# COMPATIBILITY OF FEATURES AND PHONETIC CONTENT. THE CASE OF NASALIZATION

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## ABSTRACT

This paper reviews data on the compatibility of nasalization with manner and voicing features. First, it addresses the relations between nasalization and manner features and discusses the scales of nasalization spreading in the light of aerodynamic and acoustic factors. Second, it examines the interdependent relations between voicing and nasality. These observations lead to propose disfavoured sequences involving nasals. The paper argues that aerodynamic and acoustic interactions between features determine their likelihood to combine within segments and when segments follow each other.

**Keywords:** Nasalization, voicing, aerodynamics, cooccurrence restrictions, sequential restrictions.

## 1. INTRODUCTION

This paper focuses on the interaction of nasalization with other features within and across segments. Along the lines expressed by Ohala [6], it argues that abstract feature specifications, e.g. [+nasal], [-voice], [+cont], devoid of detailed phonetic content cannot adequately account for how features combine into segments and how they affect each other when they occur in contiguous segments, e.g. in context-dependent phonological processes or sound change. Specifically, it argues that restrictions on the combination of features, in particular the feature [nasal], are determined by phonetic factors.

Current phonological approaches view independent articulators, such as the oro-nasal valve, the laryngeal valve and the oral articulators as belonging to different nodes or tiers. Since velic opening and closing is (mostly) independent of the movements of the oral articulators and the action of the vocal folds, different velum positions (open/closed) can in principle occur simultaneous to different articulatory constrictions and glottal states. All the logical possibilities of combination of feature specifications, however, do not occur in languages, nor are all features equally likely to combine. There seem to be dependency relations between independently controlled gestures which fail to be captured by formal representations, as convincingly argued by Ohala [6]. Such dependency relations are partly due to physical (aerodynamic) interactions between articulatory gestures, or the acoustic consequences of such interactions.

Ohala and Ohala [8] provide a thorough account of the aerodynamic and acoustic factors underlying how nasality interacts with other features, in particular manner and place features. In the following sections I will first review the interaction between nasality and manner features in consonants in the light of recent research. Second, I will examine the phonetic basis for the interactions between nasality and voicing. Finally, I will turn to how the conflicting requirements of frication and nasality are reflected in the lower lexical frequency of fricatives followed by nasal vis-à-vis oral segments in a variety of languages.

## 2. NASALIZATION AND MANNER FEATURES

Walker [16] attempts to characterize the compatibility of segments with nasality on the basis of observed patterns in nasal harmony. She posits a nasal harmony hierarchy ranking segments according to their incompatibility with nasalization: “ *NASOBSTRUENTSTOP » *NASFRICATIVE » *NASLIQUID » *NASGLIDE » *NASVOWEL, where the less compatible a segment is with nasalization, the higher-ranked its constraint”.

Interestingly, the nasal compatibility hierarchy reflects aerodynamic and acoustic factors rather than being an explanatory device by itself. This hierarchy of the permeability of segment types to nasalization closely resembles that of Schourup [12], also based on examining cases of spreading of nasalization. Schourup’s scale, in progression from least to most likely to nasalize, can be stated as follows: obstruents < liquids r, l < glides j, w < laryngeals h, ʔ < vowels.

## 2.1. Obstruents

Work by Ohala has explained the aerodynamic constraints underlying the compatibility of manner (and place) features and nasality. Stops and fricatives require the creation of a high backpressure behind the constriction for the noise burst at consonant release for the former, and the generation of turbulence for the latter. If the obstruent constriction is anterior to the velopharyngeal port (i.e., labial to uvular), a tightly sealed velum is necessary to build up intraoral pressure. A lowered velum would allow air to escape through the nasal cavity and prevent the build up of pressure for the stop burst or the fricative noise. Glottal and pharyngeal fricatives and stops, for which the build up of pressure takes place further upstream than the velic valve, and therefore a lowered velum would not affect the pressure build up, can be nasalized [8, 12]. Nasalized glottal fricatives, /h̃/, have been widely reported in languages [4], and they occur phonetically in American English, e.g. *home* [h̃ə̃ʊ̃m]. Thus the requirement of a raised velum, and consequently the incompatibility of nasalization and obstruency, applies exclusively to obstruents articulated in front of the point of velic opening (buccal obstruents). This is captured by Schourup's scale, which places laryngeal obstruents next to vowels, but not by Walker's hierarchy, which does not take into account interactions between constriction location and nasality.

Studies where oro-pharyngeal pressure during the production of speech sounds was varied with a pseudo-velopharyngeal valve (a tube inserted at the side of the mouth via the buccal sulcus), simulating different degrees of nasalization [10, 14], show that in producing an obstruent there can be some opening of the velic valve, but the impedance of this valve has to be high relative to that in the oral constriction so that the air will mostly escape through the aperture with lower impedance and create a burst or friction at the oral constriction. Indeed Basset et al's [1] nasal airflow data on French show that stops and fricatives preceding and following contrastive nasal vowels (CṼ, ṼC), which involve a considerably lower velum position than nasal consonants, exhibited a majority of cases of anticipatory and carryover nasalization, respectively (56% and 92%). Clearly such coarticulatory velum lowering was not sufficient to prevent the build up of oral pressure as stop bursts and frication are present in the data in most cases. Ohala et al [10] argue that velic openings which do not impair the build up of pressure for audible turbulence would be insufficient to create the percept of nasalization in the consonant.

Along the same lines, Warren et al [17], studying velopharyngeal impairment, suggest that a velic opening of 10mm$^2$ during the production of oral stops can be tolerated without any perception of nasality, whereas nasal consonants require a velic opening greater than 20mm$^2$. Thus the size of the velic opening relative to that of the oral constriction needs to be taken into account.

## 2.2. Trills and taps

Liquids are the next least compatible segments with nasality in both scales. Within liquids, a distinction between trills and other liquids is in order. Trills are crucially dependent on high airflow through the oral constriction to make the tongue-tip vibrate. Solé [14] reports that, during the production of trills, tongue-tip trilling was extinguished not only when oral pressure was vented with a pseudo-pharyngeal valve with a lower or a similar impedance to that at the oral constriction, but also when catheter areas had substantially higher impedance. This indicates that small variations in oral pressure impair tongue-tip trilling and, consequently, that trills are highly incompatible with a lowered velum for nasalization. This is in line with the observation that nasal trills have not been reported in languages of the world. The same aerodynamic variation with the pseudo-pharyngeal valve had no effect on the production of taps, which were unimpaired by venting. Taps involve a ballistic muscular contraction for the apical contact, compatible with a lowered velum, as opposed to the aerodynamic force for trills. Nasalized taps have been reported in a variety of languages [4], including American English (e.g. *center* [ɾ̃]). Thus, a distinction between trills –which cannot accommodate a lowered velum for aerodynamic reasons– and other rhotics which can be nasalized (e.g. taps, approximants) is warranted.

## 2.3. Sonorants

Other segment types –laterals, approximants, glides and vowels, which do not crucially depend on a large volume velocity– can accommodate a lowered velum for nasalization without severely compromising the integrity of the segment. As a result, these segment types can be nasalized (see, for example, Basset et al's [1] data). During nasalized sonorants, the acoustic output is a combination of the volume velocity from the nose and the mouth, with the mouth output being dominant when the area of the oral constriction is larger than the area of the velopharyngeal opening (assumed to be approximately $20mm^2$, Stevens [15]), that is, when the sound radiates mostly through the oral aperture with a lower impedance relative to that at the velic valve. However, if the area of velopharyngeal opening exceeds the area of the oral constriction, the nasal output dominates and the nasalized sonorant may become a nasal consonant. This is most likely the origin of the allophonic variation in the Kolokuma dialect of Ijo (cited in [2]), where an /l/ becomes an [n] before a nasalized vowel (due to coarticulatory lowering of the velum and dominance of the nasal output), but remains a lateral before an oral vowel.

For the acoustic reasons underlying the alternation between nasals and nasalized glides ([ŋ] and [w̃]) in a number of languages (e.g., Paya, Lua and Breton [2]), see Ohala and Lorentz [7].

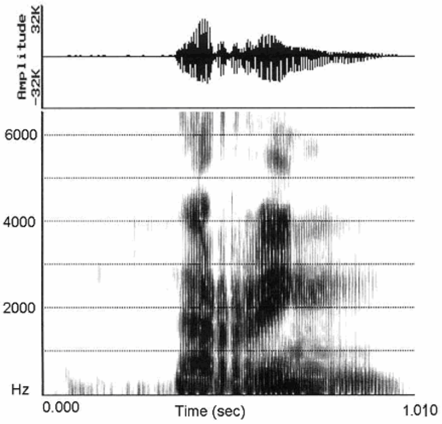
## 3. NASALIZATION AND VOICING

Because of acoustic-auditory factors glottal vibration favors the percept of nasality, and for aerodynamic reasons nasality favors glottal vibration.

### 3.1. Voicing favors nasality

Acoustic-auditory reasons are at the origin of nasal and nasalized segments being predominantly voiced. It is known that the sound source (glottal pulsing or turbulence) excites mostly the cavities anterior to the constriction where the sound is generated, which contribute to resonances and antiresonances, whereas the back cavities do not contribute much acoustically [15]. The different nature and location of the source of sound for voiced and voiceless nasals accounts for their different acoustic result. In voiced nasals, glottal pulses excite the oral and nasal cavities, yielding the characteristic spectrum of nasals. By contrast, lack of glottal pulsing for voiceless nasals impairs the low frequency amplitude modulation characteristic of nasals. In addition, turbulence for voiceless nasals is generated primarily at the nostrils, whichever the place of articulation of the nasal; since the oral and nasal cavities posterior to the nostrils do not contribute resonances, the different nasals do not differ much acoustically (except in the transitions in adjacent vowels), and because there is no downstream cavity to amplify and shape the low intensity frication at the nostrils, voiceless nasals have a low intensity [8]. This is illustrated in Fig. 1, which shows a distinctive voiceless nasal, [n̥], and the voiced nasal [ŋ] in Lai-chin.

**Figure 1:** Waveform and spectrogram for Lai-chin 'Hna-ring' (name of a village).



[n̥ a r i ŋ]

As shown in Fig. 1, voiceless nasals lack the low frequency resonances characteristic of nasal coupling, and the resulting frication has a low intensity and indistinct spectral characteristics, which makes them nonoptimal sounds auditorily and thus rarely used in languages. The same is true of voiceless nasal vowels.

The aerodynamic difficulty involved in concurrent nasalization and frication has been addressed in a number of studies [8, 10, 13]. Nasalized fricatives, however, have been reported to occur in languages and it has been observed that *voiced* nasalized fricatives tend to lose their friction and become nasalized approximants (e.g. in Guarani), whereas *voiceless* nasalized fricatives tend to lose nasality and retain frication [4, 2]. Aerodynamic factors may account for why voiced fricatives –with a lower oropharyngeal pressure, due to the glottal resistance and the need to keep oro-pharyngeal pressure low for voicing, as well as a lower intensity of frication vis-à-vis voiceless fricatives– tend to lose their friction and become approximants when nasalized [10].

The tendency for perceptible nasalization to be favored by voiced relative to voiceless fricatives may have an acoustic explanation. For the reasons stated earlier, nasalization contributes more acoustically to voiced than to voiceless fricatives (phonetically frictionless continuants, given the difficulty to retain friction with nasal venting). Vocal fold vibration at the larynx for voiced fricatives resonates in the nasal cavity —as well as in the oral cavity— thus adding perceptible acoustic properties of nasal coupling (intense low frequency murmur, spectral zeroes, and increased F1 bandwidth in neighboring vowels) to the weak frication due to glottal impedance and nasal leakage. By contrast, in voiceless fricatives the sound source is forward of the velopharyngeal opening (except for glottal and pharyngeal fricatives) and the sound generated excites mostly the anterior cavity with very little acoustic coupling to the posterior nasal cavity. As a consequence, nasalized voiceless fricatives with audible frication do not differ much auditorily from non-nasalized fricatives, that is, the acoustic cues for nasalization are hardly detectable [4, 2].

### 3.2. Nasality facilitates voicing

Due to aerodynamic reasons nasality favors voicing in neighboring obstruents. The interaction between nasality and voicing in consecutive segments is illustrated in post-nasal voicing. It is known that voicing is difficult to maintain during an obstruent [5]. However, if an obstruent is preceded by a nasal, voicing during the obstruent is facilitated by nasal leakage before full velic closure is achieved and, after velic closure, by the velum continuing to rise toward the high position for obstruents, thus expanding the volume of the oral cavity. Both mechanisms, nasal leakage and oral cavity expansion, lower the oropharyngeal pressure which accumulates in the oral cavity and thus prolong transglottal flow for voicing [3].

Such phonetic effects have phonological significance in languages with a phonological post-nasal voicing rule (e.g. Japanese), in phonological alternations between voiceless stops and prenasalized voiced stops (e.g. Terena), and in sound change. In addition, languages with distinctive voiceless stops, [p t k] and prenasalized voiced stops [mb, nd, ng] but no simple voiced stops (e.g. Melanesian languages), and languages where voiced stops are phonetically prenasalized (e.g. Tok Pisin, Northern Japanese), suggest that nasal leakage is utilized to facilitate voicing in the consonant. If prenasalization was indeed an articulatory maneuver to facilitate voicing in stops, one would expect it to apply most often to stops in which voicing is more severely endangered (i.e. velars, with a smaller back cavity and lesser area of compliant tissue), followed by coronals (with a comparatively larger cavity), and labials. This is precisely what the distribution of prenasalization in Japanese dialects [16] in Table 1 shows:

**Table 1:** 'Phonetic manifestations' of voiced stops in Japanese dialects.

| **Dialect group** | **Phonetic manifestation** |
|---|---|
| A | [$^{m}$b $^{n}$d ŋ] |
| B | [ b $^{n}$d ŋ] |
| C | [ b d ŋ] |
| D | [ b d g] |

Of those dialects which prenasalize voiced stops intervocalically, some prenasalize the three voiced stops [b d g], others prenasalize only [d g], and still others prenasalize only [g], such that there is an implicational relationship [$^{m}$b] ⊃ [$^{n}$d] ⊃ [ŋ]. Interestingly, Yamane [16] shows that the historical process was in fact one of loss of prenasalization, since all voiced stops were prenasalized in Old and Early Middle Japanese. Historical records show that prenasalization in the central dialects of Japan was first lost in labials in Middle Japanese, [$^{m}$b] > [b], later in coronals in Modern Japanese, [$^{n}$d] > [d], and only recently in velars. Thus, the distribution of prenasalized stops reflects historical stages in the language. The progression in the loss of prenasalization correlates with well-known aerodynamic constraints on the maintenance of voicing related to back cavity size [5].

Similar aerodynamic factors may explain the results obtained by Basset et al [1] for French, which revealed a tendency for voiced but not voiceless obstruents to show nasal leakage preceding and following a nasal vowel. Such velic lowering during the oral closure for voiced stops (essentially prenasalized stops) but not voiceless stops was also found for Ṽ+stop sequences in Hindi [9]. Ohala & Ohala provide an acoustic-auditory explanation for voiced stops having more tolerance for nasalization than voiceless stops in terms of nasalization undercutting the stop or voiceless character of voiceless but not voiced stops. Aerodynamic factors, however, may also be at play. Prenasalized stops involve a delayed velic raising relative to the oral closure for the stop (i.e., a desynchronization between the oral articulators and the velum). Nasal leakage during the oral constriction for the stop contributes to keeping a low oropharyngeal pressure which favors transglottal flow for voicing. Certainly, voiced obstruents which do not rely as heavily on high intensity noise cues as voiceless stops may tolerate a lower rate of oral pressure rise and a lower pressure peak than voiceless stops. Thus nasal leakage may be seen as a maneuver to fine-tune the conflicting requirements of a low oropharyngeal pressure for voicing and high airflow for obstruency. In this way, the pervasive interaction between nasality and voicing can be accounted for by aerodynamic and acoustic constraints.

## 4. SEQUENTIAL RESTRICTIONS OF FEATURES

In the preceding sections we have seen that the phonetic interaction between phonological features may take place not only when features co-occur, but also when features occur in adjacent segments and coincide in time due to coarticulatory overlap. Because the way in which features affect each other across segments is at the origin of restrictions on the sequencing of sounds and the likelihood that segments follow one another, we decided to investigate if the conflicting requirements of frication and nasalization when they occur in contiguous segments is reflected in a lower lexical frequency of medial fricative + N sequences than of comparable fricative + C sequences.

The transitional frequency of nasal and oral consonants following voiced and voiceless fricatives was calculated in lexicons generated from CELEX ‘Lemma database’ for the languages available in the database, English, German and Dutch. The results are displayed in Table 2, which shows the number of combinations found for the fricatives in the rows followed by the nasal and oral segments in the columns for the three languages. Shadowed cells indicate the cases where fricative + N sequences have a lower frequency of occurrence than fricative + C sequences, as predicted. Table 2 shows that in the majority of cells with a substantive number of combinations, fricative + nasal sequences are less frequent than comparable fricative + C sequences. (This is the case in spite of the large number of /sn, ʃn, vn/ clusters in English resulting from a word ending in a fricative followed by the suffix ‘-ness’, which were included in the count).

**Table 2:** Number of combinations of sounds in the rows (C1) followed by sounds in the columns (C2) in word medial position calculated in the CELEX ‘Lemma database’ for (a) English, (b) German, and (c) Dutch.

(a) ENGLISH

| C1↓C2→ | **n** | t | d | l | r | **m** | p | b |
|---|---|---|---|---|---|---|---|---|
| s | **330** | 2653 | 34 | 617 | 47 | **146** | 679 | 72 |
| z | **15** | 17 | 38 | 46 | 14 | **122** | 18 | 40 |
| ʃ | **88** | 8 | 9 | 78 | 12 | **32** | 10 | 13 |
| ʒ | **0** | 0 | 0 | 0 | 0 | **0** | 0 | 0 |
| θ | **19** | 6 | 3 | 42 | 113 | **9** | 10 | 7 |
| ð | **1** | 1 | 4 | 4 | 1 | **9** | 0 | 2 |
| f | **16** | 209 | 14 | 247 | 193 | **9** | 17 | 18 |
| v | **110** | 14 | 13 | 222 | 28 | **24** | 19 | 17 |

(b) GERMAN

| C1↓C2→ | **n** | t | d | l | r | **m** | p | b |
|---|---|---|---|---|---|---|---|---|
| s | **55** | 2653 | 80 | 379 | 175 | **495** | 395 | 370 |
| z | **2** | 0 | 0 | 2 | 4 | **0** | 0 | 0 |
| ʃ | **134** | 1826 | 3 | 445 | 235 | **114** | 30 | 621 |
| ʒ | **0** | 0 | 0 | 0 | 0 | **0** | 0 | 0 |
| x | **169** | 1193 | 41 | 139 | 50 | **64** | 118 | 20 |
| f | **78** | 478 | 24 | 489 | 515 | **49** | 113 | 47 |
| v | **0** | 0 | 0 | 0 | 8 | **0** | 0 | 0 |

(c) DUTCH

| C1↓C2→ | **n** | t | d | l | r | **m** | p | b |
|---|---|---|---|---|---|---|---|---|
| s | **568** | 3400 | 0 | 1770 | 570 | **1521** | 3360 | 10 |
| z | **0** | 0 | 976 | 1 | 0 | **0** | 0 | 1537 |
| ʃ | **1** | 0 | 4 | 3 | 6 | **11** | 4 | 9 |
| ʒ | **0** | 0 | 0 | 0 | 0 | **0** | 0 | 0 |
| x | **181** | 2799 | 2 | 131 | 1232 | **16** | 107 | 1 |
| χ | **185** | 0 | 529 | 388 | 1474 | **191** | 0 | 259 |
| f | **43** | 797 | 1 | 898 | 698 | **123** | 162 | 0 |
| v | **1** | 0 | 507 | 459 | 401 | **0** | 0 | 322 |

A one-sample chi-square test with weighted cases showed that the proportion of fricative + /t, d, l, r/ was significantly greater than the proportion of fricative + /n/ sequences ($\chi^2_{(1)} = 266.69$, $p< 0.0001$ for English; $\chi^2_{(1)} = 1333.24$, $p< 0.0001$ for German; and $\chi^2_{(1)} = 1808.9$, $p< 0.0001$ for Dutch). Similarly, the proportion of fricative + /p, b/ sequences was greater than that of fricative + /m/ sequences ($\chi^2_{(1)} = 18.85$, $p< 0.0001$ for English; $\chi^2_{(1)} = 14.96$, $p< 0.0001$ for German; and $\chi^2_{(1)} = 274.23$, $p< 0.0001$ for Dutch). The results suggest that at least in Germanic languages there is a bias against fricatives followed by nasal segments that endanger their high airflow requirements.

A cross-linguistic count carried out by Rossato [11] also concludes that there is a bias against fricative + nasal sequences. On the basis of the lexical frequency of syllable structure in 14 languages from the ULSID database, she classifies consonant clusters as ‘favored’, ‘disfavored’, and ‘especially disfavored’. Of the 20 types of consonant clusters analyzed, fricative + nasal sequences fall in the ‘especially disfavored’ category, due to their low lexical frequency, along with three other clusters.

In summary, the results show that, as expected, fricatives combine less frequently with following nasals than with non-nasals. The constraint against sequencing fricatives and nasals seems to be a robust phenomenon at least in Germanic languages, as suggested by the data in Table 2.

## 5. CONCLUSIONS

The review of the data presented here suggests that the likelihood of features to combine depends on their articulatory-aerodynamic and acoustic requirements. As stated by Ohala [6], dependency relations between features due to speech aerodynamics, acoustics or perception cannot be captured by models such as Feature Geometry or Optimality Theory. For example, the aerodynamic interaction between nasalization and voicing (in postnasal voicing) illustrates that what happens at the velum can influence the continuation or extinction of voicing. Such dependency relations cannot be accounted for in a model where the nasal feature is at a different branch from the laryngeal features and, therefore, cannot specify voicing. Similarly, aerodynamic and acoustic factors are at the origin of nasalized voiced fricatives losing frication earlier vis-à-vis voiceless fricatives. Current phonological models, however, do not allow laryngeal features which are at a different branch from supralaryngeal features to dictate frication.

For acoustic reasons, the nature and location of the sound source (anterior or posterior to the velopharyngeal opening) determines the acoustic coupling to the nasal cavity and the perceptibility of nasalization (in the case of voiceless vs voiced nasals and nasalized fricatives). This is difficult to capture by current phonological models.

Finally, finer quantitative detail is needed than what available phonological notations may allow us to represent. For example, in sounds where air flows out of the nose and the mouth (nasalized continuants), the size of the velopharyngeal opening for nasalization relative to the area of the oral constriction is crucial because, due to the quantal nature of speech, small variations in the size of either opening may involve an abrupt acoustic change: fricative vs approximant (for nasalized fricatives), or nasal vs liquid/glide (for nasalized approximants).

## 6. REFERENCES

[1] Basset, P., Amelot, A., Vaissière, J., Roubeau, B. 2001. Nasal flow in French spontaneous speech.*JIPA* 31, 87-99.

[2] Cohn, A.C. 1993. The status of nasalized continuants. In: Huffman, M.K., Krakow, R.A.(eds.) *Nasals, Nasalization and the Velum*. San Diego: Academic Press, 329-367.

[3] Hayes, B., Stivers, T. 1996. A phonetic account of postnasal voicing. Ms., Dept. of Linguistics, UCLA.

[4] Ladefoged, P., Maddieson, I. 1996. *The Sounds of the World’s Languages*. Oxford: Blackwell.

[5] Ohala, J.J. 1983. The origin of sound patterns in vocal tract constraints. In: MacNeilage, P.(ed), *The Production of Speech*. New York: Springer Verlag, 189-216.

[6] Ohala, J. 2005. Phonetic explanations for sound patterns. Implications for grammars of competence. In: Hardcastle, W. J., Beck, J. M. (eds.), *A Figure of Speech. A Festschrift for John Laver*. London: Erlbaum, 23-38.

[7] Ohala, J. and Lorentz, J. 1977. The story of [w]: an exercise in the phonetic explanation for sound patterns. Berkeley Ling. Soc., *Proc. Ann. Meeting* 3.577 - 599.

[8] Ohala, J., Ohala, M.1993. The phonetics of nasal phonology: Theorems and data. In: Huffman, M. K., Krakow, R. A. (eds.), *Nasals, Nasalization and the Velum*. San Diego, Calif.: Academic Press, 225-249.

[9] Ohala, M., Ohala, J. 1991. Nasal epenthesis in Hindi. *Phonetica* 48: 207-220.

[10] Ohala, J., Solé, M.J., Ying, G. 1998. The controversy of nasalized fricatives. *Proc. 16th International Congress on Acoustics (ICA/ASA)*. Seattle, Washington, 2921-2922.

[11] Rossato, S. 2004. Quelques statistiques sur la nasalité vocalique et consonantique. *Actes des 25èmes Journées d’Études sur la Parole*. Fès, Maroc, 433-436.

[12] Schourup, L. 1972. Characteristics of vowel nasalization. *Papers in Linguistics* 5, 530-548.

[13] Shosted, Ryan. 2006. *The aeroacoustics of nasalized fricatives.* Univ. of California, Berkeley. PhD dissertation

[14] Solé, M.J. 2002. Aerodynamic characteristics of trills and phonological patterning. *Journal of Phonetics*30,655-688.

[15] Stevens, K.N. 1998. *Acoustic Phonetics.* Cambridge, MA: The MIT Press.

[16] Walker, R. 2000. *Nasalization, Neutral Segments, and Opacity Effects*. New York: Routledge.

[17] Warren, D.W., Dalston, R.M., and Mayo, R. 1993. Hypernasality and velopharyngeal impairment. *The Cleft Palate-Craniofacial Journal* 31(4):257–262.

[18] Yamane-Tanaka, N. 2005. The implicational distribution of prenasalized stops in Japanese. In: Weijer, J. M., Nanjo, K., Nishihara, T.(eds.), *Voicing in Japanese*. New York: de Gruyter.