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On the Benefit of Larynx-Microphone Field Recordings for the Documentation and Analysis of Polyphonic Vocal Music

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ON THE BENEFIT OF LARYNX-MICROPHONE FIELD RECORDINGS FOR THE DOCUMENTATION AND ANALYSIS OF POLYPHONIC VOCAL MUSIC

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1. INTRODUCTION

In a previous study Scherbaum et al. (2015) have demonstrated that recordings of body vibrations during singing contain all the essential information of a singer´s voice regarding pitch, intonation, and voice intensity, but are practically unaffected by the voices of other singers (except for extreme situations). This allows the recording of the contribution of each singer while they are singing together. Because of these characteristics, Scherbaum et al. (2015) proposed the utilization of body vibrations recorded as an additional source of information for the documentation and analysis of traditional polyphonic vocal music. Questions remained, however, regarding the applicability of this approach under field recording conditions and if it indeed provides useful information not obtainable by other means. These questions were at the focus of an exploratory field trip to Upper Svaneti/Georgia during the summer of 2015. Here I report on selected results of the analysis of recordings (larynx microphone and audio) of 20 Svan songs sung by two different trios in Lakhushdi and Ushguli in Svaneti/Georgia recorded during this pilot study.

2. FIELD EXPERIMENT

The region of Svaneti, located on the southern slopes of the high Caucasus Mountains in Northwestern Georgia, is the home of a highly distinctive musical heritage. Svan songs represent a living part of ancient traditions and are believed to be one of the oldest forms of Georgian vocal polyphony (e. g. Araqishvili, 2010). During the field trip of 2015, a total of ten singers in three villages in Upper Svaneti/Georgia, were willing to take part in the experiment and have themselves recorded in four different trio combinations with a combination of conventional stereo microphones, a video camera but in particular also with larynx microphones tied around their necks.

The analysis of body vibration recordings allows to address a number of interesting musicological problems from a new perspective. For the following illustration, three topics have been selected: documentation, intonation and interaction of singers, and the tuning of traditional Georgian vocal music.

3. DOCUMENTATION OF MICROTONALITY

One of the most obvious uses of body vibration recordings is in the context of documentation. In contrast to conventional field recordings, larynx-microphone recordings capture the contribution of each singer separately and in a way which allows automatic pitch recognition and note estimation with high precision. Fig. 1 shows an example of the individual pitch and note tracks for the song Elia Lrde, recorded by three larynx microphones. The pitch and note estimation was done with the TONY software (Mauch et al., 2015) on each of the recordings and subsequently combined in Fig. 1. The lyrics were manually added to the output file.

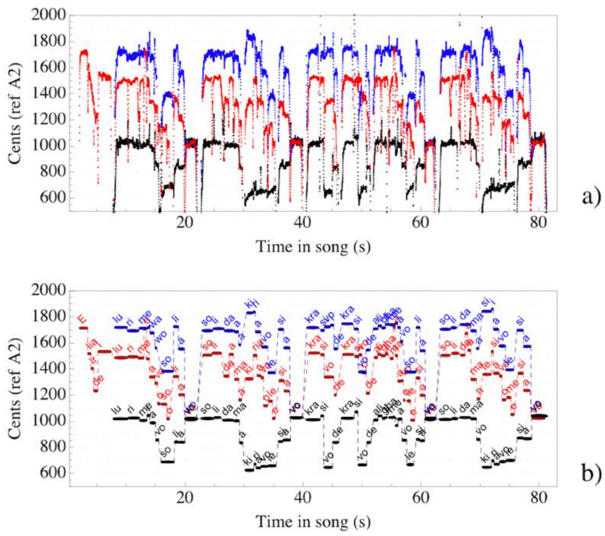

Figure 1. Pitch tracks (a) and annotated note tracks (b) for the song Elia Lrde (singers: Islam Pilpani (red), Gigo Chamgeliani (blue), Murad Pirtskhelani (black)). Pitches are given in cent relative to A2 (110 Hz).

Several advantages of documenting oral tradition music this way come to mind. First, the process captures all microtonal details (naturally limited to the precision permitted by the sampling process and the subsequent analysis) of the music and does not force it into a possibly inappropriate (tempered) notation system. It is completely transparent and reproducible. Furthermore, it documents the music in a digital form which allows susbsequent processing in a multitude of new ways. To illustrate this further, Fig. 2 shows the beginning of the song Elia Lrde displayed in a way which allows to see both the complete melodic and harmonic content including microtonal details in a single plot.

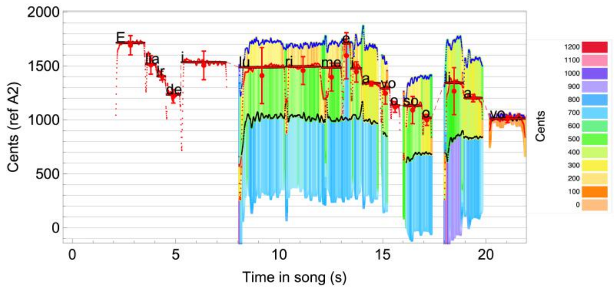

Figure 2. Melodic and harmonic content of the beginning of the song Elia Lrde. The black, red and blue dotted lines show the pitch tracks for the bass, middle and top voice respectively. The spaces between the middle and top voice and the bass and middle voice are color coded according to the corresponding interval sizes between the voices. The space below the bass voice is shaped and color coded according to the interval between bass and top voice.

4. INTONATION AND COMMUNICATION BETWEEN SINGERS

One of the most fascinating aspects of the intonation process in polyphonic a-cappella music is how the individual singers find and maintain their pitches and timbres and how their perception of their own and the other voices influences them in this process (e.g. Mauch et al., 2014). Larynx-microphone recordings in combination with regular microphones can help to monitor the intonation process in an interesting way. Fig. 3 shows again the song Elia Lrde, but only for the beginning of the polyphonic part and only for the top voice. The dense dotted line at the bottom part of Fig. 3 shows the sequence of pitches (determined by the TONY pitch tracking algorithm) for the first few seconds. The horizontal blue lines show pitches of the determined notes with the red error bars indicating their corresponding standard deviation. The blue and red traces in the top part of the figure show the sensory roughness values (Vassilakis, 2007) for the top voice and the mix of all voices, respectively, which before the onset of the polyphonic part is only determined by the contribution of the middle voice.

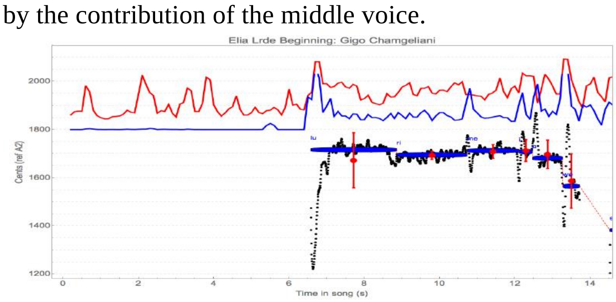

Figure 3. Voice track of the top voice onset together with sensory roughness track for top voice and mix of all voices.

From Fig. 3 it can be noted that the voice slides to the target pitch from below. Interestingly, this “sliding phase” is so soft that it is not really audible on the acoustical microphone but is clearly detected on the larynx microphone. It coincides with a short time of increase of sensory roughness (blue trace) which is also observed on the mix of all voices (red trace). In the present context, change of sensory roughness is seen as a simple proxy for change of timbre. Roughly speaking, while tuning in to the other singers, the singer of the top voice adjusts both pitch and timbre at the same time. Interestingly, the other singers do the same, which points to a strong mutual interaction. This feature was consistently observed for all voices during intonation. Further analysis of these records in this direction (intended to be addressed in a future analysis) might provide interesting information regarding the factors controlling the intonation process (pitch or interval precision, sensory roughness, etc.) in a polyphonic a-capella setting.

5. TUNING OF TRADITIONAL GEORGIAN VOCAL MUSIC

Part of the fascination and archaic beauty of Georgian vocal polyphonic music in general, but Svan music in particular, stems from the abundant use of chords which to ears trained on western music sound "unusual". In addition, part of the distinctiveness of this music is the fact that the scale(s) from which the pitches for these chords are drawn are not tuned to the 12 tone equal temperament scale (12-TET scale) on which most western music nowadays is based. While the non-tempered nature of traditional Georgian vocal music can be considered consensus amongst musicologists, the particular nature(s) of the Georgian sound scale(s) is an ongoing topic of intense and controversial discussion (Erkvanidze, 2002; Gelzer, 2002; Westman, 2002; Kawai et al, 2010; Tsereteli and Veshapidze, 2014). Complicating the evaluation of the different propositions on what could be called "the Georgian sound-scale controversy" is the fact that it is hard to judge if at least part of the controversy is actually caused by methodological differences or by fundamental disagreement. The analysis of the present set of recordings might be able to contribute to this discussion from a completely new perspective. Since synchronized pitch information from all voices can be derived unambiguously, the analysis of larynx-microphone recordings can help to shed some light on some of the principal questions behind this issue.

Sound-scale and tuning analysis can be done in many different ways, possibly leading to very different results even if the same sound recordings were used. When we listen to polyphonic music, we will perceive melodies and chords. In piano music for example, the intervals which we can hear in a melody and the intervals which we can hear in a chord both draw from the same "interval inventory", namely the set of all intervals which can be played on the piano. With vocal a-capella music interval perception can interfere with the intonation which can lead to pitch drifts of the whole ensemble (e. g. Howard, 2007; Mauch et al., 2014). In such a situation, the interval sizes in a melody (horizontal perspective) might differ from the interval sizes in a chord (vertical perspective) which in turn would make the results of a tuning analysis dependent on the way the intervals are determined. Larynx-microphone recordings provide a very convenient way to quantitatively analyse the magnitude of this effect and if it might affect the determination of sound scale(s).

5.1 The harmonic interval set

In order to obtain a first impression of the harmonic interval set, in other words the set of concomitantly perceived intervals, in the song Elia Lrde, Fig. 4 jointly displays the melodic and harmonic content of the complete song.

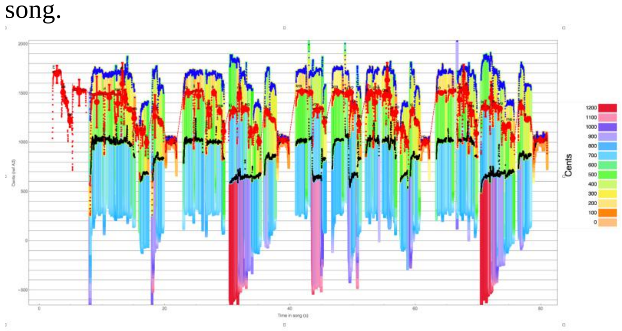

Figure 4. Melodic and harmonic content of the complete song Elia Lrde. The black, red and blue dotted lines show the pitch tracks for the bass, middle and top voice, respectively. The spaces between the middle and top voice and the bass and middle voice are color coded according to the corresponding interval sizes between the voices. The space below the bass voice is shaped and color coded according to the interval between bass and top voice.

From Fig. 4 it can be seen that the colors representing the intervals between the bass and the top voice are mostly light blue which corresponds to pitch differences of around 700 cents (a fifth), interrupted once in a while by red colors, which corresponds to 1200 cents (an octave). The color codes for the pitch differences between the bass and the middle voice indicate values of approximately 500 cents (a fourth), once in a while interrupted by a difference of 700 cents (a fifth). Consequently the differences between the middle and the top voice correspond to values around 200 cents (a major second), once in a while interrupted by values of approximately 500 cents (a fourth). At times all three voices approach the same pitch value (unisone). So in a single glance, Fig. 4 reveals the harmonic character of the song Elia Lrde.

For the subsequent analysis, only those pitch samples from the complete pitch tracks were selected which belong to stable notes (as determined by TONY) which have a minimum duration of 1 sec of which the first 0.4 and the final 0.25 sec are discarded for the analysis. The purpose of these restrictions is to discard sliding phases at the beginning (as e. g. seen in Fig. 3) and the end of a note and to focus on intervals which could be called "stably established" by all three singers. The resulting pitch-track sample sets are shown in Fig. 5.

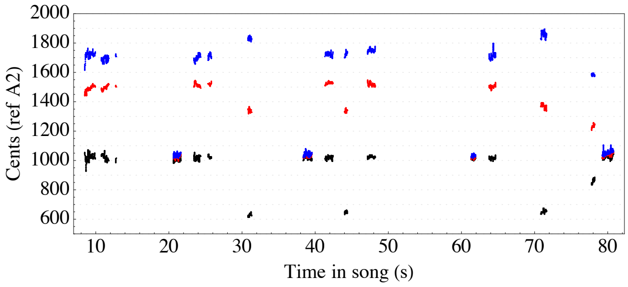

Figure 5. Pitches for concomitantly perceived intervals of at least 1 sec duration for the song Elia Lrde (singers: Islam Pilpani (red), Gigo Chamgeliani (blue), Murad Pirtskhelani (black)). Pitches are given in cent relative to A2 (110 Hz).

Yet another way to look at the harmonic interval set is by plotting the statistical frequency distribution of the stable concomitant intervals shown in Fig. 5. which results in the distribution shown in Fig. 6.

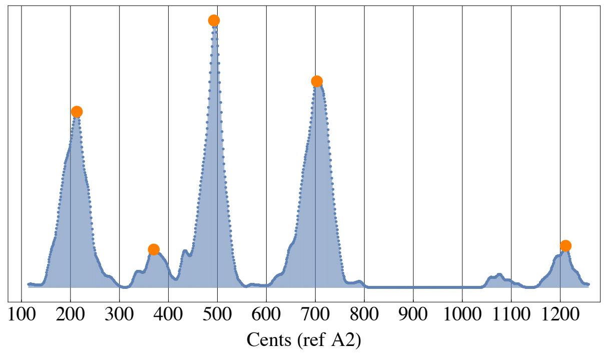

Figure 6. Frequency distribution of the stable concomitant intervals. The peaks (orange disks) occur at values of 213, 370, 494, 704, and 1212 cents. For comparison, in Pythagorean tuning the fourth and the fifth correspond to 498 and 702 cents.

The most prominent intervals visible from this perspective appear at 213, 370, 494, 704, and 1212 cents. This corresponds to a slightly sharp major second, a "neutral" third, a fourth, a fifth and a slightly sharp octave. For comparison, in Pythagorean tuning, which can be build up from a series of fifth and which was already described in Babylonian artifacts (West, 1994), the fourth and the fifth correspond to values of 498 and 702 cents which is pretty close to what is observed here.

5.2 The melodic interval set

In contrast to the harmonic interval set, the determination of the melodic interval set requires the estimation of the pitch step sizes of successive notes in each of the voices. In this context, all note durations (not only the long ones) where considered. The resulting statistical frequency distribution is shown in Fig. 7.

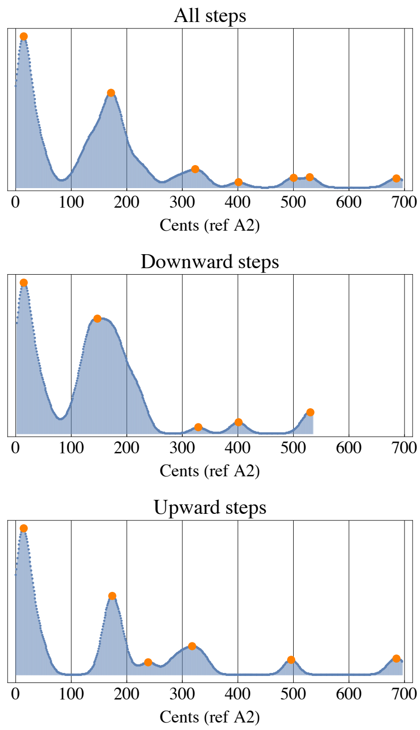

Figure 7. Melodic interval distribution in the song Elia Lrde obtained from the pitch differences of successive notes in all three voices. The peaks, marked by the orange discs, of the overall step size distribution (top panel) appear at 14, 172, 323, 401, 500, 529 and 685 cents. The peaks in the distribution of the downward steps (middle panel) appear at 15, 147, 328, 401 and 530 cents. The peaks in the distribution of the upward steps (bottom panel) appear at 14, 174, 239, 318, 496 and 685 cents.

Fig. 7 reveals a number of interesting features. The peak at approximately 15 cents corresponds to the small amplitude fluctuation discussed above but are not really seen as a real feature of the melody. The most prominent deliberate melodic pitch step shows up at 172 cents for all steps combined but appears to be smaller (147 cents) for downward steps than for upwards steps (174 cents). The peaks in the distribution for all steps combined are not very far from the integer multiples of the most prominent melodic interval at 172 cents (which would be at 344, 516 and 688 cents) which could therefore be interpreted as the basic building block of the melodies. Interestingly, this value coincides very well with the value Tsereteli and Veshapidze (2014) determined as basic distance for their proposed equidistant Georgian sound scale.

5.3 The analysis of a single voice

AS far as I know, Tsereteli and Veshapidze (2014) derived their sound scale model essentially by analysis of individual voices, in other words by melodic and not by harmonic analysis. In order to investigate the consequences of this approach on the current records, the middle voice of the song Elia Lrde was selected (Fig. 8 top panel) and the corresponding pitches of the note set as determined by TONY were determined. The melodic intervals were calculated with respect to the mean value of the lowest notes in the song (at 1017 cents in the top panel). The resulting statistical frequency distribution is shown in the bottom panel of Fig. 8.

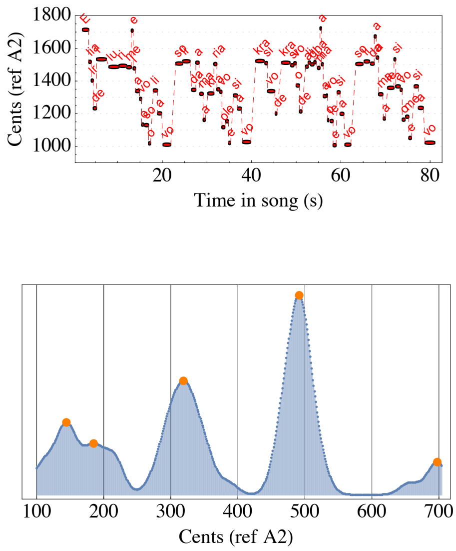

Figure 8. Frequency distribution of melodic intervals obtained by analysis of the middle voice of the song Elia Lrde. The peaks marked by orange discs appear at 144, 185, 319, 491, and 697 cents.

The location of the peaks of the interval frequency distribution reasonably well matches the melodic interval distribution shown in Fig. 7. This would be in line with the hypothesis that it is the basic melodic step size which will control the resulting sound scale model. The double peak below 200 cents might be due to the difference in the upward and downward melodic step size.

5.4 Melodyne´s scale detective

Using larynx microphones, the melodic and harmonic interval set of a song can be precisely determined since the individual voices are already separated during recording but time synchronisation is kept. With traditional audio recordings, however, the situation becomes blurred because polyphonic pitch determination is still subject to considerable technical challenges. A few commercial software packages exist which have tried to attack this problem with mixed success. One of those, the recently released Melodyne 4 (Celemony GmbH), contains polyphonic pitch tracking and a feature called direct note access (DNA) which claims to allow to access the properties of the individual notes detected in an audio record. In addition, it contains a feature called “scale detective” which allows the determination of a sound scale corresponding to the analysed audio material. Since the underlying algorithms are unknown, it is impossible to test the performance of these tools in a scientific way, but a comparison of algorithms in the present case might provide some information regarding their applicability for tuning analysis in cases where only audio material is available, e.g. historical phonograph records.

For this comparison, the notes for all voices determined from the individual larynx microphone recordings by the TONY algorithm were jointly used for the analysis of the frequency distribution of intervals determined from the pitch differences of note pairs. In this case, the distinction between melodic and harmonic intervals is lost because some pitch pairs may belong to the same time and hence be harmonic while the majority will be correspond to different times and hence has to be considered melodic. It is suspected that this setup best matches the situation of the scale detective in Melodyne which faces the additional challenge of polyphonic pitch determination. The resulting distribution is shown in Fig. 9. The vertical dashed lines correspond to the pitch values found for a seven degree scale using the mix of all larynx microphone recordings (red lines) and the conventional audio stereo record (blue lines).

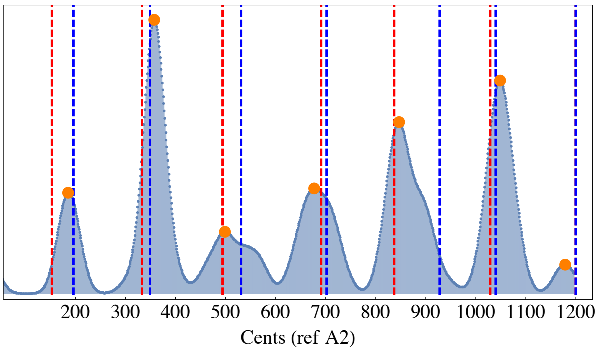

Figure 9. Frequency distribution of intervals obtained by analysis of all three voice of Elia Lrde. The peaks marked by orange discs appear at 187, 358, 499, 678, 847, 1049, and 1179 cents and 144, 185, 319, 491, and 697 cents. The application of Melodyne´s (release 4) scale detective on the mix of all larynx microphone recordings and the audio stereo recording results in sets of pitch values of {196, 349, 531, 702, 928, 1040, 1200} (blue lines) and {153, 333, 494, 691, 837, 1029, 1200} (red lines), respectively.

The results of applying Melodynes scale detective to the mix of larynx microphone recordings results in pitch values which are reasonably close to the peaks of the frequency distribution of intervals shown by the values indicated by the orange discs. Except for the first one, these values are reasonably close to the integer multiples of the basic melodic pitch step size of 172 cents which would be at 172, 344, 516, 688, 860, and 1032 cents. The fact that the first peak appears closer to 200 cents than for the analysis of the individual voice could be due to the fact that in particular the seconds in this mixed data set are a mixture of harmonic and melodic intervals as already discussed above. The results of applying Melodynes scale detective to the audio stereo signal are similar except for the pitch value at 928 cents. Since the algorithm is not known, the reasons for this remain unknown.

5.5 How robust are these features?

In order to test the robustness of the observed features, the analysis was extended in two ways. First, all voices in the recordings of five songs sung by Islam Pilpani, Gigo Chamgeliani, and Murad Pirtskhelani in Lakhushdi were analysed regarding the containing melodic and harmonic interval sets. The results are shown in Figs. 10 and 11, respectively.

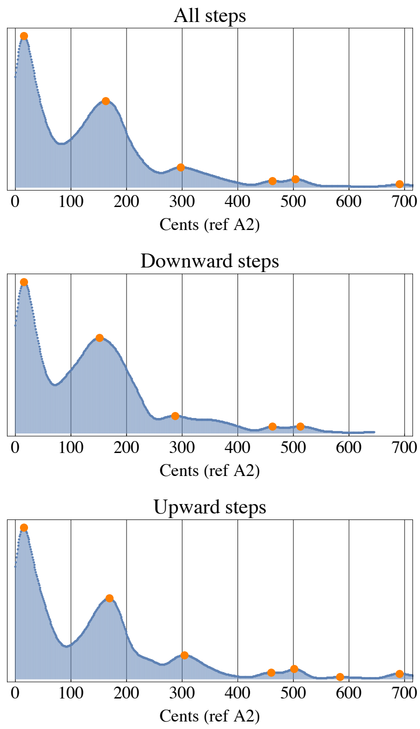

Figure 10. Frequency distribution of all melodic intervals obtained by analysis of all voices in the songs Elia Lrde, Jgragish, Kviria, Lile and Riho sung by Islam Pilpani, Gigo Chamgeliani, and Murad Pirtskhelani. The peaks, marked by the orange discs, of the overall step size distribution (top panel) appear at 15, 163, 298, 462, 504, and 691 cents. The peaks in the distribution of the downward steps (middle panel) appear at 16, 152, 287, 463, and 513 cents. The peaks in the distribution of the upward steps (bottom panel) appear at 15, 169, 304, 460, 502, 584, 691 cents.

The results in Fig. 10 are similar to the ones for the single song Elia Lrde in that the dominant melodic interval for all voices and all songs is still on the order of 150 - 170 cents. In addition, the feature that the pitch steps downward are systematically smaller than the upward steps is also observed for all songs.

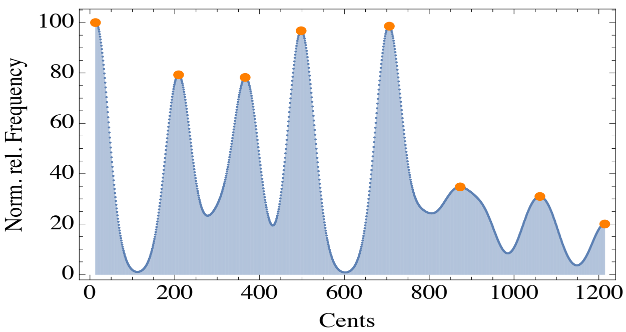

Figure 11. Frequency distribution of all harmonic intervals obtained by analysis of all voices in the songs Elia Lrde, Jgragish, Kviria, Lile and Riho sung by Islam Pilpani, Gigo Chamgeliani, and Murad Pirtskhelani. The peaks (orange disks) occurr at values of 13, 209, 366, 498, 706, 873, 1061, and 1214 cents.

The harmonic interval set derived from the analysis of all songs songs sung by Islam Pilpani, Gigo Chamgeliani, and Murad Pirtskhelani turns out to consist of 7 steps and is clearly not equidistant. The “major 2nd” at 209 cents, which would not exist if the scale were equidistant, is clearly present in all songs and all voices. The fourth and the fifth at 498 and 706 cents are very close to just tuning as will be further discussed below.

The second test to check the robustness of the observed features was to analyse the recordings of 15 songs sung by Jano Charkseliani, Zoia Charkseliani, Lola Nizharadze in Ushguli in the same way. The corresponding melodic and harmonic interval distribution from all voices and all songs are displayed in Figs. 12 and 13, respectively.

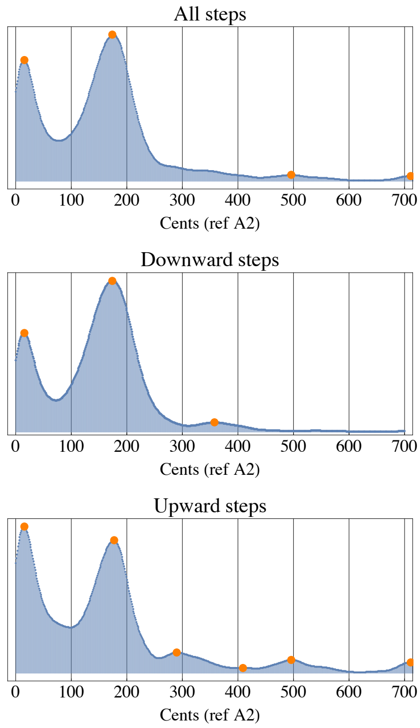

Figure 12. Frequency distribution of all melodic intervals obtained by analysis of all voices in 15 songs sung by Jano Charkseliani, Zoia Charkseliani, Lola Nizharadze in Ushguli. The peaks, marked by the orange discs, of the overall step size distribution (top panel) appear at 15, 174, 496, 711, and 814 cents. The peaks in the distribution of the downward steps (middle panel) appear at 15, 174, and 358 cents. The peaks in the distribution of the upward steps (bottom panel) appear at 15, 177, 290, 409, 496, 711, and 814 cents.

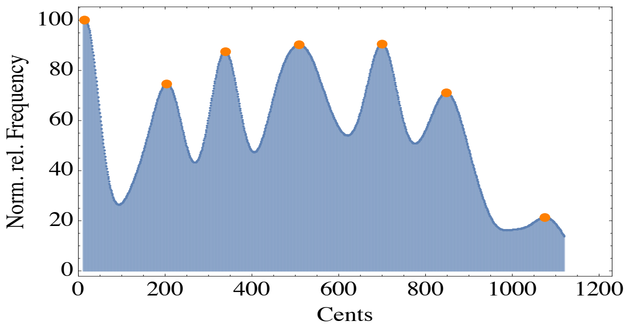

Figure 13. Frequency distribution of all harmonic intervals obtained by analysis of all voices in 15 songs sung by Jano Charkseliani, Zoia Charkseliani, Lola Nizharadze in Ushguli. The peaks (orange disks) occur at values of 15, 204, 339, 509, 700, 849, and 1075 cents

Again, the harmonic interval set is clearly different from the melodic one. The melodic 2nd is again at approximately 170 cents while the harmonic one is at 204 cents. The harmonic interval set derived from the Ushguli recordings is very similar to the one derived from the Lakhushdi recordings while the melodic interval sets differ in that the Ushguli recordings do not show a difference between downward and upward movements.
From the analysis so far, it looks like there is a significant difference between the interval set for the chords and the one for the melodic movements. Below, the harmonic interval sets derived from the analysis of the recordings in Lakhushdi and Ushguli are compared to the ones which were proposed by Erkvanidze (2002) as models for Georgian tunings, to the one proposed by Tsereteli and Veshapidze (2014) but also to the Pythagorean scale and Ptolemy´s diatonic scale as well as the modal scales derived from 12 tone equal tempered (12-TET) tuning (Fig. 14).

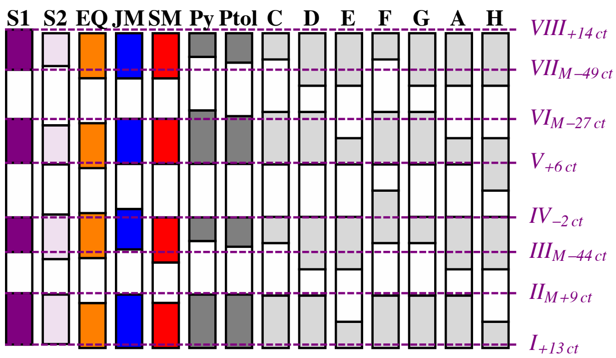

Figure 14. Comparison of the interval sizes of the harmonic interval sets derived from the analysis of the recordings in Lakhushdi (S1) and Ushguli (S2) with the equidistant scale suggested by Tsereteli and Veshapidze (2014) (EQ), the joined (JM) and split (SM) mode scales suggested by Erkvanidze (2002), the Pythagorean scale (PY), the Ptolemy diatonic scale (Ptol) and the modal scales derived from 12 tone equal tempered tuning (modes C- H).

Obviously, the harmonic interval set derived from the analysis of the recordings in Lakhushdi and Ushguli (S1 and S2) are quite different from the rest of the modal scales derived from the 12 TET based scales, but over all it is difficult to interpret the mutual relationships simply from the visual appearance in Fig. 14. One way to visually represent the information contained in Fig. 14 in a more intuitive way is by making use of methods from high-dimensional visualization and multi-dimensional scaling analysis. For this purpose one can view each interval set as a feature vector in a high-dimensional space the dimensions of which are given by the number of different intervals present in (here 7). What would actually be interesting to "see" is the set of the individual points (to which the feature vectors point to) in this seven dimensional space, which of course can only be calculated but not "seen". However, one can try to project the points from the high-dimensional space onto a map (similar to the way the three-dimensional surface of the Earth is projected onto a two-dimensional map) in such a way, that the neighbor-relations between nearby points in the high-dimensional space is preserved. One of the techniques by which this can be achieved is the non-linear Sammons map (Sammon, 1969). The resulting distribution of scales (or interval sets) is shown in Fig. 15.

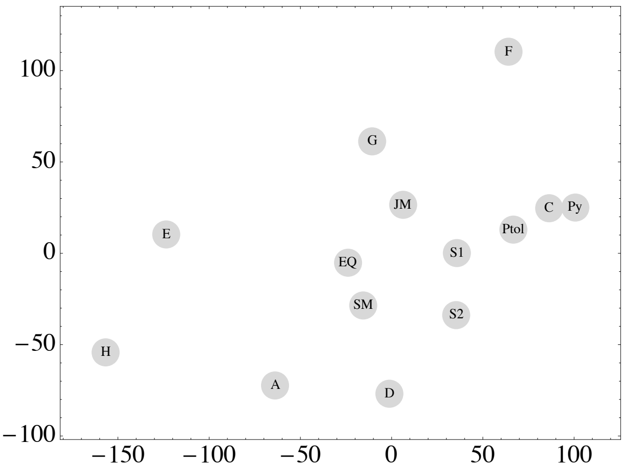

Figure 15. Sammon´s map for the scales in Fig. 13. The mutual distances between the scales quantitatively reflect their similarity in a Euclidean sense.

Each labeled disc in Fig. 15 corresponds to one of the scales (or interval sets) in Fig. 14. The proximity of the scales in Fig. 15 corresponds to the similarity of the corresponding interval vectors in a Euclidean sense. Fig. 15 shows that the harmonic interval sets obtained from the recordings in Lakhushdi (S1) and Ushguli (S2) are most similar to each other, followed in similarity by the scale suggested by Erkvanidze (JM) and Ptolemy´s diatonic scale (Ptol).

6. DISCUSSION AND CONCLUSIONS

Based on the material presented above it seems justified to say that field recordings of body vibrations can provide new and very valuable information on the tunings and intonation of traditional singers which would be difficult to obtain by only conventional audio recording setups. Most importantly, larynx microphone recordings capture the contributions of the individual singers undisturbed by the other singers and therefore offer the possibility to investigate the melodic and harmonic interval inventory of a song separately. The results of the analysis of 20 Svan songs sung by two different trios in Lakhushdi and Ushguli suggest a clear and significant difference between the melodic and the harmonic interval set. For one of the trios, the melodic interval set even showed differences in step sizes between downward and upward movements. It is worth noting, that this is not a feature unique to Svan songs, as I learned from S. Arom (pers. comm., Arom, 2016). I cite from his comments: "Both observations absolutely corroborate what I experienced when, years ago, I was transcribing (only by ear, alas…) the polyphonic songs of the Aka Pygmies: when listening to the isolated recording of a singer's voice and to its combination with another voice, the perception of the intervals is different !".

The sizes in which melodic movements in the analysed songs happen occur in multiples of roughly 170 cents which would be consistent with an interval set with intervals of equal size, while the concomitantly perceived intervals are related to sets in which the different degrees are clearly non-equidistant. In the context of the discussions on the Georgian sound scale(s), a quote which is atttributed to the German physicist Werner Heisenberg, nobel laureate and one of the fathers of quantum mechanics comes to mind: "We have to remember that what we observe is not nature in itself, but nature exposed to our method of questioning.". The results of the present analysis seem to suggest that the analysis of individual voices or monodic segments will result in an equidistant scale model, while the analysis of concomitant intervals will result in a non-equidistant scale model.

In conclusion, it seems worth to investigate further if the different propositions regarding the "Georgian sound scale" could be reconciled by assuming that the difference between the melodic and the harmonic interval set is a general and robust feature of traditional Georgian vocal polyphony. At present this is admittedly only a speculation based on a very limited data set but as an hypothesis it seems worth to be tested further. The consequences of such a model would be that during melodic movements of a song the singers would continuously readjust the tunings of their intervals to the desired values which is similar to what a brass instrument player is doing when playing in an orchestra (pers. comm. Arom, 2016). This might actually also explain some of the seemingly random pitch fluctuations observed in the individual pitch tracks of these highly skilled traditional singers.

7. ACKNOWLEDGMENTS

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