A NASOFIBERSCOPIC STUDY OF NASALIZED DIPHTHONGS IN BRAZILIAN PORTUGUESE

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ABSTRACT

This study analyses the velum movement in Brazilian Portuguese nasalized diphthongs. The study was made with a nasofiberscope to study the size and the movements of the velopharyngeal opening during the production of monosyllabic words containing oral and nasal diphthongs [ej], [ẽj̃], [aw] and [ãw̃]. The data show that the velum lowering is gradual and that different movements are observable in the velopharyngeal opening. These data confirm previous observations showing that there are several phases in Brazilian Portuguese nasalized diphthongs. The velum lowering has three different phases. The findings show that: the anticipatory velum lowering is variable, while the closing movement is stable and the presence of the nasal appendix appearing in all the nasalized segments.

Keywords: Brazilian Portuguese, Nasalization, Velum Movement, Fiberscope and Nosography.

1. INTRODUCTION

This is an ongoing research that provides nasofibrescopic data of typologically rare and understudied nasalized diphthongs from Brazilian Portuguese (BP). This study follows the structure and the methodology of Lovato et al. [9] to analyze the general characteristics and the articulatory velum movement during the speech production. The complexity of this kind of analysis limits the amount of data to study the nasality and the nasal diphthongization, even though it is important to the field. The contribution to BP is to infer some answers to elucidate the variability of these phonemes and its phonology, production and characterization. The BP has 4 decreasing nasal diphthongs: /ãj̃, õj̃, ãw̃, ũj̃/ and five nasal vowels /ã, ẽ, ĩ, õ, ũ/. According to Cagliari [5], all the nasal vowels and the nasal diphthongs are diphthongized in BP. There is a nasalized diphthongization assimilation process that is favorable for emerging a homorganic nasal consonant in coda [5]. In the *Paulistano* variant, the front diphthong nasal vowel /ẽ/ is diphthongized as [ẽj̃ⁿ]. The tongue rises towards the palatal region after reaching the vowel target. The glide emerges, resulting in a palatal constriction [6]. Thus, the nasal diphthongization produces a spurious diphthong. To control the tongue movement, we analyzed the front and back oral diphthong /ej/ and /aw/. The /ãw̃/ is a controller to understand the tongue and velum movements. The back nasal diphthong is produced as [ãw̃ᵑ]. So, the set of coarticulatory adjustments results in a homorganic nasal consonant that assimilated the place of the articulation of left context boundary, emerging then the nasal appendix [3] [5] [6] [7] [9] [11] [12]. Thus, to describe and analyze the phonological opposition: /aw/ vs. /aw̃/ and /ej/ vs. /ẽ/ and its phonetic realization: [ãw̃ᵑ] and [ẽj̃ⁿ], we used a fiberscope and photo-nasography (PNG) to provide images of the nasal cavity to answers some research questions as: (a) to evaluate the opening and the closing velopharyngeal port trajectories, during the nasal diphthongization; (b) to understand the velum adjustment and the role of the lateral walls movement (PNG data) during the production of nasality; (c) to describe the velum movement in correlation of the acoustical signal to the front nasal vowel and the back nasal diphthongs.

2. MATERIALS AND METHODS

2.1. Speaker

A 30-years old female was recorded. She is a native speaker from the *Paulistano* variant of BP.

2.2. Material

Twenty monosyllabic words were recorded, opposing oral and nasal sequences of diphthongs, including minimal and near pairs from BP. All the words have a CVG and a CṼG̃ sequence during the production, which includes the nasal vowels, oral and nasal diphthongs. These words were recorded in the carrier sentence: "*Digo* ___ *todo dia*" ([dʒigʊ__todʊ dʒiɐ] – "Say ____ every day"). We set a voiceless dental consonant /t/ after the target word to minimize the articulatory boundary effects on the coda. The *corpus* is similar to previous works [7]. The participant repeated 2 times the stimuli in a normal speech rate. Data were processed with

MATLAB through homemade software and *Praat*.

Table 1: Front and back oral and nasal diphthongs. Stimuli are in Portuguese and glosses are in English.

Diphthongs			
Front			
Oral		**Nasal**	
[dej]	*gave*	[tẽj̃]	*have*
[sej]	*known*	[sẽj̃]	*without*
[nej]	*Ney*	[nẽj̃]	*neither*
[hej]	*king*	[hẽj̃]	*REM*
[lej]	*law*	[bẽj̃]	*good*
Back			
Oral		**Nasal**	
[paw]	*wood*	[pãw̃]	*bread*
[maw]	*bad*	[mãw̃]	*hand*
[taw]	*these*	[tãw̃]	*so*
[saw]	*salt*	[sãw̃]	*sane*
[kaw]	*lime*	[kãw̃]	*dog*

2.3. Data Acquisition

The data were collected in the European Hospital Georges Pompidou in Paris. For being an invasive experiment, a doctor performed the recording section and the speaker was under utopian anesthesia. To visualize the nasal cavity, a *3mm* flexible silicone tube was inserted on the speaker nostrils into the middle turbinate. A micro-camera (Olympus OTV-SF) on the fiberscope recorded the videos; capturing 25 images per second, resulting in one picture every 10*ms*. The phototransistor with a mini cold light illuminated the nasal cavity and its walls, as shown in the figure 1 and 2.

Figure 1: Detail of the camera insertion in the nasal cavity. Nasofiberscope video-endoscopy position to data collection. Adaptation of Amelot [2].

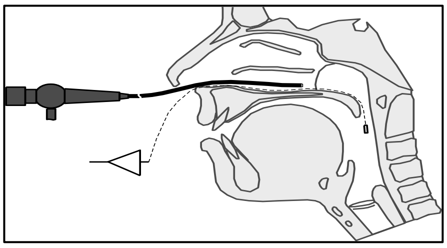
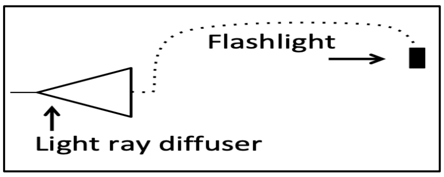


Figure 2: Illustration of the light diffusion inside the cavity. Adaptation of Amelot [2].

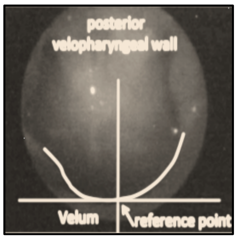


Inside the nasal cavity, the flashlight was placed 2*cm* away from the image sensor, as shown in figure 2. The speaker nasal cavity length is *14cm*. The fiberscope position does not interfere on the velum movements. To record the acoustic data, a microphone was attached to the endoscope. These data were digitalized and sent to a computer. The acoustic signal was sampled at 48 kHz with resolution of 16 bits.

2.4. Measurements

The parameters to characterize the set of velum movements are: temporal duration (*ms*) and spatial velum movement (*px*). Through synchronization between the fiberscope images and the acoustic signal, it was possible to quantify the velum movement and the distance between the lateral pharyngeal walls (LPW). We also analyzed the video separately from the acoustic signal. From the videos, we extracted the frames to measure image-by-image of the soft palate movement. This was possible through the variation between intensity and the trans-illumination that passed over the nasal cavity. We also created a default measurement to represent the reference point. This point was set during the breath phase, when the soft palate is in the lowest aperture, as shown in figure 3.

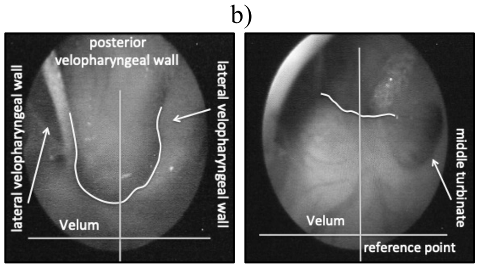
Figure 3: A frame showing the reference point (Rf), according to Amelot [2]. Anterior view from the nasal cavity.



To evaluate the soft palate movement and the LPW data, we measured the delta between lowest and highest points. In figure 4, we can see the difference between the velum position and the Rf point, the lowering (a) and raising (b) movements.

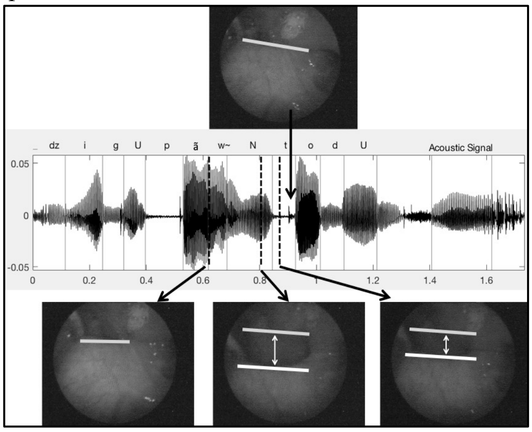
Figure 4: Example of velar measurement. The Frames are showing the velum lower and higher points [2]. Anterior view from the nasal cavity.

a) b)



From the correlation between the fiberscope and acoustics, it is possible to indicate, on the waveform, the opening and closing velum's movement, as shown in the figure 5 below:

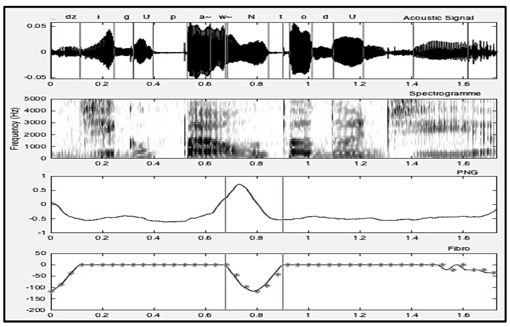
Figure 5: The alignment among nasofiberscope frames and acoustic output data. Target word: "*pão.*"



From the spectrogram we made the acoustic segmentation and extracted the acoustic durations. To simplify the analyses, the nasal diphthongs were segmented into three phases. (1) From the nasal vowel release since the (2) the nasal glide, when the F2 moves towards to F1 and the higher frequencies moves towards the lower frequencies or, to back nasal diphthongs. Already for the front nasal vowel, the F2 moves toward F3. (3) The appendix nasal is the last part of the nasal diphthong and is represented for the nasal murmur (N). That is characterized by reinforcement of the lower frequencies, and the higher frequencies are amortized, as shown in figure 6 (a and b):

Figure 6: The alignment among data. (a) Waveform, (b) spectrogram, (c) LPW movement (d) lowering and closing velum movements. Target word: "*pão.*"

a)
b)
c)
d)



In (c), we can see the LPW movement (PNG). The peak on this line indicates de most distance between the LPW. In (d), the vertical lines show the beginning and the ending of the velum movement. On the graphic, the gestural goes thought the drawdown and the valley. This movement set refers to the lowering movement, the maximal velum aperture and the velum's raising. We can see at the figure 6 the illustration of the extraction of velum movement.

3. RESULTS AND DISCUSSION

3.1. The nasal appendix

The acoustics analysis shows that the nasal appendix (represented as N) is present in all the cases. Its duration had a total μ = 109 *ms* and σ = 26 *ms* (n = 20). The mean of the total acoustic duration of nasal segments is bigger than the oral counterpart, corroborating with previous studies [7] [9] [10]. In [9] the nasal appendix appeared in 85% and its duration is similar, in the context of occlusive coda boundary.

Table 2: Acoustic Duration (*ms*) of front and back oral and nasal diphthongs: Mean (SD) (n=10).

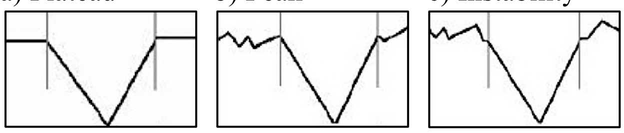
	Diphthongs			
	Vowel	**Glide**	**Appendix**	**Total**
[ẽj̃]	98 (10)	77 (18)	111 (20)	286 (20)
[ãw̃]	102 (20)	95 (16)	108 (33)	305 (32)
[ej]	157 (32)	95 (24)		252 (46)
[aw]	149 (17)	130 (30)		279 (25)

3.2. The velum movement

The beginning of the velum lowering had three different behaviors start to open [2], as: (a) plateau, (b) peak before opening or (c) instability (over vibratory movement). This gestural manner could be illustrated according to Amelot [2], in the figure 7:

Figure 7: Illustration of the velum behavior. The grey lines represent the beginning and the ending of the velum. Adaptation of Amelot [2].

a) Plateau b) Peak c) Instability



The percentage of the velum oscillation to (a) is 80% of the cases. The small opening and closing movements represented on (b) and (c) are 10% of the cases, respectively (n=20).

Table 3: Temporal coordination among fiberscope data and LPW data, to soft palate displacement. Front and back nasal diphthongs. Mean (SD) *ms* (n = 8).

	Velum Duration	
	Fiber	**LPW**
[ẽj̃]	356 (83)	342 (50)
[ãw̃]	328 (57)	324 (26)

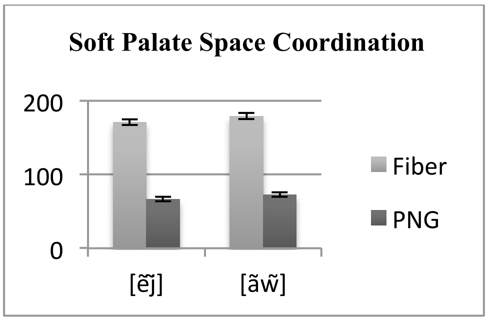
The velum trajectory has a homogenous duration for the velum and LPW displacement. However, there is a difference between the measures of the soft palate lowest point (fiberscope data) and movement of the LPW (PNG data), as the following table 4.

Table 4: Spatial coordination among fiberscope data and LPW data. Velum displacement. Front and nasal diphthongs: Mean (SD) *px* (n = 10).

	Velum Valley / Peak	
	Fiber	LPW
[ẽj̃]	- 171 (29)	66,5 (7)
[ãw̃]	- 179 (41)	72,8 (5)

There are a few differences between the values of front and back nasal diphthong. This difference is bigger comparing the data of the spatial variation amount between fiberscope and LPW. Through this graphic below is possible to visualize this spatial variation.

Graphic 1: Spatial velum movement among fiberscope data and PNG data to soft palate displacement. Front and nasal diphthongs: Mean (SD) *px* (n = 10).



The PNG variation shows the movement of the LPW is similar and, this determines the correct global velum movement [7]. This movement can change the segment quality, on this data LPW movement is not variable, but with nasal vowels is variable [1] [2].

3.3. Temporal Correlation: acoustic and velum duration

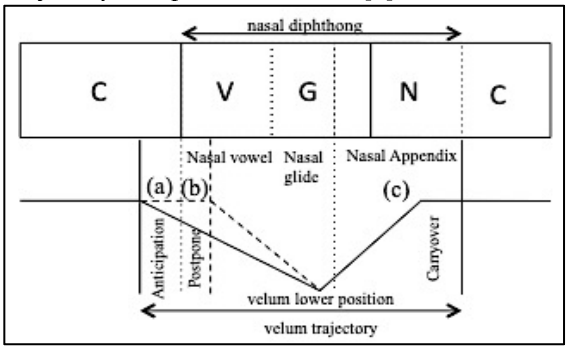
The correlation between the nasal vowel onset and the velum lowering gesture can be divided in two behaviors: when the velum movement starts before (anticipation) or after (postpone) of the nasal vowel release. The delta between the acoustic durations of the oral and nasal gestures exposes that the beginning of soft palate lowering/opening is variable. On the table 5, we do not add the duration values of the item *mãe* or *nem* because the velum is already lowered. To *mãe*, the means are: (a) 182 (72) *ms* to fiberscope data and (b) 240 (56) *ms* to LPW (n=2). To *nem*, the mean for the 2 occurrences are: (a) 232 (17) *ms* to fiberscope data and (b) 245 (18) *ms* to LPW (n=2).

Table 5: Delta of the temporal coordination. Opening: nasal vowel onset and velum lowering (*ms*). Carryover: appendix duration and the velum offset. Mean (SD).

	Velum Lowering – Opening (n=8)			
	Anticipation		Postpone	
	Fiber	LPW	Fiber	LPW
[ẽj̃]	67 (53)	103(111)	40 (30)	16(1)
[ãw̃]		116 (95)	59 (49)	26 (24)
	Velum Closing – Carryover (n=10)			
	Fiber	LPW	Fiber	LPW
[ẽj̃]	84 (66)	16(1)	84 (65)	27 (9)
[ãw̃]	135 (46)	26 (24)	135 (54)	30 (11)

The figure 8 has illustration of the temporal gestural coordination of nasal coarticulation. According to Lovato [9], our results could be schematized as:

Figure 8: Illustration of the temporal velum trajectory. Adaptation of Lovato [9].



This illustration shows that there is a gestural synchrony between oral and nasal articulation to mark the end of the nasal diphthongization in the coda. There is no coordination between the velum lowering and the nasal vowel onset (a, b). The offset articulation (c), the relation between the acoustic nasal appendix, the velum closing and the LPW distance is more stable and coordinated in our data, due to the left boundary /t/.

4. CONCLUSION

We conclude that in BP, nasal diphthongization is the result of the timing variation of the velum mechanism of opening and closing movements, associated with the tongue movement [7]. The coordination between oral and nasal gestures affects the realization of nasal vowels and diphthongs. Even if the nasal vowel is considering as a monophthong, both types of segments have a nasal appendix as an outcome of the tongue raising and a velum carryover articulation. Our data show that the velum trajectory and the narrowing of the LPW are important parameters to velopharyngeal control. While the anticipatory velum lowering is variable, the closing is a controlled.

5. REFERENCES

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