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The scale in played music

By Frans Fransson. Johan Sundberg, Per Tjernlund

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Introduction

An essential aspect of played music is the tone scale, i.e. the series of fundamental frequencies used in playing. It has been shown that the series of fundamental frequencies blown on a flute is dependent on whether or not the player performs a tonal interpretation of the notes he plays (Fransson 1963, Coltman 1968). For instance, if a flute player plays from notation he adopts a scale that is different from the scale he uses in playing each note separately according to successive dictation, cf. Fig. 1. Analyses of the fundamental frequencies used in music playing may inform about the—innate or learned—properties of the human pitch perception system. The purpose of the present paper was to examine to what extent the series of fundamental frequencies used in playing is affected by various factors such as the music played, the instrument, and whether or not the musician plays on a known or an unknown instrument.

Experiments

Three professional first-rate members of a symphony orchestra (flute, oboe, violin) served as subjects. They all played the same piece of music several times, first on their own instruments and then, as regards the wood wind players, on an instrument which they had never seen before. The music was 5 bars taken from J. Andersen's cadence for Mozart's second flute concerto, K. 314. The tonality is G major. The sound was recorded on tape and the musicians selected for analysis three versions of each series. The musicians also improvised on their own instrument or played another piece of music on it. The flutist's own instrument was an A. R. Hammig, and the other flute was of unknown mark. The oboe of the oboe player was marked Marigaux and the other one Cabart. All instruments were of similar modern construction.

Analysis

The tape recordings were analyzed with respect to the distribution of fundamental frequencies using the automatized procedure for this purpose which has been presented previously (Sundberg & Tjernlund 1969, Fransson, Sundberg, Tjernlund

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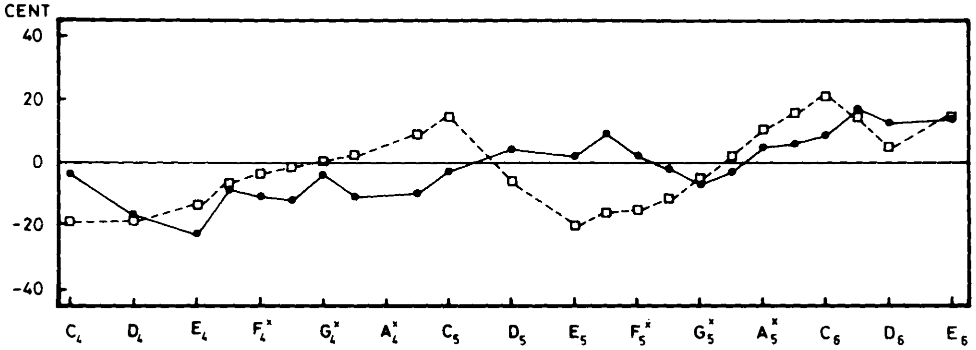

Fig. 1. Deviations from the equally tempered scale in flute playing after successive dictation of each note (□) and of a notated melody (●).

1972). The method operates with a hardware fundamental frequency measuring system connected to a computer. The computer measures the period time and processes the data statistically. The results are presented in terms of fundamental frequency histograms. The frequency values of the modes in the distribution were measured. These frequencies will be referred to as the *scale tone frequencies*. Experiments showed that the method allows determination of intervals between scale tones with an accuracy of ±5 cents. Absolute frequency values can be measured within ±17 cents only, because of errors in the tape speed. Due to the wide ambitus (more than 2 octaves) and the spectral properties of the acoustic signals, the cutoff frequency of the variable lowpass filter in the hardware system was varied synchronously with the fundamental frequency in the music.

Results

Fig. 2 a, b, and c presents the results. In the case of the flute and the oboe the values obtained from the three recordings of the cadence mostly agree within 10 cents. The differences between the values resulting from playing on different instruments and pieces of music is generally of the same order of magnitude. These two observations suggest that the influence on the scale tone frequencies of the instrument and the music is rather small. In the case of the violin the situation is slightly different. A tendency to play one note sharp and its semitone neighbours flat yields a zig zag pattern to some parts of the curves. This reflects a trend to play narrow semitone steps. For most of the tones the agreement between the values pertaining to the three recordings of the cadence is very high. This is an astonishing fact in view of the almost unlimited freedom which the player has in determining the fundamental frequencies. The agreement suggests that the scale tone frequencies are rather independent of random variations in this case. Then, the differences between the two curves in Fig. 2 c are probably effects of the music. However, if we compare the scale tone frequencies which both pieces of music have in common, we find that these differences are smaller than 10 cents in all cases but two. These two exceptions (F_4 and B_4) may be due to differences in the harmonic function of the tones.

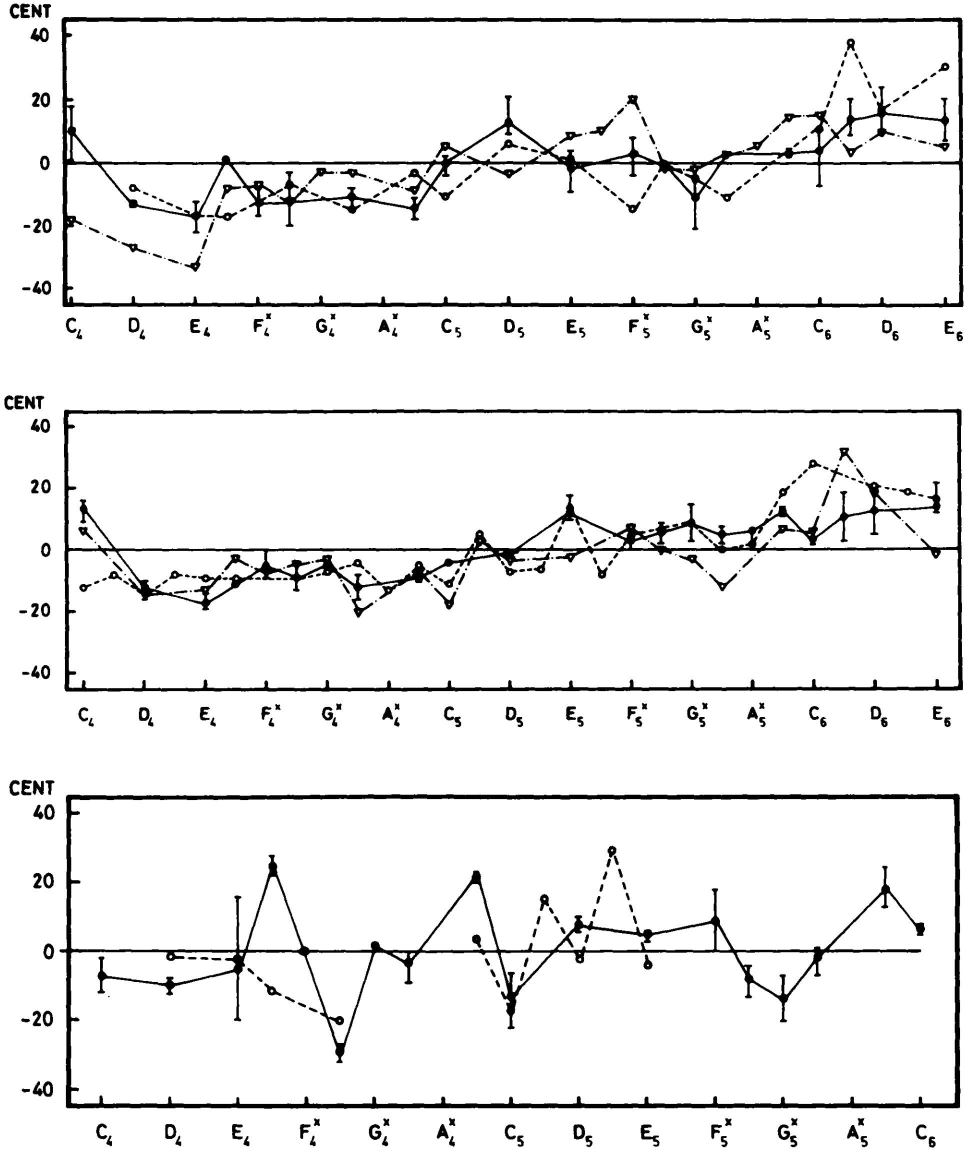

Fig. 2. Deviations from the equally tempered scale in flute playing (upper graph), oboe playing (middle graph), and violin playing (lower graph). ●: averages obtained from three recordings of a solo cadence played on the musician's own instrument. The bars show the extreme values.

Two upper graphs: ○: averages obtained from the same cadence played on an instrument that was unknown to the musician. ▽: averages obtained when the musician improvised on his own instrument.

Lower graph ○: averages obtained when the musician played the melody "Schön Rosemarin" (G major).

However, by and large the results shown in Fig. 2 support the assumption that with few exceptions the music and the instrument do not influence the scale tone frequencies appreciably.

The curves obtained from the flutes and the oboes show a clear rising trend, i.e.

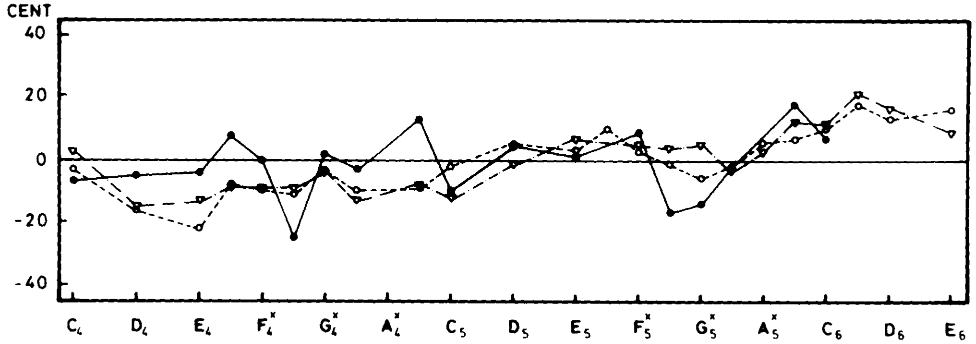

Fig. 3. Mean deviations from the equally tempered scale obtained in flute playing (○), oboe playing (▽), and violin playing (●).

the deviations from the equally tempered scale are mostly negative in the lower part of the range and grow towards positive values with rising pitch. In the case of the violin the notes in the lower half of the range show more negative values than do the higher notes, on the average. In Fig. 3 the average scale tone frequencies obtained from the three instruments can be compared. The values pertaining to the woodwind instruments are very similar and deviate from those of the violin in some notes only. These deviations occur in semi-tone steps which are played smaller on the violin. If we disregard these effects the three curves in the figure agree rather well. This agreement suggests that the musicians work with similar patterns of scale tone frequencies. The average of the curves is likely to inform about the pitch scale which is used in music playing. These averages are given in Fig. 4. Evidently, the points show a stretched scale, i.e. the octave in the scale exceeds 1 200 cents slightly and most of the smaller intervals are expanded to a corresponding degree. The stretch is 15 cents per octave, approximately.

According to several authors, the intervals in music playing are of magnitudes similar to those of the Pythagorean scale (Greene 1937, Nickerson 1949, Lottermoser & Meyer 1960, Shackford 1962). If we want to describe the results shown by the

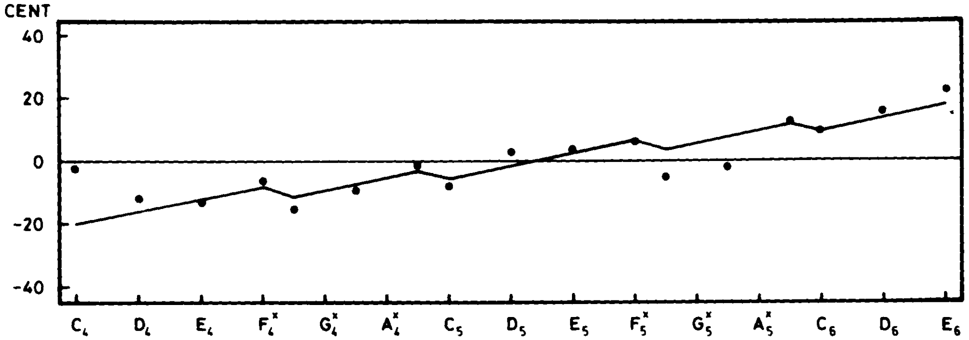

Fig. 4. Mean deviations from the equally tempered scale obtained in flute, oboe, and violin playing (●). The solid line shows the model scale consisting of full tone steps of 204 cents and semitone steps of 97.5 cents. The tonal orientation is G major.

points in Fig. 4 schematically, we may use the Pythagoran full tone steps (204 cents), and, in order to arrive at the stretch of 15 cents per octave, we chose a semitone step of 97.5 cents. The results for a tonal orientation of G major is indicated in the same figure. It can be seen that the measured mean deviations from the equally tempered scale approximate the idealized scale fairly well.

Discussion and conclusions

The results presented above may seem very dependent on the experimental situation used in this specific experiment. For instance, in playing with other instrumentalists a musician would scarcely use a stretched scale, as the stretch would generate beats in the chords. We may assume then, that the use of the stretched scale is restricted to solo playing. It has been shown that the musical context may affect the frequency of single notes (Sirker 1973). Such occasional deviations from the mean frequency of a note do not affect the scale tone frequency of that note appreciably because of the statistical processing of the data: the stretched scale tone frequencies exist primarily as mean values. These mean values have been shown to be rather insensitive to the instrument and to the music and similar in the three musicians investigated here.

It may also be questioned if the stretched scale has any relevance outside the cultural sphere of the modern symphony orchestra. Obviously the manner in which the octave is divided into intervals differs between cultures. However, a different question is how wide the octave is that is divided. In our results the octave was found to exceed the 1 200 cents of the mathematically pure octave by about 15 cents. Certain facts suggest that this stretch can be expected to be found in other cultures also. It has been shown that the acoustic properties of the flute and the oboe make a stretched scale expectable (Benade & French 1965, Nederveen 1969). It is interesting that such scales are accepted: we may imagine that if such scales were not appreciated, these instruments would be considered poor from the musical point of view. Also, it is interesting that a stretched scale is preferred on the piano (Martin & Ward 1961). Moreover the octave stretch of 15 cents found in our measurements agrees almost exactly with the stretch determined in tests where musically trained subjects matched the pure musical octave between two complex tones presented in succession (Terhardt 1969/70, Sundberg & Lindqvist 1973). An explanation for this octave stretch is suggested by Terhardt: He found that the pitches of neighboring partials in a harmonic spectrum move away from each other slightly due to a mutual masking effect. This increases the pitch interval between the two lowest partials. Terhardt hypothesizes: "our sense of musical intervals and thereby the octave is acquired; we acquire the knowledge of harmonic relations in earliest life when we learn to recognize and understand speech sounds" (Terhardt 1971). This seems to imply that octaves of similar physical magnitudes may be expected to be found even outside our modern symphony orchestra. Measurements of the octave interval in other musical cultures may yield interesting and possibly revealing results.

As mentioned, it is reasonable to assume that the stretched scale is appreciated in our culture, since instruments generating such scales are appreciated. Possibly, the stretched scale should preferably be introduced in other instruments which have a predetermined tuning and which are used for one-part solo playing mainly. For instance the electronic organ, the upper range of which is frequently used for solo playing of rapid passages, might be more appreciated if the scale in this range were stretched.

In musicological literature the thought is sometimes expressed that the appreciation of music is partly dependent on how pure (i.e. close to the harmonic intervals) the music is played. It seems that our results add one more reason for doubting that the physical pureness of the intervals in melodic playing can be taken as a musical advantage of a performance. The average scale is stretched, and this implies that not even the octaves in the scale are mathematically pure. Nevertheless, they seem to be perceptually pure.

Acknowledgements

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References

Benade, A. H. & French, J. W.: "Analysis of the Flute Head Joint", J. Acoust. Soc. Am. 37 (1965), pp. 679–691.

Coltman, J. W.: "Acoustics of the Flute", Physics Today *21*: 11 (1968), p. 25–32.

Fransson, F.: "Measurements on Flutes from Different Periods", STL-QPSR 4/1963, p. 12–16.

Fransson, F., Sundberg, J. & Tjernlund, P.: "Grundfrequenzmessungen an schwedischen Kernspaltflöten", in *Studia Instrumentorum Musicae Popularis II* (ed. E. Stockmann), Stockholm 1972, pp. 77–96.

Greene, P. C.: " Violin Intonation", J. Acoust. Soc. Am. 9 (1937), p. 43–44.

Lottermoser, W. & Meyer, Fr.-J.: "Frequenzmessungen an gesungenen Akkorden", Acustica *10* (1960), p. 181–184.

Martin, D. W. & Ward, W. D.: "Subjective Evaluation of Musical Scale Temperament in Pianos", J. Acoust. Soc. Am. 33 (1961), p. 582–585.

Nederveen, C. J.: *Acoustical Aspects of Wood-Wind Instruments*, Amsterdam 1969.

Nickerson, J. F.: "Intonation of Solo and Ensemble Performance of the Same Melody", J. Acoust. Soc. Am. *21* (1949), p. 593–595.

Shackford, C.: "Some Aspects of Perception", J. Mus. Theory Part 1, *V* (1961), pp. 162–202 and Part 2, *VI* (1962), pp. 66–90.

Sirker, U.: "Objektive Frequenzmessung und subjektive Tonhöhenempfindung bei Musikinstrumentenklängen", Swedish J. Musicology 55 (1973), pp. 47–58.

Sundberg, J. & Tjernlund, P.: "Computer Measurements of the Tone Scale in Performed Music by Means of Frequency Histograms", STL-QPSR 2–3/1969, p. 33–35.

Sundberg, J. & Lindqvist, J.: "Musical Octaves and Pitch", J. Acoust. Soc. Am. *54* (1973), pp. 920–929.

Terhardt, E.: "Die Tonhöhe harmonischer Klänge und das Oktavintervall", Acustica *24* (1971), pp. 126–136.

Terhardt, E.: "Oktavspreizung und Tonhöhenverschiebung bei Sinustönen", Acustica 22 (1969/70), pp. 348–351.