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MEASUREMENT OF THE EMOTIONS IN MUSIC FRAGMENTS

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Abstract: It is shown that expected emotional response to music fragments can be measured by non-linear conversion of acoustic oscillation spectrum, selection of infrasound signals-stimuli, and identification of signal ensembles that include the sequence of not fewer than three signals-stimuli.

Keywords: measurement of emotions, music, infrasound oscillations

1. INTRODUCTION

As a rule, the conventional methods of research of human emotional response to music are based upon results of polls and/or analysis of listeners' biophysical parameters, i.e. these methods enable the response to be estimated a-posteriori. Such methods are necessary for investigating the sensory apparatus in humans and brain functioning, as well as for a number of other applications.

However, the a-posteriori character of the research impedes the development of solutions aimed at optimization of the original musical impact. The purpose of the optimization is to obtain the required effect: a maximum expressiveness at a minimum cost.

In order to develop concert, TV, advertising and show businesses, as well as art-therapy, it is necessary to find the methods of objective estimation of an expected emotional response of a human to music.

Essentially, we are referring to the a priori estimation of emotions that a composer and a performer will pass to a listener.

In its turn, if we aim to obtain an effective experimental estimate, it is necessary to have a special "instrument", that is:

- a convenient formalized picture (measuring model) of emotional perception of music and
- a background and explanation of the origins of this phenomenon.

Dr. H.R. Schiffman wrote that the special ability of brain related to music perception is a result of evolution, and "its purpose is to provide some important biological function" [1]. According to [2], this special ability is a by-product of evolution.

Both ideas mentioned above do not present the basis for developing a required measuring model.

2. ELEMENTARY EMOTIONAL STIMULI

The proposed approach is based on a hypothesis about the genesis of emotional perceptivity of music during the process of evolution. The hypothesis itself was stated in [3, 4] and reads as follows.

During the process of evolution of living organisms, the need to perceive signals that stimulated readiness for actions has emerged. These signals are the signals warned about approaching natural disasters, enemies, as well as "food" or a male (female).

It is known that infra-sound frequency oscillations and oscillations of a lower part of the sound range frequency (hereinafter, all these oscillations are referred to as IF oscillations) associated with such situations cause a specific behavior of living creatures [5-7].

IF oscillations characterized by their amplitude and frequency are the primary signals that define an elementary emotional response.

It is important that the same response - emotional stress preparing a subsequent action - has a multiple meaning. The same very response comes before fear, aggression, or happiness depending on additional previous or expected information.

The sequence and dynamics of IF oscillations form a developed emotional response.

Living creatures felt IF oscillations long before the appearance of acoustic hearing apparatus (for example, a protective response of medusas to tsunami many hours before its approach is well known). Apparently, the differentiation of these signals arose and started evolving at that time.

Necessary reactions to the IF oscillations and their combinations have remained and developed during the process of evolution of living organisms since these reactions provided survival of species, but these reactions have not changed fundamentally.

When reptiles came out of water onto dry land, their sensitivity to IF oscillations decreased, because the density of medium around most part of the body became significantly lower. The necessity for reptiles to keep the ability to perceive IF information of vital importance has resulted in emerging a more developed apparatus: the development of hearing apparatus improved the ability of living creatures to survive on dry land.

The responses to IF signals, which had been formed in water before, remained. But for all that, the range of perceived oscillation frequencies was extrapolated to the band that is specific for the medium with lower density and higher mobility.

As a result, the living creatures who have hearing can perceive IF oscillations both by body directly and by “ear-brain” system indirectly.

The experiment of Dr. R. Wood showed that for a human, IF oscillations are also emotionally important [8]. A recent experiment during the concert in Great Britain, when the performance of music was accompanied by infrasound (17 Hz) from a special generator [6], did not significantly affect this conclusion.

IF oscillations can cause panic; while a long stay in silence leads to depression. The reception of signals confirming that the environmental processes are natural appears to be a contributing factor in emotional harmony of behavior.

Living creatures (from insects to primates) have the possibility to give the information of vital importance, which is of course emotionally coloured, to the other members of their "society". It can be done by the reproduction of a certain set of sound signals.

There are indirect evidences that when such a set is processed in the "ear-brain" system, the IF oscillations contained the required emotional information are singled out.

The emergence of homo sapience and the development of human society resulted in more noticeable differentiation of dangers and more developed palette of emotional responses.

According to a famous biologist Dr. V. Dolnik, the Cro-Magnon man (unlike the Neanderthal man) survived because he could enrich the oscillations of the sound frequency (SF) he was using and put into them emotionally filled logical content along with comparatively simple emotions [9]. So, he learned the art of speech.

Speech enriched the palette of emotional signals, because the formation of language is, first of all, increase in the number of the sound signals with emotional content.

Thus, the perceptivity of speech intonations and later of music was determined by evolutional necessity and fixed in genes as a reaction of living creatures to IF oscillations.

For mammals, as well as other living creatures with the developed hearing apparatus, an additional mechanism of IF oscillations perception can be explained by the non-linearity of the function of the SF oscillations conversion in the “ear-brain” system [3, 4, 10].

As it is known, if the conversion function is non-linear, the input oscillation spectrum enriches itself, and IF oscillations can be formed in it. Generally, the higher a power of a polynomial describing the conversion function of the system is, the greater the number of new (combinative) spectrum components is formed in this system.

The combinative component is characterized by its frequency f_k and order p_k.

$$f_k = \left| \sum_{i=1}^{m} n_i f_i \right| , \qquad p_k = \sum_{i=1}^{m} |n_i| \qquad (1),$$

where n_i is any integer (positive or negative),

f_i is the frequency of any of interactive oscillations,

and m is the number of input interactive oscillations of different frequencies.

Usually, with the order increase, the amplitude of combinative component decreases quickly, but irregularly. The amplitude depends on the evenness of p_k. With the p_k increase, the importance of the evenness decreases.

It seems reasonable to assume that the “ear-brain” system carries out the non-linear conversion of SF oscillations, as well as the subsequent selection of IF oscillations which are elementary signals-stimuli.

As it follows from this hypothesis, in order to obtain an objective estimation of music expressiveness, it is possible to design a device that will be able to select IF signals-stimuli stimulating elementary emotional response.

To make this device work, at the first stage it is necessary to single out the elementary emotional stimuli and reveal their emotional meaning.

It was proposed to use a key and tonality as a foundation, since they are comparatively simple musical characteristics related to emotions. In order to identify the tonality, the basic elements of tonalities - the tonic triads - were taken.

The triads are the elements which are often used in order to study the emotional effect of music fragments [11, 12, etc.]. The rightfulness of the implementation of a chord as an element having emotional colour was registered by Dr. V. Elkin [11]. It is also indirectly confirmed by [13], where the experimental results were given. In these experiments, healthy testees gave clear and close estimates of various musical fragments of 3-5 c.

The authors of this paper performed a theoretical investigation of interaction of the SF oscillations related to tonic triads in the non-linear converter.

The calculations were made for 12 major and 12 minor tonalities using the even-tempered scale (the main tune used at present) and the Pythagorean scale.

Sharp and flat tonalities were considered to be enharmonic ones.

In the study, the original calculation method developed by Dr. R. Taymanov [14] was applied. The procedure enables the minimal frequencies to be singled out in the combinative components spectrum. Order p can be also calculated.

The results of calculations [3, 4] and analysis of well–known facts related to music perception [15-17] have shown the following:

- In the middle part of the audio-frequency range, the oscillations corresponding to the sounds included in tonic triads with their interaction in the non-linear system described by a polinomial of a power ≥ 4 cause a combinative component spectrum containing infra-sound range oscillations.
- The difference in emotional perception of the major key and minor key corresponds to the difference in the IF combinative component spectrum.

In the middle part of the audio-frequency range, the major key is characterized by the IF combinative components of a much higher level (the order of the components is lower) than those of the minor one.

In particularly, for major tonic triads, $p \geq 4$; for minor tonic triads, $p \geq 5$.

The values of the order and frequency of combinative components depend on a tonic.

- In the lower and higher parts of the audio-frequency range, the difference in emotional perception of major and minor keys decreases significantly.

This effect explains "blooming" of key colour near the sound scale boarder: in the lower part, music has a "major" hint, and in the higher part it has a "minor" hint.

- The range of speech sounds is practically identical to the middle part of the sound range.

This perfectly agrees with the statement related to the formation of speech on the basis of the increase in the number of emotional sound signals, which is given above.

- Since resolution of the "ear-brain" system is finite, when the volume of sound is low, the emotional difference of major and minor keys decreases. When the volume of sound grows, the difference becomes evident.
- For the ancient Pythagorean scale, the difference between various tonalities (as used here) are significantly greater than for the even- tempered one.
- In the even-tempered scale there is a common background of IF combinative components for both major and minor tonic triads.

Apparently, this is an additional reason why the expressiveness of the even-tempered scale decreases in comparison with the Pythagorean one. (Musicians playing the instruments with a changing pitch often "vary" from the even-tempered scale).

- The major and minor triads are defined by listeners not only in case they are performed simultaneously (in chords), but also in series [11, 12].

This proves the idea that the "ear-brain" system is characterized by a lag effect (memory). (In [13] the shortest time interval necessary to cause emotions was estimated as (2.5 - 3 c). The authors of [18] defined the duration of the initial (hidden) time of emotion formation (0.15 - 0.30 c). These data enables to obtain a quantitative estimate of the time lag.

Probably, the genetic fixation of the response to IF oscillations and their combinations was realized on the basis of the proximity of the IF frequencies which are important for emotions to the frequencies of processes which are important for physiology (bio-rhythms).

The biorhythms frequencies [19] are given in Table 1.

Table 1. Biorhythms frequencies [19]

Biorhythm	Frequency range, Hz
Delta-rhythm	**0.5 – 3.5**
Theta-rhythm	**4.0 – 7.5**
Alfa-rhythm	**8.0 – 11.5**
Beta-rhythm	**12.0 – 29.5**

An additional argument for the current hypothesis is the possibility to explain the stronger emotional effect of the bells ringing as well as the sounds of drums.

The results of research given in [10, 20] have shown that the bell ring spectrum includes oscillations with frequencies, the difference in which is equal to several Hz.

Consequently, the sound oscillations reproduced by a bell produce intensive IF oscillations (p=2) when they are passing through non-linear system.

The frequencies of the drum beats usually lie within the biorhythms range. When a listener hears a loud drum beat, he perceives the IF oscillations as the difference of neighbouring harmonics in the sound range. If the listener is close to a performer, the visual reaction and the sense of touch contribute to this effect.

The current hypothesis explains the well known effect of major music on the growth of plants. The major music causes IF vibration in plants, which contributes to passing saps from roots to leaves. The minor music does not cause such a vibration.

The evidences of the proposed hypothesis which is given above enables us to say that at least the signals-stimuli causing an elementary emotional response can be singled out and estimated.

3. SIMPLEST EMOTIONAL IMAGES

When an ensemble of SF oscillations which form a signal-stimulus is generated, human memory bears an association with a specific emotional image.

The simplest emotional image is formed on the basis of the ensemble of SF oscillations, which includes a sequence of not fewer than three IF signal-stimuli.

For example, such specific emotional images are the images including the sequence of chords of relative tonalities (according to steps I-IV-V or I-IV-V-I) within the circle of fifths. IF combinative components in the circle of fifths are shown in Fig 1 and 2 for major and minor keys.

			Cis-dur	**As-dur**		
		Fis-dur			**Es-dur**	
octave	**H-dur**					**B-dur**
small	**3.5**	**0.5**	**0.4**	**1.5**	**3.8**	**7.2**
first	**7.0**	**1.0**	**0.8**	**3.1**	**7.6**	**14.4**
second	**14.0**	**2.1**	**1,6**	**6.1**	**15.2**	**28.8**
small	**5.2**	**6.9**	**3.1**	**6.1**	**4.1**	**3.8**
first	**10.3**	**13.8**	**6.3**	**12.2**	**8.1**	**7.4**
second	**20.6**	**27.6**	**12.4**	**24.4**	**16.2**	**14.8**
	E-dur					**F-dur**
		A-dur			**C-dur**	
			D-dur	**G-dur**		

Fig.1. The circle of fifths. Frequencies of the IF combinative components which identify major tonic triads (Pythagorean tuning). Order p=4. Background components with p=5 have been taken away.

The values of frequencies and orders given in the figures were calculated according to the method [14].

Unlike the elementary emotional response, the simplest emotional image is characterized by more varied emotional reaction. The examples are given in the text below and in Fig.3.

In particular, among the major tonalities with the same order, Cis-dur, Fis-dur, and, to a lesser extent, As-dur are characterized by the lower frequencies of the IF components.

The sequence of chords according to steps I, IV, V can be considered to be responsible for the emotional response.

Fis-dur: 0.5 – 3.5 – 0.8 Hz (at first, the IF frequency increases and then falls down).

Cis-dur: 0.4-0.5-1.5 Hz (the frequency increases slowly).

As-dur: 1.5-0.8-7.6 Hz (at first, the frequency decreases a little and than increases significantly).

Dr.Elkin wrote in [11] that in his experiments most listeners recognized the Fis-dur musical fragments to correspond to the feeling of contemplativeness. (For example, this is the tonality of E.Grig's “In spring”).

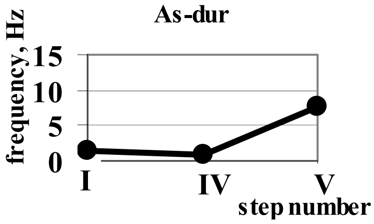
Cis-dur: gives the feeling of the transit from contemplativeness to energy (F.Shopin's Etude No 17, op.25), while As-dur carries bright energy and joyful mood (F.Shopin's Polonaise №6, op.53).

Analogously, for the minor keys (the value of the order is given in parentheses):

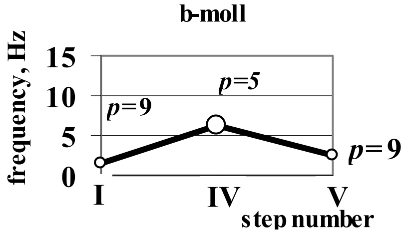
For example, as-moll: 4.2 (5)-15.4(6)-6.3(5) (the frequency first goes up and the amplitude falls down a little, then the frequency decreases to some extent and the amplitude rises). The level of IF components is maximal for minor key here, so there is a slight shadow of the major key ("The gondola song", F.Schubert).

			b-mol	**f-mol**		
		es-mol			**c-mol**	
octave	**as-mol**					**g-mol**
small	**4.2 (5)**	**3.2 (5)**	**1,6 (9)**	**1.2 (9)**	**10.4 (6)** **14.8 (4)**	**10.9 (6)**
first	**8.5 (5)**	**6.3 (5)**	**3,1 (9)**	**2.4 (9)**	**20.8 (6)**	**21.8 (6)**
second	**17.0 (5)**	**12.6 (5)**	**6,2 (9)**	**4.7 (9)**		
small	**7.7 (6)**	**10.3 (6)**	**13,7 (6)**	**9.2 (6)**	**12.2 (6)**	**8.1 (6)**
first	**15.4 (6)**	**20.6 (6)**	**27,4 (6)**	**18.4 (6)**	**24.4 (6)**	**16.2 (6)**
second						
	cis-mol					**d-mol**
		fis-mol			**a-mol**	
			h-mol	**e-mol**		

Fig.2. The circle of fifths. Frequencies of the IF combinative components which identify minor tonic triads (Pythagorean tuning). The order of combinative components *p* is given in parentheses.



a)



b)

Fig. 3. Examples of the simplest emotional images
a) As-dur, *p*=4 (energetic character);
b) b-moll (tragic character)

Es-moll: 3.3(5)-4.2(5)-1.6(9) (the frequency increases a little and then falls down, at the same time the amplitude of the IF component falls down too). The shadow of the major key caused by a relatively high level of IF components at the first two steps goes gradually down).

F-moll: 1.2(9)-1.6(9)-20,8 (6)] (the level of the IF components is very low). For example, F.Shubert's "Fantasy for two pianos" (problems, tragedy).

B-moll: 1.6(9)-6.3(5)-2.4(9) (at first, the level and frequency of the IF components are very low, than they rise sharply, and after that fall down again). The corresponding musical compositions are characterized by the transition from sorrow to tragedy. Particularly sad examples are the famous F.Shopin's "Dead March" (from Sonata No 2, op.35) and P.Tchaikovsky's Symphony No 4, part 2.

The change in the sequence of the IF signals-stimuli forms a new emotional image. Its colour depends also on the previous and /or subsequent emotional images.

Hereby, the proposed interpretation of the idea of the simplest emotional image is proved by the correlation between the emotional response of listeners to the classical music fragments written in the certain tonalities and the diagrams corresponding to the emotional images in the field of biorhythms.

The research results [11, 12] show that the statistical estimates of the emotional response to the key and tonality are stable enough.

In essence, this research confirms the idea that the simplest signals-stimuli and the key simplest emotional images are based on biological background.

The emotional response of people with healthy psychic to these signals and images has a sharp peak of the distribution function. This response is typical.

The deviation of a man's emotional response from the typical one can serve as an indicator of the deviation of psychic from normal.

Certainly, the listener's mood influences the emotional estimates to a great extent. However, the errors related to the subjective perception can be reduced significantly if the mood of testees is harmonized in advance [21].

Thus, the simplest emotional images which short music fragments (or other sounds combinations) contain can be experimentally estimated with the help of a special device.

The elementary signals-stimuli comprising the emotional image can be singled out of the music fragment using the non-linear conversion realized in this special device.

Each signal-stimulus is characterized by an amplitude, frequency, and time parameters. Their values can be related to references through a documented unbroken chain of calibrations.

The emotional image depends also on the sequence of the elementary signals-stimuli.

So, measurement of the emotions in music fragments is similar to measurements of colour or analytical measurements in which a set of several parameters determinates a complex value.

Experimental estimation of the simplest emotional image corresponds to the definition of the term "measurement" according to [22, 23].

The sequence of the simplest emotional images determines the emotional content of music.

If we speak about the content of music, it is also possible, but more difficult to obtain the estimate of the expected emotional response, because the formation of more complicated emotional images depends, to a great extent, on cultural traditions and psychological type of listeners.

In order to continue experimental research in the field of measurement of emotions which music and speech fragments contain, the mathematical simulator of the non-linear "ear-brain" system and the simplified version of the corresponding software were developed.

The first results have been obtained using chords and music fragments.

The results of these computer experiments confirmed the conclusions drawn from the calculating analysis. The results also revealed a great role of timbre and articulation of sound.

At present, the works aimed at the improvement of the mathematical simulator and software in order to facilitate determination of the emotionally significant components are on the way.

4. CONCLUSION

Perception of the emotions in music fragments can be explained by the fact that music includes signal ensembles which form emotional images. The vital importance of these images is fixed in genes.

In order to measure emotions in the sequence of sound signals (music fragments), it is suggested to apply the device able to store (delay) music, to make non-linear conversion of SF oscillations, select and decode IF combinative components, as well as to single out (identify) the emotional images.

The proposed approach gives the basis for the objective quantitative estimation of the expected emotional effect of musical compositions and of quality of musical instrument sound.

It also can help to explain the special features of emotional response of listeners to various means of improving musical expressiveness.

The current approach opens new possibilities for applied developments in the other fields such as technical acoustics, telecommunication, biophysics, psychotherapy, linguistics, and art.

The first results of the problem-oriented research as well as the patents obtained by the authors of this paper confirm that these possibilities can be realized.

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