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ОБ ИЗМЕРИТЕЛЬНОЙ МОДЕЛИ ЭМОЦИОНАЛЬНОГО ВОСПРИЯТИЯ МУЗЫКИ
ABOUT A MEASURING MODEL OF EMOTIONAL PERCEPTION OF MUSIC

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Abstract - The problem of finding the parameters of musical composition, which cause emotional perception of music and at that, can be measured, has been formulated. A hypothesis has been advanced and proved under which the perception of music is realized in an inertial nonlinear system, the emotional reaction of a listener depending on the parameters of a combinative spectrum.

The regularities have been discovered which distinguish the combinative spectrum of oscillations at the output of the non-linear system under the influence of music components written in various major and minor keys.

The regularities discovered are important for psychotherapy, biophysics and science of art and can be used for developing new musical instruments.

Keywords: measurement, music, and emotion.

1. INTRODUCTION

In opinion of the authors, expressed in [1], the greatest secret of music is that nobody knows the way it affects our brains.

Psychotherapists using the effect of music as medical treatment say that emotional reaction of a listener to music depends, most of all, not on a melody, but on other structural elements, such as a key and tempo.

The observations made by Mr. Platon are evidence of this fact, too.

Since the invention of an equally tempered tune, two main keys, the major and minor ones, came to be developed.

The compositions of the major key are usually defined as cheerful and bright (good/high spirits) in contrast to minor musical compositions, though some exceptions can occur.

Among the major and minor keys composers single out some that are considered to be the most expressive.
As a rule, they use these keys to get the listeners into a specific mood.

For example, the си b минор is often used for composing the music of tragedy nature, but the до мажор is used for creating a festival mood.

In transferring to the other key the effect of the musical composition frequently changes.

However, there is no information about the research studies devoted to physical reasons of these distinctions.

The challenge was to find the parameters of musical compositions or structural components of music, which defined the emotional effect of music and at the same time could be measured.

The great Galley said, ”Measure everything that is accessible for measuring and make accessible everything what is inaccessible for it”.

2. METHOD USED AND THE RESULTS

2.1. Basis hypothesis

As it is well known, both men and animals perceive not only audible sounds, but also inaudible ones, sometimes the infra-sound causing a sharp emotional response [7,8].

In due time a lot of publications were devoted to the experiments carried out by Mr. Wood, in the course of which the influence of infra-sounds upon the audience provoked panics. It should be marked that the animals feeling an increased intensity of infra-sound oscillations leave the place where they live due to their presentiment about an approaching disaster.

In other words, it is just the infra-sound acting at the level of sub-consciousness, which causes a specific behavior reaction.

The following hypothesis was advanced: while listening to the music, the effect connected with the influence of infra-sound oscillations, appears.

The reason for such infra-sound oscillations to appear is non-linearity of the “ear-brains” system causing formation of the infra-sound combinative components under the influence of two or more sounds.

Infra-sounds generated by music influence the emotional response of a man. This response depends on the intensity and frequency range. The major music and the minor one distinguish themselves by parameters of these oscillations, the individual major and minor keys differ from one another to a smaller degree.

The super-low frequency part of oscillation spectrum appearing when the sound combination is passing a nonlinear system was studied. Thirds and tonic triads were chosen as such sound combinations. The choice was due to the

fact that these combinations were the basic chords of musical keys.

The thirds were synthesized up from a key-note (tonic): major and minor thirds for major and minor keys correspondingly. The tonic triads were taken as triads.

The validity of their choice was confirmed by the experimental investigation [3] carried out by a psychotherapist.

The major tonic third is synthesized at steps I and III, while the minor tonic third at steps I and -III, where "-" means semitone decrease of a step. At that, the step III for the major key and the step –III for the minor key have therewith the main key color [6].

The basic (tonic) triad is synthesized at the steps I, III and V for the major keys and at the I, -III and V steps for minor keys.

The step V is a common one for the keys of the same name, but it is combined with the steps III and –III, correspondingly.

2.2. Method of calculation

To check the hypothesis advanced, the calculations of the combinative component parameters appearing as a result of sound interaction in the thirds and triads mentioned above, were carried out

We would like to remind that a combinative component is characterized by its frequency and order.

The frequency of the combinative component is equal to an algebraic sum of frequencies of component harmonics converted. The order is a sum of harmonic component numbers in the combinative component.

Usually if the order increases, the amplitude of a combinative component decreases quickly. Sometimes (depending on the form of non-linearity) the additional suppression of odd or even components takes place. But it can be noticed only if the value of order is relatively low. Further the evenness does not affect practically.

In this study the original method of calculation being a part of the methodology of frequency converter analysis and synthesis developed by one of the authors, was applied [9-11].

The calculations were made for 12 major and 12 minor keys using the equally tempered tune (the main tune used at present) and the Pythagorean tune.

It is believed that the Pythagorean tune despite its well-known defects in the tenseness of some interval sounding [5], permits to provide a greater expressiveness of musical phrases.

That is why, the musicians playing the instruments having a non-fixed height of sounds (violinists and others) frequently "swerve" from the equally tempered tune.

The frequency values of a sound scale normalized to the frequency of the note of A are given in Table 1.

It is quite evident that in the lowest frequency part of the sound range, even the combination oscillations of the order of p=2 frequency will get into a field of infra-sound.

If the frequency range of infra-sound is limited by the frequency of 14 Hz from above, and 0,2 Hz from below, then it will be easy to show that in the lower part of the large octave, contra octave and subcontra octave the frequency differences form an infra-sound.

Table 1. The frequency values of a sound scale normalized to the frequency of the note of A

Note	Frequency values		Note	Frequency values	
	Equally tempered tune	Pythagorean tune		Equally tempered tune	Pythagorean tune
a	1	1	dis (es)	$2^{6/12}$	$\sqrt{2}$
ais (b)	$2^{1/12}$	256/243	e	$2^{7/12}$	3/2
h	$2^{2/12}$	9/8	f	$2^{8/12}$	128/81
c	$2^{3/12}$	32/27	fis (ges)	$2^{9/12}$	27/16
cis (des)	$2^{4/12}$	81/64	g	$2^{10/12}$	16/9
d	$2^{5/12}$	4/3	gis (as)	$2^{11/12}$	243/128

Since the formation of these oscillations is the characteristic feature both of the major and minor in an equivalent manner, these octaves are non-informative from the point of view of the analysis being done. (Taking into account that the boundaries of infra-sound frequencies have been chosen approximately, the boundaries of a "non-informative" part of the range also are approximate.

In this connection the calculation has been made for the small, one-line and two-line octaves.

In the given stage of investigations, to reveal dominating regularities appropriate sharp and flat keys have been considered as enharmonic ones.

The frequency of A in the one-line octave is considered to be equal to 440 Hz.

2.3. Results of calculation

The calculation has shown that since for both the equally tempered tune and Pythagorean one within all the major keys of the octaves being investigated, the oscillations corresponding to the sounds included into the major key thirds, generate, under their interaction in a non-linear system, combination components lying within an infra-sound range (beginning from 5 Hz). These combination oscillations are of the order of p=9.

In the minor keys, for corresponding minor basic thirds, the infra-sound oscillations (beginning from 7 Hz) have a higher order, p=11, that is they significantly distinguish themselves by a lesser level.

This difference between the major and minor is much more observable for the basic triads. In all major keys the oscillations corresponding to the sounds belonging to the basic triads, interacting in the non-linear system, generate oscillations of an order which lie in the infra-sound range (beginning from 2,8 Hz).

In the minor basic triads the combination oscillations of infra-sound frequencies of the order of p=4 are not generated.

In this case the major and minor keys of the equally tempered tune, which are of the same named, the combination components of the same frequency with a higher order, p=5, are generated. They correspond to the interaction of the

teps I and V, that are common for the keys of the same name.

The background of the highest order, of p=5, does not affect the identification of the key: the major or minor one. Obviously, in perception of the major music the level of background is relatively low (both due to the fact that the order of corresponding oscillations is more by one and that this order differs from dominating infra-sound components in evenness.

These components are typical for the Dis-dur (Es-dur) of the Pythagorean tune too and are caused by the irrational ratios of the signal frequencies corresponding to steps I and V.

Fig.1 illustrates the distinction of various major keys from one another. On fig.1 the dependence of frequency of the components that occur in tonic triads on the key-note (on the key-note frequency) is shown for the equally tempered and Pythagorean tune. The order of these components p=4.

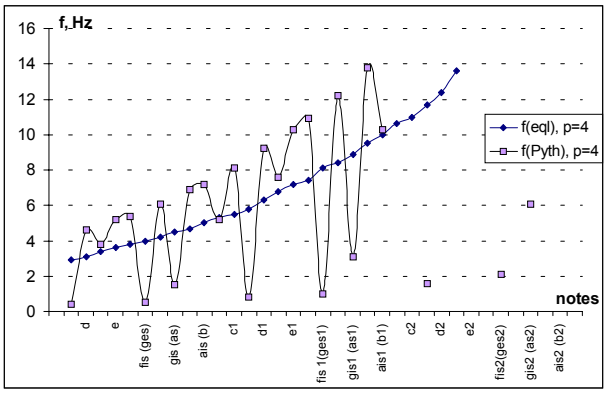

Fig.1. The dependence of frequency of the components that occur in major tonic triads on the key-note

For the equally tempered tune when the key varies from C-dur to H-dur, the frequency of the p=4 order components being considered is monotonously increased.

For the Pythagorean tune, this dependence is not monotonous and some keys distinguish considerably from the others.

For the major, the distinction of the keys Cis-dur (Des-dur), Fis-dur (Ges-dur) and, to a lesser extent, As-dur is brightly expressed. Their basic triads are characterized by lower frequencies of the infra-sound components, than the corresponding triads of the other keys, these values being the intermediate ones for As-dur.

It should be noticed, that in Des-dur Des (D flat) is a key-note, Ges (G flat) is the step IV and As (A flat) is the step V. That is, these keys are relative, combined with circle of fifths. The serious of chords belonging to relative keys is a natural method intensifying the emotional influence. At that, the emotional coloration of a musical phrase is characterized by the transfer from the triad formed on the step IV to the triad formed on the step V.

In the minor keys, in the case of the equally tempered tune when the key is being changed from c-moll to h-moll (with an increase of the key-note frequency), the frequency of infra-sound components generated in the basic triads considered on the octaves monotonously increases in the same manner as for major, but their order is higher: p=5.

For the Pythagorean tune this dependence is not monotonous and some keys differ strongly from one another. Here three groups can be singled out.

The first group includes the gis-moll and dis-moll (es-moll). For their basic triads, he order of infra-sound components, (p=5) is lower (the level is higher) han for all he rest ones.)

The second group of the f-moll and b-moll is characterized by the fact that the order of infra-sound components (p=9) is much higher than in the case of other keys. Correspondingly, the level of these components is significantly lower.

In the third group including all other keys of he minor, the order of infra-sound oscillations is equal to 6. Though, their parameters significantly differ from the parameters of major keys, as to parameters chosen they do not significantly differ from one another.

Distinction of various minor keys from one another is illustrated in Fig. 2, where the dependence of frequency and order, p, of the oscillations appearing in minor basic triads, on the key-note is shown for the case of the equally tempered and Pythagorean tune.

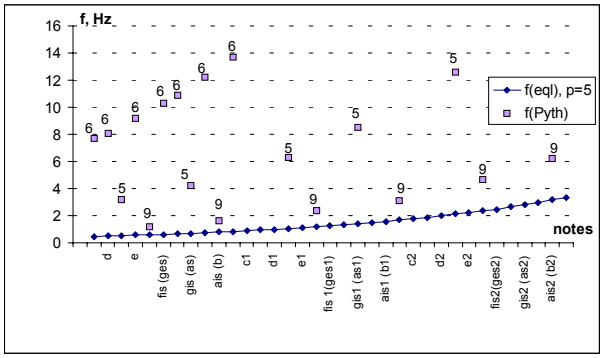

Fig.2. The dependence of frequency of the components that occur in minor tonic triads on the key-note (for p=5, p=6, p=9)

Almost the same dependence that is shown in the Fig.1 and 2 is valid for the thirds, but it has a weakened form.

It seems important to compare the received results with estimations of the emotional coloration of keys, given by V.Elkin who is a qualified musician and a famous art-therapist.

It is noticed in [3] that the emotional response of listeners to the musical compositions composed in Cis-dur (Des-dur and, Fis-dur (Ges-dur), differs from the perception of other major keys. These keys are included in the part of major keys which is characterized by contemplativeness. This mood is inherent, for example, in such masterpieces of the world classics as the compositions composed by F.Shopin “Fantasy-Impromptu” (a middle part) and Etude №7, op.25 (both Cis-dur), “In spring” by E.Grig (Fis-dur) and Etude №5, op.10 by F.Shopin (Ges-dur).

According to estimation made in [3], the Cis-dur (Des-dur) is characterized by the transfer from contemplativeness to energy. Really, considering seriously triads on the steps I, IV, V, beginning from not of des in the small octave one can

get the following chain of infra-sounds of p=4: 0,4 Hz – 0,5 Hz - 1,5 Hz.

To the other hand, the As-dur is characterized by bright energy, for example, Etude № 13, op.25 and Polonaise №6, op.53 by F.Shopin. The corresponding chain of infra-sounds beginning from the as in the small octave: 1,5 Hz – 0,8 Hz - 7,6 Hz.

Obviously, the lack of higher infra-sound frequencies in some chords makes the major sounding not so victorious as in other keys, such as C-dur, for example and others. Quiet sounding of the compositions composed in these keys can be connected to the frequency range about 3 Hz and lower. In the As-dur the frequencies are a higher, the transfer up (to 7,6 Hz) is much higher and this key generates much more joyful mood.

Taking into account the data of the above comparative analysis of he major and minor, it is possible to suggest that the compositions performed in the gis-moll and dis-moll (es-moll), can be percepted as somewhat differing from other minor keys because they have some nuance of the major.

For example, the "Barcarole" by F.Shubert has been composed in the as-moll, Prelude № 12, op.11, v.2 by A. Scryabin in the gis-moll, Prelude № 8 from "Well tempered clavier", p.1 by I.-S. Bach as well as "Intermezzo" from "Rome carnival" by R.Shuman, have been composed in the as-moll.

According to [3], they are characterized by aloofness and less tragic character, that is, they are not typical for the minor.

It should be emphasized that these keys are relative too.

The compositions composed in the f-moll and b-moll the basic triads of which generate an infra-sound oscillations of the lowest level only, should, obviously, be percepted as particularly sad.

Really, just in these keys there have been composed such compositions of a tragic character as "Parting" by M.Glinka, theme of the Ballade №4 by F.Shopin, "Fantasy for two pianos» by F.Shubert (f-moll), as well as a famous "Dead march" (part 3 of Sonata №2, op.35) by F.Shopin (b-moll)

These two keys also are relative. Besides of it, the f-moll and b-moll are parallel keys to the Cis-dur (Des-dur) and As- dur, which were considered above.

It can be noticed without any details that modulations, variations of a timbre, tempo or articulation also change a spectrum of infra-sound oscillations formed. Therefore they affect emotional coloration of musical composition perception.

2.4. Analysis of main results

The analysis of main results showed the following.

1. The oscillations corresponding to the sounds included in tonic triads and thirds with their interaction in the non-linear system cause a combinative component spectrum containing infra-sound range oscillations.

In the middle part of a sound scale, major key characterized by infra-sound combinative component oscillations of much higher level (less order) than for the minor key.

It follows from the above that the difference in emotional perception of the major and minor key corresponds to the difference of combinative oscillation spectra of the major and minor tonic triads and thirds.

2. . It is possible to conclude from clouse1, that the "ear-brain" system can be modeled by a nonlinear converter of acoustic waves, and the biophysical premise for the peculiarity of major key influence is perception of infra-sound combinative oscillations by brain.

3. Since the major and minor tonic thirds and triads are defined by listeners both while playing simultaneously (in cords) and in series, it should be admitted that the "ear-brain" system is characterized by inertness.

4. The level of infra-sound oscillation for tonic thirds is much lower than that for the corresponding basic (tonic) triads. The biophysical premises for emotional difference of basic thirds are significantly weakened.

5. . Within an octave infra-sound combinative spectrum components differ from each other in frequency and depend on the key-note.

6. For the Pythagorean tune the difference between various keys (as used here) are more evident than for the equally tempered tune.

7. The effect *of musical phrases increases because of the influence of the chords belonging to relative keys.*

8. The additional factor amplifying emotional effect is the combination of chords belonging to parallel keys.

9. It follows from the items 1-8, that possible emotional effect of musical compositions can be measured.

3. ACNOLEGMENTS

The authors are grateful to V.Elkin and V.Afanasyev for interesting and useful discussions tat gave rise to carry out this work.

4. CONCLUSION

Thus, possible effect of musical compositions can be measured.

The non-linear inertial transducer of acoustic oscillations with the receiver of infra-sound oscillations can be accepted for a model of emotional perception of music. The system of "ear-brain» seems to be such a transducer.

The authors have managed on the basis of he above model of perception to explain the distinguished features of emotional response of the listeners to various keys of a musical tune and their changes, as well as to other means of musical expressiveness.

The results of experimental investigation [3] correspond to the theoretical estimates the authors have given.

The model described requires some development and some improvement of the quantity parameters on the basis of measurement experiments, but in the present form it can be useful for investigations in psychotherapy, biophysics and science of art. The results can be also used in development of new musical instruments.

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