MAGNETIC RESONANCE MEASUREMENTS OF THE VELUM PORT OPENING

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ABSTRACT

M.R.I. techniques have been used to describe velum opening of French vowels. Data based on 18 joined axial slices of 4 mm thickness were recorded with two subjects. Differences in velum opening are calculated from areas measured in the tract between the lowered velum and the back pharynx wall. A 3 D modelling of this tract is also proposed.

1. INTRODUCTION

Magnetic resonance imaging (MRI) has been used to obtain mid-sagittal cuts of the vocal tract and to extract area functions from the latter [1], [2]. Recent progress in MRI allows us to gather data much faster and with better accuracy than before. Magnetic resonance imaging allows us to obtain accurate slices of the velum opening in the coronal, transversal, and sagittal plans, without any invasive effect for the subject. MRI completes a set of techniques already used to study nasality phenomena such as those described in Krakow and Huffman [3]. MRI has been used to make measurements of the nasal cavities, [3], [4], but up to now, no measure of velic lowering has been presented.

In this paper we describe velum opening for French nasal vowels. Images have been recorded at the Magnetic Resonance Unit of the Erasmus Hospital, Free University of Brussels.

2. METHOD

2.1. Corpus

Data have been recorded on two speakers, one female (subject 1) and one male (subject 2), both of them native French speakers living in Brussels. The task of the subjects was to pronounce and to sustain each of the nasal vowels [ɛ̃], [œ̃], [ɑ̃], [ɔ̃]. A reference was a word that contained the vowel to be pronounced. This reference word was given a few seconds before the recording session by one of the experimenters. The reference words and the vowels contained in these words are the following : 'un bon vin blanc' [œ̃bɔ̃vɛ̃blɑ̃].

2.2. Image Acquisition

The imaging was done with a 1.5 T M.R.I. system with a quadrature Head-Neck coil (Philips Gyroscan NT ACS, Best The Netherlands). The images consisted of 1 stack of 18 transversal slices. This proton density weighted acquisition took 13.8 seconds with the following parameters: TR = 1716 ms, TE = 9 ms, gradient profile low-high, ETL = 11; Partial Fourier encoding: 60 %. Field of view: 250 x 200 mm, Matrix 161 x 256. A stack of transversal slices was defined with slice thickness 4 mm and no gap between adjacent slices of the stack. Accurate position of the stack was planned on a sagittal survey image realized during similar phonation. The stack is set above the epiglottis with slices perpendicular to the oro-pharynx wall. A double presaturation band was applied to avoid foldover artifacts. Acquisition was launched immediately after the beginning of phonation.
[0532-01.GIF]

2.3. Image Analysis

Until now, there has been no automatic and reliable method for determining the area of a section of the vocal tract in M.R.I. Thus, measurements were carried out according to the following procedure: outlines of the sections are traced by hand on a transparent sheet. By means of a digitization tablet, the outlines are introduced in the computer and each area is computed by a polygon surface computation algorithm. This digitization process however, might be biased by some human factor. A test of the accuracy and reproducibility of area measurements was carried out. Three different outlines corresponding to 3 different sections, a large, a medium and a small one were used as test samples. Each outline was measured 10 times. Mean and standard deviation are given for each section. Results show that standard deviation is similar in the 3 cases and is lower than 0.005 cm2. This accuracy can be considered as satisfactory for our purposes.

2.4. Geometrical Modelling

The mathematical tools used in our 3D modeling of the velum is based on a software project developed for the study of the abdominal aorta [5]. The MRI images are transfered to a graphics workstation and then processed to produce - in a first step - a set of contours. These contours are obtained by means of an elastic matching process as described below : For each image, we initialize a closed free-form curve (like a NURB for example) in the interest area . This curve is defined by a set of control points. A set of criteria is computed at this point to caracterize this area : pixel level, density gradiant or texture analysis. Then, this curve is growing by a global moving of

its set of control points. Each moving is controled by the local properties of the curve and the image properties.
The initialization of the elastic matching process in the first image is done interactively by the user. For all the followings, this initialization is done through an estimated starting position which is computed from the location of the previous contours. We obtain a semi-automatic process that is supervised by the user who can, at any moment, re-initialize it in a given section. When all the contours are computed, a 3D set of points is generated by the adding of the spacial parameters of each images.
In the second step, a generalized cylinder match this set of points. The generalized cylinder model provides a smooth and structured representation of tubular cavities : First, we compute the central axis of the tubular cavity (by means of least squares approximation). Then, a set of closed sections is computed along this axis to match the set of points. The generalized cylinder is finally defined as a cubic uniform B-spline surface passing by these sections. Two parameters are using to describe this surface as a function *S(u,q)*: the axial parameter *u* gives the position of a section along the axis and the angular parameter *q* describe this section.
[0532_01.MOV]

3. RESULTS

3.1. Nasal Vowels

Figure 1 a, b, c, d give the most significant slices obtained for the vowels [ɛ̃], [œ̃], [ɑ̃] and [ɔ̃]. from subject 1. The slices presented from left to right (SL4, SL5, SL6) show the area situated behind the velum followed by the separation of the oral tract and of the nasal tract. Tissues between darkened zones are those of the velum (nasal opening at the bottom and oral tract at the top). Slices situated below SL4 give areas at the pharynx level, those being further above SL6 are in a non-significant region for our study.

The examination of the images presented on Figure 1 a, b, c, d allows us to consider interesting differences that exist between the front vowels [ɛ̃] and [œ̃] and the back vowels [ɑ̃] and [ɔ̃] for subject 1. Figure 1 a [ɛ̃] and 1 b [œ̃] show that neither the velum nor the uvula are in contact with the tongue dorsum with front vowels. The oral tract and the nasal tract are both open. The tongue groove which is more pronounced for front vowels is clearly visible for both vowels but much more pronounced for [ɛ̃], which is more front than [œ̃]. These facts are consistently repeated with the three other subjects of the study. Figure 1 c and 1d show some important differences for back vowels. Slices 5 and 6 presented at Figure 1 d show that for [ɔ̃], which has the more back articulatory position, the oral tract is completely closed by the contact of the velum with the tongue dorsum. This observation has consistently been made for both subjects. Figure 1 c [ɑ̃] shows that the uvula hits the tongue's sagittal groove at SL5, leaving free airway on both sides of the contact. This fact is likely a consequence of the more open articulatory position of [ɑ̃] than [ɔ̃].
[0532_02.GIF]

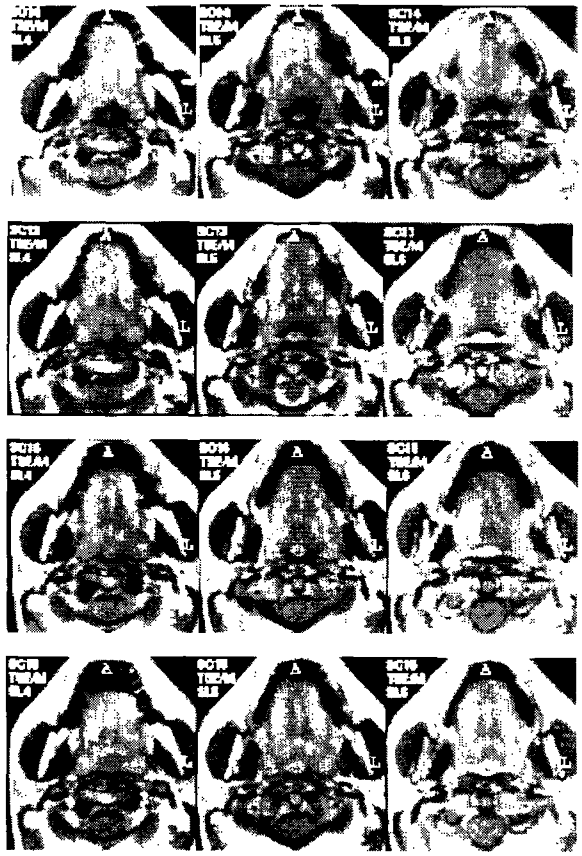

Figure 1. Magnetic resonance images of transversal slices obtained for subject 1. Three sliceslices are given for each nasal vowel. Slices are presented from left to right and labelled SL4, SL5, SL6. The first slice, SL4, gives the smallest area measured for each vowel. The second and the third slices, SL5 and SL6, show the separation of the nasal and oral tracts for [ɛ̃], [œ̃], [ɑ̃] but not for [ɔ̃]. The scale is the same for all slices.

3.2. Velum Area Measures

For each recorded image and for every nasal vowel, all areas corresponding to all the slices have been drawn for the two subjects. The areas of all slices have been measured by the method described above, and the results are given (in cm2) in Table 1 and table 2. The number of measured slices for the two subjects is not the same, due to differences in vocal tract length.

Examination of the M.R.I. scans shows that for vowels [œ̃], [ɑ̃], [ɔ̃] produced by subject 1, slice 5 is the first slice showing a clear separation between the oral and the nasal tract, while for [ɛ̃], slice 6 shows this separation. Above this point, there is a progressive enlargement of the areas considered. This enlargement varies from one vowel to another. For this subject, based on these data, we can consider that the velar port (VP) area of slice 5 [œ̃], [ɑ̃], [ɔ̃], and slice 6 [ɛ̃] provides the measure of the velum opening. The relative differences in VP size between the vowels are the following: [ɔ̃] < [ɑ̃] < [ɛ̃] < [œ̃]. The two back vowels [ɔ̃] and [ɑ̃] have smaller openings and the two front vowels [ɛ̃] and [œ̃] have bigger openings. The smallest opening of the nasal tract for [ɔ̃] is the consequence of the higher and more back position of the tongue body among the examined vowels. The observed differences in velum opening clearly illustrate the articulatory differences between vowels. The bigger size of the port for [ɑ̃] compared to the port for [ɔ̃] is explained by the fact that even if [ɑ̃] is a back vowel, it is more open than [ɔ̃] and therefore the constriction is situated lower in the tract. There are fewer differences between the two front vowels [ɛ̃] and [œ̃], whose articulatory differences lie in the more central and rounded positions of [œ̃]. The VP of [ɛ̃] is slightly larger than [œ̃]. Differences between all nasal vowels produced by subject 1 are presented at Figure 2, which displays the areas (in cm2) with respect to the slice number. From slice 5, where the measures of velum areas start, there is a progressive enlargement of the tract but the relation between vowels remains more or less constant even if there are some changes in the order of vowels. This fact being not significant because these measures account for the size of the tract at the entrance of the nasal cavities much above the velum.

Cross sectional areas [cm^2]

Slice	[~E]	[~%]	[Ã]	[Õ]
1	2.11	1.13	1.00	1.02
2	2.43	0.87	0.92	0.90
3	2.70	1.57	1.01	1.00
4	0.94	0.92	0.66	0.59
5	1.06	0.98	0.81	0.70
6	0.95	1.01	0.85	0.69
7	1.09	1.56	1.13	1.03
8	1.45	1.51	1.29	1.24
9	1.58	2.09	1.70	1.89
10	2.27	2.26	2.30	2.12
11	2.41	3.41	3.57	2.89
12	---	---	---	---

Table 1. Cross sectional areas of 11 slices taken from a region above the glottis to the nasal cavity for french vowels pronounced by subject 1

Cross sectional areas [cm^2]

Slice	[~E]	[~%]	[Ã]	[Õ]
1	1.62	2.41	1.86	2.10
2	1.14	1.11	1.10	1.23
3	1.19	1.30	0.77	0.59
4	1.21	0.66	0.49	0.38
5	1.77	1.24	0.44	0.48
6	2.18	1.28	0.57	0.36
7	2.42	1.86	0.65	0.75
8	2.48	1.65	0.65	0.53
9	3.10	2.56	0.80	0.76
10	4.00	2.54	0.88	0.73
11	2.18	3.77	1.82	1.22
12	1.68	1.63	1.84	1.20
13	2.29	2.06	1.93	1.31
14	2.27	1.81	2.02	1.26
15	2.85	2.83	2.89	2.11
16	3.90	2.82	3.08	2.65
17	4.30	4.33	4.11	4.05
18	5.23	4.23	4.52	4.78

Table 2. Cross sectional areas of 18 slices taken from a region above the glottis to the nasal cavity for french vowels pronounced by subject 2

Data for subjects 2 are given in Table 2. Images show that for subject 2 slice 12 is the level for measuring velum opening for vowels [œ̃] and [ɛ̃] while slice 13 is the level for measuring velum opening for vowels [ɔ̃] and [ɑ̃]. The relative differences in VP size between the vowels are the following: [ɔ̃] < [œ̃] < [ɛ̃] < [ɑ̃]. For this subject [ɑ̃] has the largest area, [ɔ̃] is the smallest. The four VP sizes of this subject are quite small and rather similar one to another. This confirms that velum lowering and changes in the articulatory position of the tongue are executed to realize a nasal vowel when the latter is compared to a coresponding oral vowel.

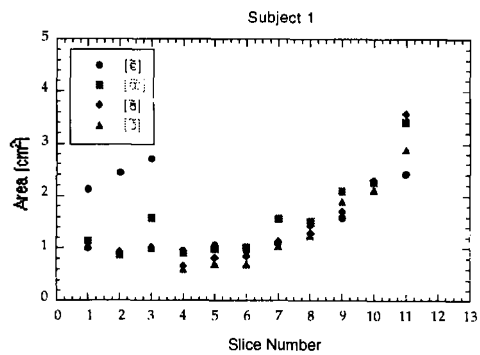

Figure 2. Plot of differences between all nasal vowels pronounced by subject 1..

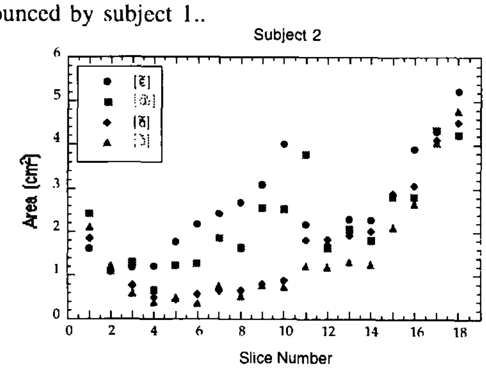

Figure 3. Plot of differences between all nasal vowels pronounced by subject 2.

A 3 dimensionnal visualization of the pharynx and of the nasal tract (for subject 2) obtained by the method described in section 2.4, is given in figure 4. One can see that the size of the pharynx is much bigger for the front vowels compared to the back vowels. The size of the nasal tract is comparable for all vowels as it was showed by the measures given in table 2 and figure 3.

[~ɛ̃]   [œ̃]   [ɑ̃]   [ɔ̃]

Figure 4. 3D reconstruction of the pharynx and of the nasal tract for the four nasal vowels of subject 2. [0532_03.GIF]

3.3. Comparison of Oral and Nasal Vowels

Figures 4 and 5 show pharyngeal areas, in addition to the velum opening data. For each vowel and for each speaker, the dimension of the pharynx is given by every measured area below the slice used for determining the velar port opening.

The pharynx spans differently from one speaker to an other, but differences in pharyngeal dimensions between vowels are very consistent from one speaker to the other. For both subjects, [ɛ̃] has the largest areas in the pharynx followed by [œ̃]. This is not surprising since both are front vowels. For our subjects differences in pharyngeal dimensions for back vowels are the same: [ɑ̃] is slightly bigger than [ɔ̃]. The plots presented on Figures 2 and 3 show that the constriction of the pharynx is smaller and involves more slices for back vowels. For both subjects [ɔ̃] has the most important constriction. Pharyngeal dimensions are given at Tables 1 and 2.

The area of the slices located in the pharynx has been measured for oral vowels corresponding to the nasal vowels of this study. The same M.R.I. recording procedure has been applied, for all speakers, for the oral vowels [ɛ], [œ], [ɔ] and [a]. Differences in size between oral and nasal vowels are obvious, nasal vowels having a much more constricted pharynx than oral vowels. The pharynx is always larger for the oral vowel, with only [ɔ] and [ɔ̃] being similar in the lower and upper parts of the pharynx. These results are similar to those of Zerling [6] who analyzed the differences between the four French nasal-oral vowel pairs using cineradiographic data. Zerling's vocal tract profiles obtained from X-ray tracings show that there are significant differences between oral vowels and their nasal counterparts with the most significant and consistent articulatory differences being found between [a] - [ɑ̃] and [ɔ] - [ɔ̃]. The observation made in Zerling study, with two male speakers, that the tongue body position of the nasals is more retracted in comparison with the corresponding vowels [a] and [ɔ] can also be seen for the four subjects included in our study, for all vowels. These facts confirm arguments presented by Maeda [7] who claimed that if velic lowering can not precisely be controlled, then articulatory adjustments play an essential role in causing the acoustic effects that result in a nasal percept. Maeda proposed that velum lowering and tongue backing must be considered as a single articulatory complex used to produce nasal counterparts to oral vowels. Maeda added that labialization is also part of this articulatory complex, but this was not taken into consideration in our study, due to constraints on the acquisition of the images.

4. Conclusion

The results of this study show that the magnitude of nasal coupling is quite variable accross different subjects. These variations are accounted for by intrinsic morphological differences between the subjects. However the magnitude of the oral-nasal coupling seems to be smaller than has been assumed in acoustic studies. These results also show that differences between nasal vowels and their oral counterparts are accounted for by velum lowering and by a modification of the position of the tongue body, which is more back for nasal vowels.

5. REFERENCE

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