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INFORMATION EQUATION OF EMOTIONAL STATE

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Abstract

This paper proposes a mathematical model of human emotional states within the framework of information theory. Building on P. V. Simonov's model and the works of V. F. and L. M. Prisnyakov on emotions such as love and fear, the study introduces a generalized information equation of emotional state. The model combines two components - subjective internal experiences and physiological manifestations - and incorporates key parameters: internal emotional tension, information density of stimuli, need satisfaction coefficient, and neural process mobility. The resulting equation reflects the interaction between cognitive and physiological aspects of emotions and corresponds to catastrophe theory, distinguishing stable and unstable emotional states. Validation with experimental data, particularly Izard's studies on infants, demonstrates good agreement with theoretical predictions. The proposed model provides a quantitative basis for analyzing emotions and suggests new directions for predicting and regulating emotional processes in psychology.

Keywords: emotional states, information theory, mathematical modeling, catastrophe theory, physiological reactions, cognitive processes.

There are many definitions of emotion, as well as approaches to studying emotional states. We will proceed from the definition that emotions are integral evaluative responses of the body to the influence of external and internal environmental factors, as well as to the results of one's own activity. Emotions manifest as subjective experiences of varying modality and intensity and are accompanied by specific motor responses of external and internal organs. Emotions are generally considered to be experienced as feelings that *motivate, organize, and guide* perception, thinking and action.

Currently, there are numerous theories of the human emotional state. All of these theories are qualitative and descriptive. A slight exception is the theory of P. V. Simonov, who believed that emotions arise as a result of a lack or excess of information necessary to satisfy a need. P. V. Simonov proposed a "formula of emotions" that defines the degree of emotional tension as the difference between the strength of the need and the magnitude of the deficit of pragmatic information necessary to achieve the goal

$$\boldsymbol{E = f\,[П(\,И_н - И_c),\ldots]} \qquad (1)$$

where $\boldsymbol{E}$ is the emotion, its degree, quality, sign; $\boldsymbol{П}$ is the strength (type) and quality of the current need; $\boldsymbol{И_н}$ is information about the means prognostically necessary to satisfy the need, $\boldsymbol{И_c}$ is information about the means that the subject has at the time the need arises; $\boldsymbol{(И_н - И_c)}$ is an assessment of the probability (possibility) of satisfying the need based on innate and ontogenetic experience.

According to P. V. Simonov, information[19] depends on:

- individual (typological) characteristics of the subject - temperament, will, motivational sphere;
- dynamic psychophysical processes, i.e., the time of manifestation of the emotional reaction (relatively rapid - affect, prolonged - feelings).

The first mathematical models of individual emotions - love and fear - were developed in 1995 by V. F. Prisnyakov and L. M. Prisnyakova. The starting point for these models was the definition of the **coefficient** of the **emotion** in question as a value reciprocal to the difference in information between *some ideal standard of information* stored continuously in a person's memory- for example, a life-threatening situation (in the case of describing the emotion of fear) or a person of the opposite sex (in the case of love) - and the *actual information* entering the memory at the given moment. This approach, using the theory of information processing in human memory, yielded interesting theoretical results, which, in the case of love, were supported by empirical data.

Let us use the ideas presented in these works to describe emotions *in general*.

[19] We use the term "information" in a pragmatic sense, as a reflection of a set of elements that ensure the life of an individual, the subject's knowledge, his skills, the body's energy resources, the ability to organize the required actions, etc.

Based on some of the ideas of P. V. Simonov's qualitative information model of emotions, we obtain an *equation for the human emotional state*. To do this, we imagine the information set describing human emotions as consisting of two subsets. The first defines information about *internal experiences*, about the "virtual," *irrational expression of emotions*. The information set in memory about this part of emotions will be denoted by **U**. The second R_{ph} is information about motor processes, information *expressing emotions in physiological means* of expression: in the form of specific (motor) reactions of the face, limbs, heart (pulse), blood, tears, etc., i.e., in physiological reactions, facial expressions, posture, and actions. The total information set about the body's reactions - irrational and physiological - will be equal to

$$U_{\Sigma} = U + R_{ph} \qquad (2)$$

The ratio of the total information about an individual's emotions to the total information received from outside about irritating stimuli represents a certain *coefficient of emotional amplification*. This coefficient can be considered proportional to the need $\mathfrak{R}$ and inversely proportional, $\Delta I = I' - I$, to the difference between the standard of information I' about need satisfaction – for positive emotions, or about need dissatisfaction – for negative ones, and the actual value of information I received in memory. This is evident from the following two examples. If I' is information about the ideal of an individual of the opposite sex, and I is actual information about him, then the difference $\Delta I = I' - I$ determines the degree of the feeling of love - the smaller ΔI, the stronger the feeling. For the case of a feeling of fear, if I' is information about the information standard of fear, and I is information about the actual danger, $\Delta I = I' - I$ determines the degree of fear - the greater ΔI, the lesser the fear. From this it can be seen that emotions are inversely proportional to ΔI. In general, we will assume that I' is *a standard volume of information* that, in an ideal case, fully ensures the fulfillment of a stimulus, satisfying or dissatisfying for a given individual. It is determined by innate or ontogenetic experience and can change throughout a person's life. In this respect, our model differs from P.V. Simonov's model, in which ΔI is a certain estimate of the probability of need satisfaction. The two-factor theory of emotions by Schachter and Singer is close to our concepts: emotion is the result of the cognitive interpretation of diffuse physiological arousal, and cognitive labels are borrowed from personal experience or the social environment.

Based on the above, we define the *coefficient of emotions* (the coefficient of satisfaction or dissatisfaction of a need) as a value inversely proportional to the relative stimulus information $\Delta I / I'$:

$$\varepsilon = I'/(I' - I) = 1/(1 - \nu) \qquad (3)$$

Here $\nu = I/I'$ - *information density of emotional stimulus*

Taking the above into account, it can be assumed that the amount of information about the total emotions U_{Σ} is proportional to the volume of information about the event in question I, that the subject has at a certain moment in time τ (information tension). The coefficient of this proportionality, which determines the emotional amplification of information, will be equal to the product of the need coefficient $\mathfrak{R}$ (which "evaluates" a specific type of stimulus), the emotion coefficient ε, and a certain coefficient μ[20] that corrects for the mobility of neural processes

$$(U + R_{ph}) = \mathfrak{R}\, \mu\, \varepsilon\, I = \mathfrak{R}\, I\, \mu / (1 - \nu) \qquad (4)$$

At this stage of knowledge about the internal state of a person, we can only quantitatively evaluate information about changes in physiological (motor - facial) reactions, which, if we neglect the latent period of their appearance, we will accept as proportional to the square of the volume of information I received in the person's memory in the form of a stimulus[21], i.e.

$$R_{ph} = aI^2 \qquad (5)$$

where a is some empirical coefficient of proportionality, depending on the type of emotions and temperament of the individual.

The following considerations may serve as the basis for such a dependence. It is known that there is a genetic link between individual drives (physiological states) and individual emotions. At the biological level, emotion arises "as a sensation caused by processes occurring in the nervous and muscular systems." Emotion is also activated simultaneously by neurochemical neuromuscular, affective, and cognitive processes. The biological functions of emotions can include not only facial reactions, but also changes in acoustic characteristics (frequency of vocal cord vibrations), pantomimic manifestations, motor manifestations (movements of the head, eyes, limbs), changes in blood flow, pulse, general mobilization of muscle energy resources, etc. In our case, R_{ph} represents *information* about the physiological (motor) expression of emotions. If we accept as an axiom that external information about the event in question with a magnitude I is transformed by the body into a physiological expression of emotions with a gain coefficient proportional to I, then we arrive at the quadratic[22] dependence adopted in (5). The validity of

[20] This assumption does not preclude the introduction of other factors, should they be found to have a significant impact on emotions, or the replacement of a direct proportional relationship with some known nonlinear one. In our first-approximation model, we limit ourselves to direct proportionality, leaving the reader the option to further complicate it.

[21] This can be explained by the peculiarity of the autonomic nervous system, which consists of two parallel but antagonistic systems. The sympathetic nervous system prepares the body for emotional expression, while the parasympathetic nervous system relaxes the body and restores energy reserves. Both of these systems perform internal functions and are nonlinearly dependent on the incoming stimulus.

[22] It should be noted that for inanimate matter (particularly liquids and gases), a quadratic relationship is generally accepted. In humans, commands for appropriate changes are sent consciously (which is characteristic of living things), but

the adopted assumption can be demonstrated by verifying the obtained results with experiments. As we will see later, we have obtained satisfactory agreement between the calculations and some known experiments, confirming the acceptability of the adopted assumption[23].

Let us rewrite (4) taking into account (5) as follows, dividing the left and right parts term by term by the standard of information on the need under consideration I' adopted as the normalizing parameter

$$(U/I' + aI^2/I') = I\,\mathfrak{R}\,\mu / (1-\nu)I'$$

After transformations, this equation is reduced to the following form

$$(\sigma + \alpha\nu^2)(1/\nu - 1) = \mathfrak{R}\mu \equiv \gamma \qquad (6)$$

Here $\sigma = U/I'$ is the parameter of internal emotional stress, $\alpha = a\,I'$.

We will call equation (6) the *information equation of a person's emotional state*. Its state parameters are the *potential of internal emotional tension* $1 \geq \sigma \geq 1$, *the information density of the emotional stimulus* $\nu\ (\leq 1)$, (or the coefficient of satisfaction (or dissatisfaction) of the need ε), *the price of the need* □ (0 □□) and the coefficient of mobility of nervous processes μ. (≥ 1). If μ of the least mobile type - the phlegmatic is taken as 1, then the other character types will have $\mu > 1$. As a measure of mobility, we can take the value reciprocal of the subjectively experienced time[24], the value of which for a phlegmatic person is $\tau = 1.1$ *sec* $(\mu = 1)$. Then for a melancholic we get $\mu = 1.1$; for a sanguine person $\mu = 1.38$; for choleric person $\mu = 1.57$.

We will call the product $\mathfrak{R}\mu = \gamma$ the *criterion of individuality of emotions*.

Here we would like to make one *remark*. We do not adhere to the point of view of some authors that if $I < I'$, then we have positive emotions, and if $I > I'$, then we have negative ones. Such an approach might be appropriate if all emotions of the same type had the same modality. In our approach, the standard of information necessary to ensure the fulfillment of the initial stimulus of satisfaction or, conversely, dissatisfaction of a given subject is the largest in volume, i.e., always $I' \geq I$. Therefore, negative emotions in this approach are determined by their meaning upon examination (for example, fear or joy), and information about negative emotions in our model will always be positive[25]. Positive and negative affects are considered asymmetrical. Positive emotions are poorer in physiological means of experience, more difficult to differentiate, and have fewer linguistic designations, although they occupy a disproportionately large part of subjective experiences. This point of view coincides with approaches that distinguish not between positive and negative emotions, but rather between "emotions that contribute to an increase in psychological entropy, and emotions that, on the contrary, facilitate constructive behavior."

Thus, we have 4 coordinates of the emotional state σ, ν, $\mathfrak{R}$ и μ (or, instead of the last two, their product γ). The parameter of the need price $\mathfrak{R}$ is uniquely determined by the initial condition for a known emotional modality, taking into account the person's temperament and other individual characteristics. Therefore, in what follows, we will consider the parameters of the emotional state as the Cartesian coordinates of points in three-dimensional space σ, ν and γ. If the need price $\mathfrak{R}$ is fixed, then a certain state of the individual corresponds to this set of values σ, ν and γ. We will agree to call the state determined by the set of values σ, ν and $\gamma = \mathfrak{R}\,\mu$, the state $(\sigma, \nu, \gamma\ (=\mathfrak{R}\mu))$. The transition of an individual's state $(\sigma, \nu, \gamma\ (=\mathfrak{R}\mu))$ to the state $(\sigma + d\sigma, \nu + d\nu, \gamma + d\gamma)$ will be called an elementary process. The final process corresponds to the transition from the state (σ', ν', γ') to the state $(\sigma'', \nu'', \gamma'')$. Any final process can be represented as a sequential set of elementary processes. The increments $d\sigma$, $d\nu$, $d\gamma$ are independent of each other. The choice of increments determines the type of elementary process by which the subject is transferred from a given state to an adjacent state. Some of the differentials may be equal to zero.

We will call the three-dimensional space in the plane of the parameters σ, ν, γ **E**-space. Obviously, each state of the individual corresponds to a specific point in **E**-space. If we mark the points corresponding to the limiting realizable values of the parameters, then the resulting geometric locus constitutes the boundary of the region of the subject's actually realizable states.

their execution in the body is more hydrodynamic and mechanical, i.e., more "inanimate" than "living."

[23] By the way, this axiomatic approach has been widely practiced in mathematics for 2000 years.

[24] First introduced by B. Tsukanov

[25] Generally speaking, the concept of a negative emotion is meaningless. Information cannot be taken away—only the carrier of the information can be destroyed, and the information itself does not diminish when transferred from one source to another, meaning the original information set, when divided, remains the same in power.

Figure 1. Geometric representation of an assembly-type disaster

There is a one-to-one correspondence between the set of points forming this bounded spatial region and the set of actually possible states of the subject. Therefore, it is necessary to speak of points representing the subject's emotional state, or representing (figurative) points. Thus, by analogy with technical disciplines, we can consider *spaces of emotional states*. In this space, states are represented by points, and quasi-static processes by lines. A process line, generally speaking, can pass through any point in the region of physically feasible emotional states of an individual.

The obtained equation (6) can be transformed to the form using known and fairly simple transformations

$$X^3 + AX + B = 0,$$

where $X = \nu_* / \nu - 1$,

which precisely describes the surface of *an assemblage catastrophe*. This assemblage - the simplest "interesting" catastrophe (see Fig. 1) - is ubiquitous, manifesting itself in countless domains. It should be noted that a relatively young field of analysis - catastrophe theory - has already enabled the "exact" sciences - physics, chemistry, and engineering - to derive considerable practical benefit from it. This is primarily due to the numerical answers it provides to the quantitative questions posed. In the field of psychology, a mathematical model corresponding to a catastrophe is being proposed for the first time. It is well known that catastrophe theory also allows us to distinguish between areas of stability and areas of instability. Emotions represent precisely a catastrophe, an area of instability in the human condition. Therefore, the development of mathematical models corresponding to catastrophes can serve as confirmation of the model's[26] validity, and its implementation opens up ways to manage a person's emotional state.

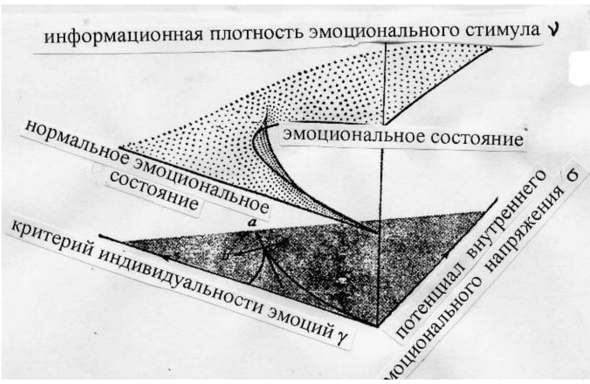

Figure 2. Assembly-type catastrophe in coordinates: potential of internal emotional stress σ - information density of emotional stimulus ν - criterion of individuality of emotions γ.

[26] All events in our physical world are described using four coordinates, i.e., limited to a four-dimensional control space. For this case, René Thom proved a remarkable theorem: in a dynamic system with four external variables, exactly seven topologically distinct types of discontinuities can occur. Furthermore, any physical discontinuity belongs to one of these seven types. This underlies one of the most important, and often overlooked, achievements of catastrophe theory: any model with a given number of variables must lead to one of the corresponding catastrophes. Otherwise, the model is incomplete or even incorrect, meaning that catastrophe theory can also serve as a criterion for the validity of a mathematical model.

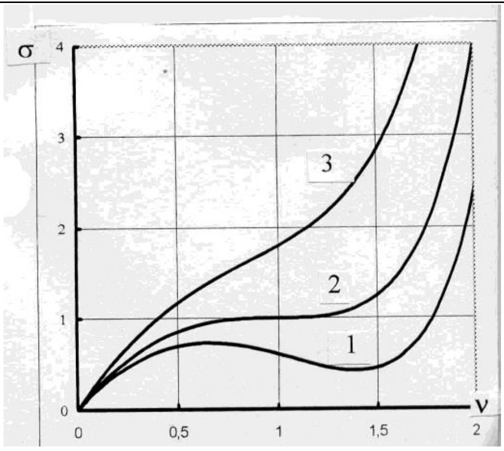

Figure 3. Dependence of the potential of internal emotional stress σ *(ordinate axis) on the information density of the emotional stimulus* ν *(abscissa axis), for different values of the criterion of individuality of emotions* γ*: 1 - emotional state with physiological manifestation, accompanied by emotional release, 2 - critical state, 3 - hidden emotional state*

Thus, the resulting equation (6) makes it possible to quantitatively determine the relative values of the parameters of a person's emotional state. The range of possible changes, according to our rough estimates, is $\sigma = 0.1 - 10$; $\nu = 0.05 - 1$, $\gamma \sim 10$ ($\alpha = 1 - 500$). The use of relative values in our model allows us, at the initial stage, to determine, using expert assessments, the quantitative values of various initial quantities that we are not yet able to measure. However, this does not preclude the possibility of moving to absolute values of psychological variables in the future, and, moreover, to serve as a theoretical basis for experiments and to seek ways to measure the variables of the emotional process. We will demonstrate the emerging possibilities of using this equation through an example of its analysis.

First, we rewrite equation (6) in this form

$$\nu^3 - \nu^2 + [(\sigma+\gamma)/\alpha\}\nu - \sigma/\alpha = 0 \qquad (7)$$

The roots of this cubic equation for the information density of the emotional stimulus ν at a fixed α are a function of σ and γ. The type of curves $\sigma(\nu,\gamma)$ is shown in Fig. 3. As can be seen, three types of curves are distinguished, corresponding to such cases:

1) the lower curve, corresponding to three real and distinct roots of equation (7);

2) the middle curve – three real and equal roots;

3) the upper curve – one real root and two imaginary ones.

The first case occurs at low values of the need price $\Re$ and a low coefficient of nervous system mobility μ, i.e., at low values of their product γ. As can be seen from Fig. 3, we have an unstable mode of emotional expression, which serves as a discharge of internal experiences through external motor reactions – laughter, screaming, heartbeat, tears, running, etc. Incidentally, the transition from the minimum point on the lower curve to the maximum point, apparently, corresponds to a mode in which it is easy to detect a lie using a lie detector.

The extremum points are found from the following considerations. If equation (6) is written in this form

$$\sigma = \Re\mu/(1/\nu - 1) - \alpha\,\nu^2 \qquad (8),$$

then to determine these points it is necessary to consider the equation $\partial\sigma/\partial\nu\backslash_\gamma = 0$::

$$\nu_{mm}\,(1 - \nu_{mm})^2 = \Re\mu\,/\,2\alpha \qquad (9)$$

The function $\theta \equiv \nu_{mm}\,(1 - \nu_{mm})^2 = \gamma/2\alpha$ on the left-hand side of equation (9) determines the minimum and maximum points on the curve of the dependence of the emotional tension parameter σ on the density of the emotional stimulus ν_{mm}, corresponding to the extreme values (see Fig. 4). The value of these points is located at the intersection points of the graph of the function θ with the values of $\gamma/2\alpha$. From examining the graph in Fig. 4, it is evident that with a decrease in the product $\Re\mu = \gamma$, the minimum point shifts toward a decrease in the value of the density of the emotional stimulus ν, and the maximum point shifts toward an increase in its value, i.e., "motor emotional manifestation (discharge) of physiological excitation" occurs in a larger range of ν, in a larger range of change in stimulus information.

If the maximum point of this function at a certain value of the density of the emotional stimulus ν_{min}, corresponding to the minimum of emotional tension σ, coincides with the value ν_{max}, corresponding to the maximum of emotional tension σ, then our zigzag lower curve degenerates into a certain "critical" curve without a maximum and minimum (the middle curve), which are compressed to a certain critical point with coordinates σ_c; ν_c and γ_c. This second case of the solution of equation (7) with three real and equal roots corresponds to the following critical values of the independent variables we use:

$$\sigma_c = \alpha/27;\ \nu_c = 1/3;,\ \gamma_c = (\Re\mu)_c = 8\alpha/27 \qquad (10)$$

Note that the critical value of the emotional stimulus density is equal to $\nu_c = 1/3$, i.e. the transition to the critical curve occurs when the magnitude of the emotiogenic stimulus reaches one-third of the emotion standard value. Obviously, curve 2 separates the region of the unstable process (curve 1) from the stable one (curve 3).

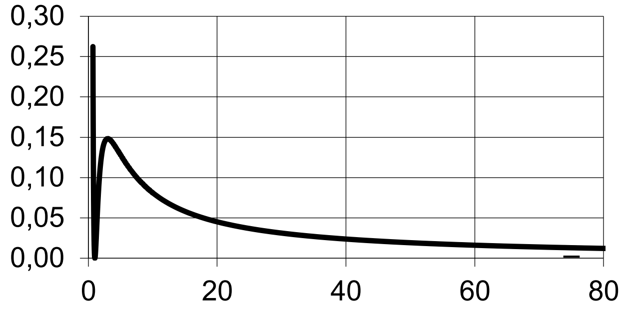

Figure 4. Graph of the dependence of the function $\theta = \nu_{mm}(1 - \nu_{mm})^2$ *(ordinate axis) on* $\nu_{min/max}$ *(abscissa axis), corresponding to the minimum* σ *– left ascending curve, and the maximum* σ *– right descending curve.*

The third case of the process of increasing emotional tension depending on the influx of external stimulus information occurs with elevated values of the emotion individuality criterion $\gamma = (\Re\mu) > \gamma_c = (\Re\mu)_c$. Clearly, higher values of the emotion individuality criterion γ correspond to the most stable temperaments and subjects with the most stable nervous system mobility. This case is characterized by a negligible expression of emotions through physiological mechanisms. This allows us to neglect the last term in equation (8) and write the following formula for the increase in emotions in the case of elevated values of the parameter γ:

$$\sigma = \Re\mu/(1/\nu - 1) \qquad (11)$$

or

$$\sigma(1/\nu - 1) = \Re\mu \qquad (12)$$

This equation shows that for large values of the product $\Re\mu$, the curves $\sigma = f(\nu, \Re\mu = const)$ are hyperbolas that have one intersection point with the horizontal line and, as a result, one real and two imaginary roots. There are no extrema points on this curve.

To verify the theoretical results obtained, we will use known (and, it must be said, few) experiments described by variables of emotional expression that allow calculations in the plane of the parameters of the proposed theory. Emotions of the same type are more difficult to identify in an adult than in a child. Therefore, measurements of physiological parameters determining emotional processes in four-and-a-half-month-old children, carried out by Izard, are of particular value. In these experiments, the emotions of anger and interest were studied by measuring heart rate and videotaping the child's facial reactions. The basis for processing graphs suitable for their comparison with calculations in the plane of the used parameters was the graph shown in Fig. 5, in the form of changes in heart rate f during the experience of the emotions of anger and interest. We will represent these experimental data in the plane of variables: the potential of internal emotional tension σ (ordinate axis) - the information density of the emotional stimulus ν (abscissa axis). It is obvious that the increase in heart rate $\Delta f = f - f_0$ is proportional to the magnitude of emotions (f_0 = 145 beats/min - heart rate without emotions).

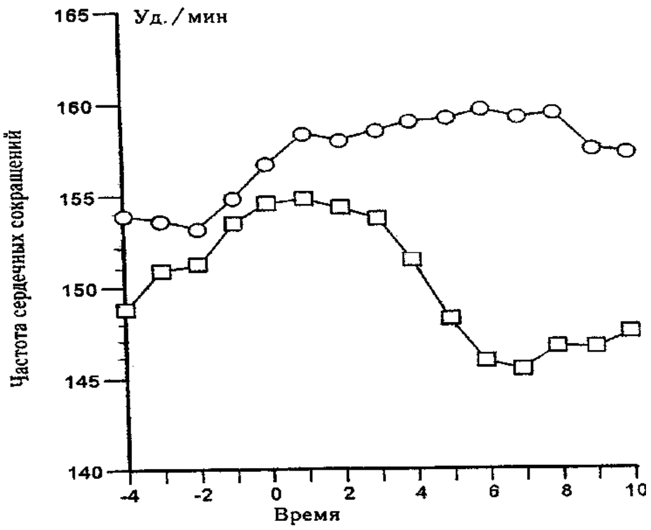

Figure 5. Features of the functioning of the cardiovascular system in children aged four and a half months during their experience of the emotion of interest (1) and the emotion of anger (2). 0 the beginning of facial expression

If we take as a normalizing parameter the possible permissible range of deviation of the heart rate in the case of emotional stress f' = 15 beats/min, then this relative change in the heart rate can be considered equal to another relative value - the potential of internal emotional stress[27], i.e. $\sigma = U/I' = \Delta f/f'$. If we accept that during the period of emotional influences the rate of incoming information from the outside $\acute{R}$ = const, then $\tau = I/\acute{R}$ и $\tau' = I'/\acute{R}$, i.e. the information density of the emotional stimulus $\nu = I/I' = \tau/\tau'$. The value of τ', which determines the value proportional to the information standard I', is taken to be τ' = 20 sec for the case of children experiencing the emotion of interest, and τ' = 50 sec for the emotion of anger. These values were selected after numerous calculations as the values that provide the best agreement with the experimental data. The value of the constant $\alpha = a\,I'$ is also unknown. Numerical calculations have shown that for experiences of the emotion of interest $\alpha = 40$, for emotions of anger $\alpha = 38$. Again, we see the advantage of introducing relative quantities – the proportionality constant α is a dimensionless quantity. Moreover, due to its zero dimension, it can be expected to change little for other types of emotions and other experimental conditions.

Now, regarding the value of the emotion individuality criterion $\gamma = \mathfrak{R}\mu$. Determining it requires independent research into both the value of the need $\mathfrak{R}$, and the neural process mobility coefficient μ, which generally presents no particular difficulties. In our calculations, we adopted $\gamma = 10$ as the value providing the best agreement between the calculations and experimental data[28]. However, strictly speaking, the question of this value remains open. We note that the obtained numerical values of the normalizing variables can, as a first approximation, be used to predict the development of human emotions using an equation like (6).

Table 1.

Processing of experimental data by Izard and calculations according to (6) for the case of a child experiencing the emotion of interest.

$\Delta\tau$, sec	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
τ, sec	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ν	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7
f, beats/min	148.5	151	151.5	153.5	154.5	155	154.5	154	152	147.5	146	145.5	146.5	146.5	147.5
Δf, beats/min	3.5	6	6.5	8.5	9.5	10	9.5	9	7	2.5	1	0.5	1.5	1.5	2.5
σ_{exp}	0.23	0.4	0.43	0.57	0.63	0.67	0.63	0.6	0.47	0.17	0.07	0.033	0.1	0.1	0.17
σ_{calc}	0	0.43	0.71	0.86	0.9	0.8	0.7	0.5	0.3	0.1	0	0.12	0.6	0.7	

Table 2.

Processing of Izard experimental data and calculations according to (6) for the case of a child experiencing the emotion of anger.

$\Delta\tau$, sec	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
τ, sec	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ν	0	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.22	0.24	0.26	0.28
f, beats/min	154	153.5	153	155	157	158	157.5	158	159	159.5	160	159.5	159.8	157.5	157
Δf, beats/min	9	8.5	8	10	12	13	12.5	13	14	14.5	15	14.5	14.8	12.5	12
σ_{exp}	0.6	0.57	0.53	0.67	0.8	0.87	0.83	0.87	0.93	0.97	1	0.97	0.99	0.83	0.8
σ_{calc}	0	0.185	0.36	0.5	0.62	0.73	0.82	0.89	0.9	1	1	0.97	0.96	0.94	0.91

The results of the calculations carried out using formula (6) and the processing of the experimental data are presented in Tables 1 and 2, and in Figs. 6 and 7 (point $\Delta\tau = 0$ corresponds to the beginning of the facial expression).

An examination of Figs. 6 and 7 confirms the satisfactory agreement between the theoretical results and the experimental data. The question of explaining the initial drop in heart rate for the case of anger remains open (see curve 1 in Fig. 7 for τ=0-2). Naturally, we are aware that in the calculations we selected some parameters in such a way as to obtain satisfactory agreement between the calculations and experiments. But there is every reason to consider these quantities - f', f_0, τ', γ, α, - to be sufficiently conservative, in particular for emotions of one type, and therefore they can serve as a primary basis for refining the equation of emotional state as applied to a specific type of emotion, and for predicting emotional processes of various types. In this case, the meaning of the variables included in (6) and the numerical coefficients should naturally correspond to the type of emotion under consideration.

[27] That is, we accept a direct proportional dependence $I' \sim f'$ (this conclusion is another illustration of the usefulness of representing variables in relative form).

[28] Again, using relative parameters allows you to select control parameters without much difficulty.

So, in the case of *fear*, U is the internal experience of fear, dread, R_{ph} is the physiological reaction to information expressing fear - flight, screaming, etc., I' is the information standard of the type of fear in question - an attack by an animal, a robber, an emergency, natural disasters, etc., ε is the fear coefficient equal to $\varepsilon = I'/(I' - I) = 1/(1 - \nu)$; I is real information about fear; $\Re$ is the price of the need (danger to life, to health, to loved ones, to a career, etc.); μ is the coefficient of mobility of nervous processes. With this content of variables, we arrive at the equation of the state of fear in the form (6). For the case of *anger*, U is the internal experience of irritation, rage, R_{ph} is the physiological manifestation (discharge) of anger - shouting, threats, facial expressions, etc., I' is the information standard of physical or psychological lack of freedom, ε is the anger coefficient, equal to $\varepsilon = I'/(I' - I) = 1/(1 - \nu)$; I is real information about the restriction of freedom; $\Re$ is the price of the need for freedom of human activity to achieve the desired goal.

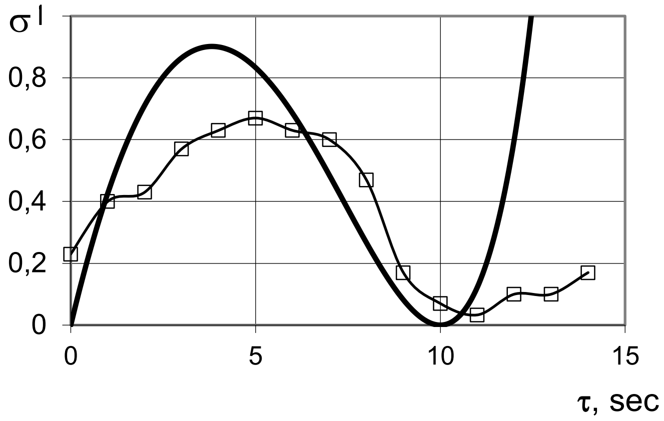

Figure 6. Comparison of Izard's experimental data on the emotional state of a 4.5-month-old child during the experience of the emotion of interest with calculations using formula (6) in the plane of parameters: potential of internal emotional tension of interest σ (ordinate axis) - information density of the emotional stimulus ν (abscissa axis), with the value of the criterion of individuality of emotions γ=10; 1 - experimental data, 2 - calculation

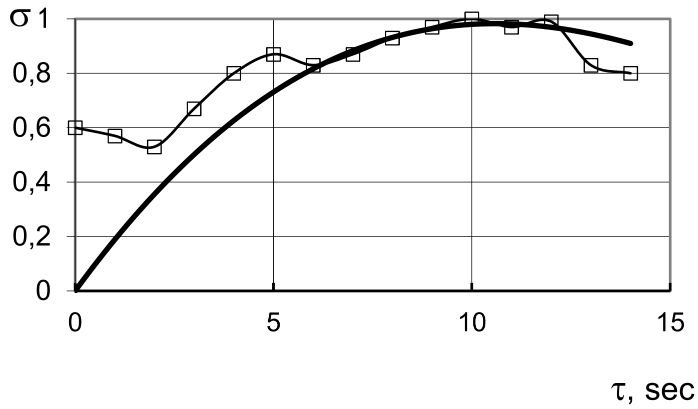

Figure 7. Comparison of Izard's experimental data on the emotional state of a 4.5-month-old child experiencing the emotion of anger with calculations using formula (6) in the plane of parameters: potential of internal emotional tension of anger σ (ordinate axis) - information density of the emotional stimulus ν (abscissa axis), with the value of the criterion of individuality of emotions γ=10; 1 - experimental data, 2 - calculation.

Therefore, if we put this meaning into the specified variables, then we arrive at the equation of the state of anger in the form (6).

Thus, the presented theoretical analysis makes it possible to control the course of emotional processes using the value of need $\Re$ and the nervous system's mobility coefficient μ.. This model is only a first approximation, and changes in the independent variables used require further study, in particular the development of a method for their quantitative determination. This task is beyond the scope of this work.