The Acoustics of Voiceless Nasal Vowels

Ryan K. Shosted

Department of Linguistics, University of Illinois, Urbana-Champaign;
rshosted@uiuc.edu

Introduction

Can nasal vowels, like oral vowels, devoice? While phonemic voiceless nasal consonants are found in a variety of languages, phonemic voiceless nasal vowels appear unattested (Ladefoged & Maddieson, 1996; Crothers et al., 1979). Typological evidence also suggests that phonological processes of vowel devoicing eschew nasal vowel targets. Of the 55 languages with voiceless vowels or vowel devoicing processes catalogued by Gordon (1998), only four of these also have phonemically nasal vowels. These are Bagirmi, Montreal French, Mbay, Mixtec, and Brazilian Portuguese. While it is clear that nasal vowel devoicing is impossible in French and Portuguese, a review of the other languages reveals no positive evidence that it is possible (or impossible) for nasal vowels to be realized without vocal fold vibration.¹

This paper asks whether acoustic factors may present barriers to the perception of voiceless nasal vowels. A series of perceptual experiments using whispered nasal and oral vowels of Brazilian Portuguese will test whether “devoiced” nasal vowels are more difficult to identify than “devoiced” oral vowels. The acoustic characteristics of whispered nasal vowels will also be examined to see if they provide any clues as to the typological rarity of nasal vowel devoicing.

Perception Experiment

A female speaker of Brazilian Portuguese was recorded pronouncing oral/nasal minimal pairs in whispered and modal voice. Since nasal vowel devoicing is impossible via phonological rule in Brazilian Portuguese, whispered voice was used as a surrogate for voicelessness. During whisper, the vocal folds assume a slightly different configuration than during voicelessness. However, both phonation types share a lack of vibration at the glottis, the most relevant feature for the present study. All tokens had either word-final stress or were monosyllabic and terminated with either a nasal or oral vowel.

In Experiment 1, the final vowel was excised and a Hamming taper was applied. Two stimulus classes resulted from this process: natural whispered nasal and natural whispered oral tokens. Using Burg’s LPC method, 16-coefficient acoustic filters were created for all the vowels. These filters were then applied to a white noise source to produce four classes of synthesized tokens: whispered nasal, whispered oral, modal nasal, and modal oral. The final two classes were used as controls. In Experiment 2, whole word tokens were excised and amplitude-normalized. Three native listeners of Brazilian Portuguese participated.

In the first experiment, male and female subjects listened to 276 natural and synthesized vowel tokens along with fillers. The tokens were presented in randomized order using E-Prime. Each vowel extract was played for the subject once, and the subject was asked to choose whether s/he heard /a e i o/ or /u/. In the second experiment, subjects heard whispered versions of 20 oral/nasal minimal pairs, accompanied by fillers (832 stimuli in total). Subjects heard each stimulus and chose whether it ended in a nasal or oral vowel.

Perceptual sensitivity and response bias were calculated (Macmillan & Creelman, 2005). Experiment 1 suggests that perceptual sensitivity to vowel category is degraded by nasality in the absence of a voicing source and that the perception of mid-vowels /e o/ suffers more than the perception of the corner vowels /a i u/. Experiment 2 suggests that the nasal/oral distinction is perceptually robust in whispered vowels. Based on the Acoustic Theory of Speech Production (Fant, 1960) and changes to F1 predicted by nasal coupling, it is tempting to wonder whether the distinction between oral and nasal whispered vowels is most salient for vowels with maximal or minimal F1, /a i u/, and less salient for those vowels with intermediate F1 values, /e

¹ Nasal vowel devoicing is impossible in Brazilian Portuguese only because nasal high vowels do not occur in unaccented final position (note, however, that non-high nasal vowels can occur in unaccented final position, e.g. órfã ‘orphan,FEM’). In Montreal French, nasal vowel devoicing is impossible because only high vowels devoice and there are no high nasal vowels. Thus, a proper test case remains elusive.
o/, as observed in Experiment 1. This result, however, did not obtain in Experiment 2.

**Acoustic Measures**

Whispered oral, whispered nasal, modal oral, and modal nasal vowels were compared to one another with regard to their duration. While voiced nasal vowels are typically longer than voiced oral vowels (Whalen & Beddor, 1989), this distinction appears to be lost when the pairs are whispered.

![Figure 1: Boxplots show the duration of whispered versus modal, nasal and oral vowels in Brazilian Portuguese.](image)

**Conclusion**

Despite the fact that voiceless nasal vowels are not difficult to produce, they are uncommon—if not entirely unknown—in phonological systems. This study shows that the quality of whispered vowels is more difficult to distinguish if the vowel is nasal than if it is oral. It also shows that duration contrasts, important for cueing the difference between oral and nasal modal vowels, may be lost when the vowels are whispered. To the extent that whispered vowels can provide a window to the acoustics and perception of voiceless vowels, these results suggest an acoustic-perceptual explanation for the absence of voiceless nasal vowels.

**References**


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1 Ohala (1983: 202-206) has argued that vowel devoicing is an aerodynamic outcome relating to tongue constriction and concomitant increase in back pressure. For this reason, he argues, high vowels are common targets. Because pressure is continuously vented during the production of nasal vowels, one might well agree with him that there is little likelihood of a nasal vowel undergoing epiphenomenal devoicing. However, while high-vowel devoicing is clearly preferred, there are still languages (like Tongan) that devoice low vowels despite a lack of supraglottal pressure increase (Gordon 1998: 98, ff. 106). Thus, one cannot rule out voiceless nasal vowels on aerodynamic grounds alone.