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MOVEMENT OF THE LIPS AND VELUM IN SPEECH: VARIATIONS IN AERODYNAMIC PARAMETERS

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ABSTRACT. This comparative study of the coordination of lip and velum movements during the articulation of the nasal consonant [m] in a symmetric vocalic context in French, and of the aerodynamic parameters associated with these movements, provides evidence of the functioning modes of the velum and their dependence upon the nature of the vowel in its location with respect to the nasal consonant. During the articulation of the vowel preceding the nasal consonant, the lowering of the velum was first accompanied by a decrease in the volume of air in the nasal passages. The subsequent increase in nasal air flow only occurs by the end of the preceding vowel and during the emission of the nasal consonant itself. However, the raising of the velum for the next vowel occurs in two stages: an initial fast rise during the first phase of the vowel, then a much slower rise during the final portion. This research sheds new light on our understanding of the relationships between the trajectories of lip and velum movements and the acoustic events that are associated with them.

INTRODUCTION

Previous research [1-3] was conducted for the purpose of defining the relationships between two types of interacting articulatory events: (1) the joint movements of the lips and velum, and (2) the acoustic events that result from these interacting movements (consonant or vowel nasality cues, nasalization). The various opening and closing phases of the lips and velo-pharynx were analyzed and compared on a videotape recording of fiberoscopy via nasal entry in order to visualize the movements of the velum. Two main types of velum movements were discerned as a result of this analysis: micro-movements in which the velum is lowered or raised even in the absence of nasal articulation, and macro-movements, which always occur in conjunction with a nasal consonant or vowel. But some important information was still lacking before we could relate these phenomena to their associated acoustic parameters. At what point is the velum low enough to create a sufficiently large opening in the velo-pharynx for air to flow into the nasal passages, leading to the corresponding resonance that is produced?

A complementary study of buccal and nasal air flow and volume was undertaken. The new aerodynamic data obtained are expected not only to provide us with more data on the coordination of lip and velum movements in speech, but also to create better conditions for establishing the relationship between the physiological and acoustic events that occur during the production of nasal vowels and consonants.

EXPERIMENTAL PROCEDURE

The reader should refer to the articles mentioned above [1-3] for information concerning the videotape recording of the physiological events. On the other hand, the conditions under which aerodynamic data were gathered here were different from those in prior publications [4], and will therefore be explained below.

1. Corpus

In order to more clearly reveal the specific characteristics of the bilabial nasal consonant [m] and its context-dependent variations, the eight sentences recorded all contained the phonic sequence -velo- or "velo", where V was [a], [i], or [u]. Sentences like "C'est ça masse et mouton" or "Dis sa mass six fois" were used to analyze the nasal consonant [m] in the symmetrical [a] context.

The presence of the unvoiced fricative [s] leads to substantial raising of the velum, which is highly visible on the fiberoscopic images and shows up on the buccal air flow curve as two peaks separated by a drop. To enable comparison, the corpus was pronounced ten times by a speaker (DA) who had previously recorded the same sentences without nasal fiberoscopy.

2. Apparatus: recording of aerodynamic parameters

The aerodynamic parameters were recorded on a POLYPHONOMETER III [5], which is essentially composed of two gridded pneumo-tachograph with low time constants. Air flow exchange in the nose and mouth can be measured separately. Integration of the air flow rates gives buccal air volume (BAV) and nasal air volume (NAV).

Buccal air flow (BAF) was measured via a mouthpiece specifically adapted to the subject's morphology in order to prevent any possible air leaks, while avoiding hinderance to lip movement and intermaxillary opening. Nasal air flow (NAF) was captured by means of tubes adjusted
to fit each nostril. Microphones located in the measurement channels recorded the nasal and buccal phonograms. The r.m.s. value of this signal integrated over 10 ms gives the acoustic intensity of the vocal emission. In addition, a laryngophone placed around the subject’s neck ensured that the vocal signal recorded would be void of interference by noise.

Recording was done sentence by sentence, since the polyphonometer is designed so that the speaker remains in control of synchronization throughout the entire experiment.

The acquisition and processing of aerodynamic data were done on the PHYSIOLOGICA work station [6]. This device consists of a Vectra ES-12 micro-computer and a DT 2801A data acquisition board which enable the user to perform the following operations: (1) Generate the sentences of a spoken corpus at the rate chosen by the speaker. (2) Input up to 16 parameters at a sampling frequency of 1 kHz per parameter, and store data magnetically. (3) Print out the recorded signals and measure amplitude and duration. Other operations such as calibration and mathematical calculations are possible. Markers used for further processing are set by moving the cursors. (4) Statistically process the measured data after having created files for their storage. Statistical processing is done using a program called SYSTAT.

3. Data reduction and measurement

The ten recordings of the 8 sentences were segmented and labelled using 18 markers so as to account for the succession of aerodynamic events in the v /
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Duration in milliseconds was calculated on the basis of the markers set on the aerodynamic curves, not on the basis of the phonetic labels.

RESULTS

The results obtained for ten recordings of [s-sam-s] by speaker DA will be analyzed first in order to determine the intra-individual variability of aerodynamics parameters. These results will then be compared to the videotape recordings of the same sequence by the same speaker.

1. Duration and volume for buccal air-flow phases

Segmentation of the BAF curve on the basis of aerodynamic criteria revealed 5 segments corresponding to the successive phonetic units. For each segment, mean duration (in ms) and volume (in cm³), along with variation coefficients (expressed as a %) were calculated (fig. 2).

For segment C1-C4 (first [s]), mean duration was 111.5 ms with a variation coefficient of 7.6%, and volume was 44.6 cm³ (15%). For C4-C6 (i.e., the curve) corresponding values were 102 ms (7.5%) and 23 cm³ (12%). For C6-C11 (i.e., the [a] occlusion), duration was 82 ms (11%) and volume was slightly negative: -0.8 cm³. For C12-C14 (i.e., the final [s]), we obtained 140 ms (6.5%) and 27 cm³ (10%). For the second [s], duration was 205 ms (9.3%) and volume was 44 cm³ (18%).

Less variation was observed in duration than in aerodynamic parameters. Aerodynamic parameter variation was greater on the [s]’s (the second [s] being geminate) than on the [a]’s.

As for the volume/duration ratio, although the increase in duration on the second vowel (unstressed) was accompanied by an increase in volume (proportionally low), the double duration of the consonant did not lead to an increase in volume (fig. 2).

![Figure 2. Variation of BAF as a function of duration for the [s-sam-s] sequence.](image)

2. Duration and volume for nasal air flow phases

Three main movements can be distinguished on the NAV curve (fig. 3). (C1-C3 will not be discussed here due to its high degree of variability: 37% for a 64.7 ms duration and 75% for a 0.5 cm² value!)

For C3-C7 (interval between two zero crossings on the NAV curve corresponding to a drop in air flow), duration was 131 ms (22%) and volume was -2.3 cm³ (30%).

C7-C12 (beginning of air flow into the nasal passages) lasted 97 ms (13%), using 12 cm³ of air (13%). Finally, air continued to flow on C12-C17 for 280 ms (10%) with a volume of 9.6 cm³ (23%). The phases defined do not correspond to phonetic units. Variability was always greater for volume than for duration. Less variability was observed in nasal air flow during the bilabial occlusion (which served as an anchoring point). However, greater variability was found for the velum lowering and raising phases (C3-C7 and C12-C17), the latter appearing to be more controlled.

![Figure 3. Variation of NAV as a function of duration for the [s-sam-s] sequence.](image)

3. Comparison of aerodynamic data with data from lip and velum videotapes

Lip and velum movement curves were plotted from the image-by-image measures made on the videotape projected on a television screen (1 image every 20 ms) (fig. 4). Velum lowering began at the point where the velum was in its highest position, i.e. at the onset of the first fricative consonant, the measures (defined with respect to the velum’s lowest point, i.e. during calm breathing) ranged from 22.8 mm to 16.88 mm. During the articulation of the vowel [a], the lowering movement accelerated, causing the values to go from 15 mm to 5.55 mm over 4 images. The lowest point was reached on the second-to-the-last image, during the [a] occlusion (4.33 to 2.33 mm). The raising of the velum on the second [a] was slower, going from 5.66 mm to 17.33 mm in 8 images. Raising continued more slowly on the second [s], extending over to the first [s] images (going from 18.22 to 23.23 in 17 images).
The particular behavior of the velum during lowering or raising was manifested differently in the two types of physiological examination methods used. Considering the data cumulatively, it appears as though the lowering of the velum does not lead immediately to the entry of air into the nasal passages. The lowered velum may therefore be hypothesized to only actually detach itself from the posterior pharyngeal wall when reaching the final phase of the vowel [a] (lowering-relaxation). Only then may air enter the nasal passages (thus producing nasal resonance). Instead, the lowering of the velum at the beginning of the [a] affected resonance in the oral part of the vocal tract.

On the other hand, nasal resonance did occur on the second [a]. It was due to slower velum raising, which enabled the coupling between the oral and nasal cavities to be maintained after the articulation of the nasal consonant [m].

In a language like non-meridional French which has nasal vowels as part of its phonological system, the distinction between nasal vowels (such as [ɑ]) and nasalized vowels (such as [ɔ]) continues to be made. The corresponding lip-movement curve indicates that the lips are more open during the articulation of this nasalized vowel (maintaining a high buccal air volume, while the air in transit in the nasal passages slowly decreases, as we have seen previously).

Figure 4: Curves representing lip and velum movements: [سامس-], speaker DA.

As the present study has shown, the need for additional examination data strangely argues in favor of the use of a work station such as "Physiologia." Not only is this station well adapted to simultaneously conducting different physiological analyses, it can be used now, and even more so in the future, to constitute data bases that will not be strictly articulatory, but rather acoustico-articulatory.

REFERENCES


CONCLUSION

In the current state of our knowledge in the physiology of speech production, the establishment of a relationship between articulatory events and acoustic events must not be done hastily -- dynamic models of physiological events as complex as those presented here are not yet available.

As it stands, it is rather our knowledge of acoustic phenomena that has led us to a different interpretation of the movements of the velum than an interpretation that might have been derived from the fibrescopic images.