

# Measurement model as a means for studying the process of emotion origination

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**Abstract.** In the last edition of the International Vocabulary of Metrology the concept “measurement” was spread outside the field of physical quantities. This fact makes it relevant to analyze the experience of developing the models of multidimensional quantity measurements. The model of measurements of expected emotions caused by musical and other acoustic impacts, is considered. The model relies upon a hypothesis of a nonlinear conversion of acoustic signals to a neurophysiological reaction giving rise to emotion. Methods for checking this hypothesis as well as experimental results are given.

## 1. Introduction

In the last edition of the International Vocabulary of Metrology [1] the concept “measurement” was spread outside the field of physical quantities. This fact can be explained by changing society priorities. In the 21-st century the need for a quantitative estimate of properties characterizing health, knowledge, and abilities of human, as well as that of economical and social processes, has significantly increased [2, 3]. In many cases these properties are multidimensional (multiparametric). For specialists in the field of metrology the above mentioned fact results in the necessity to cooperate with specialists who got used to other approaches to the quantitative estimates of experimental data, as well as to increase attention to the problems of measurement model development.

While developing a model for measuring a non-physical quantity characterizing human or society, it is desirable to apply a hypothesis demonstrating a mechanism of this quantity formation. Particularly, this statement can concern any human physiological reaction, including emotion. Such an approach enables the most important parameters determining a measurand value to be singled out. At the first stage of development, the model can be substantiated only by theoretical ideas, calculations and assumptions. The subsequent experimental justification of the model paves the way for measurement of properties immeasurable before, thereby contributing to better understanding of the scientific concepts concerning the investigation subject. A model considered below is an example demonstrating the efficiency of such an approach.

## 2. Model of emotion measurements

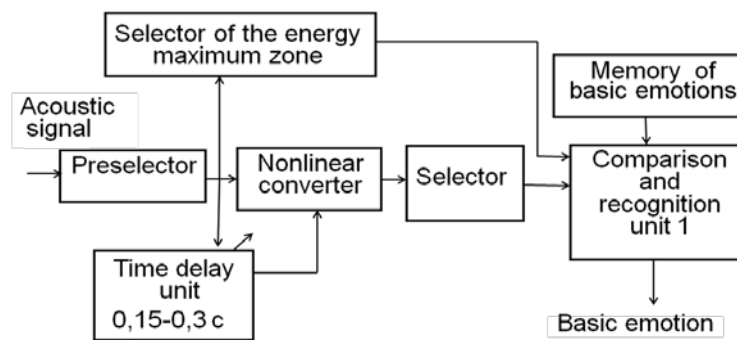
The model described in [4] and developed later on in [5-8] is a model of a hypothetical mechanism linking a musical or some other acoustical impact with an expected emotion of a listener. It was developed on the basis of an evolutionary analysis of bioacoustic signals, a number of hypotheses and calculations. It relies upon a well-known fact that within the process of evolution of living organisms in water, they felt a need to perceive some signals which alerted the others to approaching natural



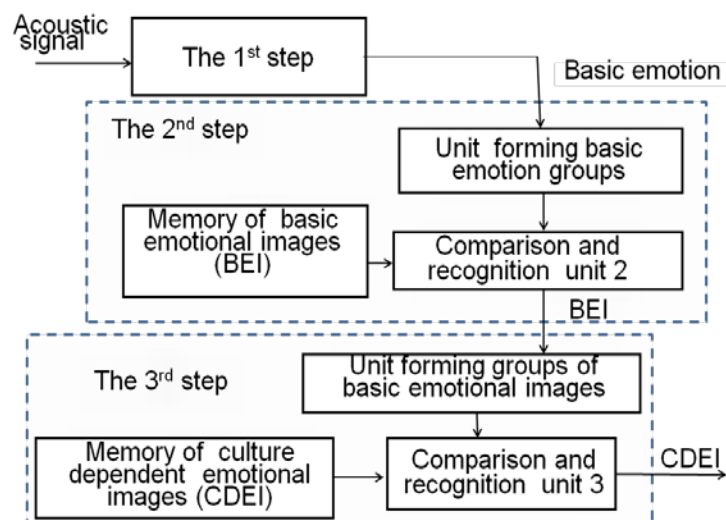
disasters, enemies, “food” or a male (female). The earliest sensor system provided the sense of touch (the perception of water pressure changes within the infrasound frequency range). When amphibia and reptiles left water to occupy dry land, where the density of a medium became significantly lower, the sensitivity to the oscillations signaled about the vitally important situations reduced. A new possibility was formed on the basis of a sensitivity growth within a higher frequency range, nonlinear conversion of the perceived oscillations and selection of intermodulation oscillations with infra-low frequency, which simulate a reflex reaction of an organism, i.e., “proto-emotion”.

The emotion in this model is defined according to a neurophysiological response being identified with the help of memory and as a consequence, giving rise to a transfer to a state an emotional colour of which can be identified by feeling or behavior of a listener.

The measurement model consists of three steps. The first one reflects a “mechanism” of forming the simplest (earliest) basic emotions that are common for people and animals. This step is connected with the reflex brain activities. The second and third steps give an idea of the way how complicated emotions are formed. They consider universal human and culture-dependent emotional images concerning cognitive activity, history of people, upbringing, education, belonging to a definite socio-culture group, etc. The first step of the measurement model and 3 steps model are shown in figure 1 and figure 2, accordingly.



**Figure 1.** The first step of the measurement model.



**Figure 2.** 3 steps measurement model.

The question arises with regard to the localization of the non-linear converter. The mechanism of the nonlinear conversion of acoustic signals in ear is well-known [9]. However, one of the main assumptions that underlies the model is as follows. The basic emotion is activated as a result of the

joint nonlinear conversion of acoustic signals that are perceived at the moment and were perceived earlier. This procedure and the subsequent selection of intermodulation products within the range of brain biorhythms, can be performed only in the brain. (Assumptions on the non-linear conversion in a part of the brain directly connected with an organ of hearing, in recent years have been also pointed out by specialists in the field of neurophysiology [10].

### **3. Methods of checking up the main blocks of the first step of the measurement model**

Experiments were aimed at proving the existence of characteristic neurophysiological reactions to sound stimuli in accordance with the model proposed. Stimuli were synthesized with the help of computer from sinusoidal oscillations in order to exclude the influence of subjective features of a performer and instrument timbre parameters. As the stimuli, tonic triads and sounds containing modulation at frequencies within the range of brain biorhythms (oscillations with single-sideband and frequency modulation) were used. It is known that musical intervals and sets of them have emotional colour [5]. Preliminary calculations [4, 5] have shown that after nonlinear conversion of sounds of major tonic triads or sounds with the corresponding modulation, components of a comparatively high level within the infra-low frequency range are formed. According to the above-mentioned hypothesis, they lead to the basic emotion generation. In experiments, the stimuli that cause such reactions played the role of the “deviant” ones. Minor tonic triads do not cause the components of such a level within the considered frequency range. Therefore, they were used as “standard” stimuli. The experiments included presentation of standard and deviant stimuli to participants and synchronous registration of electroencephalograms (EEGs).

During the studies, test procedures were improved by optimizing a duration and presentation order of the stimuli as well as data processing method.

The first experimental procedure can be called classical. Tonic triads of 4 tonalities were applied as the stimuli, measurement series being different in the tonalities. Each series included 20 equal triads. EEGs of the participants were recorded in pre test eyes closed and eyes open conditions in silence, then in eyes closed (to minimize external influence) during the stimulus presentations. The analysis of the EEGs was performed using a Short-time Fourier Transform with a rectangular time window. After that, spectrograms were built. The analysis of the spectrograms obtained revealed that the repetition of the same stimuli used in this procedure causes the “loss of interest” in them. As a consequence, a signal/ noise ratio degrades when the number of stimuli increases, although it was impossible to expect this ratio to be very high even under ideal conditions. The thing is that on one hand, the emotional colour of an individual triad is weak and cannot result in neurophysiological reactions of a significant level within the infra-low frequency range. On the other hand, EEG is influenced by many various random factors of physiological and cognitive character, such as respiration, muscle activity, tiredness, attraction of attention to irrelevant thoughts or side impacts, etc. It is rather hard to diminish their influence during the experiments. To decrease the “loss of interest”, a quasi-random sequence of stimuli was formed, in which different stimuli were presented in an order unknown for participants.

The second procedure used the presentation of stimuli as a continuous record. It included major tonic triads (B-dur in the small octave, C-dur in the first octave, D-dur in the second octave) and oscillations with the corresponding modulation. According to the calculations, these sound combinations generate oscillations with the frequencies 5 Hz, 8.45 Hz, and 12.65 Hz. The deviant stimuli were presented in a quasi-random order. Minor tonic triads (b-mol in the small octave, c-mol and d-mol in the first octave) played the role of standard stimuli and were inserted between the deviant ones. According the third procedure, the stimuli were also presented in a quasi-random order, but after each stimulus a participant performed simple arithmetic calculations to remove an emotional mark left by the previous stimulus.

### **4. Analysis of results**

The non-stationary character of EEGs caused the necessity to modify the data processing in the spectral field and to refuse from usage of the standard Fourier-analysis, since it does not permit a high

resolution capability with regard to time and frequency to be simultaneously achieved. It “averages” a great number of nonrandom influence factors making the results worse. An analysis of special features of the measurements gave grounds to carry out the data processing within the time domain, and to evaluate the relative variation of EEG signal power within band  $\pm 0.5$  Hz around the calculated frequency value. The process of analysis was realized in several stages:

- a) Revealing outliers in the EEG (noise, pickups) and removing these outliers from records.
- b) Calculation of values of the ratio of signal powers  $U_s$  и  $U_d$  for each standard and deviant stimuli, correspondingly.  $U_s$  and  $U_d$  were calculated for two time windows characterized by duration  $T_{win}$ : the 1st window was taken during the stimulus presentation (with time delay  $T_{st}$  from the stimulus beginning in order to determine the moment of starting participant’s perception of a stimulus), while the 2nd one was taken just before the 1st one.
- c) Revealing and removing outliers in the obtained samples of values  $U_s$  and  $U_d$ .
- d) Evaluation of samples medians:  $med(U_d)$  for the deviant stimuli and  $med(U_s)$  for the standard stimuli.

The procedure reflected in point b), taking into account the possible variation of the moment of individual reaction, allows this moment of time to be determined the best way. It corresponds to the maximal ratio of the power values (from the values obtained at different  $T_{st}$  and  $T_{win}$ ).

The problem concerning the choice of a method for removing outliers became extremely important. In deviant samples the number of values is rather small. At the same time, the laws of distribution of the quantities  $U_s$  and  $U_d$  are unknown. In the calculations, medians of samples were applied [11, 12] since the median is robust with regard to the outliers under conditions of an unknown distribution law.

The results of data processing on 12 tested participants are illustrated in figure 3. The median of  $med(U_d)/med(U_s)$  calculated for all the participants (the time window position optimal for each participant was chosen) is 2.56 for the frequency of 5.0 Hz and 1.97 for the frequency of 12.65 Hz.

Application of the Bayesian decision theory allowed additional confirmations of the above-mentioned hypothesis that the nonlinear conversion is a part of the emotion formation process (see table 1). Calculations were carried out for a set of values  $T_{win}$  within the range from 0.1 s to 0.5 s and  $T_{st}$  in the range from 0 s to 0.4 s. For each pair, the frequency probabilities of correct “detection” of standard ( $pH_{ss}$ ) and deviant ( $pH_{dd}$ ) stimuli were calculated. As a result, there was obtained a pair of values  $T_{win}$  and  $T_{st}$ , for which  $pH_{ss}$  and  $pH_{dd}$  are maximal.

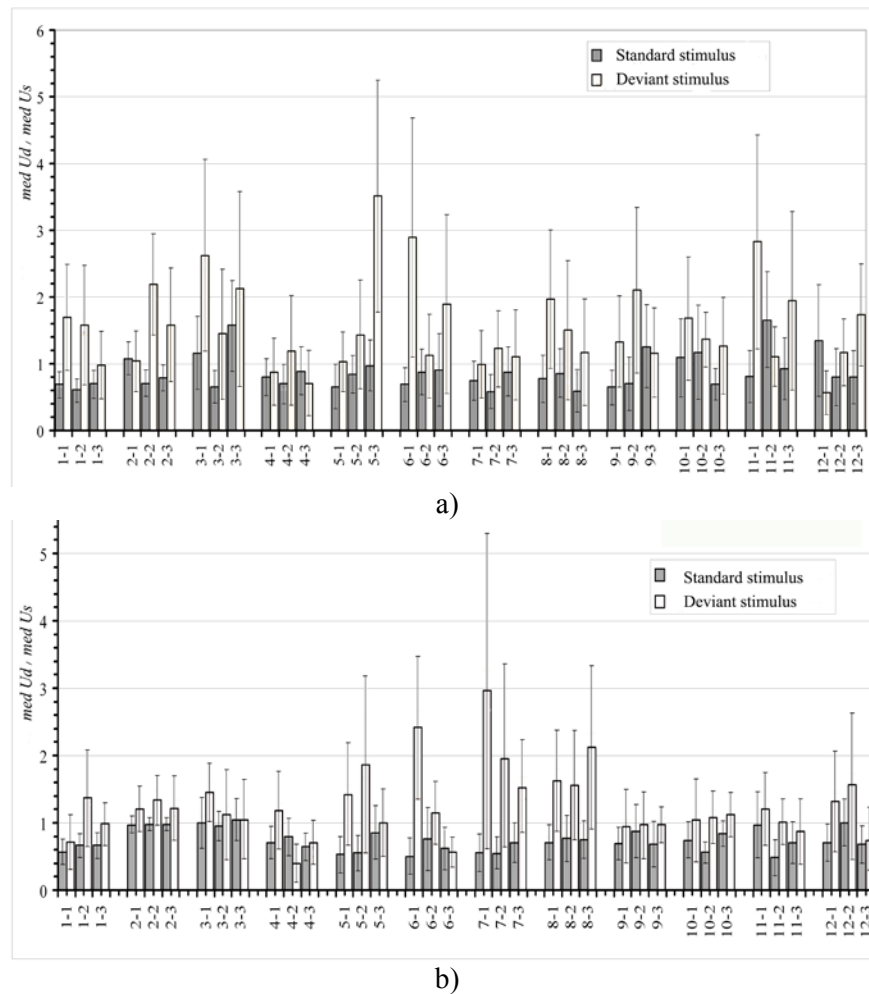
The probabilities  $pH_{ss}$  and  $pH_{dd}$  were calculated in the following way. It was considered that in spite of unknown laws of the  $U_s$  и  $U_d$  distribution, some assumptions can be applied:

- 1) For the standard stimuli  $mode(U_s) = 1$ , i.e., under the influence of the standard stimuli at the frequencies of interest, there is no neurophysiological reaction, since in the standard stimuli themselves after the nonlinear conversion there are no infra-low-frequency components.
- 2) For the deviant stimuli  $mode(U_d) = 1.2$ , i.e., the power of EEG at the frequency of interest, when the deviant stimulus is presented, exceeds the EEG power at this frequency before the presentation of the stimulus at the least by 20 %.
- 3) Dispersion of the  $U$  distributions for the standard and deviant stimuli are equal.

Under such conditions the threshold  $U_0$  was calculated as

$$U_0 = \frac{mode(U_s) + mode(U_d)}{2} = 1.1 \quad (1)$$

For each standard stimulus at  $U_s < U_0$  the decision was taken concerning the correct “detection” of the standard stimulus. For each deviant stimulus at  $U_d \geq U_0$  the decision was taken concerning the correct “detection” of the deviant stimulus. In other words, under these conditions the reaction of the participant caused by the standard and deviant stimuli corresponded to the expected reaction within the framework of the hypothesis proposed. In realization of this procedure there were calculated values of  $n_{ss}$ , i.e., the number of the standard stimuli the response to which corresponded to the expected standard stimuli reaction, and values of  $n_{dd}$ , i.e., the number of the deviant stimuli the response to which corresponded to the expected response to the deviant stimuli.



**Figure 3.** Medians of the EEG power ratios in the 1st and 2nd time windows ( $T_{win} = 0.3$  s) for standard  $med(U_s)$  and deviant  $med(U_d)$  stimuli.

Along the X-axis the symbolic notations of participants (1 – 12) are indicated (participants 1 and 2 were tested according to the second procedure, participants 3-12 were tested according to the third one); the number given through a hyphen is a symbolic notation of the moment when the 1st time window starts relative to the stimulus beginning (0.1 s, 0.2 s, and 0.3 s).

a) 5 Hz;

b) 12.65 Hz

$$pH_{ss} = \frac{n_{ss}}{N_s}, \quad pH_{dd} = \frac{n_{dd}}{N_d}, \quad (2)$$

where  $N_s, N_d$  are the number of the standard and deviant stimuli.

For determining a pair of  $T_{win}$  and  $T_{st}$  values at which both standard and deviant stimuli are “detected” in the best way, the total probability of the correct “detection” was calculated:

$$p = \frac{n_{ss} + n_{dd}}{N_s + N_d}. \quad (3)$$

**Table 1.** Calculation results.

No	5 Hz					12.65 Hz				
	$T_{st}$ (s)	$T_{win}$ (s)	$p$	$pH_{ss}$	$pH_{dd}$	$T_{st}$ (s)	$T_{win}$ (s)	$p$	$pH_{ss}$	$pH_{dd}$
3	0.1	0.2	0.73	0.71	0.76	0.1	0.2	0.64	0.64	0.65
4	0.1	0.2	0.67	0.66	0.69	0.1	0.4	0.66	0.69	0.57
5	0.4	0.2	0.69	0.65	0.78	0.2	0.1	0.71	0.69	0.79
6	0.2	0.4	0.72	0.69	0.80	0.1	0.2	0.69	0.69	0.71
7	0.2	0.4	0.75	0.76	0.75	0.2	0.2	0.70	0.68	0.72
8	0.2	0.4	0.63	0.64	0.63	0.2	0.1	0.68	0.68	0.69
9	0.1	0.3	0.69	0.71	0.67	0.4	0.2	0.64	0.65	0.63
10	0.1	0.4	0.66	0.64	0.71	0.0	0.4	0.60	0.54	0.73
11	0.3	0.1	0.70	0.68	0.74	0.4	0.2	0.75	0.81	0.61
12	0.4	0.4	0.71	0.73	0.67	0.1	0.3	0.62	0.67	0.53

Then, for each participant of the test they chose those values of  $T_{win}$  and  $T_{st}$ , at which the  $p$  value is maximal.

The results obtained are the evidence of the fact that the deviant stimuli steadily generate components with the infra-low frequencies predicted by the calculations, while the standard stimuli do not give rise to the generation of such components.

## 5. Conclusion

It has been shown that the impact of tonic triads causes the neurophysiological reaction forecasted by the measurement model. These results prove that the non-linear conversion of sound frequency oscillations and selection of infra-low frequency intermodulation products take place in the brain.

In combination with other data, this result permits a conclusion to be drawn that the measurement model proposed earlier can serve as a model of the neurophysiological mechanism of forming the basic emotions, which are common for people and animals.

In its turn, this conclusion enables scientists to begin the study of the 2<sup>nd</sup> and 3<sup>rd</sup> steps of the model that reflect the mechanism of universal human and culture-dependant emotional images. Then it will be possible to go over to the investigation of emotional feeling processes caused by perception of music, and later on to proceed to the development of corresponding measuring instruments.

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