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NASOPHARYNGEAL TRACT TRANSFER FUNCTIONS MEASUREMENTS WITH WHITE NOISE EXCITATION

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Abstract :

To understand acoustic phenomena involve in the production of the nasal vowels, we have built an experimental setting to obtain vocal tract transfer functions. Our setting is an improved version of FUJIMURA & LINDQVIST's method [1]. The vocal tract is excited through the skin of the glottis by a white noise and the transfer functions are obtained by averaging the F.F.T. spectra [2]. Results are rather complex, but we show that formants at 250 Hz and 1000 Hz of the transfer function of the nasal velar consonnant could be imputed to the first resonances of the nasopharyngeal tract : this would agree FENG's predictions [3]. Other poles could be explained by sinus cavities.

Introduction :

Study of acoustic production of nasal vowels is a delicate point because the respective influences of the nasal and paranasal cavities in speech production are not clearly understood. We think that the systematic analysis of transfer functions, measured in well controlled productions, can help us to explain the phenomenon.

MAEDA [3], carrying on works of DELATTRE [4], has drawn attention to the importance of the first low formant (250 Hz) as a nasality characteristic. FENG et al. [5] [6], considering the naso-pharyngeal tract, have shown the possible influence of the small area at "limen nasi" upon this first resonance. In order to reconfirm these results by direct measurements, we have built an experimental setting to obtain vocal tract transfer functions [2].

Experimental setting and method :

FUJIMURA & LINDQVIST [1] excited transcutaneously the vocal tract at the glottis with a pure tone swept in frequency, and measured the sound level at lips or at the nostrils. In our improved version of this method, the vocal tract is excited with white noise.The subject applies a small loudspeaker membrane externally at the level of the thyroid cartilage, checking that there is no noticeable sound leakage at the junction between the loudspeaker and the skin. The loudspeaker in then fed with a white noise signal with a flat spectrum (less than 3 dB fluctuation) between 20 Hz and 20 kHz (fig. 1). The output signal is picked up, at a distance smaller than 1 cm at the lips or at one of the nostrils by rather directing Electret microphone, and recorded through a P.C.M. Coder into a BetaMax video tape recorder. The signal is as well sent back to the subject by means of headphones; this allows an interesting feature : a control thanks to auditory feedback [2].

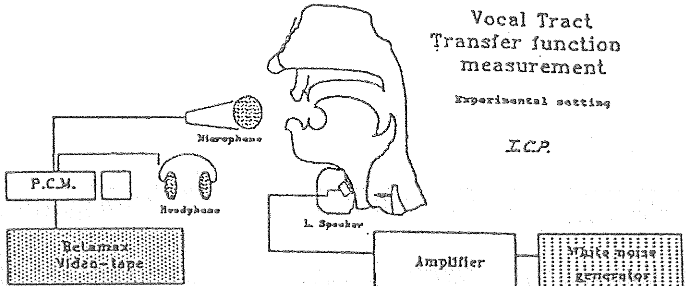

Figure n° 1. Experimental Setting.

Naso-pharyngeal tract transfer functions :

In our study, we are interested in one of the nasality charateristics : the low pole (around 250 Hz), which can possibly have its origin in a "HELMHOLTZ resonance" - as suggested by FENG & al. [5] [6]. The Helmholtz resonator consiste of the naso-pharyngeal tract - acting as the body - and the nostrils - acting as the neck of the resonator.

The frequency of the resonance depends of the volume V of the resonator, the length l and the area A of the neck according to :

$$F0 = \frac{C}{2\pi}\sqrt{\frac{A}{l.V}}$$

In order to find the relation between the low pole frequency and the limen nasi area, we have varied artificially this area with a series of small plexiglas tubes [2]. The transfer functions of the naso-pharyngeal tract are then measured. The naso-pharyngeal tract is considered as a simple tube constitued of the larynx, the pharynx and the nasal cavities.

Results :

For nine subjects, we have systematically measured and drawn the transfer functions for each nostril, for four possible limen nasi areas and for each of the vowels [a], [i], [u] and [o]. We have obtained a minimum of six measurements for each case. Most transfer functions display a structure much more complex that our simulated functions. Therefore, some measured spectral peaks and valleys seem to have fairly constant values. For each subject, the formants and zeros frequencies are very consistent. The standard deviation do not go up ten percent.

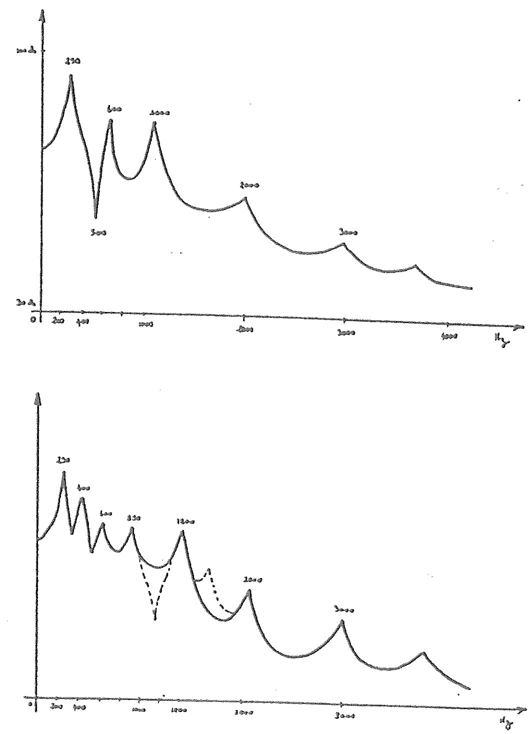

Figure n° 2. Standard naso-pharyngeal transfer functions.

So we can draw standard transfer functions for each subject. It divides up into two classes. One classe shows a simple transfer function with only six poles ans one zero between 0 and 5000 Hz. The other is more complex : up to nine peaks and up to three zeros in this interval (see figure n° 2).

A striking observation is that the lowering of the first resonance frequency of the naso-pharyngeal tract due to the decreased area at limen nasi is much less that we expected : whereas the Helmholtz formula leads to a decrease by more than 100 Hz, when reducing the diameter from 4.5 mm to 2 mm, we have hardly measured a decrease bigger than 30 Hz (see figure n° 4).

Discussion :

The formant Fn1, Fn5, Fn7 and Fn9 (respectively around 250, 1000, 2000 and 3000 Hz) are the resonances of the naso-pharyngeal tract if we consider this tract as a simple tube. Measured values agree with FENG'simulations (figure n° 3) [5] [6].

Fn2, Fn3 and Fn4 (respectively around 400, 600 and 800 Hz) could be explained by sinus cavities. We have often found zeros between these formants. Fn6 (around 1700 Hz) is the result of the disymetry of the two nostrils.

The lower limit of the first formant could be explained by wall vibration effects, in the same way described by ISHIZAKA & FLANAGAN [7] and FANT [8]. Considering that the Helmholtz formula gives the resonance for the hard wall case, we have applied the approximate formula proposed by FANT, with a tentative value of wall vibration frequency Fw around 200 Hz :

$$F0 = \sqrt{Fw^2 + Fh^2}$$

We can see the results in the figure n° 4, where we have draw the HELMHOLTZ formula, the FANT's correction and the measured values. We can notice that FANT's correction and measured values draw the same curve : Fn1 seems to be a HELMHOLTZ resonance. However, the volume of the resonator for the corresponding Helmholtz frequency (around 150 Hz) should be very large - more that 800 cm3. The simple naso-pharyngeal tract can not be this resonator. The sinus cavities can not also explain this resonance. We must perhaps consider other coupling between head cavities and vocal tract.

Anyway, we can now ensure that the first low formant of the nasal vowels and of the nasal velar consonant is not a glottal formant - as suggered by MAEDA [9], because all records of measured transfer functions are obtained with the glottis competly closed.

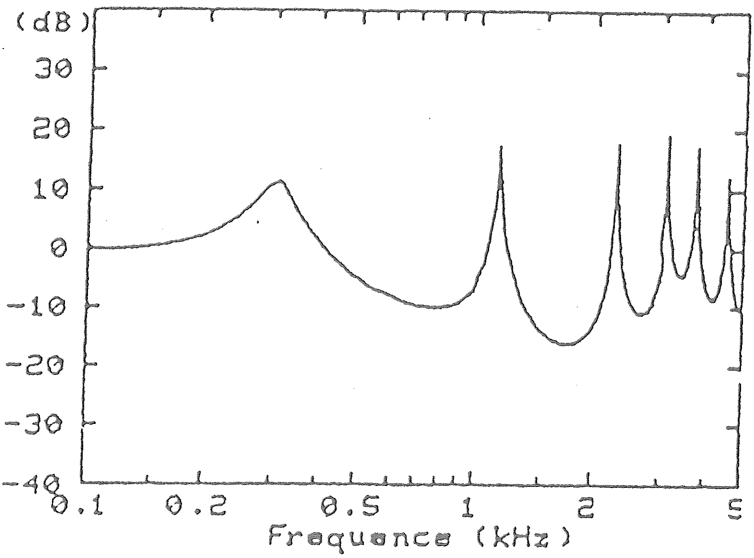

Figure n° 3. FENG'simulation of naso-pharyngeal tract transfer function.

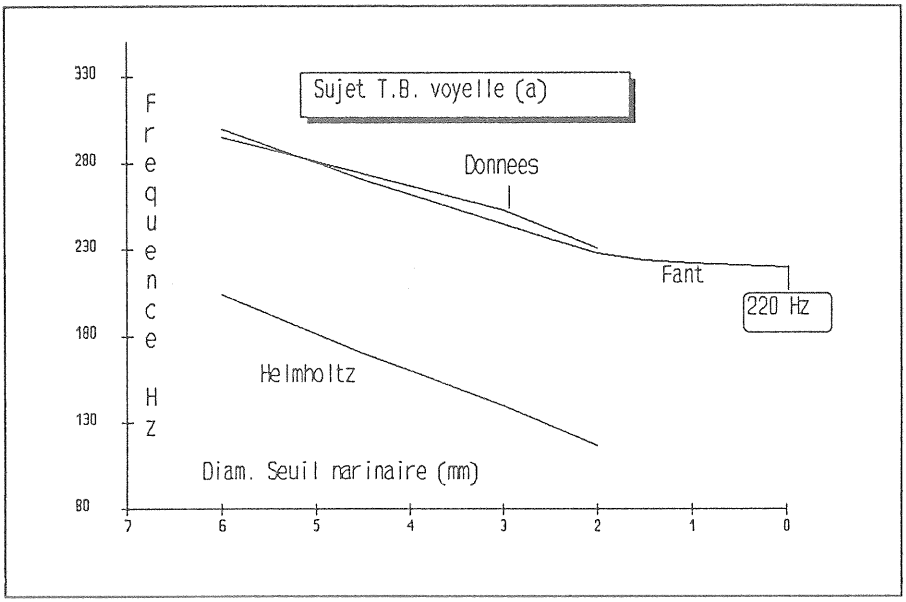

Figure n° 4. Frequency of Fn1 and "limen nasi" diameter.

Conclusion :

A renewed method for direct acoustic measurements of vocal tract transfer functions has been described. This method supply very consistent results. This should provide us with a quantity of fresh datas on the vocal tract, useful for vowels as well as for consonants.

The very low first formant of the nasal vowels and of the nasal velar consonant seems to be a HELMHOLTZ resonance. Nevertheless, because of the wall vibration effects, we can not consider that this formant is the resonance of the only naso-phraryngeal tract. The sinus cavities can not also explain this very low frequency : the volume of these cavities is too small. How important can be the role of the head cavities in the explanation of this phenomenon ?

References :

[1] O. FUJIMURA & J. LINDQVIST, "Sweep-Tone Measurements of Vocal-Tract Characteristics", J. Acoust. Soc. Amer. 49, 541-558, (1971)

[2] E. CASTELLI & P. BADIN, "Vocal Tract Transfer Functions Measurements With White Noise Excitation. Application To The Nasopharyngeal Tract", Proceed. SPEECH'88 7th FASE Symposium, 415-422 (1988)

[3] S. MAEDA, "Une paire de pics spectraux comme corrélat acoustique de la nasalisation des voyelles", 13èmes JEP GALF, 223-224, (1984)

[4] P. DELATTRE, "Les attributs acoustiques de la nasalité vocalique et consonantique", Studia Linguistica, 103-109 (1965)

[5] G. FENG, "Modelisation acoustique et traitement de la parole. Le cas des voyelles nasales", Thèse Dr. I.N.P. GRENOBLE (1986), p = 233

[6] G. FENG, C. ABRY & B. GUERIN, "The nasopharyngeal Tract : a Target for Nasality. Acoustic Simulations vs. Sweep-tone measurements", 12th Int. Congr. Acoustics, A3-8. (1985)

[7] K. ISHIZAKA & J. L. FLANAGAN, "Synthesis of Voiced Sounds from a Two-Mass Model of the Vocal Cords", B.S.T.J. 51, 1233-1268, (1972)

[8] G. FANT, "Vocal Tract Wall Effects, Losses, and Resonance Bandwiths", STL-QPSR 2-3/1972, 28-52, (1972)

[9] S. MAEDA, "The Role of the Sinus Cavities in the Production of Nasal Vowels", IEEE Int. Conf. ASSP, 911-914, (1982)