

FORMANT TUNING IN BYZANTINE CHANT

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ABSTRACT

We present an investigation of formant tuning in the context of the Byzantine Ecclesiastic chant voice. The recordings selected for the analysis are part of the DAMASKINOS prototype acoustic corpus of Byzantine Ecclesiastic voice. More specifically, we analyzed recordings from 10 different chanters in ascending musical scales of the diatonic genre, for the /a/ vowel. The method of analysis included a semi-automatic segmentation of the audio material, extraction of the measurements in PRAAT and the final post-processing in MATLAB. Results show clear evidence of formant tuning in at least six of the chanters, proving that the technique is in use by the modern Byzantine music performers.

1. INTRODUCTION

In 1960, Gunnar Fant presented the theory of a source-filter production model for vowels, in his work “Acoustic Theory of Speech Production” [1]. According to this model, the voice source produces a harmonic series, consisting of the fundamental frequency f_0 and a large number of harmonic frequencies, the partials [1].

Specifically, when applied to vowel production, the speech signal could be thought as the result of the source signal, produced by the glottis, and the resonator or vocal tract filter. A linear mathematical model supports this theory, which allows for relatively simple handling of calculations. The vocal tract filter can be further considered as a linear time-invariant filter for very short periods of time, making the system even more mathematically tractable.

The resonance frequencies of the vocal tract are called formants, designated as F1, F2, F3, etc. in ascending order, and they can be displayed as spectral peaks in the frequency response of the vocal tract filter [1]. The vocal tract has four or five important formants that are used to amplify and dampen certain frequencies. The length and shape of the vocal tract determine the formant frequencies, resulting in the production of the different vowel sounds of the radiated speech signal. The lowest two formants F1 and F2 largely determine the vowel [1],

while the remaining higher order formants are related to the quality of tone [2].

Adjusting the vocal tract in order to align formants with harmonics, thereby amplifying certain portions of the vocal spectrum, is known as *formant tuning* [3]. This intuitive act, that is highly dependent upon the vertical laryngeal positions, has been used from trained singers in the past, in cases where the singing voice should be heard across large spaces along with other sound sources, like for example music orchestras [3].

In the past, research concentrated on the relation between the quality of the voice and the formants. Later works [4,5], revealed the existence of the singer’s formant, which can be explained acoustically as a clustering of formants, F3 and F4, or F4 and F5, and even in some cases F3, F4, and F5. The singer’s formant enables a singer to be heard over an orchestra, since there is little competition from the orchestra near the frequency range of the singer’s formant [4]. This is a way for the singer to save some vocal effort, in other words it results in “vocal economy” [3].

Formant tuning is considered as another vocal strategy used by trained singers when trying to produce the ideal voice and economizing on vocal effort. Several works have been published concerning formant tuning strategies applied by classically trained Western operatic voices [6,7,8,9], as well as contemporary [10] and traditional [11] ones. Recent works [8,9] give a description of the formant tuning literature with details about the different methods and their limitations [9]. Three trends seem to be the dominant ones: a. F1 and F2 are tuned to a partial, b. F1 and F2 are not related anyhow to harmonics of the f_0 and c. F1 and F2 are tuned just above their nearest partial in a way so that they don’t coincide.

While literature on formant tuning continues to grow for other types of vocal music genres, Byzantine Ecclesiastic chant voice hasn’t been studied in the same context. Current work tries to fill this gap by providing an initial approach, along the path followed by other recent investigations on this subject, and presents the first results of this preliminary analysis.

2. BYZANTINE CHANT MUSIC

Byzantine Chant Music (BCM) is a religious type of monophonic vocal performance practiced mainly in churches. Its main purpose is to serve the religious needs of the Orthodox Christian worship, providing a musical accompaniment for the ecclesiastical poetry [12,13]. BCM follows aesthetical rules formed over the course of

centuries, traditionally transferred from master performers to apprentices. It is a microtonal music since it contains intervals smaller than the conventional contemporary Western theory semitone.

The temperament used in modern Byzantine chant is based on a 72 equal divisions of the octave, called *moria* (plural form of *morio*) [13]. Compared to the 12-tone equal temperament followed by the Western theory, a Western semitone would equal to 6 *moria* in this 72-tone equal temperament system. Byzantine music uses the term *echos* to refer to a specialized type of musical mode [12,13], denoting not only the musical scale being applied in a melody with a definite “tonic” or main note called *vasi* (Greek word for “base”), but also specific musical phrasing [13].

There are three musical genera in Byzantine chant: the diatonic, the chromatic and the enharmonic [12,13]. The fundamental intervallic differences between the three genera, apart from musical aesthetics, serve different musical meanings, when considered in a specific lyric context. This leads to another classification of the three genera and its subdivisions, based on the *ethos* of the music genre, as Chrysanthos of Madytos, one of the main three reformers of the modern Byzantine music theory, named it [12,14].

The musical scale used by the chanters in this work belongs to the diatonic genre and it is shown in Figure 1.

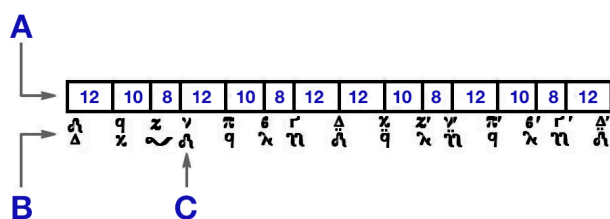


Figure 1. Diatonic genre scale used in Byzantine chant. A: Scale intervals measured in *moria* (72-tone equal temperament). B: Symbols used for the scale degrees. C: Scale’s tonic.

3. MATERIALS

The materials selected to be analyzed in the present work are part the DAMASKINOS prototype acoustic corpus of Byzantine Ecclesiastic voice [15,16]. The DAMASKINOS corpus was designed and developed in the Department of Informatics and Telecommunications, University of Athens. Our aim was to create a standard, tagged corpus of BCM, from a statistically representative sample of modern performers. The entire corpus consists of the recordings of twenty chanters carefully selected from entire Greek territory, recorded strictly under the same controlled conditions of digital recording, with a second channel for the electroglottograph signal (EGG), as well as other measurements like glottal flow and subglottal pressure. The musical performance of each subject followed a structured protocol and included: a) specific music sections of all the musical genera from the entire repertoire of Byzantine chant (*papadika*, *stehera*, *irmologika*) and b) musical exercises in all the musical scales per genre. All the sections were recorded, except from being chanted, at their spoken and musical

recitation as well, in normal intensity of voice and in the basic octave of C3 [15]. The contents of the corpus were tagged using multiple layers of metadata [17]. These data mainly consist of the lyrics syllables, the musical notation symbols of the Byzantine music score and the musical intervals. Each of these types of data forms a tagging layer on its own. A couple of extra layers are used for parts of the recordings where the chanter overlooked the written score, by means of musical expression (intervals, score) [17].

In this work we used a subset of the DAMASKINOS corpus, which consists of ascending musical scales for the vowel /a/, performed by a total of 10 chanters. During recordings, the chanters were asked to perform the intervals of the diatonic scale presented in Figure 1 for the specific vowel. Chanters were free to choose the performed pitch span that suits best to their vocal range.

4. METHODS

The measurements used in our analysis were acquired using the PRAAT software. PRAAT is a valuable software tool in the field of phonetics and voice analysis in general [18]. It is a flexible tool, which provides functionality that could handle most of the tasks needed in this work. It handles all the widely used audio file formats by importing the audio files as objects on which various operations can be applied. Apart from sound files, PRAAT can create and make use of tagging files in the form of layers called *tiers*. Tiers consist of boundaries and intervals between them. Labels can be added at these intervals making it easy to tag sound recordings. Several tiers can form a TextGrid object. To summarize the main PRAAT features we used in our analysis: a. it handles large audio files, b. it extracts measurements of the vocal parameters using its built-in functions, c. it uses tagging layers for audio file annotation, and d. it uses a scripting language for automating processing. Indeed, PRAAT can manipulate, edit and analyze long stereo audio files. Annotation of the files is done with tagging layers, using boundaries to mark time exact points in the recording, and the intervals in-between them to insert the metadata. One of the most powerful features of PRAAT is inevitably its scripting language. This language includes variables, loops, jumps, formulas, procedures, arrays, etc. which provide the flexibility to implement complex algorithms in combination with the ready-to-use analysis commands found in PRAAT.

The functions that were mostly used in our measurements are the ones for pitch and formant analysis. For pitch analysis PRAAT uses an algorithm that performs an acoustic periodicity detection on the basis of an accurate autocorrelation method [19]. Formant values are calculated with the algorithm by Burg [20,21]. PRAAT is a commonly used speech analysis tool and its accuracy has been thoroughly tested in several related papers [22,23,24]. Furthermore, PRAAT measurements are used in many investigations as the baseline for accuracy comparisons [25,26,27,28].

We started processing the audio files by using a series

of PRAAT scripts that analyzed intensity and pitch, in order to annotate the audio file, by marking the basic musical units, which correspond to the scale's degrees [17]. Our final purpose was to extract separate audio files for each scale's degree. This was a three-step process: 1. voiced – unvoiced parts of the audio file were labeled using a tag layer, 2. for each voiced part boundaries were placed at pitch transitions between the scale's degrees, and 3. intervals in-between boundaries were labeled according the audio segment's average pitch. Before moving forward to the next step we were able to fine-adjust the placement of the boundaries. The transition zones between notes have been excluded. Each audio segment between boundaries was extracted to a separate audio file with average time duration of 1 sec.

Next, we analyzed each of the extracted files, using PRAAT's readily available functions, in order to acquire the actual measurements we needed. Three vocal parameters were measured every 10 msec: pitch value for f_0 , frequency values for the formants F1 and F2. Other measurements, like sound intensity level, formant bandwidths, formant levels and partials levels were also extracted, although not used in the current work. All data were stored in tab-delimited text files. Final processing was done in `Matlab`. First the data files were imported, the mean values were calculated for pitch and formant frequencies and the corresponding graphs were plotted.

5. RESULTS

Displaying the actual measurements for each chanter is the next step in our investigation. This involves plotting the frequency tracks of the two lowest formants F1 and F2, along with the partials h_2 - h_8 , where $h_n = n \cdot f_0$ and f_0 is the fundamental frequency of the vowel. In Figure 2 we present these measurements for each chanter. Both axes represent frequency values in semitones, measured from D2 (73 Hz).

Results for chanter 1 show a clear tendency of the F1 and F2 formants to follow the slope of the h_2 and h_4 respectively, above the C4 note. This is clearly depicted by a simultaneous characteristic bend in the track of both F1 and F2 around the pitch of C4.

Formants F1 and F2 of chanter 2 follow a similar pattern. The simultaneous bend at about the same pitch, as the one noticed for chanter 1, is found in F1 and F2 of chanter 2, although F2 jumps over to the h_3 partial at the scale's peak note.

Chanters 3 and 4 are two more complicated cases. While both of them show signs of formant tuning, it is not clear if this is done intentionally. Specifically, chanter 3 seems to tune F1 to h_3 , then to h_2 , while getting higher in the pitch range between C3 and D#4. On the other hand, chanter 4 shows a quite similar F1 track to the one described for chanter 3. Indeed F1 tunes initially to h_3 from C3 to F3, then tunes down to h_2 from A3 to D4. In both 3 and 4 chanters F2 tunes to h_3 at the highest part of the scale, namely between E4 and A4.

Formants F1 and F2 for the chanters 5 and 6 seem to be unrelated to the partials. Despite the fact that for some

tones they seem tuned on the harmonics, the overall image of the two formants tracks, leads us to believe that this was a coincidence and not the result of an intentional tuning effort. An exception seems to occur at the top 3-4 notes where F2 is tuned to h_3 or h_4 .

Chanter 7 tunes its F1 to the h_2 partial starting approximately at D4 and keeps it tuned up until the ultimate note of G#4. Formant F2 for the same chanter tunes to h_4 at about C4 then jumps to h_3 at F4.

Chanter 8 seems to start tuning its F1 formant to h_3 at about E3 and then tunes it to h_2 at G#3. Its F2 formant remains relatively constant until A3 where it tunes to h_4 .

Chanter 9 mainly tunes F1 to h_2 at E4, but also shows signs of tuning F1 to h_3 at the region between F#3 and A3. Its F2 formant tunes to h_4 above E4 and then jumps to h_3 at the last note of its range.

Chanter 10 is the clearest evidence of formant tuning among the sample of 10 chanters. It keeps its F1 tuned to h_2 throughout the range of B3-G4 that is 6 consecutive notes. In the same pitch region F2 is tuned to h_4 for the first 5 notes then finally tunes to h_3 .

6. DISCUSSION

Previous research has shown that singing voice classification could be based on the formant frequency values and vocal range [29,30,31]. This way a psaltic voice can be classified in one of the classical music voice types. Moreover, although BCM performers have not been exposed, traditionally, to classical vocal training techniques, formant tuning can be considered as an intuitive act [3], and therefore be performed by non-classical trained voices as well.

The pitch range that draws our attention is the one referred to as the *passaggio*, which is D4-G4 for tenors and B3-E4 for baritones [6,9,29]. It has been found that formant tuning is mostly observed in and above this range [9]. This can be easily seen in our results. Most chanters tend to tune their F1 and F2 to partials at this pitch range, although there were cases of formant tuning at lower scale degrees.

Considering an accuracy margin of about 20 Hz for the tuning of the formant frequencies [32,9], as well as the maximum distance criterion of 50 Hz between the formant and its nearest harmonic, used in similar works [9], a 2 semitone approximate distance between the formant F1 and the partial h_2 , in the frequency range of E4, could still be counted as tuning [9]. This could easily explain the distance between the F1 and h_2 , found in the results for chanter 1, since it can be considered inside the formant tuning tolerance limits.

The distance in semitones between each formant F1, F2 and their closest partial for the vowel /a/, is displayed in Figure 2. As before, the data presented in the graph are for the ascending diatonic scale, for all ten chanters (*Ch1-Ch10*). In order to draw safer conclusions, only notes above C4 (22 semitones above D2) have been accounted for. Indeed, the particular pitch range is near the *passaggio* region, where formant tuning is more likely to occur.

By examining the F1 graph of Figure 3 we notice that at

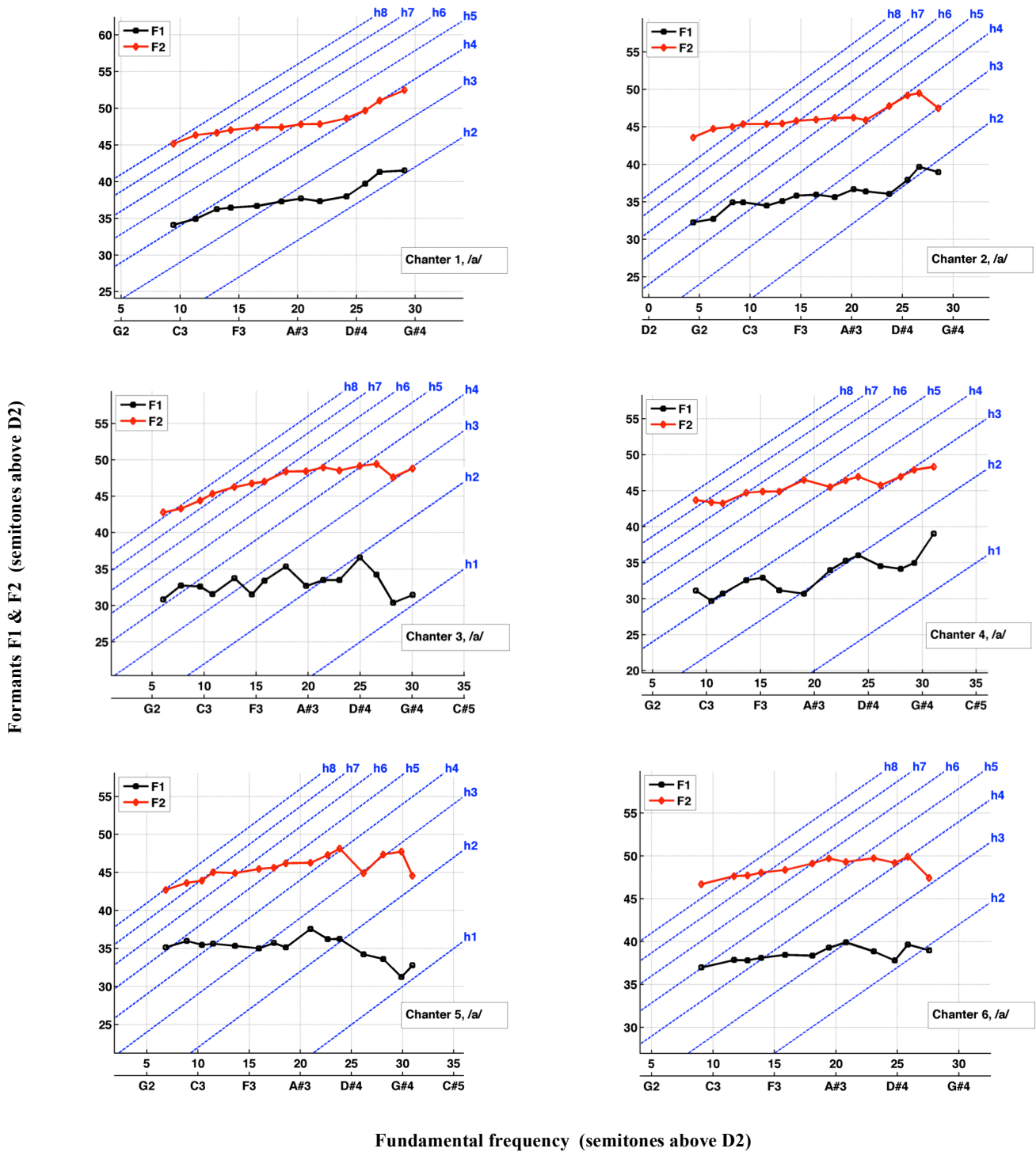


Figure 2. Frequencies, in semitones from D2 (73Hz), of the formants F1 and F2 for the vowel /a/. Results are presented for each chanter for the ascending diatonic scale. Harmonics h2-h8, where $h_n = n \cdot f_0$ and f_0 is the fundamental frequency of the vowel, are displayed by the diagonal blue lines.

least 6 of the total of 10 chanters, analyzed in the current investigation, tend to tune their F1 to the h2 harmonic, at the pitch range above C4.

Formant tuning was most apparent in cases where the F1 and F2 remained relatively constant throughout the scale, before reaching a breaking point near the beginning of the passaggio region, like in the cases of chanters 1, 2, 8, 9 and 10. Another observation is that F2 formant of the ultimate scale's note was tuned to either h3 or h4 in all

chanters. In fact the F2 graph of Figure 3 shows that, above C4, all chanters seem to have their F2 tuned to one of the h3, h4 partials.

Regarding the question as to whether there is a common tuning strategy followed by most chanters, the answer is not obvious. Although in many cases we observed similarities between the chanters for F1 and F2, we tend to believe that each chanter follows his own personal strategy to achieve the aesthetic result he desires.

Formants F1 & F2 (semitones above D2)

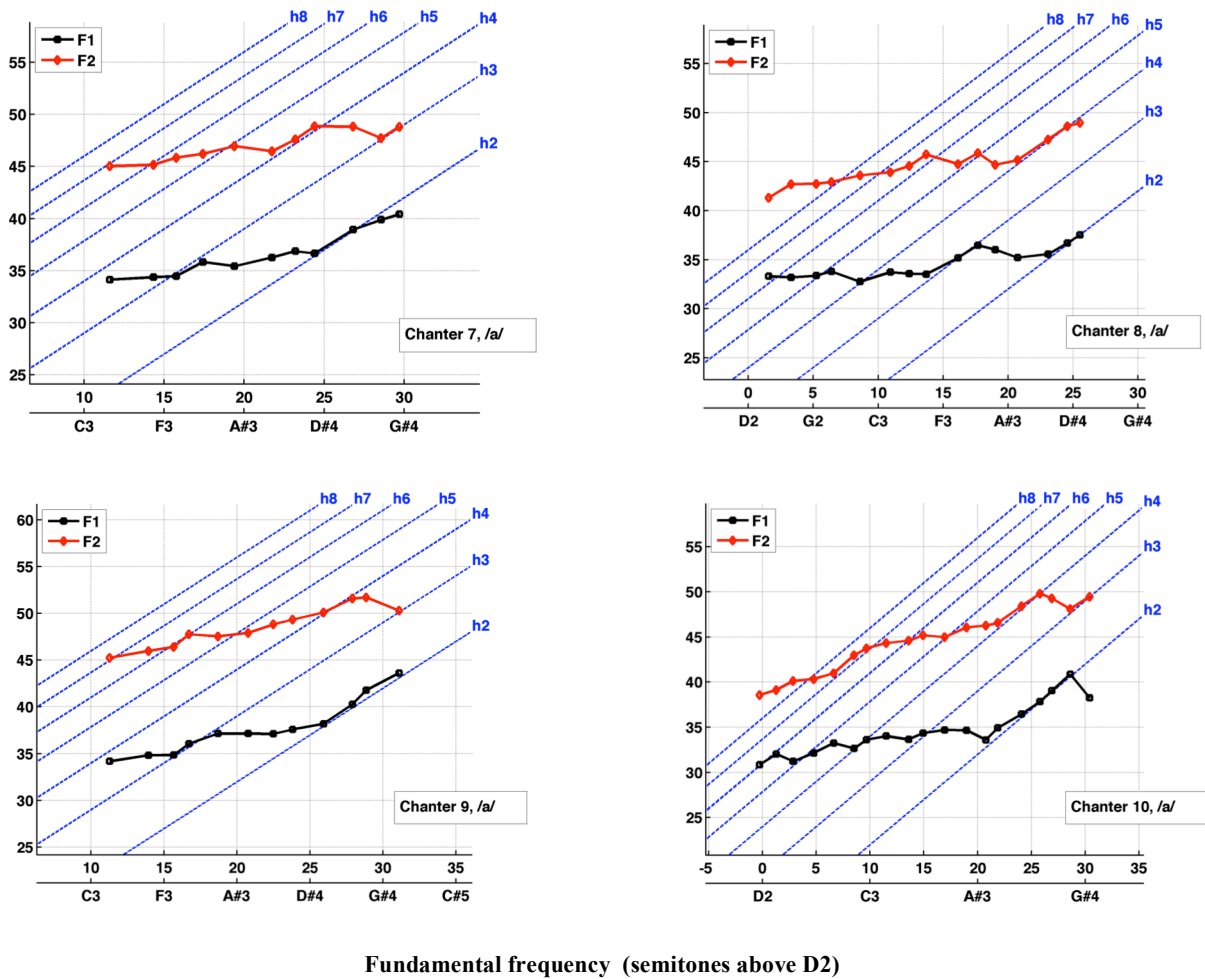
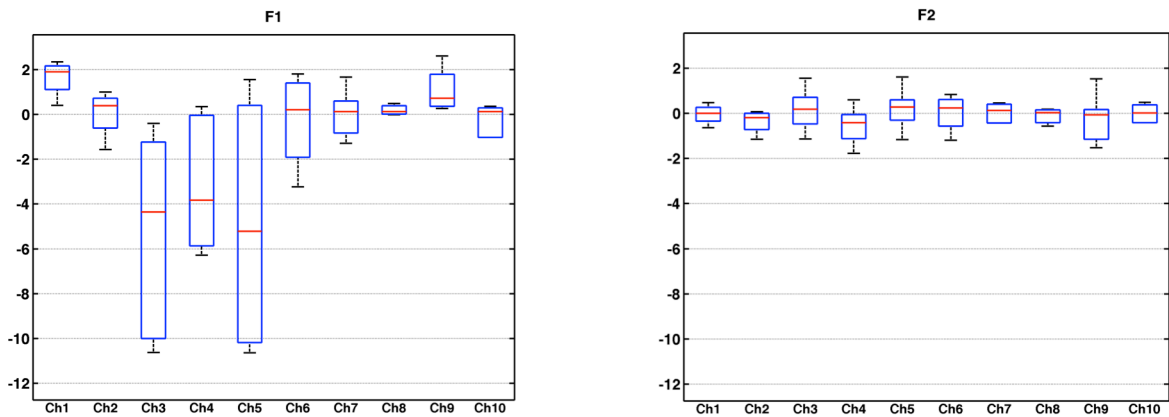


Figure 2. (Continued)

Min. distance from closest harmonic (semitones)



Chanters

Figure 3. Distance in semitones between the first formant F1 and its closest harmonic and between the second formant F2 and its closest harmonic, for the vowel /a/. Results of all ten chanters (Ch1-Ch10) are presented for the ascending diatonic scale, for pitches above C4.

This last assumption agrees with the answer given by Sundberg et al. [9] and Henrich et al. [32] to a similar question, for the passaggio transition. Our opinion is also supported by the fact that most professional Byzantine chanters usually have not been given a systematic phonetic training as part of their vocal pedagogy that could lead in standardizing the Byzantine chant vocal

technique.

7. CONCLUSIONS

It is evident from both Figure 2 and Figure 3 that formant tuning is in use by the modern Byzantine chant

performers. Not only at high f_0 but also at the lower and middle scale regions, formant tuning has been observed in most of the total 10 chanters analyzed in the current investigation.

Going through the examples of formant tuning found in our results, formant F1 coincided, in most cases, with the partial h_2 , while formant F2 was tuned either to h_3 or h_4 , in all cases.

A closer examination of the vocal range above C4 reveals that all chanters, in our sample, had their F2 resonance tuned to the partial h_3 or h_4 .

In contrast to other types of singing voice, our results cannot be directly compared to other findings for the BCM in the field of formant tuning, since, to our knowledge, there aren't any similar publications on this subject. However when compared to results of professional male opera singers [9] from recent investigations, one might conclude that there is a stronger formant tuning tendency in BCM.

8. FUTURE WORK

Future work will mainly cover extracting and displaying more data from the DAMASKINOS corpus. For a start, this would include retrieving data from all the chanters of the corpus. Analyzing data from other vowels as well, would give us a clear picture as to whether chanters show a preference in formant tuning for specific vowels.

Analyzing and comparing results obtained from ascending and descending scales of the same genre could provide good insights into the intentionality of formant tuning. While Miller and Schutte [6] found no evidence of formant tuning in descending scales for baritone singers, considering our assumption that Byzantine chanters follow personal formant tuning strategies, as well as the opinion expressed earlier about the intuitive character of formant tuning, this comparison could give strong evidence on the intentionality of the technique in Byzantine chant.

Another important and interesting part of a future investigation would be the comparison of formant tuning strategies followed by BCM performers who have also been trained as professional opera singers and vice versa. The design of the DAMASKINOS corpus has included singers that meet the above conditions.

Finally, searching for a possible relation between formant tuning and different genera in BCM could also lead to important facts, both about the modern practice of Byzantine chant performance and also about the intentionality factor stated before.

Acknowledgments

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: "THALES - Investing in knowledge society through the

European Social Fund", under the project: "ERASITECHNIS: Processing, Analysis, Synthesis and Context-Based Retrieval for Multimedia Music-Related Data Bases of Traditional Music and Dancing Recordings", MIS 375435.

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