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Summary :

AN AERODYNAMIC, FIBERSCOPIC, ACOUSTIC AND
PERCEPTIVE STUDY OF THE NASAL VOWELS OF
FRENCH (203 p.)

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Abstract :

This pluri-parametric study focuses on the nasal vowels of French by means of aerodynamic and fiberoptic data, acoustic modeling and perception tests. We study in detail the correlation between measurements of airflow, velum position, acoustic evidence and its perception.

Nasality has already been a subject of several earlier studies.

From a physiological point of view, the universal correlate of nasality is the lowering of the velum.

From an acoustic point of view : i) the opening of the velo-pharyngeal port makes the nasal cavity a derivation of the nasal tract which results in the creation of extra formants and anti-formants, ii) the narrowing of the oral tract at the velar level results in a modification of the oral tract's natural resonances. Some of the air is released through the nasal cavity and the nasal airflow is therefore positive and iii) the articulation of the nasal vowels is different of oral vowels, they have their formants of one's own.

From a phonological point of view, the nasal feature is generally considered to be binary; a vowel or consonant is either oral or nasal. Chomsky and Halle (1968) describe the feature of nasality in articulatory terms; the nasal sounds are produced with a lowered velum and the distinction, [+ nasal] [-nasal], summarizes the fundamental distinction of velum lowering or raising.

The relationships between openness and airflow are, however, not linear:

On one hand, Warren (1967) showed that there is a correlation between the degree of openness of the velo-pharyngeal passage and the nasal airflow.

On the other hand, the openness of the velo-pharyngeal port is not always sufficient for the production of nasal airflow. Baken (1987) showed that there was also an effect of impedance; the velum may very well be lowered without there necessarily being significant nasal airflow (e.g. the vowel, /a/).

Finally, Benguerel (1974) indicates that it is possible to observe a flow of nasal air (generally of weak amplitude and short duration) while the velo-pharyngeal port is completely closed.

There are five axes which are particularly interesting to us in this study:

- i) The temporal relationship between the openness of the velum and the appearance of nasal airflow.
- ii) The relationship between the degree of openness of the nasal tract and the quantity of nasal airflow released.
- iii) The relationships between the acoustic and physiological measurements on one hand, and perception on the other.
- iv) The relationships between the openness of the mouth, the openness of the velo-pharyngeal port, impedance in the vocal tract, and the flow of nasal air released.
- v) And the consequences of our results on phonological descriptions.

I. Interest to do a study on French nasal vowel

The advantage of the French Language.- The nasal vowels are particularly interesting to study in French, for French is one of the 71 languages of the world out of the 451 references in the UPSID1 database (Maddieson, 1984) which contrast nasal vowels with oral vowels phonologically.

The vowels use two tracts.- A second point of interest is that, articulatorily, vocalic nasality involves both the nasal and oral tracts, although their interactions are non-linear. We can therefore tackle one of the major problems in phonetics; this concerns the precedence of articulation on acoustics or acoustics on articulation in speech production.

Facility of observation.- A third advantage is that the movements of the velum can be observed using relatively non-invasive techniques.

II. Techniques and methods

- The aerodynamic data (oral and nasal airflow) provide a **direct indication** of the nasal airflow.
- The fiberoptic data give a direct **indication of the openness** of the velo-pharyngeal port.
- **The correlation between** the aerodynamic data together with the fiberoptic data give an indication of the relationship between the velo-pharyngeal port openness and the nasal airflow
- The acoustic data reveal **the correlation** between velar movements and/or airflow and the resulting acoustic signal.

¹ UPSID is an acronym for the UCLA Phonological Segment Inventory Database.

- And the perceptive data tell us at what point nasality is perceived.

A preliminary study using four speakers confirmed that speakers use at least two different strategies to close the velo-pharyngeal port. We selected two speakers, a man and a woman, who use the same sphincter-type strategy to close the velum.

III. *Le corpus*

The corpus is divided into three parts:

1. 108 logatomes of the type :

"Dites $C_1V_1C_1V_tC_1V_1$ trois fois $C_1V_1C_1V_tC_1V_1$, $C_1V_1C_1V_tC_1V_1$, $C_1V_1C_1V_tC_1V_1$ " (Say $C_1V_1C_1V_nC_1V_1$ three times) or $V_1 : [a, i, u, y]$, $V_t : [ʀ, ʁ, Ø]$ where the consonants are differentiated by the manner of articulation, the place of articulation, and voicing $C_1 : [p, t, k, b, d, g, s, z, l]$, (example : "dites bababa trois fois").

Each sentence was repeated two times during the airflow measurements. The same sentences were then recorded using fiberoptic instrumentation. A large number of items had to be discarded due to either pronunciation errors, incorrect positioning of the fiberoptic, excessive mucus secretion at the level of the opening of the velo-pharyngeal port which hindered visibility, or incorrect calibration of airflow. About ¼ of the items were eliminated due to one or the other of these problems. At the end we were, however, able to extract a sequence for each context.

2. To this we added 24 sentences for each speaker, also recorded with the equipment for measuring airflow and then using the fiberoptic. These sentences are differentiated by the accent or by the prosodic situation (example: cet homme est énorme et m'embête ~ cet homme est énormément bête). The reason for using these sentences is to verify whether there is a difference in nasality performance according to the prosodic context.

3. And finally, we were able to obtain short sequences of non-read speech under fiberoptic as well as aerodynamic conditions (total: 5 minutes 43 seconds for both speakers). These sentences were used to study what happens in "natural" speech and can be compared to the speech of the sentences that were read.

IV. *Results*

Aerodynamic results :

Temporally data:

- The temporal evolution of the nasal airflow can be described as follows: the airflow is initially nil (on the zero line). In the environment of a nasal phoneme, the airflow first is negative (the curve passes under the zero line), then positive. This dip (unexpected but already noted in the literature) is without doubt the result of velum lowering which creates negative pressure in the nasal cavity and a temporary in-draft.
- The length of the nasal vowel is more important than the length of the oral vowel. The nasal vowel is shorter in the environment of a voiceless consonant. Their length is longer in spontaneous speech.
- The nasal airflow is longer than the length of the phoneme in 91% of the cases. Its length is longer in spontaneous speech.
- For the logatomes, we observe a delay of the nasal airflow. The delay becomes anticipation for the read sentences and spontaneous speech. More the speech is not controlled; more there is anticipation of nasal airflow.
- The nasal airflow spread beyond the offset of the nasal vowel. Temporally, carryover will be less if the consonant (C1) following the nasal is a fricative. More the speech is not controlled; more there is carryover of nasal airflow. There is more carryover if the nasal vowel is in the offset of the word.
- There is always nasal airflow after the nasal vowel. There is less carryover if nasal vowel is following by fricative.
- We find denasalisation in spontaneous speech. And inversely, we find spontaneous nasalisation.
- In spontaneous speech, we found cases of nasalization for the three nasal vowels. And inversely, we found cases of denasalization of nasal vowels.

Quantitatively data :

- Of the three nasal vowels, the vowel, [œ], has the greatest nasal airflow.
- There is a large difference in nasal airflow between the two speakers, the man and the woman (this difference is probably due to gender based anatomical differences).

Further to these results, we conclude that the nasal airflow depend directly of the oral airflow. We think there is a correlation between the length of the nasal airflow and the length of the vowel for the logatomes. The carryover is longer for obstruantes and the delay is shorter for

fricatives. This correlation does not exist in spontaneous speech. We think there is a strong correlation between the nasal airflow and the resistance into the vocal tract. The speech reading gesture involves nasal airflow on the onset of the first phoneme of the sentence. We confirm that obstruantes appear as voiced when following a nasal consonant. In spontaneous speech, we observe carryover of nasal airflow during voiced and voiceless consonants, without change their acoustical properties.

B) Fiberscopic results :

Temporal data :

- The movement of opening and closing the velum is greater than the duration of the phoneme.
- We find several velum opening in the beginning of the sentences. In most cases, after a pause the velum moves from the open position and is not completely closed again for the first non-nasal phoneme of the sentence.
- The length of the velar movement is more important than the length of the nasal vowel.
- More the speech is spontaneous more velar movement is important.
- In most of cases, the velar movement begins before the onset of the vowel and stops after the offset of the vowel. And the carryover is more important than the anticipation.
- We note that The lateral walls participate in the movement of the velum and contribute to the augmentation or diminishment of the velo-pharyngeal port openness as the case may be. The movements of the lateral walls stem from the position of the velum. The velum starts to open before the nasal vowel, arrives at a maximum openness before the acoustic midpoint of the vowel, and then closes progressively. The maximal closure is situated after the acoustic end of the nasal vowel (segmentation based on the appearance and disappearance of the second format).
- This seems to show that articulatory movements are relatively better “controlled” than their aerodynamic consequences.
- The measurement of the distance between the maximum openness and the beginning of the phoneme is the most stable measurement.
- Between vowels: the movement of opening and closing is generally shorter for the nasal vowel, [ŋ], than for the other two vowels

Quantitatively data :

- The velo-pharyngeal port is most closed for the vowel, (Vn) [ø].
- For both speakers, the vowel with the greatest velar opening is [ɛ].

C) Aerodynamic and fiberoptic results:

We note that there is not necessarily a direct link between the beginning of the velum movement and the beginning of the nasal airflow. There is, however, a minimum time during which the velum opens progressively and the nasal airflow has not yet started. The velum movements start well before the nasal airflow. It is sometimes possible to observe nasal airflow when the velum is in its uppermost position, especially at the end of the nasal vowel.

The movements of the velum are more or less predictable, but this is not the case for nasal airflow.

For one consonant (C1) or one vowel (Vn) the less they need a large velar opening, the earlier the nasal airflow appears. The impedance in the nasal tract must, therefore, be great enough for the air to pass through the nasal tract. We note that this concerns the nasal vowels and consonants which do not require the mouth to be very open.

D) Acoustic results:

Is it possible to show phenomena linked to nasality and their bearings on spectrographic data more easily using the velum movements and/or nasal airflow?

We note that:

As expected, the moment of the appearance of nasal airflow is more often identifiable using the signal (65%) than the movement of the velum opening (42%).

The maximum opening of the velar movement is easier to spot than the beginning and the end of the movement.

As for the rates of airflow, we found that the vowel [ø] is differentiated from the other two vowels. In fact, for [ɛ] and [ɛ̃] the beginning of the nasal airflow modifies the aspect of the acoustic signal while for [ø], the acoustic phenomena show up with the closure of the oral tract.

E) Perception test results:

Finally, the perception section was meant to perceptively validate (or not) the results which we had obtained.

For this section, we based our work on the articles of (Ohala and Ohala, 1995) and (Lahiri and Marslen-Wilson, 1991).

We made two tests. We chose both sequences for which the nasal vowel was produced with a large delay of the nasal airflow and other sequences where we had observed an anticipation of the nasal airflow. We used the process of gating for the nasal vowel in order to estimate the moment at which the vowel started to be perceived as nasal. We also added an experiment where we used gating starting from the end of the vowel. We found a stronger nasal airflow at the acoustic end of the nasal vowel. With the second test, we wanted to know the relationship between nasal airflow and the perception of nasality.

And we wanted to have an idea of the degree of nasalization perceived at the beginning, the middle, and the end of the nasal vowel. In total, 30 subjects responded to one of the two tests.

Results for the first test:

The listeners did not recognize the nasal more rapidly when it displayed a great deal of anticipation. In fact, the nasal is identified quite late. A good number of subjects did not identify the vowel, [ɛ̃], interpreting it rather as the vowel, [a]. We could therefore be led to conclude that nasal airflow is not the essential factor for nasal perception and that the nasal is identified as being nasal due to the end of the nasal airflow.

Results of the second test

The items are recognized quite rapidly as nasal by all of the listeners before the acoustic midpoint, though not necessarily in the first segment. At most, the listeners recognized the nasal vowel after 60 ms of gating. We think that the indicator of nasality is in fact found towards the end of the vowel, though this is not systematic. It seems, therefore, that there is not a direct link between nasal airflow and perceived nasalization. However, there should be an interaction between articulation and nasal airflow and the nasal will be more accurately recognized when their adequacy is optimal.

In both tests, the vowel [ɛ̃] is the vowel perceived most accurately and most quickly.

V. Conclusion

In conclusion, we find that there are inter- and intra- speaker differences for the aerodynamic and fiberoptic data. Nasal airflow and velo-pharyngeal port openness are strongly dependent on the immediate consonantal context (close co-articulation). And velar movements are also strongly dependent on the preceding vocalic context (more distant co-articulation).

The answers to the questions asked at the beginning of the study:

i) **First**, the temporal relationship between the opening of the velum and the appearance of the nasal airflow:

The opening of the velum occurs well before the appearance of nasal airflow. There is no fixed time t where the velum has attained a sufficient degree of openness for the air to pass through the nasal tract. This time differs according to the context and the nasal vowel itself.

And as contradictory as it may seem, the less open the velum is, the earlier the nasal airflow starts.

ii) **Second**, the relationship between the degree of openness of the nasal tract and the quantity of nasal airflow released:

There is no direct relationship between the degree of openness and the quantity of air released. The maximal velar openness corresponds essentially to the beginning of the release of the nasal air.

iii) **Third**, the relationships between the acoustic and physiological measurements on one hand, and perception on the other:

These relationships are complex. It is quite easy to see the correlation between nasal airflow and/or oral airflow and the acoustic signal. The correlation between the velar movements and the acoustic signal is more difficult to see (if it truly exists). Nasal airflow is not the only indicator for nasal perception (the articulation of the vowel itself is probably involved). It appears that there is a direct relationship between the impedance in the oral tract and the nasal airflow released.

iv) **Fourth**, to know the relationships between the openness of the mouth and velo-pharyngeal port, the impedance in the vocal tract and the nasal airflow released:

It appears that there is a direct relationship between impedance in the oral tract and the nasal airflow released. This impedance is therefore related to the opening of the mouth. And if we follow the hypothesis of (MOLL, 1962), this opening of the mouth should influence the openness of the velum. The implications of articulatory movements are not linear; rather they involve other articulators. A complete study should have an indication of the position of all the articulators at the moment of the production of the phoneme.

v) **Fifth**, the consequences of our results on phonological descriptions:

We wanted to know if phonological descriptions of nasality could be based solely on the movements of the velum, in particular, its lowering. We think, in view of our conclusions, that nasality could be described quite well with as + or – airflow. Describing nasal vowel phonology with this feature would allow us to show that a nasal vowel such as [2E] seems more oral than the vowel, [Ø]. This distinction cannot be made with the trait of + or – velum lowering alone. There would be a slightly more complex description of the nasal vowel such as the following:

VI. *Outline*

This study is divided into two parts:

In the first part, after having given a definition of nasality, we give a short review of nasals in the world's languages, and then we explain the situation of nasal vowels in French. We describe the different methods used to analyze nasality. We give a short review of the anatomy of the nasal cavity, the velum, and the different muscles which may be involved. We explain how the tongue works, as well as the muscles which work with the tongue and velum and may be a basic structure in the relationship between the two. And we quickly review different studies which have already worked on nasality and their hypotheses.

In the experimental part of this study, we describe and analyze all of the results obtained with the different techniques used.