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# PITCH PERCEPTION : FIVE VOICES WITH FOUR SARDINIAN SINGERS

*CASTELLENGO Michèle*, LORTAT-JACOB Bernard**, LÉOTHAUD Gilles****

* Laboratoire d'Acoustique Musicale (Univ. Paris 6, CNRS-UMR 7604, Ministry of Culture)
** Laboratoire d'Ethnomusicologie (CNRS, UMR 9957 )
*** Département de Musicologie (Univ. Paris 4)

*E-mail : michele.castellengo@upmc.fr*

**Abstract**

Schouten's residue pitch theory and Terhardt's virtual pitch theory account for our ability to hear a low pitch when some high components in harmonic relations are produced. Such theories are based on experiments with pure tones in laboratory environment and for simple melodic conditions. The present research concerns an outstanding real musical production studied by B. Lortat-Jacob. He observed that, in some polyphonic vocal productions of traditional Sardinian music, in addition to the four male singers, an extra voice could be heard. The whole spectrum is extremely complex and not really stable.

Selective filtering with Phase Vocoder shows that:

- Only two components are responsible for this fifth voice; when these components are removed the voice disappears.
- The two components appear in the so-called "dominant region" and sound like the second and the third harmonics of a new fundamental.

This phenomenon appears when voice fusion is achieved. The incidence of harmonic tuning relations and of vowel formant techniques on this phenomenon are examined.

## 1- INTRODUCTION

Among traditional music productions of the Mediterranean area, polyphonic vocal songs from Sardinia are particularly remarkable and have been extensively studied by B. Lortat Jacob [1]. The present paper refers to a particular vocal style in use especially for the songs of the Holy Week, and sung by the Brotherhood of the Oratorio of Castelsardo village.

The choir comprises four voices, which are, from the lowest to the highest one: *bassu*, *contra*, *bogi* and *falzittu*[1]. The musical structure is related to the "falsobordone" style and is principally based on major and minor triads. From the lowest to the highest ones, the voices are most often tuned as the fundamental, the quint, the octave and the upper third.

Voice timbre is rather rich and the whole choir gives a complex harmonic sound sensation. However, when the performance is perfect according to the singers, a strange additional voice appears in the higher part of the spectrum. This phenomenon is an exciting pitch perception problem.

[1] It must be noticed that the term *falzittu* does not refer here to a voice register. This traditional name designate the high voice, but using the same chest register as the others.

## 2 – PASSION SONG "QUINTINA"

### The fifth voice

When hearing a Sardinian Passion Song for the first time, the beautiful voice quality and the special merging sensation of the four voice charm the listener. He is also interested with the strange polyphonic style including successive parallel chords. But when he discover that an aerial feminine voice is present in that choir, his attention is fully turned to it. In our musical example the additional voice pitch is heard two octaves above the bassu voice. For a chord based on G2 = 100 Hz, we find G4 = 400Hz for the 5$^{th}$ voice fundamental.

### Spectral analysis of a chord.

Figure 1 gives the analysis of a triad sung with the vowel "*a*". On the left is the sonagram analysis showing the characteristic gliding attack of the voices at the beginning of the chord. In the middle is the average spectrum taken between the time interval marked by the two cursors (1.5s).

One may observe that the fundamental components are rather weak, and that no particular feature appears at 400 Hz. The two maxima of the spectrum lie around 1250 Hz and 750 Hz. In polyphonic voice production, these spectral strengthening may be produced by the vowel formants, but they may also result from harmonic coincidence of the chord components. Moreover, the musical intervals are in "just intonation" like "a cappella" choirs do. In particular, the two notes of the major third G/H are in the same ratio as in an harmonic third (4/5).

On the right part of Figure 1, the theoretical harmonic spectra of each individual voice are drawn at the same frequency scale as in the analysis. Three triple coincidences are visible on the bassu harmonic numbers 6, 10 and 12, which correspond to the notes D5, H6 and D6. Except for D6, they are not in relation with the pitch looked for. There are also many double coincidences, but which of them must be taken in account?

## 3 – QUINTINA AS VIRTUAL PITCH

### Perceptual trial

In order to find a relevant interpretation of the acoustical parameters responsible for the pitch, the following experiment was made. Listen to a short choir sequence of three descending notes, and immediately after a solo voice sings the 5$^{th}$ melody: the analysis the two productions is presented in Figure 2. The 2$^{nd}$ and the 3$^{rd}$ harmonic of the solo voice are tuned on two choir formants area clearly visible in the figure. This observation suggests that the additional voice is a virtual pitch resulting from high spectrum components. This is confirmed by the very different timbre of this voice as compared with the others..

### Pitch perception

A single periodic tone give a clear pitch sensation which can be easily related to the frequency of the fundamental (or 1$^{st}$ harmonic). Since the early observation made by Tartini and Romieu in the 18$^{th}$ century, we also know also that two tones produce a "third tone". Many experiments were done by Helmholtz and other authors on combination tones in order to test the objective or subjective aspects of this phenomenon. Since the exhaustive work realized with different signals (sinus, pulse tones, frequency modulated tone), by Ritsma [2], Plomp [3], Houtsma [4], Terhrardt [5], some rules have been well established. The pitch sensation (low pitch) produced by the combination of higher components (spectral pitch) which are or not in harmonic relation, occurs clearly in the following conditions:

- The spectral components must be closed to the lower harmonic (2, 3 and 4), that is, these components fall inside different critical bandwith.
- The components must be situated in the so called "dominant region" of the spectrum which lie roughly between 800 and 2000 Hz.
- Finally, two components only are needed to create a low pitch.

**Synthesis experiments**

To validate the hypothesis, the rejection of two components of the spectrum was carried out. Using Phase Vocoder software[2], the second and the third harmonics of the "5th voice" are eliminated: immediately, the pitch disappears. Further, the extraction of these two components clearly reproduces the melody. Finally, removing only the fundamental changes the tone quality of the voice but does not destroy the 5th voice perception.

## 5 – "VOWEL TUNING" IN THE PASSION SONGS

The different Passion songs are based on holy texts like Miserere and Jesu. However it is rather difficult to understand the true words. According to B. Lortat-Jacob, the singers know intuitively that they must change the vowel timbre for many reasons. Firstly, to give each voice a suitable tone quality, rather round for the bassu, and rather brilliant for the falzittu; secondly, to achieve a perfect fusion effect.

From the acoustical point of view, vowels are very complex sound "objects" which may be characterized by their formant parameters: central frequency, bandwith, intensity. When these parameters are modified, we hear modifications that lead to different vowel identifications, but also modifications in the voice color. It is well known that the two lower formants are essential for the vowel identification. As shown in Figure 3, the 2nd formant plays the most important role in the vowel tone sensation: for example, one often compares the "pitch" of vowels, saying that *e* is acute and *o* is low, despite a common 1st formant. Moreover, the 2nd formant changes within the dominant region, which is also the 5th voice area. Since the bassu voice mostly moves within a fourth interval, from G1 (100Hz)[3] to C2 (125Hz), its 8th and 12th harmonics, which correspond to the 2nd and 3rd harmonics of the 5th voice, respectively fall in the interval 800-1000Hz and 1200-1500 Hz.

It appears now that "tuning" the vowel color – i.e. the 2nd formant – of *a* and *o* may be critical for producing a clear 5th voice producing. These vowels are devoted to the three lower voices. On contrary, the falzittu voice, which uses vowels *e* and *ε,* mainly contributes to the general sound quality of the choir.

## 6 – CONCLUSION

Formant tuning is a well-known vocal technique to produce spectral melody. In the case of the Sardinian Passion Song, the pitch is produced by two components in fifth ratio, situated between 800 and 2000 Hz. The phenomenon occurs when perfect interaction between harmonic fusion and vowel tuning is realized, on the right musical interval and in the spectral dominant region. Another four-voice Sardinian song using the same chord and in the same tessitura does not produce the effect described here. The apparition of the quintina requires an exceptionally fine, subtle and attentive communication between the four singers.

## 7 – REFERENCES

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[5] Tehrardt E., Stoll G., Seemann M, (1982; Pitch of complex signals according to virtual-pitch theory: tests, examples, and predictions. *J. Acoust.Soc.Amer.*, **71**, 671-678.

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[2] Audiosculpt, an analysis/synthesis software developed at Ircam.

[3] The Sardinian singers do not refer to an absolute pitch. But they choose very carefully the starting note and the frequencies given here roughly correspond to the performance recorded.

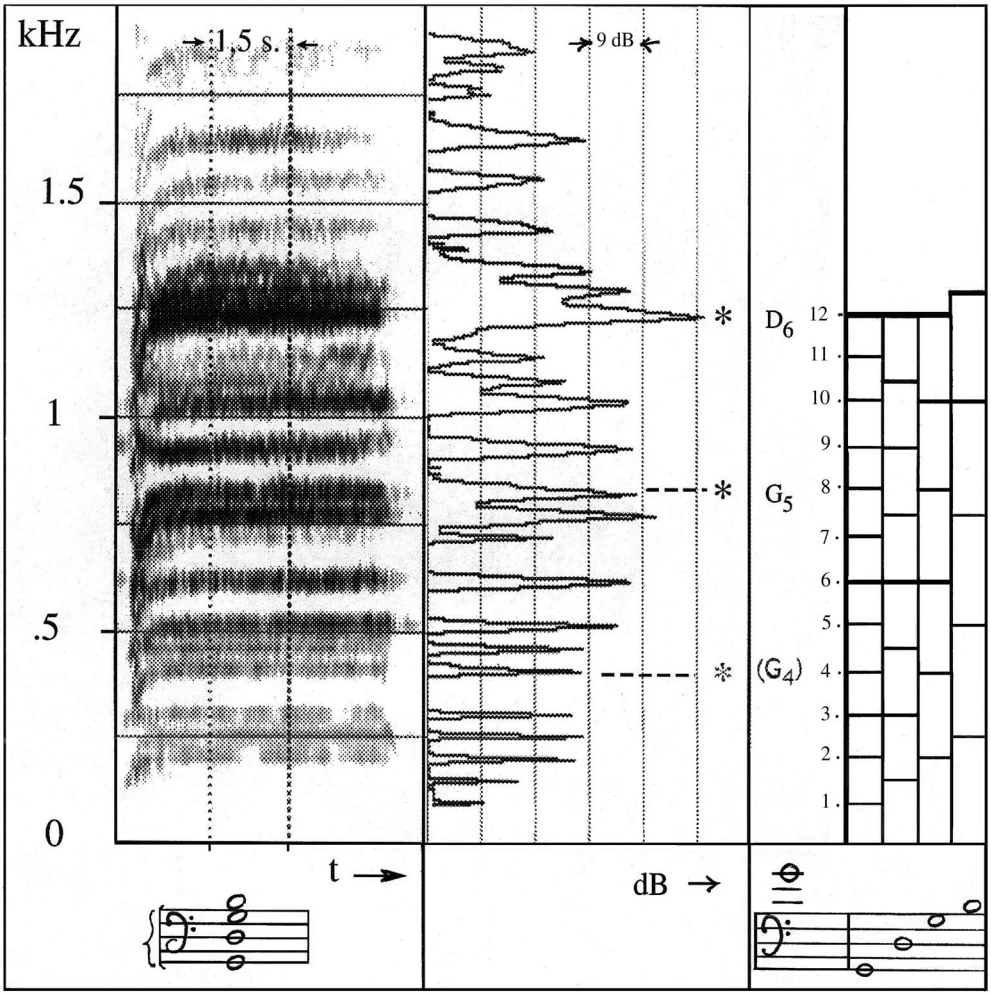


**Figure 1 - Analysis of a chord**.
Left: sonagram analysis; middle: average spectrum; right: harmonics of each voice

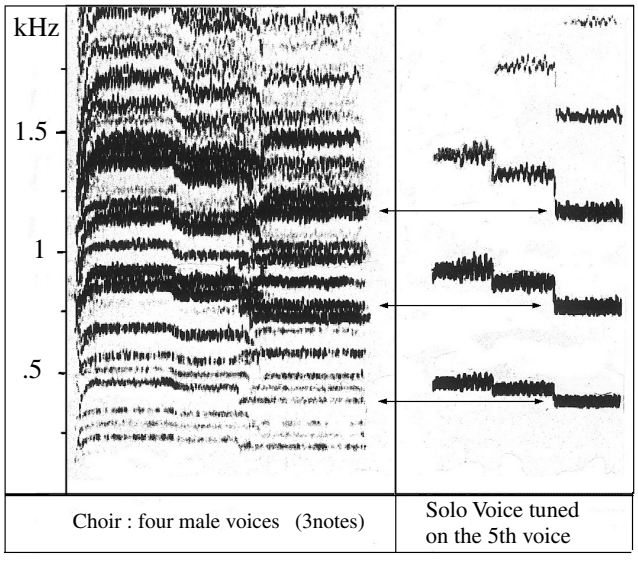


**Figure 2 - Sonagram analysis.**
Left : Sardinian choir singing three successive chords; right: solo voice singing the melody of the 5th voice

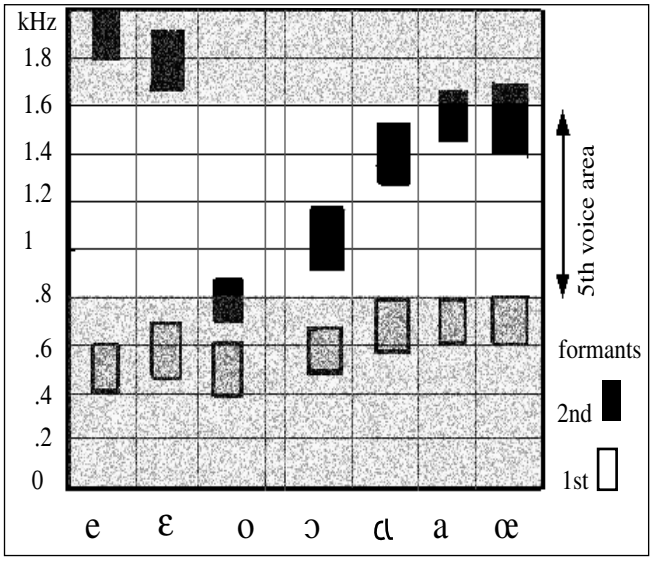


**Figure 3 - Frequency aera of the quintina** compared to the two first vowel formants in use in the song. Note the importance of the 2nd formant.