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USE OF TECHNOLOGIES OF HIGHER NERVOUS ACTIVITY AND PSYCHO-PHYSIOLOGICAL HUMAN FUNCTIONS STUDYING IN EXTREME CONDITIONS

P.V. BILOSHITSKY[1], *O.M. KLYUCHKO*[2], *Yu. V. KRAVCHENKO*[3], *M.V. MAKARENKO*[3], *K.S. LYMAN*[4], *A.G. LIZUNOVA*[5]

[1]Tychyny Uman State Pedagogical University, Ukraine
[2]National Aviation University, Kyiv, Ukraine
[3]Bogomoletz Institute of Physiology of the National Academy of Sciences, Kyiv, Ukraine
[4]Washington State University, USA
[5]Luxoft Global Operations GmbH: Zug, CH, USA

E-mail: bilosh827@ukr.net

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Applied techniques and some results of studies the higher nervous activity (HNA) of the people, their psychophysiological functions (PFF) by Ukrainian scientists and doctors were described, as well as influences of extreme conditions on HNA.

Purpose. To show the results of the influence of extreme mountain conditions at high altitudes (hypoxia, etc.) demonstration and further research of changes in the psychophysiological functions of the brain under these conditions; description of the developed professional selection methods.

Methods. Comparative analysis of a large number of the data from experiments and observations. Physical, mathematical, and program modeling. Methods of HNA, brain research: electroencephalography, diagnosis of personal neurodynamic features, etc. Three methods of PFF research: parameters of the neurodynamic level, parameters of the neuropsychological level, and personal specifics. The adapted questionnaire scheme (QS) based on Cattell's 16-factor personality tests was applied.

Results. The influence of hypoxia and other factors of mountain conditions on HNA was studied deeply. The results were presented. Also, results of registered changes of EEG were presented in such extreme conditions. The influence of a number of stress factors in extreme conditions (hypoxia, etc.) has been demonstrated. Some basic methods of HNA research used in such conditions were described, and the results of investigations of individual typological features of the nervous systems were presented. Methods for studying human psychophysiological functions were described. Studies of human personal characteristics were described in detail. Data recorded by the PNN-3 device were taken for the diagnosis of personal neurodynamic features. The parameters of the neuropsychological level were determined using the following methods: "triangles" (the level of development of short-term visual memory), "instrument scales" (working memory, attention functions, etc.), and "red and black tables" (allocation and switching of attention). Cattell estimated personality structures, features, and types of behavior of operators in stressful situations based on adapted QS. Mathematical models of the reliability of human nervous system functioning under extreme conditions were developed.

Conclusions. The obtained results were taken as the basis for the developed professional selection methods for special contingents, pilots, operators, etc. Physical, mathematical, and program models of the reliability of the human nervous system functioning in these conditions were proposed.

Key words: higher nervous activity, psychophysiological functions, extreme conditions, high altitudes.

Studies of higher nervous activity (HNA) were in focus of attention of the Ukrainian physiologists in the last decades, along with the interest of professionals all over the world [1–8]. The works of researchers at the National Academy of Sciences of Ukraine (NASU) that were done in extremely stressful conditions contribute to our understanding of the human brain functioning in such critical extreme conditions, at high altitudes, in stressful situations, in case of hypothermia, oxygen deficiency, overloads. They are important for training and organizing of the work of pilots, astronauts, operators, climbers, rescuers, representatives of other special forces. The spectrum of such research of human HNA reactions under stressful conditions, done by Ukrainian scientists, was extremely wide — from the improvement of professional selection methods and study of the nervous system functioning reliability at high altitudes to the deciphering of changed speech of pilots in emergency conditions or the treatment of patients with some forms of schizophrenia. HNA studies form the theoretical base for the improving of the system of training, distribution, and placement of personnel in various branches of the economy. They stimulate the development of new methods and criteria for evaluating success of a person's professional activity, as well as the system of professional selection.

Special precision techniques were developed for HNA studying in the 20-th–21-th centuries [9-15]. Great numbers of researches in neurophysiology are devoted to studying of molecular bases of registered HNA phenomena [16–21]. Some novel methods, technologies were possible to develop only along with the progress of computer-based techniques [7, 10–13]. Brain research, further studies if HNA stimulated the development of the novel theoretical directions of brain investigations that are also linked with the progress in information and computer technologies [22-29]. Special, close attention was paid to the phenomena of HNA functioning in extreme conditions, when human organisms are in environment "conditionally suitable for life" — in Antarctica [30, 31], in conditions of space flights [32–42]. In such conditions, all the forces of organism are concentrated on preserving its life and functions of numerous organs and systems are changed consequently. A person's stay in the mountainous conditions, at high altitudes, precisely creates the preconditions for the development of changed states of the organism [43–48], and the works of many Ukrainian scientists, researchers in the whole world were devoted to these and linked problems [32, 33, 36, 41–43, 47, 48–52]. Such experience is rather valuable for Ukraine today, in war reality, when many people often (and sometimes suddenly) find themselves "between life and death.". Currently, such studies theoretically can be carried out in special baro-chambers for pilots and sportsmen training in c.Kyiv condition, as well as at the mountains of Ukrainian Carpathians (altitudes more than 1500 m above sea level (a.s.l.)) [43].

The scientific novelty of this article is in the fact that the authors justify the importance and effectiveness of the developed methods application in our present days, in the situation of real war in contemporary Ukraine. Never before these results and developed methods have been analyzed from the point of view of performing such functions in war conditions in Ukraine [43, 44, 46, 47]. The article describes unique experiences, series of results of many years researches of NASU scientists in extreme conditions, which, for some reasons, was not widely known. But it is exactly in our days these knowledge is new and valuable in Ukraine. We believe that for the professional selection of pilots, persons in special contingents, military personnel of various specialties, rescuers, etc., such knowledge is of great practical importance and novelty. This also can be told about the restoration and rehabilitation of health of the above-listed groups of people. For the fulfillment of some activities in conditions of modern war, the scientific methods, studies, and observations described in this article should be put in basis. They can also be used in combination with other well-known methods, including foreign ones.

The scientific and technical developments described in the article, the original developed methods are quite specific, taking into account the closed circle of people for whom they were developed. Thus, works on the topic were carried out by various scientific groups in different countries of the world too, and observation of all such works is much larger than the scope of this article [1–43]. The authors set themselves the task to make overview of some methods developed by groups of Ukrainian professionals — scientists, doctors, engineers who worked before 2013 at EMBS (ICAMER) scientific base of NASU (Caucasus Mountains, altitudes 2100 m a.s.l. and above) [43, 44, 46, 47].

Below, we would like to present developed techniques and some obtained results for the

study of changes in HNA that occur at high altitudes in highlands, with the influence of hypoxia on HNA. Accordingly, the authors would like to describe the results of the research of human brain psychophysiological functions changes in extreme mountain conditions, and to describe some methods of professional selection developed by Ukrainian scientists, especially for the people who fulfill an operating work, for professionals who work in extreme conditions.

Influence of hypoxia, other factors of mountain conditions on higher nervous activity

Well-known that high mountain conditions are very specific, they influence greatly on all human organism, and these influences cause their impact both in positive as well as in negative directions [43, 44, 46]. The central nervous system is phylogenetically the youngest formation of the brain of humans (as well as all mammals), especially the higher structures of the brain, are the most sensitive to the oxygen deficiency (hypoxia), which is a specific characteristic of mountains conditions. — and exactly in these conditions the humans live in the high mountains.

The influences of hypoxia of various nature on the HNA causes disturbances and disorders in functions of a central nervous system, which were described in [36, 38, 41, 43, 44, 47]: changes in the fine histological structure of nervous tissues, activity of individual neurons, in reactions of HNA, disorders of human psyche changes in electroencephalograms (EEG). Numerous works by domestic and foreign authors [43, 46, 47] were devoted to studies of hypoxia effects on nervous system. Physical, mathematic and program models of hypoxia effects on humans, other biological organisms and linked effects also were created by the groups of some Ukrainian researchers [43, 48–52].

Well-known the point of view that the phase changes in functional state of the central nervous system (CNS) happens during acute hypoxia. The observed level of changes in HNA is determined by a degree of oxygen starvation. Thus, in case of hypoxybaria, which occurs during mountain climbing or can be artificially done in a pressure chamber at low altitudes (2,000–3,000 m above sea level (a.s.l.)), there are registered:

– violation of differentiations;

– increase of positive conditioned reflexes;

– reduction of latent periods of motor reactions;

– acceleration of solving of the tasks on the strength of conditioned reactions, but delayed execution of the same tasks on inhibition, increase of general motor and speech activity.

The listed phenomena may indicate that in the case of slight oxygen deficiency, first of all, internal inhibition is damaged [43, 44, 47]. The excitation processes are, probably, influenced in a lesser extent. That is why of its some domination appear.

Use of some traditional methods for HNA studying in extreme conditions

The method of analysis of electroencephalography (EEG, brain activity record) is well known [53–59]. Sure, it was applied too as the method for brain investigations and diagnostics at Caucasus mountains' conditions above the 2100 m a.s.l. [43]. Recordings of EEG in the first phase of hypoxia development evidence about some brain functions changes that happen in mountain conditions. In the EEG, high-frequency oscillations of β-rhythm were strengthened due to the influences on the cortex of large hemispheres, and on the reticular formation, which were activated, consequently, by the stimulation of chemoreceptors of the sinocarotoid zone.

In the case of increased hypoxia, conditioned reflexes become unstable and decrease. The latent period of motor reactions increases markedly. Velocity of the work for correction slows sharply, force relations between stimuli are disturbed, appearance of compensatory and paradoxical phases is registered, motor activity decreases; lethargy and drowsiness appear.

The nature of these described reactions indicates that along with significant oxygen deficiency, the excitatory process become more complicated too; consequently, both main nervous processes are disturbed. In case of oxygen deficiency — increasing of the inhibition processes progress too [43–47].

During hypoxia development (phases 2 and 3 of hypoxia), the slow oscillations (θ- and Δ-rhythms) dominated initially in the EEG. Further, they gradually become episodic, and then disappear during the development of extremely severe hypoxic conditions [47] (Table 1).

Many authors note [47] that although the general nature of HNA changes in different people caused by oxygen deficiency are the same, but the degrees of these changes manifestation differs for various persons at the same altitudes (Tables 2, 3).

Table 1

Changes in EEG rhythms in extreme mountain conditions, starting from the third to the twentieth day of person's stay at altitudes of 2100m a. s. l.

No.	Type of the rhythm	Phase of hypoxia development	Registered effects	Nature of effects and their development
1	β-rhythm	1st phase	high-frequency oscillations of β-rhythm were strengthen	Due to the influences on the cortex of large hemispheres, and on reticular formation, which were activated, consequently, by the stimulation of chemoreceptors of the sinocarotoid zone. With hypoxia increasing, conditioned reflexes become unstable and decrease. Latent period of motor reactions increases markedly; appearance of compensatory and paradoxical phases is registered; motor activity decreases; lethargy, drowsiness appear, etc.
2	Δ-rhythm	2d and 3d phases	slow oscillations of Δ-rhythms dominated initially in EEG	Further, the oscillations gradually become episodic, and then disappear in course of development of extremely severe hypoxic states
3	θ-rhythm	2d and 3d phases	slow oscillations of θ-rhythms dominated initially in EEG	Further, the oscillations gradually become episodic, and then disappear in course of development of extremely severe hypoxic states

These two tables are logically related with HNA studying at high altitudes. They illustrate the registered facts of observations (groups of facts), the logic of which is as follows. Low partial pressure of oxygen in the environment (1) leads to corresponding changes in blood composition (2), which are presented in Tables 2, 3. The blood oxygen-transporting functions, accordingly, undergo changes (3). At the same time, oxygen deficiency in organism, changes in the blood's performance of its oxygen transport functions cause changes in psychophysiological functions and HNA (4). So, the tables illustrate the logical sequence of groups of events that lead to the changes in psychophysiological functions and HNA described in the article (1) — (2) — (3) — (4) (cause-and-effect relationship). At the household level, the following effects of hypoxia on the HNA and psychophysiological functions of a person are familiar to the general public. Well known such phenomena that when climbing the mountains, a person often demonstrates a number of behavioral and psychophysiological changes: "clouding of consciousness", hallucinations, inadequate and/or inhibited behavior, euphoria or sudden depressive states development, etc. Similar phenomena were registered for pilots under certain conditions during aircraft accidents at altitudes (changes in speech, language of communication, etc). In extreme conditions, when quick and adequate reaction is necessary — the above effects can lead to the impossibility of a person (pilot, military, rescuer, climber, etc.) to perform necessary functions, or even cause his death or the death of persons dependent on his activity.

Reduced oxygen content is more easily endured by people and animals with strong, mobile, balanced nervous processes. Examined ones with weak nervous processes endured hypoxia conditions are worse. Oxygen content in the arterial blood of such people (and animals) in the last cases decreased more significantly with a decrease of oxygen partial pressure in the inhaled air than in the other tested subjects.

The different nature of response to oxygen deficiency is explained as genetically determined individual organisms' sensitivity to oxygen deficiency due to organisms' biochemical individuality, as well as features of vegetative regulation, and other factors.

The majority of researchers associated the phase nature of changes in conditioned reflex activity during the development of acute hypoxia (various degrees) on the large hemispheres cortex [43]. However, some authors emphasized the significant importance of functional changes that happen in hypothalamus at hypoxia in case of its close interaction with reticular formation [43].

The results of numerous studies indicate that changes that occur in organism under the influence of mountain hypoxia disappear upon further adaptation to the highlands [43–45]. Reactions that occur in organism in process of adaptation to mountain heights can be quite

useful for this organism. Adaptation to the high-altitude climate trains the activity of all body systems, in particular the nervou system, increases the organism's resistance to oxygen deficiency [43–45].

Due to these results, the methods for increasing of organism's functioning reliability in various extreme situations were grounded. There were substantiated to the methods of adaptation to mountain climate for the treatment of many disorders and diseases associated with hypoxia (blood diseases, bronchial asthma, schizophrenia). It was found that the most optimal regimen of high-altitude training was the method of active stepwise high-altitude adaptation. It was substantiated that this method is a very useful tool for health strengthening for the great numbers of population, increasing labor productivity, improving sport indices, and some diseases treating [43–47, 60].

Some basic methods of higher nervous activity researches used in extreme conditions. Investigations of individual typological features of the nervous system

The problem of similarities and differences between various individuals attracted interest of researchers for a long time. But only after I.P. Pavlov's discovery of the individual-typological properties of HNA (strength, mobility and balance of nervous processes), a real scientific investigations of psychophysiological characteristics of mammals and humans started.

The studies of individual typological features of the nervous system has been carried out during long years, as well as their significance for the work, sports, education and other types of human activity under the conditions of various environmental factors affecting organisms. There were also studies of characteristics at neurodynamic level. PNN-3 - one of the original devices developed by NASU engineers. It was for the diagnostics of personal neurodynamic features. With PNN-3 help it was possible quickly (in 6–7 min.) to obtain quantitative characteristics of functional mobility of nervous processes and working capacity of a brain (strength of nervous processes). In the base for determination of these typological features was the principle of the maximal speed of differentiation of positive and inhibitory stimuli accounting that were set in the "feedback" mode, and the maximal amount of processed information in a given time. In addition, with the help of this device, it is possible to determine simple sensorimotor reactions and reactions to choose one of three, and two of three light signals.

Quantitative estimation of two main properties of HNA using PNN-3 data. To obtain a quantitative estimation of two main properties of HNA, we will describe the calculations of the test results. Determinations of functional mobility of persons' nervous processes characteristics were done in such a way. 120 signals of red, yellow, and green "flowers" (four series of 30 stimuli) were showed to the tested person. During the performance of this task, the three-digit counter of the device registers the current value of exposure to stimuli (with an accuracy of 0.01s), and a single-digit counter records their minimum exposure (with an accuracy of 0.1s). During the test, the experimenter records the current and minimal exposure values every 15s, and at the end of the test - the total time of the task in seconds. Obtained results were input into the research protocol to calculate characteristics of functional mobility level for nervous processes.

To determine the working capacity of the brain, the tested person was offered a task, that was similar to the above described ones. However, the numbers of offered signals were not fixed. The duration of the task was normalized.

Description of some methods for human psychophysiological functions studying

For the research of human psychophysiological functions the scientists in extreme mountains conditions used three methods of research of psychophysiological functions:

– research of neurodynamic level parameters;

– research of the parameters of the neuropsychic level;

– research of personal specificity.

The study of the parameters at neurodynamic level is important informative method of a person's psychophysiological functions research.

A. When researching the parameters of the neuropsychic level, the "triangles" technique was used to determine the level of development of short-term visual memory. Examined person is successively offered four variants of the task card. Each card is exposed for 10 s, after which the tested person has to find the specified figures in the unit "cash". 30 seconds are given for recognition and selection. The indicator of short-term visual memory capacity is the

average arithmetic value of the number of recognized triangles in four samples.

B. The "scale of devices" technique is intended for the study of operating memory, visual perception of instrument information, and the function of attention. Examined person is asked to evaluate and summarize the values of 3–4 arrow devices according to special schemes and to write the value of the sum of the readings from device indicators, taking into account the sign and price of division. The results of the examination were determined by the number of correct answers and time interval necessary to complete the task; consequently the coefficients of useful work and productivity were calculated.

C. The "red and black tables" technique was designed to study ability to allocate and switch attention. The principle of the method was based on finding black numbers from 1 to 24 in ascending order, red numbers from 24 to 1 in descending order (the examined person has to find and name numbers of different colors in mixed order). Indicators of the ability to concentrate and switch attention are the time spent by the examined person on the test.

Study of human personal characteristics

The study of examined persons' characteristics permits predicting the success in his professional activities [43, 48, 50, 51, 60–62]. Sure, in our cases the main attention was paid to such professions as rescuers, pilots, alpinists, astronauts, operators of complex technical systems, others — so much professions that are linked with the work in extreme conditions. Extreme conditions for the person — his brain and organism in whole. Personal characteristics were put in base of different methods of professional selection; we will tell about this briefly below.

Examination of individual personal characteristics of a person, which are manifested in the style, temper, and direction of his activity, are of great importance. Characteristics of personality determine professional suitability less than special inclinations and preferences. A personal approach to the estimation of professional suitability permits to study individual personal characteristics of the candidate, characteristics of his temperament, character, motives and direction of his activity, which are taken into account in complex for the predicting of professional suitability [43, 48, 50, 51, 60–62]. In this regard, the personality structure of operators, features, and type of their behavior in stressful situations were studied. For this the adapted questionnaire scheme (QS) based on Cattell's 16-factors personality tests was applied.

Concerning the adapted 16-factors personality *scheme-questionnaire by Cattell (QS)* that was used to estimate the peculiarities of temperament and character features of individuals, it is necessary to explain the next items. This QS contained 187 questions and statements, for each of which the examined person is offered three options for answers, one of which is the best for reflection of his opinion. The examined person noted the results of the survey on a special form, putting "+" marks in the corresponding cell of the answer sheet. Integral indicators formed from the averaged value of the point estimates made it possible to use them to forecast the success of this operators' professional activity. The study of the dependence between several variables (that is, between the indicators of success of operators' work, on the one hand, and the whole complex of a number of psychophysiological, physiological, and personal functions, on the other), were carried out using the methods of correlation and multiple correlation analyses. Predicted employment success can be calculated using linear regression equations.

Description of scheme-questionnaire of Cattell (QS). Survey schemes contain a list of questions or statements, each of which examined person has to answer by choosing one of the proposed options. The certainty of the answers allows you to standardize strictly the processing of survey, increases its reliability, and creates a basis for processing the received data using methods of mathematical statistics. The adapted version of QS based on Cattell's 16-factors personality tests contains 600 statements from the first person that relate to the examinee's well-being, his relationships with others, the presence of neurotic symptoms, and other issues.

The processing of the examination results consists of a computer comparison of the answers with special "keys" - a set of answers characteristic of people with the maximum degree of expressiveness of a certain personal quality. The more the examined person answers coincide with the "key", the more pronounced the close personal quality is.

The results of the study were evaluated by three rating scales, ten main scales, and seven additional scales. The degree of expressiveness of each personal quality was estimated according to the formula and expressed in standard units. The answers were truthfulness, reliability

of obtained results, and examined person's attitude to the examination were measured using rating scales. The scale of "untruth" consists of statements to which a candid testee usually gives a completely certain answer.

The value on the scales of "untruth" corresponds to the number of answers characteristic of examined persons trying to create a favorable impression about themselves with their answers. Thus, it allows for estimating the truthfulness of the examined person in the case of test performance.

The probability scale makes it possible to estimate how non-standard, unusual, compared to the majority of the examined persons, the test's answers to the statements of the QS were. The probability scale increases when the main scales are raised:

– hypochondria;
– depression;
– hysteria;
– psychopathy;
– interests;
– paranoia;
– psychasthenia;
– schizophrenia;
– mania;
– social introversion.

In this way, it is associated with the overall height of the QS profile, with the expressiveness of many psychopathological tendencies, and therefore, can be considered an integral index of neuropsychological instability. An increase in the probability is observed in persons with difficulties in personal contacts, in persons with psychopathic features. A moderate increase in the probability may reflect internally tension, and dissatisfaction with the situation. Very high valueson the probability scale indicate the improbability of obtained results. This may be the case when the examined person, without reading the content of the statements, randomly answers "correctly" and "incorrectly".

1) *The adjustment scale* is designed to adjust the statements on some basic scales, taking into account the testee's openness. Individuals with high scores on this scale tend to deny personal inadequacy, difficulties in controlling their own behavior and interpersonal relationships, tend to comply with socially accepted norms and demand the same as others. Individuals with very low valueson this scale tend to exaggerate the degree of interpersonal conflicts and the complexity of existing symptoms of neuropsychological instability.

2) *The hypochondria scale* estimates the expressiveness of hypochondriac tendencies, which are manifested in the subject's anxiety about the state of his health. The statements of the scale refer to basic somatic functions. In people with high values on the scale, their somatic condition becomes an object of long-term anxious observation. Even a slight disease causes a strong reaction of anxiety of such people. Properties of hypochondriacs limit their activity and breadth of interpersonal contacts. Low values on the scale indicate a lack of concern about one's bodily health. Such persons are more active, energetic, and sociable.

3) *The depression scale* estimates the presence of signs of depression in the examined person, consisting of pessimism, anxiety, feelings of helplessness and uselessness, futility, slowing down of thinking and actions. People with high valueson the depression scale are perceived by others as gloomy, withdrawn, silent people. Low valueson this scale are characteristic of cheerful, active, sociable persons with a sense of their importance.

4) *The hysteria scale* measures the degree of expressiveness of hysterical features, which are manifested in egocentrism, the desire for demonstrative behavior, increased suggestibility, the desire to do anything to attract the attention of others. Very high valueson the scale may raise suspicions about the presence of hysterical neurosis. People with low indicators are withdrawn, not active enough in interpersonal contacts.

5) *The psychopathy scale* is designed to estimate the psychopathization of an individual in which elements of antisocial behavior prevail. Individuals with high values on this scale disregard generally accepted social norms, moral and ethical values established by the rules of behavior. Combined with a high activity level, this contempt can manifest in angry and aggressive reactions. The behavior of such persons is poorly predictable, they are not afraid of possible punishment. Individuals with low values on the scale tend to follow generally accepted rules and norms of behavior.

6) *The scale of interests* estimates the degree of identity of the examined person's interests and attitudes with the traditional social role of men and women. High values on the scale for a man testify to the expressiveness of some female features of the examined person (sentimentality, sensitivity, sensitivity to shades of interpersonal relationships, etc.) Low values correspond to the expressiveness of

such masculine features as initiative, activity, tendency to competitions, etc.

7) *The paranoia scale* is used to estimate the effectiveness of rigidity, which is manifested in vulnerability, suspiciousness, mistrust, hostility to others, and ill-will. Such people are selfish, self-loving, tend to overestimate of their own personality.

8) *The psychasthenia scale* is designed to estimate anxiety. Individuals with high scores on the scale are characterized as anxious, restless, indecisive, and careful. In their behavior, they try to anticipate and avoid possible dangers and difficulties in advance. Such persons usually think carefully about their actions. Individuals with low values on the scale are characterized by the absence of unreasonable anxiety, decisiveness, and flexibility of behavior.

9) *The schizophrenia scale* is used to measure schizoid tendencies. Examined persons with high values on the scale are characterized by emotional coldness and inadequacy of emotions, originality of judgments and actions, autistic nature, so, by immersion in their inner world. They are closed, eccentric, their behavior is unnatural. At very high values on the scale, one can suspect the presence of schizoid accentuation or psychopathy. Examined persons with low scores have the opposite characteristics.

10) *The mania scale* estimates the expressiveness of hypomanic phenomena (tendencies). With high indicators, inappropriate behavior can be observed:

– excessive and poorly directed activity;
– emotional excitement;
– irritability;
– intemperance.

Small values corresponded to low activity. In the case of minimal values on the scale, the signs of depression may be registered.

11) *The scale of social introversion* estimates the degree of personal inclusion in the social environment. Individuals with high values on the scale are characterized by isolation, difficulties in interpersonal contacts, and the emergence of an anxiety reaction in case of a need for communication. Examined persons with low scores have the opposite characteristics. When interpreting the profile of the main scales, with particular attention should be paid to the scale that has the greatest importance. If it exceeds a critical level, it can be considered probable that the examined person has corresponding psychopathic tendency, which takes the form of neurotic personality.

In addition, it is necessary to take into account for the values of other scales that can strengthen the expressiveness of the main psychopathic syndrome or weaken it.

Additional scales are designed to assess the test subjects' emotional stability, ability to make decisions and perform actions in extreme situations, as well as the degree of expression of willpower and leadership qualities in them.

Modeling of the reliability of the human nervous system functioning in extreme conditions

Several researchers studied the reliability of the functioning of the human nervous system in extreme conditions of hypoxybaria at EMBS NASU [43, 47–51]. The results of modeling — physical, mathematical, program — of the functioning of human nervous system in conditions of hypoxybaria, were obtained by Yu.V. Kravchenko, and also were mentioned in [43].

The concept of reliability is widely used during the development and operation of technical systems, expressing the relationship between the object (examined person) and the process of its functioning. Reliability has a probabilistic nature and is evaluated by the parameters of the probability.

The descriptions of original developed machine tests are given below. Explanations of the used designations are given below too in the course of the description of the machine testing; the first required values and their reduction are as follows. The probability of failure P_f, the probability of failure-free (trouble-free) operation is $P_{tf} = 0{,}95$operation $P_{tf} = 1 - P_f$; the range of operations is [0;1]. Based on these parameters, the failure time T_f. is calculated. The outward parameters for calculating the reliability of technical systems are the characteristics of their elements, from the relationships of which the integral indicator of the reliability of the entire system is calculated, as well as such parameters as reliability, maintainability, and durability. However, there is a discrepancy between technical and biological reliability, which was taken into account in process of simulation.

Forced rhythms of the central nervous system (CNS) were provided due to the strong informational influence and minimization of the influence of natural factors that ensure free oscillations. This condition is satisfied by the method developed by Yu.V. Kravchenko — the method of recording of sensomotor self-oscillations under dosed mental load and

hypoxia. The method permits modeling of any mode of discrete-information load, from tense to stressful ones. It is also permits to register corresponding function of forced psychodynamic self-oscillations. Of the six functional working states of the nervous system, three states are the main ones for the simulation:

– *concentrated working state* (simulation at the level of nervous processes (NP) functional mobility), during which the maximum possible stable mode of the work (operation) occurs with 5% errors (probability of reliable work (trouble-free operation) is $P_{tf} = 0.95$, probability of failure is $P_f = 0.05$);

– *pre-stress working state* (simulation at the level of maximum mobilization of forces with 25% errors ($P_{tf} = 0.75$, $P_f = 0.25$);

– *stressful working state* or neurodynamic stress (simulation at the level of the maximum possible functioning of the NP or stress level) with 50% errors ($P_{tf} = 0.5$, $P_f = 0.5$). The latter is informational stress, which together with emotional stress are united into psychological stress, which together with physiological stress make up the general category of "stress".

The principle of feedback is the basis of a universal algorithm for modeling a given functional working state of the brain when the correct differentiation of all signals of the current series i increases the speed of presentation of stimuli V_{i+1} from the next serie $i + 1$ by a certain increment ΔV:

$$V_{i+1} = V_i + \Delta V$$

and in the case of an error, the speed decreases:

$$V_{i+1} = V_i - \Delta V.$$

The speed increase ΔV is non-linear and depends on the presentation speed V_i of the current series of stimuli:

$$\Delta V = (kV) \times 100,$$

where k — is the percentage of the change in the speed of a given functional operating (working) state (FOS). Experimentally determined values of κ for three (FOS):

– $k_{pfw} = 5\%$;
– $k_{pmm} = 2\%$;
– $k_{pc} = 1\%$.

In the case of non-linear increase in speed, there is a smooth change in the frequency of signals in the entire operating range and stable operation at high frequencies of stimulus presentation, in contrast to the case of ΔV = const. The number of signals for a series of stimuli is calculated by the formula:

$$N = (2 \times P_{tf})^{-1}.$$

For each FOS, this number has its own value:

– $N_{pfw} = 10$,
– $N_{pmm} = 2$,
– $N_{pc} = 1$.

The initial speed of V_0 signals representation is set depending on the specific task. For each examinee it is selected individually. The value of V_0 is set much lower than the theoretical level of functioning of the FOS $V_{p.fws}$ during the estimation of the dynamics of nervous processes (property, that characterize the speed of formation of temporary connections and conditioned reflexes). If the initial load corresponding to the level of functioning is used, then $V_0 = V_{p.FWS}$

The theoretical level of functioning is precalculated from the regression equation:

$$V_{p.FWS} = f(T_{p.c.}, T_{sr})$$

where $T_{p.c.}$ — latent period of the reaction of a choice; T_{sr} — is the latent period of a simple reaction.

The difference between the latent periods of these reactions $(T_{p.c.} - T_{pr})$ characterizes the time of central switching and is related to the speed of NP. Thus, by determining the functional relationship between this indicator and the level of functioning of the NP, it is possible to set individually the initial speed of V_0 signals for each examinee, providing all the examinees with the same conditions. The initial speed V_0 for a specific functional working state is calculated based on the assumption that the examinee did not make any mistakes in 30s from the start of work:

$$V_0 = V_{p.fws} \times (1 - k/100)^n,$$

where n — is calculated number of iterations: $n = \log_{(1-k/100)}(N/(30V_{p.fws}))$.

The serial signal is a meander (the durations of the exposure and extinction periods are the same), which removes the upper limit on the speed of presentation of stimuli, when the speed were changed only due to the variation of the exposure time.

The main difficulty in the development of the FOS model is to determine correctly the quality of the responses, since when the maximum speed of the presentation of signals is reached, the response is often obtained during the presentation of subsequent stimuli. Diagrams of signals passage and responses under extreme conditions of information processing were constructed. A response signal is a response to the first stimulus because it satisfies the conditions:

$$(T_{rc.} - 3G) < T_1 < (T_{rc} + 3G)$$

and

$$T_2 < (T_{rc} - 3G),$$

where G — is a root mean square deviation of the selection reaction; T_1 and T_2 — are the time from the beginning of the presentation of the first and second signals to the appearance of the leading front (the first front) of the response.

The time interval that satisfies the condition $T_{lag} = (T_{rc} - 3G)$ analyzed, which is called lag time. In other words, the time period T_{lag} during which the responses to the previous first stimulus during the current second stimulus are analyzed is called the "lag time".

In some techniques that use feedback mode (50% correct responses and errors), the limiting rate of stimulus presentation is almost not reached due to the lack of "lag time" or insufficient effective use of it.

For example, a correct motor response that began at the end of the current stimulus was actually a response to the previous signal because it coincided with the latency period of the choice response to the previous stimulus. In fact, it was processed as a response to the current signal, which in most cases was considered an incorrect reaction. This lowered the working threshold at which neurodynamic stress should be detected, and reduced the range of possible variations in individual differences among subjects. If the onset of the response falls within the lag time period T_{lag} and ends after its completion, then the residual motor response should not be considered when analyzing the response to the current stimulus. The value of T_{lag} cannot exceed the duration of the current signal.

The response is analyzed by the leading front of neuromuscular contraction (pressing a button). If the previous period of signal was less than or equal to T_{lag} then the current lag time value should not exceed the current signal period, assuming the response to the previous stimulus was correct. In this case, after the end of the lag period, the response to the previous stimulus is analyzed. Depending on its quality, either the next exposure is illuminated (in the case of a correct response), or the current extinguishing time is increased by $60/\Delta V_j$ (in the case of a false response), where ΔV_j is the increase speed reduction for the current series of signals j. The researchers paid their attention to the systematic error caused by the delay in outputting the signal to the monitor [43, 47–49]. Even with direct access to the screen memory, the time to display the image is a random value that lies in the range of 0–14 ms at a vertical sweep frequency of 60 Hz. This error can be enough significant to change (distort) sometime parameters of the test. Therefore, to eliminate this lack, the researchers refused from a display as a means of stimuli indicating; and finally, independent information display panel with a high-speed semiconductor indicator was used.

During the simulation of the FOS, a signal reception speed curve is constructed depending on their number N (Fig. 1). The average speed of information processing was 320 signals per minute.

A detailed analysis of the quality of erroneous reactions during the simulation of the focused working state permitted to reveal that at the limit speeds, when two positive stimuli addressed to the same hand are presented in a

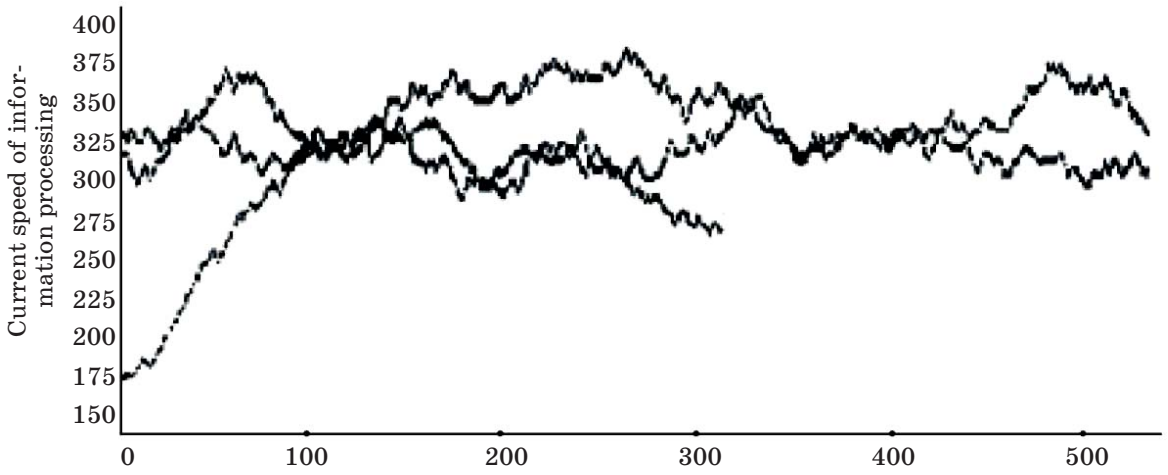

Fig. 1. **Modeling of neurodynamic stress, depending on current speed of information processing**

row, a phenomenon of summation was observed, when the reaction to the second stimulus developed against the background of residual excitation and was summed up with it.

If the time of neuromuscular contraction becomes longer than the period of passage of the current signal, then one response to two consecutive positive stimuli addressed to the same hand is recorded. But when the second positive stimulus is addressed to the second hand, the summation of neuromuscular contraction is not observed, and the probability of correct response to the second positive signal increases. Thus, the heterogeneity of the test material was observed.

"*Trigger type" of reaction.* "Trigger type" of reaction was proposed in order to harmonize this methodology and give homogeneity to the test material. In contrast to the reaction of choosing two signals out of three, when the response to two types of positive stimuli is addressed to the left or right hand, in the trigger reaction, the response to only one type of positive stimulus is addressed to both hands in turn. To reduce the oriented reaction and obtain primary data (T_{sr}, T_{rc}, G) for modeling the FOS, the set of the following tests are performed. Complexity of the tests increased gradually.

A) *Trigger-tapping test:* the examinee is asked to press buttons in turn with high-speed for 30 seconds. During the test, curves of neuromuscular contractions are constructed separately for each hand. This test permits us to determine the maximum number of pulses that the functional studied structure can transmit per unit of time:

$$F_L = N_m/30,$$

where F_L — is indicator of lability of neuromuscular apparatus (a property of the nervous system that characterizes the speed of occurrence and termination of nervous processes); N_m — is the number of neuromuscular contractions in 30 seconds.

B) *Simple visual-motor trigger response* (SVMTR). The examined person is asked to press the left and right buttons as quickly as possible, in the case of appearance of a vertical signal. If the latency period of the SVMTR is fixed at less than 100 ms, then the screen displays "Premature reaction!" With repeated pressing of the same button, "Disrupted hand queue!" is displayed.

C) *Choice trigger reaction* (CTR). The examinee is asked to press the left and right buttons as soon as possible, only in the case of vertical line appearance. If a horizontal signal appears — do not press the buttons.

During the first 30 seconds of the technique, the main load is linked with the central nervous system. Subsequent work reveals only physical muscle fatigue, which determined the testing time.

The warning about the error of premature reaction and violation of order of hands alternation is similar to SVMTR. But the following warning messages may appear in the case of a brake reaction "The next button was not pressed!" and motor response to the brake stimulus "On the horizontal - do not press the button!". The experimenter must loudly warn about the violation of motor reactions during the SVMTR and CTR.

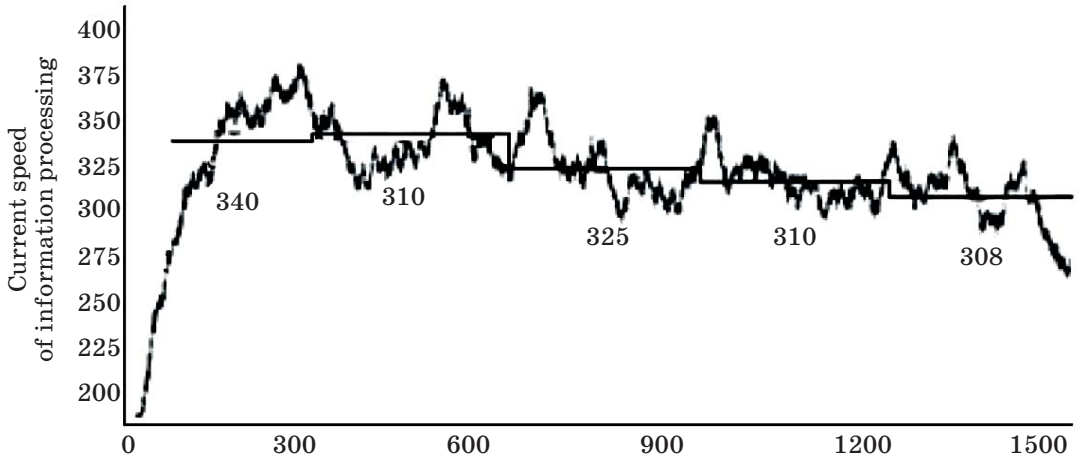

Fig. 2. **The curve of the speed of signals reception depending on the numbers of presented ones**
The average speed of information processing is 326 signals per minute, the average duration of the signal is 185 ms, the average exposure frequency is 5.43 Hz

At the end of each test, the results are processed statistically. Time data, latent periods, and response quality were recorded in computer memory.

The final schedule of neurodynamic stress modeling during 5 minutes is shown in Fig. 2, on which time compression along the abscissa axis is performed, and the slow-wave component of sensorimotor oscillations is clearly-observed.

Solution of the problem of professional selection based on psychophysiological personal characteristics

The significant volume of investigations that were carried out in extreme mountain conditions, studying of hypoxia and other factors influences on psychophysiological personal characteristics, their changes in these conditions formed the complex knowledge that were put in base of important direction — solution of the professional selection problems. Psychophysiological selection is an integral part of professional selection. It is aimed at identifying of persons who, by professional abilities and individual psychophysiological qualities meet the requirements of specific specialties. Such people are the most suitable for training in the prescribed period and the next successful professional activity [43, 47–51]. Researchers Yu.L. Maidykov, M.V. Makarenko, A.O. Navatikian, V.A. Buzunov, A.V. Karpenko, V.V. Kalnysh [43] devoted long years of investigations into these problems studying. Their findings convince us that, from a practical point of view, the problem of predicting the success in professional activity depends on two main aspects:

– determination of the requirements offered to a person by this or that activity;

– estimation of the state of his (her) respective abilities that limit this activity.

Already known, and some new methodological techniques were included in the basis of the creation of diagnostic complex, which made it possible to characterize the level of development and state of professionally significant psychophysiological characteristics of person [43]:

– functional mobility of nervous processes and working capacity of the brain, which were determined according to the method by M.V. Makarenko, N.V. Kolchenko, Yu.L. Maidikova;

– short-term memory, which was determined by the number of memorized geometric shapes, symbols;

– ability to concentrate and switch an attention — according to the Schulte-Platonov tables;

– ability of visual information processing according to the tables of A.O. Navatikian, Z.V. Kryzhanovska;

– motor reactions to a light signal;

– ability to operational, technical thinking and spatial imagination;

– muscle strength and endurance to static effort;

– features diagnosed with the help of adapted personality survey schemes.

During the examination, it was revealed that the contingent of operators united people with different psychophysiological characteristics. It was necessary to take into account the age, gender, type of nervous activity, state of the autonomic nervous system, peculiarities of cardio dynamics, breathing and oxybiotic processes in general, as well as typological features, sensorimotor and autonomic characteristics, adaptability and adapting of organism, and ability to recover. So, the need for special and individual approach to solving the problem will become obvious. Therefore, in order to estimate the reliability of the operation of the "operator machine" system, a multiparametric study of the organism in various conditions with subsequent mathematical modeling is necessary.

In the process of work, a high degree of correlation was shown between a set of indicators characterizing:

– the efficiency of operators;

– the ability to make an operational account;

– the level of development of technical thinking and spatial perception.

This circumstance permits us to recommend the use of these tests, together with predicting the success of labor activity based on regression equations at the stage of accepting a person for work, when it was not possible yet to take into account for the impact of a particular production load on his organism.

Much attention was paid during the work to the methods of research of individual characteristics applied in differential psychophysiology, physiology of work and sports, physiology of the CNS of a person. Experimentally confirmed criteria for their estimation, development and interpretation of rating scales for indicators of neurodynamic and neuropsychic functions, characteristics of personal characteristics, as a result of mathematical analysis using multiple regression equations, allowed predicting

Table 2

Calculated indicators of the hemodynamic system and hypoxic state obtained in Terskol during an examination under basal metabolic conditions on the third (1) and twentieth (2) days of adaptation [46]

Tested person		MBV, l/min^{-1}	HE	OECC, ml/beats	OCB, vol%	OCAB, vol%	OCVmB, vol%	OSVmB, %
P1	1	3.5	20.0	2.6	19	16.25	11.10	58.4
	2	3.3	23.0	2.2	20	18.84	14.59	72.9
P2	1	4.1	23.0	2.4	18	15.21	10.82	60.1
	2	2.6	23.0	1.9	21	14.70	10.46	49.9
P3	1	4.3	23.0	3.1	21	18.06	13.64	71.8
	2	3.1	18.0	3.1	19	13.33	7.84	71.2
P4	1	4.3	44.0	3.2	19	16.82	14.56	44.2
	2	4.2	29.0	2.2	19	15.96	12.39	65.2
P5	1	3.5	28.0	2.4	19	14.15	11.20	65.2
	2	3.8	37.0	1.5	19	17.48	13.57	78.2
P6	1	4.4	32.0	2.0	18	15.84	12.66	70.3
	2	4?4	32.0	2.0	19	16.15	12.97	68.3
P7	1	3.0	34.0	1.5	14	11.90	8.97	49.8
	2	2.7	24.0	2.0	16	13.60	9.53	59.5
P8	1	4.7	28.0	2.4	18	15.48	11.86	65.9
	2	3.8	23.0	2.4	18	16.20	11.99	47.4
P9	1	4.8	29.0	2.4	14	13.13	9.80	70.0
	2	3.4	24.0	2.1	16	13.60	9.19	57.4
P10	1	4.2	23.0	3.0	15	12.00	9.62	64.1
	2	4.3	40.0	1.5	18	14.49	11.93	66.3
P11	1	3.6	22.0	2.6	16	14.16	9.44	59.0
	2	4.6	24.0	2.8	19	16.91	12.78	67.3
P12	1	3.9	46.0	1.4	16	13.84	11.63	72.7
	2	3.6	38.0	1.6	18	14.40	11.76	65.3
P13	2	2.8	21.0	1.9	19	17.77	11.34	59.7
M	1	4.03	29.3	2.4	17.3	14.73	11.27	62.3
	2	3.58	27.3	2.1	18.5	15.65	11.56	63.7
m	1	0.15	2.4	0.2	0.64	0.54	0.50	2.5
	2	0.18	1.9	0.1	0.38	0.49	0.52	2.4

Note. Minute blood volume (MBV, l/min^{-1}), hemodynamic equivalent (HE), oxygen effect of the cardiac cycle (OECC, ml/beats), oxygen capacity of the blood (OCB, vol%), oxygen content in arterial blood (OCAB, vol%), oxygen content in mixed venous blood (OCVmB, vol%), oxygen saturation of mixed venous blood (OSVmB, %)

integral estimation of the success of a person's work as an operator, taking into account the criteria of studied functions.

Thus, some methods and obtained by the authors' results of HNA studies, psycho-physiological functions of a person in extreme conditions were described; they are reliable, were modified and used in extreme conditions.

1) Obtained results were taken as a basis for the developed methods for professional selection of special contingents, pilots, operators for work in extreme conditions, etc.

2) In consequences of these research we obtained better understanding of the nature of hypoxia influence on humans, other living organisms, the mechanisms of their action and adaptation to it; deep understanding of chemical and biochemical processes and phenomena that were initiated in the organism in hypoxic conditions. The processes of self-regulation and "self-correction" of states of the organism in extreme conditions, which is adaptation (at the level of organs, tissues, cells through changes in the relevant biochemical reactions) were studied.

Table 3

Indicators of the hemodynamic system and hypoxic state obtained in Terskol during an examination under basal metabolic conditions on the third (1) and twentieth (2) days of adaptation [46]

Tested person		MBV, l/min^{-1}	HE	OECC, ml/ beats	OCB, vol%	OCAB, vol%	OCVmB, vol%	OSVmB, %
PA1	1 2	4.6 3.9	12.9 15.0	5.3 4.13	19 19	16.59 18.12	8.84 11.46	46.08 59.78
PB2	1 2	4.3	29.7	2.4	18	16.62	13.25	72.18
PC3	1 2	4.6 3.6	18.5 17.0	3.6 4.19	18 22	13.75 20.60	8.35 14.69	46.17 68.35
PD4	1 2	4.5 3.4	18.7 12.7	3.3 4.1	19 19	18.03 17.74	12.69 9.85	66.16 52.46
PE5	1 2	4.0 3.7	18.9 20.8	3.2 2.8	20 21	17.53 18.28	12.22 13.47	62.41 64.39
PF6	1 2	5.0 4.6	20.0 19.0	3.4 3.4	20 20	18.21 19.28	13.22 14.87	67.51 68.15
PG7	1 2	4.2 5.5	10.5 21.2	5.1 4.0	22 21	18.05 19.81	8.55 15.08	39.77 72.02
PH8	1 2	4.1 3.1	18.9 10.3	2.7 5.0	23 22	19.07 21.39	13.79 11.64	61.45 51.86
PI9	1 2	4.3 4.6	14.5 16.7	3.9 5.3	23 22	20.42 20.84	13.53 14.87	60.3 67.91
PJ10	1 2	4.3 4.8	20.5 18.0	3.0 4.3	20 19	18.6 17.9	13.73 12.38	70.12 65.95
PK11	1 2	4.8 4.5	11.3 16.0	5.95 5.1	23 22	20.53 20.9	11.66 14.66	51.94 66.97
PL12	1 2	5.2	21.7	2.8	21 21	19.69 20.11	15.08 10.72	71.99 51.2
PM13	1 2	3.8 2.8	27.9 21.0	2.0 1.9	19 22	17.64 21.0	14.08 16.23	73.22 74.1
M	1 2	4.4 4.0	18.8 17.1	3.6 4.0	20.0 21.0	18.05 19.62	12.23 13.56	60.72 64.72
m	1 2	0.1 0.2	1.5 1.0	0.3 0.3	0.5 0.4	0.50 0.42	0.62 0.59	3.12 2.18

Note. Minute blood volume (MBV, l/min^{-1}), hemodynamic equivalent (HE), oxygen effect of the cardiac cycle (OECC, ml/beats), oxygen capacity of the blood (OCB, vol%), oxygen content in arterial blood (OCAB, vol%), oxygen content in mixed venous blood (OCVmB, vol%), oxygen saturation of mixed venous blood (OSVmB, %)

3) This made it possible to invent and develop such methods of human rehabilitation and recovery, such as the method of interval hypoxia, pharmacological correction of disorders that can occur with negative hypoxic effects, etc. [43–47]. That is, the knowledge of the mechanisms of the processes stimulated the invention of possibilities for their correction (by selecting lifestyles, medication and pharmacological correction, etc.). The invented methods were successfully applied for the training of pilots and cosmonauts, training groups of Antarctic researchers, soldiers, rescuers, athletes — winners of the Olympic Games, etc. The issues of organisms' resistance to various harmful influences in extreme conditions were dealt those scientists of the NASU, who were engaged in these specific

areas of investigations, and these results were reflected in their numerous publications. More than 300 people were examined according to methods described above. Among them were testers, climbers, candidates for astronauts, drivers, operators of different systems, including power unit operators who mainly control technological process, remotely identify and eliminate violations in the equipment's operating mode.

4) The importance of studying problems related to the brain's functional states, level of health of operational staff, including operators of various energy-intensive, highly dangerous complexes, etc., are apparent. This is due to the facts that the error of a human operator can cost not only his life. Therefore, the operator's work requires composure, endurance — errors are impossible. In order to estimate effectively the degree of operators' efficiency, the authors proposed a *comprehensive method* that evaluates:

– quality and quantity of a health;

– special operator capabilities for a certain moment;

– work capacity in extreme environmental conditions;

– recovery after fatigue;

– hidden functional reserves;

– the ability to adapt to new conditions and increased loads.

5) To estimate the psychophysiological state of the examinees, various functional tests and physical loads were used, to determine:

– individual and typological properties of HNA;

– functional mobility of the nervous system;

– brain workability;

– the functional state of the systems: vegetative, cardiorespiratory, hematopoietic, immunological, and hormonal ones.

6) Physical, mathematical, and software models of the reliability of the functioning of the human nervous system in these conditions were proposed.

7) Research in the process of adaptation to hypoxia made it possible not only to estimate objectively the state of health and working capacity of the subject, but also to increase simultaneously his functional capabilities and resistance to various harmful effects.

Author Contributions

P. Beloshitsky — general supervision, planning the work, funding, analysis of results, contributed to the article's conception and writing of some fragments of article; O. Klyuchko — data analysis, carrying of some observations, manuscript article writing, editing, translation and paper preparation, provided the new literature data for review; Yu. Kravchenko — conducted a study of psychophysiological functions changes, equipment modification and reparation; M. Makarenko — supervision of HNA investigations, conducted HNA study; K. Lyman — mathematic modeling, algorithms construction; A. Lizunova — computer simulation, algorithms construction. All authors contributed to the manuscript's revision and read and approved the submitted version.

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REFERENCES

1. *Bellmund J.L.S., Gardenfors P., Moser E.I., Doeller C.F.* Navigating cognition: Spatial codes for human thinking. *Science.* 2018, 362. eeat6766. https://doi.org/10.1126/science.aat6766
2. *Angeloni D., Demontis G.C.* Endocrine adaptations across physical and psychological stressors in long-term space flights. *Curr. Opin. Endocr. Metab. Res.* 2020, 11: 21–26 https://doi.org/10.1016/j.coemr.2019.12.005
3. *Ayzenberg A.* Torus action on quaternionic projective plane and related spaces. 2019, arXiv 2019, arXiv: 1903.03460. https://doi.org/10.48550/arXiv.1903.03460
4. *Li Y., Wang H.* Almost periodic synchronization of quaternion-valued shunting inhibitory cellular neural networks with mixed delays via state-feedback control. *PLoS ONE.* 2018, 13: e0198297. https://doi.org/10.1371/journal.pone.0198297
5. *Fingelkurts A.A., Fingelkurts, A.A., Neves C.F.H.* Natural world physical, brain operational, and mind phenomenal space-time. *Phys. Life Rev.* 2010, 7: 195–249. https://doi.org/10.1016/j.plrev.2010.04.001
6. *Jirsa V.K., Stacey W.C., Quilichini P.P., Ivanov A.I., Bernard C.* On the nature of seizure dynamics. *Brain.* 2014, 137 Pt 8: 2210–2230. https://doi.org/10.1093/brain/awu133
7. *Fruchart M., Zhou Y., Vitelli V.* Dualities and non-Abelian mechanics. *Nature.* 2020, 577: 636–640. https://doi.org/10.1038/s41586-020-1932-6

8. *Oliveros-Muñoz J.M., Jiménez-Islas H.* Hyperspherical path tracking methodology as correction step in homotopic continuation methods. *Chem. Eng. Sci*. 2013, 97: 413–429. https://doi.org/10.1186/s40064-016-2534-5
9. *Reimann M.W., Nolte M., Scolamiero M., Turner K., Perin R., Chindemi G., Dłotko P., Levi R., Hess K., Markram H*. Cliques of Neurons Bound into Cavities Provide a Missing Link between Structure and Function. *Front. Comput. Neurosci.* 2017, 11: 48. https://doi.org/10.3389/fncom.2017.00048
10. *Peters J.F., Ramanna S., Tozzi A., İnan E.* Bold-Independent Computational Entropy Assesses Functional Donut-Like Structures in Brain fMRI Images. *Front. Hum. Neurosci.* 2017, 11: 38. https://doi.org/10.3389/fnhum.2017.00038
11. *Johnson N. A.* Visualization of the Hopf Fibration. 2015. *Available online:* https://nilesjohnson.net/hopf.html (accessed on 22 September 2020).
12. *Hosny K.M., Khedr Y.M., Khedr W.I., Mohamed E.R.* Robust Color Image Hashing Using Quaternion Polar Complex Exponential Transform for Image Authentication. *Circuits Syst. Signal Process*. 2018, 37: 5441–5462. https://doi.org/10.1007/s00034-018-0822-8
13. v*on Wegner F.* Partial Autoinformation to Characterize Symbolic Sequences. *Front. Physiol.* 2018, 9: 1382. https://doi.org/10.3389/fphys.2018.01382
14. *Hart V., Segerman H.* The Quaternion Group as a Symmetry Group. 2014, arXiv 2014, arXiv:1404.6596v1. https://doi.org/10.2307/j.ctvc778jw.17
15. *Hopf H.* Collected Papers/Gesammelte Abhandlungen; *Springer: Berlin, Germany; New York, NY, USA*, 2001.
16. *Lohse M., Schweizer C., Price H.M., Zilberberg O., Bloch I.* Exploring 4D quantum Hall physics with a 2D topological charge pump. *Nature.* 2018, 553: 55–58. https://doi.org/10.1038/nature25000
17. *Daohui Zhao, Jian Zhou.* Electrostaticsmediated α-chymotrypsin inhibition by functionalized single-walled carbon nanotubes. *Physical Chemistry Chemical Physics.* 2017, 19 (2): 986–995. https://doi.org/10.1039/C6CP04962A
18. *Li X., Coffield J.A.* Structural and Functional Interactions between Transient Receptor Potential Vanilloid Subfamily1 and Botulinum Neurotoxin SerotypeA. *PLoS ONE.* 2016, 11(1): e0143024. https://doi.org/10.1371/journal.pone.0143024
19. S*amoshkin A., Convertino M., Viet C., Wieskopf J.S., Kambur O., Marcovitz J., Patel P., Stone L.S., Kalso E., Mogil J.S., Schmidt B.L., Maixner W., Dokholyan N.V., Diatchenko Lю* Structural and functional interactions between six-transmembrane μ-opioid receptors and β2-adrenoreceptors modulate opioid signaling. *Sci Rep*. 2016, 5: 18198. https://doi.org/10.1038/srep18198
20. *Zisimopoulos S., Seidel M., Lai F., Zissimopoulos S.* Structural and functional interactions within ryanodine receptor. *Biochemical Society Transactions.* 2015, 43 (3): 377–383. https://doi.org/10.1042/BST20140292
21. *Hanson A.J., Thakur S.* Quaternion maps of global protein structure. *J. Mol. Graph. Model.* 2012, 38: 256–278. https://doi.org/10.1016/j.jmgm.2012.06.004
22. *Tozzi A., Peters J.F.* Towards a Fourth Spatial Dimension of Brain Activity. *Cogn. Neurodyn.* 2016, 10:189–199. https://doi.org/10.1007/s11571-016-9379-z
23. *Ozdemir F., Özekes H.* On the Homomorphisms of the Lie Groups SU(2) and S3. *Abstr. Appl. Anal.* 2013, 2: 1–5. https://doi.org/10.1155/2013/645848
24. *Tozzi A.* The multidimensional brain. *Phys. Life Rev.* 2019, 31: 86–103. https://doi.org/10.1016/j.plrev.2018.12.004
25. *Friston K.* The Emperor's new topology: Comment on "Topodynamics of metastable brains" by Arturo Tozzi et al. *Phys. Life Rev*. 2017, 21: 26–28. https://doi.org/10.1016/j.plrev.2017.03.001
26. *Tozzi A., Ahmad M.Z., Peters J.F.* Neural computing in four spatial dimensions. *Cogn. Neurodyn.* 2020. https://doi.org/10.1007/s11571-020-09598-2
27. *Zilberberg O., Huang S., Guglielmon J., Wang M., Chen K. P., Kraus Y. E., Rechtsman M. C.* Photonic topological boundary pumping as a probe of 4D quantum Hall physics. *Nature.* 2018, 553: 59–62. https://doi.org/10.1038/nature25011
28. *Di Concilio A., Guadagni C., Peters J.F., Ramanna S.* Descriptive proximities, properties and interplay between classical proximities and overlap. *Math. Comp. Sci.* 2018, 12: 91–106. https://doi.org/10.1007/s11786-017-0328-y
29. *Peters J.F.* Computational Geometry, Topology and Physics of Digital Images with Applications. Shape Complexes, Optical Vortex Nerves and Proximities. *Springer Nature: Cham, Switzerland*. 2020: xxv+440. https://link.springer.com/book/10.1007/978-3-030-22192-8
30. *Barkaszi I., Takács E., Czigler I., Balázs L.* Extreme environment effects on cognitive functions: a longitudinal study in high altitude in Antarctica. *Front. Hum. Neurosci.* 2016, 10: 331. https://doi.org/10.3389/fnhum.2016.00331
31. *de Arcangelis L., Herrmann H.J.* Learning as a phenomenon occurring in a critical

state. *Proc. Natl. Acad. Sci. USA* 2010, 107: 3977–3981. https://doi.org/10.1073/pnas.0912289107

32. *Davis J., Stepanak J., Fogarty J., Blue R.* Fundamentals of Aerospace Medicine (fourth ed.), *Lippincott Williams & Wilkins,* 2021. https://www.amazon.com/Fundamentals-Aerospace-Medicine-Jeffrey-Davis/dp/197514385X
33. *Cohen I., den Braber N., Smets N.J.J.M., van Diggelen J., Brinkman W.-P., Neerincx M.A.* Work content influences on cognitive task load, emotional state and performance during a simulated 520-days' Mars mission. *Comput. Hum. Behav.,* 55 (Part B). 2016, 642-652, 10.1016/j.chb.2015.10.011 , https://resolver.tno.nl/uuid:230b8b12-901c-4ff4-b533-5ab07e75e99f
34. *Basner M., Savitt A., Moore T.M., Port A.M., McGuire S., Ecker A.J. , Nasrini J., Mollicone D.J., Mott C.M., McCann T., Dinges D.F., Gur R.C.* Development and validation of the cognition test battery for spaceflight. *Aerosp. Med. Hum. Perform*. 2015, 86: 942–952. https://doi.org/10.3357/AMHP.4343.2015
35. *Badran B.W., Caulfield K.A., Cox C., Lopez J.W., Borckardt J.J., DeVries W.H., Summers P., Kerns S., Hanlon C.A., McTeague L.M., George M.S., Roberts D.R.* Brain stimulation in zero gravity: transcranial magnetic stimulation (TMS) motor threshold decreases during zero gravity induced by parabolic flight. *NPJ Microgravity.* 2020, 6: 26. https://doi.org/10.1038/s41526-020-00116-6
36. *Cunha C.E.X., Oliveira A.F., Dantas G.F.G., Castro L.R., Vitor de Omena Jucá J., Vieira G.C.F., Ribeiro M.V.M.R.* Neuropsychiatric aspects of the space missions: scientific overview of the last 15 years. *Int. Physiol. Med. Rehabil. J*. 2021, 6 (1): 4–9. https://doi.org/10.15406/ipmrj.2021.06.00270
37. *Bishop S.L.* From earth analogues to space: learning how to boldly go. In: On orbit and beyond. *Springer.* 2013, 25-50. https://doi.org/10.1007/978-3-642-30583-2_2
38. *Bloomberg J., Reschke M., Clément G., Mulavara A., Taylor L.C.* Evidence Report: Risk of Impaired Control of Spacecraft/Associated Systems and Decreased Mobility Due to Vestibular/Sensorimotor Alterations Associated with Space flight. NASA Johnson Space Center. 2015. https://doi.org/10.1038/s41598-019-39058-9 ·
39. *Bloomberg J.J., Peters B.T., Cohen H.S., Mulavara A.P.* Enhancing astronaut performance using sensorimotor adaptability training. F*ront. Syst. Neurosci.*, 2015, 9: 129. https://doi.org/10.3389/fnsys.2015.00129
40. *Botella C., Baños R.M., Etchemendy E., García-Palacios A., Alcañiz M*. Psychological countermeasures in manned space missions: "EARTH" system for the Mars-500 project. *Comput. Hum. Behav*. 2016, 55: 898-908. https://doi.org/10.23923/pap.psicol2017.2817
41. *Brainard G.C., Barger L.K., Soler R.R., Hanifin J.P.* The development of lighting countermeasures for sleep disruption and circadian misalignment during spaceflight. *Curr. Opin. Pulm. Med.* 2016, 22 (6): 535–544, https://doi.org/10.1097/MCP.0000000000000329
42. *Clément G.R., Boyle R.D., George K.A., Nelson G.A., Reschke M.F., Williams T.J., Paloski W.H*. Challenges to the central nervous system during human spaceflight missions to Mars. *J. Neurophysiol*. 2020, 123: 2037–2063. https://doi.org/10.1152/jn.00476.2019
43. *Beloshitsky P.V*. Chronicle of biomedical research in Elbrus region (1929–2006). *Kyiv: Ukr.Acad. Sci.* 2014: 550. (In Ukrainian).
44. *Klyuchko O.M., Lizunov G.V., Beloshitsky P.V*. Radiation and hypoxia studies: effects of high-energy atmospheric particles on biological organisms and possibilities of their rehabilitations. *Biotechnologia Acta*. 2023, 16(6): 48–68. https://doi.org/10.15407/biotech16.06.034
45. *Klyuchko O.M., Lizunov G.V., Beloshitsky P.V*. Radiation phenomena: some natural sources, mechanisms of effects, ways of biological organisms protection and rehabilitation. *Biotechnologia Acta.* 2023, 16(3): 24–44. https://doi.org/10.15407/biotech16.03.024
46. *Lizunov G.V., Klyuchko O.M*. Health information system: radiation monitoring at altitudes above the Earth and the concept of information. *DigiHealthDay2023Symposium*, Deggendorf Institute of Technology, Pfarrkirchen, Germany, 2023, 9-10: 11. https://www.researchgate.net/publication/375101325_Health_information_system_radiation_monitoring_at_altitudes_above_the_Earth_and_the_concept_of_information
47. *Biloshitsky P.V., Klyuchko O.M., Onopchuk Yu.M*. Results of research of hypoxia problems by Ukrainian scientists in Elbrus region. *Bulletin of NAU*. 2007, (3-4): 44-50 (In Ukrainian). https://www.researchgate.net/publication/361316253_Rezultati_vivcenna_problem_gipoksii_ukrainskimi_vcenimi_v_rajoni_Elbrusu
48. *Onopchuk Yu.M., Aralova N.I., Beloshitsky P.V., Klyuchko O.M*. Mathematic models and integral estimation of organism systems reliability in extreme conditions. *Electronics and Control Systems.* 2015, 46(4): 109–115. https://doi.org/10.18372/1990-5548.46.9978

49. *Onopchuk Yu.M., Beloshitsky P.V., Klyuchko O.M.* Development of mathematical models based on the results of researches of Ukrainian scientists at Elbrus. *Bulletin of NAU*. 2008, 3: 146–155 (In Ukrainian). https://doi.org/10.18372/2306-1472.36.1609
50. *Aralova N.I., Klyuchko O.M., Mashkin V.I., Mashkina I.V.* Mathematic and program models for investigation of reliability of operator professional activity for "Human-Machine" systems. *Electronics and Control Systems*. 2017, 51(1): 105–113. https://doi.org/10.18372/1990-5548.51.11712
51. *Aralova N.I., Klyuchko O.M., Mashkin V.I., Mashkina I.V.* Mathematical model for research of organism restoring for operators of continuously interacted systems. *Electronics and Control Systems*. 2016, 49(3): 100–105. https://doi.org/10.18372/1990-5548.49.11245
52. *Klyuchko O.M., Tsal-Tsalko V.I.* Device and software for testing and training of human visual memory on the base of ATmega32 microcontroller. *Electronics and Control Systems*. 2013, 36 (2): 75–83. https://doi.org/10.18372/1990-5548.36.5850
53. B*atres-Mendoza P., Montoro-Sanjose C.R., Guerra-Hernandez E.I., Almanza-Ojeda D.L., Rostro-Gonzalez H., Romero-Troncoso R.J., Ibarra-Manzano M.A.* Quaternion-Based Signal Analysis for Motor Imagery Classification from Electroencephalographic Signals. *Sensors*. 2016, 16: 336. https://doi.org/10.3390/s16030336
54. *Enshaeifar S., Kouchaki S., Took C.C., Sanei S.* Quaternion Singular Spectrum Analysis of Electroencephalogram with Application in Sleep Analysis. *IEEE Trans. Neural Syst. Rehabil. Eng*. 2016, 24: 57–67. https://doi.org/10.1109/TNSRE.2015.2465177
55. *Pritchard W.S.* The brain in fractal time: 1/f-like power spectrum scaling of the human electroencephalogram. *Int. J. Neurosci*. 1992, 66: 119–129. https://doi.org/10.3109/00207459208999796
56. *Van de Ville D., Britz J., Michel C.M.* EEG microstate sequences in healthy humans at rest reveal scale-free dynamics. *Proc. Natl. Acad. Sci. USA*. 2010, 107: 18179–18184. https://doi.org/10.1073/pnas.1007841107
57. *von Wegner F., Laufs H., Tagliazucchi E.* Mutual information identifies spurious Hurst phenomena in resting state EEG and fMRI data. *Phys. Rev*. E 2018, 97: 022415. https://doi.org/10.1103/PhysRevE.97.022415
58. *Chariker L., Shapley R., Young L.-S.* Rhythm and Synchrony in a Cortical Network Model. *J. Neurosci*. 2018, 38: 8621–8634. https://doi.org/10.1523/JNEUROSCI.0675-18.2018
59. *Buzsáki G., Watson B.O.* Brain rhythms and neural syntax: Implications for efficient coding of cognitive content and neuropsychiatric disease. Dialogues Clin. Neurosci. 2012, 4: 345–367. https://doi.org/10.31887/DCNS.2012.14.4/gbuzsaki
60. Individual differences in adaptability to isolated, confined, and extreme environments. *Aerosp. Med. Hum. Perform*. 2018, 89 (6): 536–546. https:doi.org/10.3357/AMHP.4951.2018
61. *Barger L.K., Sullivan J.P., Lockley S.W., Czeisler C.A.* Exposure to short wavelength-enriched white light and exercise improves alertness and performance in operational NASA flight controllers working overnight shifts. *J. Occup. Environ. Med.* 2021, 63(2): 111–118. https://doi.org/10.1097/JOM.0000000000002054
62. *Brasher K.S., Sparshott K.F., Weir A.B., Day A.J., Bridger R.S.* Two-year follow-up study of stressors and occupational stress in submariners. *Occup. Med.* 2012, 62 (7): 563–565. https://doi.org/10.1093/occmed/kqs104

ЗАСТОСУВАННЯ ТЕХНОЛОГІЙ ВИВЧЕННЯ ВИЩОЇ НЕРВОВОЇ ДІЯЛЬНОСТІ ТА ПСИХОФІЗІОЛОГІЧНИХ ФУНКЦІЙ ЛЮДИНИ ЗА ЕКСТРЕМАЛЬНИХ УМОВ

П.В. Білошицький [1], *О.М. Ключко* [2], *Ю.В. Кравченко* [3], *М.В. Макаренко* [3], *К.С. Лиман* [4], *А.Г. Лізунова* [5]

[1]Уманський державний педагогічний університет ім. П.Тичини, Україна
[2]Національний авіаційний університет, Київ, Україна
[3]Інститут фізіології ім. О. О. Богомольця НАН України, Київ
[4]Washington State University, USA
[5] Luxoft Global Operations GmbH: Zug, CH, USA

E-mail: bilosh827@ukr.net

Описано застосовані методи та деякі результати досліджень вищої нервової діяльності (ВНД) людей, та результати вивчення їхніх психофізіологічних функцій (ПФФ) українськими вченими та лікарями, зокрема наслідки впливу екстремальних факторів на ВНД.

Мета. Показати результати впливу на ВНД людини екстремальних гірських умов на великих висотах (гіпоксія, ін.), дослідження змін психофізіологічних функцій головного мозку за цих умов та описати розроблені методи професійного відбору.

Методи. Порівняльного аналізу великої кількості даних експериментів та спостережень. Моделювання фізичне, математичне, програмне. Методики досліджень головного мозку, ВНД: електроенцефалографія, діагностика особистісних нейродинамічних особливостей тощо. Три методи досліджень ПФФ: параметрів нейродинамічного рівня; параметрів нервово-психічного рівня; особистісної специфіки. Застосовано адаптовану схему опитування (СО) на основі 16-факторних тестів особистостей за Кеттеллом.

Результати. Було досліджено вплив гіпоксії, інших факторів гірських умов на ВНД. Також наведено результати змін ЕЕГ, зареєстрованих у таких екстремальних умовах. Показано вплив низки стресових факторів за екстремальних умов (гіпоксія та ін.). Описано деякі основні методи дослідження ВНД, що були застосовані за таких умов, а також результати дослідження індивідуальних типологічних особливостей нервової системи. Описано методи дослідження психофізіологічних функцій людини. Детально описано дослідження особистісних характеристик людини. Для діагностики особистісних нейродинамічних особливостей взято дані, зареєстровані приладом ПНН-3. Параметри нервово-психічного рівня визначали методиками: «трикутників» (рівень розвитку короткочасної зорової пам'яті); «шкали приладів» (оперативна пам'ять, функції уваги та ін.), «червоно-чорні таблиці» (розподіл та переключення уваги). Структури особистості, особливості, типи поведінки операторів у стресових ситуаціях оцінювали, базуючись на адаптованій СО за Кеттеллом. Розроблені математичні моделі надійності функціонування нервової системи людини за екстремальних умов.

Висновки. Отримані результати було покладено в основу розроблених методик професійного відбору спецконтингентів, пілотів, операторів для роботи в екстремальних умовах. Запропоновано фізичні, математичні та програмні моделі надійності функціонування нервової системи людини за цих умов.

Ключові слова: вища нервова діяльність, психофізіологічні функції, екстремальні умови, великі висоти.