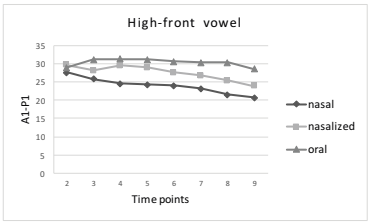

Figure 6. *A1-P1 profiles for high front vowels.*

The oral and nasalized high front vowel formants are closer to each other than the oral is to the nasal vowel in F1, as evidenced by the statistical differences (nasalized $t(36) = 1.076$, $p = 0.2895$; nasal $t(36) = 2.52$, $p < 0.05$).

For high front vowels, vowel formants (F1 in particular) seem to be able to explain the pattern of response found, as oral and nasalized vowels are close to each other but different from the nasal vowel. This proximity may explain why participants answered oral word more than nasalized word for nasalized vowels, as both the oral and the nasalized vowels are acoustically close to oral (see [8, 9] for formant comparisons). However, it does not explain why the nasal vowel was identified as nasalized and oral rather than nasal.

3.4. Mid back vowels

Figure 7 shows A1-P0 values for mid back vowels. Among the mid-back vowels, the nasal vowel (7 dB A1-P0) is significantly different from the oral (14 dB A1-P0) and nasalized (11 dB A1-P0) vowels ($t(36) = 3.593$, $p < 0.005$; $t(36) = 2.093$, $p < 0.05$), but the oral and the nasalized ones are not ($t(36) = -1.5$, $p = 0.1431$). Therefore, we would have expected confusion between nasalized and oral vowels only.

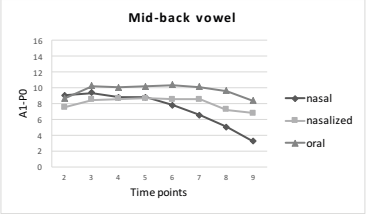

Figure 7. *A1-P0 profiles for the high front vowels.*

The mid-back vowels are fairly distinct from each other with respect to F1 and F2. Nasal and nasalized vowels differ from the oral vowel and from each other with respect to F1 (nasal $t(36) = 5.082$, $p < 0.005$; nasalized $t(36) = 2.413$, $p < 0.05$; nasal vs. nasalized $t(36) = -2.669$, $p < 0.05$). In terms of F2, the oral vowel is different from the nasal vowel ($t(36) = 3.056$, $p < 0.005$), but not from the nasalized one ($t(36) = 1.614$, $p = 0.1161$); the nasal and the nasalized vowels are not different from each other ($t(36) = -1.442$, $p = 0.1589$).

Here, nasality rather than formants explains the confusion between nasalized and oral vowels, as the nasalized vowel was identified as oral almost as often as nasalized; however, it does not explain the essentially at-chance levels of identification for the nasal vowel, as this vowel is clearly different from the other two in terms of both acoustic nasality and vowel formants (F1).

3.5. High back vowels

It is difficult to interpret the relation between high back vowel identification and A1-P1, as the nasality patterns are unclear, as can be seen in figure 8.

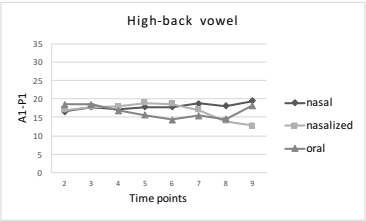

Figure 8*: A1-P1 profiles for the high back vowels.*

None of the vowels are statistically different from each other (oral vs. nasal $t(36) = 1.733$, $p = 0.092$; oral vs. nasalized $t(36) = 0.069$, $p = 0.945$; nasal vs. nasalized $t(36) = -1.664$, $p = 0.1056$). Therefore, we would have expected no discernible pattern of identification.

The identification patterns for these vowels are like the mid-front vowels', suggesting that vowel quality may influence differentiation among the three types of vowel. Although the nasal vowel is again the most distinct of the three with respect to F2, none of these vowels are statistically different from one another (oral vs. nasal $t(36) = 1.546$, $p = 0.1315$; oral vs. nasalized $t(36) = 0.301$, $p = 0.7655$).

Thus, for the high back vowels, neither acoustic nasality nor vowel formants provide a reasonable explanation for the identification patterns. This could be because the measures failed to capture the relevant cues that participants use for identification, or it could be due to failed A1-P1 measures resulting from the proximity of P1 to F2.

4. Conclusions

The goal of the current study was to examine the factors influencing vowel identification patterns in Brazilian Portuguese. While it was expected that accuracy in nasal vowels responses would be high, identification patterns showed confusion for both nasal and nasalized vowels, which were different depending on vowel quality and nasality type.

Nasalized vowels (except for the low vowel) were mostly confused with oral vowels, as expected, based on their status as members of the same phoneme. These confusions also suggest the importance of vowel quality as a robust perceptual cue: nasalized and oral vowels were often similar in terms of formants. But these vowels were different in their degrees of nasality. In fact, nasalized and *nasal* vowels had similar degrees of nasality. If nasality were inherent to the contrast between vowels, then it would likely be used as the cue to differentiate nasalized and oral vowels over vowel quality.

Nasal vowel identification patterns were more variable, as shown in table 3. This variation too is better explained by vowel formants than by nasality patterns.

Table 3: *Nasal vowel identification patterns of confusion and their relation to nasality and formants.*

Vowel	Confusion	A1-P0(1)	F1
a	nasal vs. nasalized	=	=
e	no confusion	≠	=
i	nasalized vs. oral	≠	=
o	all	≠	≠
u	no confusion	≠	≠

Nasality in nasal vowels, however, is not unrelated to formant patterns. For example, the large differences in the low vowels' formants are explained by the interaction between oral and nasal resonances [7, 8, 9]; the change from oral to nasal helped in the identification task. Since the change in quality is due to nasality, it is hard to differentiate vowel quality effect from nasality effect. The place where we could have seen just a nasality effect is in the high front vowels where there is little change in formants, as reflected in the confusion patterns. Thus, nasality, when it does not drastically affect vowel quality, seems to have little effect in distinguishing nasal vowels from oral or nasalized. It seems that, for a vowel to be perceived as contrastively nasal, there must be an associated effect on formant patterns. Nasal vowels, then, are contrastive because the nasality leads to vowel quality changes that make the vowels distinctive.

5. References

[1] M. Mateus, *Aspectos da Fonologia Portuguesa* (Textos de Linguística 6). Lisbon, Portugal: INIC, 1982.

[2] Moraes, J. "Produção E Percepção De Vogais Nasais," in *Gramática Do Português Culto Falado No Brasil: A Construção Fonológica Da Palavra*. M. Abaurre, Ed., São Paulo, Brazil: Contexto, 2013, pp. 95-112.

[3] B. Medeiros, “Nasal coda and vowel nasality in Brazilian Portuguese,” in *Selected Proceedings of the 5th Conference on Laboratory Approaches to Romance Phonology,* M. Scott, Ed., Sommerville: Cascadilla Proceedings Project, 2011, pp. 33-45.

[4] A. Lahiri, and W. Marslen-Wilson, “The mental representation of lexical form: A phonological approach to the recognition lexicon,” *Cognition*, vol. 38, n. 3, pp. 245-294, 1991.

[5] P. Beddor, and R. Krakow, “Perception of coarticulatory nasalization by speakers of English and Thai: Evidence for partial compensation,” *Journal of the Acoustical Society of America*, vol. 106, n. 5, pp. 2868-2887, 1999.

[6] G. Brito, G. “The perception of nasal vowels in Brazilian Portuguese: a pilot study,” C. Ferguson et al. *Nasalfest: Papers from a Symposium on Nasals and Nasalization*. Stanford University. Language Universals Project, pp. 49-59, 1975.

[7] I. Seara, “Analysis acoustic-perceptual of nasality of the vowels in the Brazilian Portuguese,” PhD dissertation, Dept. Linguistics, Universidade Federal de Santa Catarina, Florianópolis, Brazil, 2000.

[8] E. Sousa, E, “Para caracterização fonético-acústica da nasalidade no português do Brasil,” M. A. thesis, Instituto de Estudos da Linguagem, Unicamp, Campina, Brazil, 1994.

[9] M, Jesus. “Estudo fonético da nasalidade vocálica,” in C. Reis, Ed. *Estudos em Fonética e Fonologia do Português.* Belo Horizonte, Brazi*l:* Fale-UFMG, 2002, pp. 205-22.

[10] M. Chen, “Acoustic correlates of nasalized vowels,” *Journal of the Acoustical Society of America*, vol. 102, n. 4, pp. 2360-2370, 1997.