VOCAL TRACT VOCALIC NOMOGRAMS: ACOUSTIC CONSIDERATIONS.

A Crucial Problem: Formant Convergence.

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ABSTRACT

Presented by FANT in 1960, nomograms have not been thoroughly explored for studying vocalic productions. It took a long time before we noticed the utilization of this kind of tool with STEVENS's contributions or with the attempts by LADOGOD and BLENDON to reproduce FANT's 1960 nomogram (x/). We think that nomograms are still very powerful tools in the field of articulatory-acoustic relations for vocalic productions. For system interpretation and prediction, as well as for formal measurement up to F3, we describe below, FANT's 1960 nomogram, and we recall FANT'S explanations about the "affiliation" phenomenon. Then, we study the effect of losses, especially the effect of an intermediate lip opening (F1, F2, F3, in the case of an intermediate lip opening)

1. FANT'S VOCALIC NOMOGRAMS: A REVISIT

1.1 The Four Tubas Model: Basic Resonances

In the case of a simple vocalic production, we may observe the acoustical behavior of the vocal tract while eliminating the middle from glottis to lips, FANT defined a four-tube model (x/). Here, we retain the following configurations for the 4 sections:

- Pharynx cavity: A = 8.5 cm2, L = 7 cm, L = 5 cm
- Tongue cavity: A = 0.6 cm2, L = 1.6 cm
- Mouth cavity: A = 0.6 cm2, L = 1.6 cm
- Lips: A = 1.9 cm2, L = 1.6 cm or no lips: A = 1.9 cm2

The constriction center coordinate X is measured in cm from the tip of the tongue and is correlated to the distance from the back cavity (F1) when 0.8 cm to 1.5 cm, keeping L = 1.6 cm.

In order to understand the affiliation phenomenon, we have seen nomograms for the different cavities alone. We have supposed very low loss at the back cavity, while the other cavities present a higher value (X/). Finally, the effects of the results of our simulations with natural speech.

INTRODUCTION

Presented by FANT in 1960, nomograms have not been thoroughly explored for studying vocalic productions. It took a long time before we noticed the utilization of this kind of tool with STEVENS's contributions or with the attempts by LADOGOD and BLENDON to reproduce FANT's 1960 nomogram (x/). We think that nomograms are still very powerful tools in the field of articulatory-acoustic relations for vocalic productions. For system interpretation and prediction, as well as for formal measurement up to F3, we describe below, FANT's 1960 nomogram, and we recall FANT'S explanations about the "affiliation" phenomenon. Then, we study the effect of losses, especially the effect of an intermediate lip opening (F1, F2, F3, in the case of an intermediate lip opening).

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1.2 Formant and Coupling of the Focal Points

Fig. 2 (a, b, c, d) represents the relative resonances of the complete four-tube system (full cavities, dashed cavities) from the different cavities (dashed lines) and must be read as a simplified line. The results demonstrate clearly the affiliation phenomenon. Actually, a solid line in very close to a line drawn by the resonance of the whole system.

1.3 Losses Effects

To have a better insight into the coupling phenomena we have neglected in section 1.2 the losses and the boundary effects such as wall vibration or lip radiation. We now include these effects in the simulation. The contribution of the high frequency part of the tongue constriction, we observe a focalization of the formants ("dual focal point") in this convergence region where the affiliaction of the lower and upper resonances switches from one cavity to the other when the tongue constriction is shifted.

Coupling between two resonant systems is a classical phenomenon: it always spreads apart the natural frequencies of the two systems. More precisely, the greater the coupling, the larger the frequency spreading, and conversely, the smaller the coupling (i.e. the constriction cross area), the more prominent the formant convergence. The case of a small lip opening (X/), Fig. 2(d) shows a good example of large coupling: the HELMOLZ resonances associated with the "tongue cavity + lip cavity" resonator, and the "mouth cavity + lip cavity" resonator, are both coupled through the constriction. The case of a wide lip opening (X/), Fig. 2(b) shows a good example of F2/F3 convergence on the glottis side of the convergence point. F3 is closely associated with the front cavity, and F2 with the back cavity, whereas it is opposite on the lip side. We call it "configuration close to a solid line, focal point". The correlation of the above examples, we can, of course, define different formant convergences effect. It is the case of formant convergence close to an "open line" (X/), and configuration of the focal point with a specific lip opening (X/). The effect of the formant convergence is highly associated with the front cavity and, F3 with the back cavity, whereas it is opposite on the lip side. We call it "configuration close to an open line, focal point". The correlation of the above examples, we can, of course, define different formant convergences effect. It is the case of formant convergence close to an "open line" (X/), and configuration of the focal point with a specific lip opening (X/).

A more detailed analysis of Fig. 3 leads to a notion of the intermediate lip opening for the small glottis opening on the glottis side of the focal point, the bandwidth of F3 (which is associated with the front cavity) is greater than that of F3, whereas the lip side bandwidth of F3 (which is associated with the back cavity) is greater: this inversion is the consequence of a focal point movement associated with a focal point movement associated with a focal point movement associated with a focal point movement associated with a focal point movement. A focal point movement associated with a focal point movement associated with a focal point movement associated with a focal point movement.

2. EXPERIMENTAL ILLUSTRATION

In this section, we compare some results of the above theoretical study with equivalent situations for real speech.

2.1 F3/F2 Convergence for [i]

To a neutral attempt to reproduce FANT's monogram has been the one by LADOGOD & BLENDON (X/). They have attempted to reproduce FANT's monogram corresponding to sounds for which the tongue constriction is prominent. Fig. 15 shows the location of the alignment of the pharynx to the teeth, every other parameter being supposed constant: they noticed regular shifts of the formant frequencies corresponding to what was expected from FANT's monogram, but they mentioned that, for an intermediate lip opening, F2 may appear to have suddenly assumed a value comparable.
to that of F4 in the previous vowel. By reference to the above simulations, we know that F2 and F3 can merge into a focal point for a given position of the tongue constriction; we believe that an answer to LANDFORD & BLADON's difficulties is that F2 and F3 are actually merged into a single focal point.

To check this hypothesis, we have recorded a series of [clar] sounds, where the transitions [i] and [a] correspond roughly to a shift of the tongue constriction, every other parameter being approximately constant (except for lip opening). If F2 is a delta or post-alveolar consonant, we assume that the tongue constriction shifts from a post-oral [i] to a pre-oral [a].

[3] in [i]-[a] transition, and that the focal point will be gone through. (Figure 4) shows the evolution of the formants (traced from cepstral) for the sequence [i]-[a]. We can easily follow the front cavity resonance going from F2 to F3 and back from F3 through the focal peaks Fp1 and Fp2; it might be possible to track this resonance even until F4. The spectral representation (obtained by LPC analysis) of Figure 5 (a,b), shows a rather striking analogy with the transfer functions from Figure 3 for the transition of F2 and F3 around the convergence point. This shows that the focal points predicted by our simulations are observable in real speech. It also reinforces our view on LANDFORD & BLADON's problem, and provides an explanation for the O'KOROGHY & al. (1979) observations.

This convergence phenomenon may explain a part of the difficulties encountered by phoneticians in measuring F2 and F3 for [i] vowels, and the large dispersion of their data.

3.2 Bandwidth inversion around the F2/F3 focal point

The purpose of this section is to verify on real speech the effect of "bandwidth inversion." Thus we have recorded four sounds with [i] in 4 different contexts, [i], [o], [e] and [a], corresponding to two articulatory locations (palatal vs. alveolar) and two glottis openings (small vs. large). According to the transfer functions shown in Figure 3, we can expect the following relations for the bandwidths B2 and B3, and for the amplitudes A2 and A3 of F2 and F3:

- Glottis articulation: Bandwidth amplitudes
  - opening relation
  - relation

- Large preoral B2 = B3 > A2 > A3.

Figure 6 shows that the spectra of the [i] sounds in the four different articulation contexts check with our expectations. This reinforces the bandwidth inversion phenomenon around the focal point, and the influence of the glottis losses upon the relative bandwidth values of the formants associated with the back cavity compared to the those associated with the front cavity.

CONCLUSION

The monograms have allowed us to interpret the relations between formants and cavities, and to study the influence of the larynx. We have illustrated these results with natural speech in a qualitative way, for a focal [i]. In order to obtain quantitative predictions closer to reality, we need to use a more realistic articulatory model: a study is in progress with NASA's articulatory model [6].

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REFERENCES


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