Modern Methods of Medical Psychophysiology: Vibraimage Technology and Artificial Neural Networks

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Abstract: *The article is devoted to the improvement of psychophysiological examination methods for workers on dangerous industries. The prospect of vibraimage technology using as the means of rapid diagnostics of psychophysiological state is justified. In accordance with the tasks of medical psychophysiology vestibular-emotional reflex is considered from the point of view of the theory of physiological functions of organism regulation. Two contour model of human head micro-movements regulation is proposed, which makes possible to expand specification of vibraimage parameters. It is justified that is advisable to use the combination of linear methods of multidimensional statistical analysis and artificial neural networks to develop criteria for rapid diagnosis of psychophysiological state. Developed criteria for rapid diagnosis of psychophysiological state are described.*

Keywords: *Express diagnostics, vibraimage technology, psychophysiological examinations, medical psychophysiology, artificial neural networks.*

An analysis of the saturation with potentially dangerous objects of the technogenic sphere of all industrialized countries shows that the increase in the number and severity of the consequences of technological disasters obeys an exponential law. To protect the technogenic sphere of production from the personnel's erroneous actions (human factor), it is necessary to minimize anthropogenic risk, which is understood as a quantitative characteristic of an enterprise's security threat from an employee in the course of professional activity, due to the non-compliance of his medical and psychophysiological characteristics with the requirements of professional activity and anthropogenic vulnerability of technological processes (Bobrov, 2019). The compliance of the medical and psychophysiological characteristics of the employee with the requirements of professional activity is established during medical examinations and psychophysiological examinations (PPE). According to Federal Law N 35-F3 dated March 8, 2011, for the enterprises of the nuclear industry, PPE is an obligatory part of medical examinations conducted by medical organizations of FMBA of Russia. During PPE an assessment of the psychophysiological state of workers is carried out.

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Psychophysiological state (PPS) according to E. P. Ilyin (Ilyin, 1978) is a causal phenomenon, the reaction is not of a separate system or organ, but of the personality as a whole, with the inclusion in the response of both physiological and mental levels (subsystems) of control and regulation related to substructures and sides of the personality. Psychophysiological adaptation is also defined as the person's systemic response to the action of external and internal stimuli and factors aimed at achieving a useful adaptive result and is considered as a criterion for assessing prenosological disorders in health status during medical examinations (Bobrov et al., 2015). PPS implemented by FMBA specialists are aimed, first of all, at assessing the psychophysiological adaptation of workers, identifying prenosological disorders in the state of health in order to conduct timely rehabilitation and health-improving measures (Kaznacheev et al., 1980).

Since PPS is a systemic phenomenon/reaction, its assessment should be carried out at various hierarchical levels of the organization of the body. This requirement (in different volumes) is implemented in the hardware and software systems used in PPE. So, in the nuclear industry, PPS personnel are evaluated using the PPS-CONTROL agrarian and industrial complex at the mental, psychophysiological and physiological levels using 4 psychodiagnostic tests, 3 sensorimotor techniques and methods for assessing heart rate variability (Bobrov et al., 2015).

Testing time in this case takes about 2 hours. This separates the employee from the production process, which does not correspond to the interests of the employer, requires a large number of medical workers to conduct a survey. If for the preliminary (when applying for a job) PPE, the existing survey time is acceptable, then the improvement of periodic PPE is associated with the introduction of rapid diagnostic methods for PPS. Their use will allow you to quickly identify the group of "risk", subject to in-depth PPE, freeing the rest from psychophysiological examination. This will significantly reduce the total time of PPE for the entire professional group (workshop, department, enterprise).

Methods of PPS rapid diagnosis have no alternative in pre-shift PPE, as well as in assessing the current PPS in professional activities.

Vibraimage technology as a method of rapid assessment of the psychophysiological state in the tasks of medical psychophysiology

When considering the methods of rapid PPS diagnosis, it is advisable to proceed from the fact that the body is a complex hierarchy of interconnected and interconnected systems that make up its organization levels: molecular, subcellular, cellular, tissue, organ, systemic and organismic. The human body has thousands of regulatory systems that function to ensure the level of metabolism / intake of a substance, energy and information that is adequate to the prevailing living conditions. According to modern concepts (Mitrokhina, 2000; Myshkin, 2016), the main forms of regulation are adaptive and homeostatic regulation. Adaptive regulation mechanisms operate in a servo system mode, in which perturbation control is mainly carried out. If a mismatch occurs between the current functional state of the organism and the one required by environmental

conditions, this is a signal for changing the structure of the initial functional state or for transferring it to another level. That is, to adaptive restructuring of the functional system.

Thanks to adaptive regulation, adequate ratios are maintained in the "organism–environment" system, on the one hand, and between the individual elements of the system, on the other. The stability of the system within a certain adaptive level of activity is supported by mechanisms of homeostatic regulation aimed at maintaining homeostasis, which corrects all internal deviations in the activity of the system around the formed level. In this case, the deviations themselves are sources of control signals acting on the principle of feedback, i.e. regulatory actions are proportional to deviations of the state from a given level, which ensures the stability of the system. Thus, homeostatic regulation ensures the stability of a certain level of the functional state of the body. Both forms of regulation, mutually complementing each other, provide self-regulation of the body in accordance with the requirements of the current moment. The markers of adaptive regulation systems are labile/plastic indicators of the functional state (pulse, pressure, level of nutrients in the blood, etc.). Homeostatic regulation — "hard" (homeostatic) indicators that are actively maintained by the corresponding functional systems at a strictly defined value and whose deviation from this value leads to irreversible disturbances (pH, osmotic pressure and others). In accordance with the foregoing, for rapid diagnosis of the functional state of a person, it is necessary to use indicators of adaptive regulatory systems. Additional requirements are their ability to assess the systemic reaction of the body, the speed of assessment and its comfort for the test person. The quality of express diagnostics and the degree of its demand in practical activities depend on the completeness of compliance with these requirements.

A positive example as a method of rapid diagnosis and relevance in practice is the method of heart rate variability (HRV) (Bayevsky, 1979; Bayevsky and others, 1997). HRV analysis is a modern methodology, technology for research and assessment of the state of regulatory systems of the body, in particular the functional state of various parts of the autonomic nervous system. It is aimed at assessing one of the systems of adaptive regulation of the functional state of the body — the circulatory system. Monitoring and evaluation of the activity of blood circulation regulation mechanisms allow obtaining information on the adequacy of the reaction of the adaptive mechanisms of the body to the various effects of changing environmental conditions. The technique is operational, comfortable enough for the test person.

However, HRV is difficult to attribute to methods that allow us to evaluate the systemic reaction of the body. The results of our long-term surveys of workers in the nuclear industry, which included practically healthy people who do not have medical contraindications to work, aimed at assessing psychophysiological adaptation (PPA) at 3 hierarchical levels (psychological, psychophysiological and physiological), showed a low correlation of HRV with indicators of psychodiagnostic tests and the functional state of the central nervous system, evaluated according to sensorimotor techniques. Inter-level correlation significantly increases only for workers with a low level of PPA. This is due to the fact that with a low level of PPA, the functional reserves of the body decrease and, as a result, the number of degrees of freedom of regulatory systems decreases. The activation of the autonomous regulation loops decreases while the central

ones increase. The organism, as a hierarchical multi-level system of regulation, becomes a “rigid” system.

A new step in the field of express diagnostics of a functional/psychophysiological state is vibraimage technology (Minkin, 2007; 2020). It fully satisfies all of the above requirements for express diagnostic systems: systemic, responsive and comfortable. The object of evaluation is the functional state of one of the leading sensory systems: the vestibular system, the stimuli of which are gravity and forces that impart linear or angular acceleration to the body. Complex reflexes associated with vestibular stimulation include vestibulospinal, vestibulovegetative, and vestibuloglomotor reflexes (Handverker, 1996). The author of vibraimage technology discovered and described a new reflex of the vestibular system: the vestibular-emotional reflex (VER) (Minkin, 2007; Minkin&Nikolaenko, 2008).

Although its neurophysiological mechanisms have not yet been fully described, numerous experimental data do not raise doubts about its objective existence. The presence of automatism, abundant afferent and efferent morphofunctional connections with cortical-subcortical formations of the central and autonomic nervous systems of the brain and spinal cord, with neuroendocrine processes indicate the possibility of using the characteristics of the functioning of the vestibular system as an indicator of the body’s response to internal and external factors. The reflection in vibraimage parameters of the systemic reaction of the body was shown in many experimental works (Minkin, 2018; 2019). In particular, in the thesis of E. S. Shchelkanova (Shchelkanova, 2019), which was one of the provisions to be defended.

Since all the regulatory systems of the body are built and operate on the same principle (Myshkin, 2016), for the vestibular system, a 2-circuit model for the regulation of reflex movements of the human head can be constructed, similar in structure to the cybernetic model of heart rhythm regulation. The autonomous regulation loop is connected with the vestibular apparatus and the vestibular tract entering the medulla oblongata. The central control loop includes the vestibular nuclei of the medulla oblongata, the impulses from which enter the thalamus and projection field of the vestibular system in the temporal region of the cortex, as well as in structures located in close proximity to the pyramidal neurons of the motor region of the cortex and cortical. With optimal regulation (low level of regulatory systems of a body), control occurs with minimal involvement of higher levels of control. With suboptimal management, activation of ever higher levels of control is necessary. In terms of vibraimage, this is reflected, in our opinion, in an increase in the asymmetry of movements and an increase in the proportion of the high-frequency part of the vibration spectrum to the total power in the frequency spectrum of human head micromotion.

Consideration of VER from the position of regulatory systems theory allows to supplement the existing specification of vibraimage parameters (Minkin, 2020) with such characteristics as the level of functioning of the vestibular system; level of its activation; level of centralization of management; the general level of tension of the regulatory systems of the body, estimated by vibraimage parameters, etc. The results of an integrated assessment of PPS for the tasks of medical psychophysiology can be formulated in terms of prenosological diagnosis taking into account the level of tension

of regulatory systems (Bayevsky, 1979): 1) optimal level; 2) moderate functional stress; 3) pronounced functional stress; 4) overstrain of regulatory mechanisms; 5) depletion of regulatory systems.

Artificial neural networks in the diagnosis of psychophysiological conditions

The effectiveness of diagnostic systems in the field of biomedical research depends on the quality of the criteria used to evaluate the diagnostic object. For their construction, various mathematical methods and information technologies are used. Based on the analysis of the results of studies of the functional state of persons in extreme conditions, an information technology for the statistical synthesis of assessment criteria was developed (Bobrov, 1993). It is based on the consistent application of the methods of factorial, cluster, discriminant and canonical discriminant analysis. However, the methods of multivariate statistical analysis are linear mathematical methods. Therefore, when developing diagnostic systems, it becomes necessary to use nonlinear mathematical methods. These include artificial neural networks (ANNs) (Haykin, 1998).

A tuned, trained ANN is able to recognize new objects presented to it, relating them to one of the classes of the spectrum of states, the recognition of which it was able to train. The ability of ANNs to self-study provides significant advantages over criteria developed on the basis of linear discriminant functions. From the practice of mathematical methods using in applied biomedical research, it is known that the degree to which specialists use decision-making methods and procedures largely depends on the “degree of trust” in them. In this regard, diagnostic systems based on multivariate statistical analysis methods have a definite advantage over systems constructed using ANNs, since ANNs are black boxes with known inputs and outputs, but the structure of transformations that is closed to the user.

Our experience in the development of diagnostic systems in applied biomedical research shows that the greatest effect is achieved by the combined use of various mathematical methods, the choice of which is determined by the nature of the source data. Therefore, in medical psychophysiology, to develop criteria for the rapid diagnosis of PPS using vibraimage parameters, it is advisable to use information technology (the method of hierarchical stratification of functional states, MHSFS), which includes several successive stages:

1. Synthesis of integral indicators for assessing the studied characteristics and functions of an organism at various hierarchical levels using linear models of factor analysis or non-linear models of an auto-associative network with direct connection.

2. Synthesis of classification models of typological states of the studied characteristics and functions of an organism at various hierarchical levels using cluster analysis and/or Kohonen self-organizing neural network.

3. Synthesis of decision rules for identifying typological conditions of the studied characteristics and functions of an organism at various hierarchical levels using discriminant analysis or a multilayer perceptron.

Results

MHSFS was used to develop criteria for the rapid diagnosis of PPS using the MED database (Minkin, 2020). It was cleaned of "popping up" observations and supplemented by data from our own studies, which additionally contain the results of PFD conducted using the PPS-CONTROL agro-industrial complex. In total, the training sample included 5098 observations (examples).

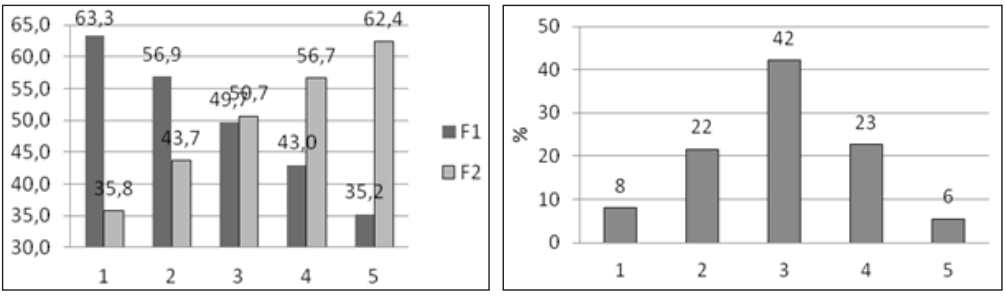
Factor analysis (FA). Factor analysis (Kim et al., 1989) allows us to classify indicators of a functional state according to the degree of correlation between themselves and the degree of lability. The correlation between the indicators is caused, as a rule, by the reflection from different sides of the characteristics of the same of the studied processes / reactions in the body: a common cause of reflection. Or combinatorics of their common meanings in the formulas for calculating derivatives / secondary indicators. FA allowed to summarize the results of assessing the relationship of vibraimage parameters by the pair values of the correlation coefficient, described in detail in the book of Minkin (Minkin, 2020). During its implementation, 10 parameters of vibraimage were used. The primary extraction of factors was carried out by the method of principal components, rotation — by the varimax method. We studied 2–4-factor models of vibraimage parameters. As a result of the analysis, a 2-factor model was chosen, since the addition of new factors insignificantly (up to 10%) increases the overall dispersion of indicators explained by them.

The 1st factor (F1) mainly included indicators characterizing the asymmetry of micromotion of the left and right parts of the human head from different sides. High positive values of the factor correspond to low, low negative — high asymmetry. In the 2nd factor (F2), indicators characterizing on different sides the contribution of the high-frequency part of the vibration spectrum to the total power in the spectrum of the frequency of micromotion of the human head. High positive values of the factor correspond to a high, low negative — a low share of the contribution. The values of the factors for their assessment were translated into T-points (M = 50 points, SD = 10 points).

The obtained factors can be considered as integral indicators, reflecting the characteristics of the regulatory mechanisms of the formation of PPS, estimated by vibraimage parameters. Factor F1 characterizes, in our opinion, the level of internal psychophysiological comfort and a decrease in its values corresponds to an increase in the asymmetry of micromotion of the head. Factor F2 — voltage level of PPS regulation mechanisms.

Automatic classification (typological PPS). According to the values of factors F1, F2, 5 typological classes of states were identified. The number of classes was set based on the concept of prenosological diagnosis described above (Bayevsky, 1979). The average values of the factors F1, F2 in the selected classes and the percentage of occurrence of each class in the training set are shown in figure (a, b).

Persons included in class 1 are characterized as very high, 2 — high, 3 — medium, 4 — low, 5 — very low levels of PPA. As follows from figure (a), as PPA worsens, there is an increase in the tension of the body's regulatory mechanisms and a decrease in the level of internal psychophysiological comfort. Distribution of persons with different PPA levels belong to normal distribution law (fig. b).



a b

Figure. Average values of factors F1, F2 in classes of typological states **(a)** and occurrence (in %) of classes of typological states **(b)**. Classes of typological states (1 — 5) are indicated on the abscissa.

Decisive rules for the identification of typological conditions. To identify typological conditions, neural networks are configured, the parameters of which are given in the table. When constructing the ANN, NeuroShell 2 and STATISTICA Neural Networks data analysis programs were used. As follows from the data in the table, the standard error in predicting the values of factors F1, F2 was 0.0002 points. The forecasting accuracy of PFC classes is 99.99%.

Table

ANN parameters for identifying the characteristics of the psychophysiological state by vibraimage parameters

Forecasting object	ANN type	Neuron function activation	Training Algorithm	Standard forecasting error
Factor F_1	MLP 10-9-1	Tanh	BFGS 109	0,0002
Factor F_2	MLP 10-4-1	Tanh	BFGS 136	0,0002
State class	MLP 2-9-5	Tanh	BFGS 39	0,01%

Note.
MLP a-b-c: multilayer perceptron, a — is the number of neurons in the input, b- in the intermediate, c — in the output layer.

Conclusion

Improving the psychophysiological examinations of workers in hazardous industries is associated with the development of methods for the rapid diagnosis of the psychophysiological state. The most promising in this case is vibraimage technology.

In accordance with the objectives of medical psychophysiology (identifying pre-nosological changes in health status by the level of impaired psychophysiological adaptation), the vestibular-emotional reflex should be considered from the perspective

of the theory of regulation of physiological functions of the body and the proposed 2-circuit model for regulating micromotion of the human head. This makes possible to expand the specification of vibraimage parameters.

To develop criteria for the rapid diagnosis of the psychophysiological state, it is advisable to use a combination of linear methods of multivariate statistical analysis and non-linear methods with the construction of artificial neural networks.

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