DOI: https://doi.org/10.15407/kvt214.04.054

ARALOVA N.I.[1], DSc (Engineering), Senior Researcher,
Senior Researcher of the Department of Optimization of Controlled Processes,
https://orcid.org/0000-0002-7246-2736, e-mail: aralova@ukr.net
RADZIEJOWSKI P.A.[2], DSc (Biology), Professor,
Professor of Educational Studies Department
https://orcid.org/0000-0001-8232-2705, e-mail: p.radziejowski@wseit.edu.pl
RADZIEJOWSKA M.P.[3], DSc (Biology), Professor,
Professor of Faculty of Management, Innovations
and Safety Management Systems Department
https://orcid.org/0000-0002-9845-390X, e-mail: maria.radziejowska@pcz.pl
ARALOVA A.A.[1], PhD (Mathematics)
Researcher of the Department of Methods for Discrete Optimization,
Mathematical Modelling and Analyses of Complex Systems
https://orcid.org/0000-0001-7282-2036, email: aaaralova@gmail.com
[1] V.M.Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine,
40, Acad.Glushkov av., 03187, Kyiv, Ukraine
[2] Kazimiera Milanowska College of Education and Therapy,
22,Grabowa str., 61-473, Poznań, Poland
[3] Czestochowa University of Technology
19b, Armii Krajowej str., 42-200, Częstochowa, Poland

INTELLIGENT DECISION-MAKING SUPPORT TECHNOLOGIES REGARDING THE OPTIMIZATION OF THE PHYSICAL TRAINING OF MILITARY SERVICEMEN

Introduction. *The NATO Medical Doctrine and the Military Medical Doctrine of Ukraine emphasize the need to apply scientific approaches to health care, physical training, and supporting special operations. Of course, the extreme conditions of professional activity require the personnel to have appropriate training and the ability to adapt. Professional selection and training should be, on the one hand, scientifically based and objective, and on the other hand, using an individual approach, should be as effective as possible. Currently, this is impossible without the use of information technologies.*

The purpose of the paper *is to develop intelligent technology on the basis of mathematical models of the body's functional systems, to support decision-making regarding the optimization of physical training of military personnel.*

Methods. *Mathematical modeling methods, numerical optimization methods*

Results. *An intelligent technology has been developed to support decision-making regarding the optimization of the physical training of military personnel, which includes a complex of mathematical, algorithmic and software for assessing the current state and forecasting the functional state of military personnel.*

Conclusion. *Mathematical support includes mathematical models of regulation of oxygen regimes of the human body, transport and mass exchange of respiratory gases in the human body, functional self-organization of the respiratory system and blood circulation, heat exchange in the human body, immune response, and the interaction and mutual influence of these systems. If there is a suitable array of personal data, it can be used for individual planning of physical training of personnel.*

Keywords: *mathematical models, intelligent technology, optimizing the physical training of servicemen, functional respiratory system, extreme conditions of professional military activity, adaptation of the body of a serviceman, numerical optimization methods.*

INTRODUCTION

In Ukraine, the requirements for the physical training of military personnel are determined based on of criteria for assessing the physical training of military personnel of NATO countries. Speed and strength physical qualities of combatants are one of the leading qualities for achieving the set military goals. Strength training can be aimed at the development of various types of strength qualities of maximal strength; speed strength — the ability of the musculoskeletal system and its structures to achieve high strength indicators in the shortest possible time; strength endurance, which characterizes the ability of the human body to maintain fairly high strength indicators for a long time. The development of physical qualities involves various methods of a static and dynamic nature and, therefore, the development and improvement of neurohumoral mechanisms of regulation not only of intra- and of intermuscular coordination, but also the development of aerobic and anaerobic energy supply mechanisms for the functions of the musculoskeletal system (MSS) [1]. Physical activity affects not only ORA, but also all internal body systems. Motor-visceral reflexes are somato-visceral reflexes as changes in the functions of any internal organs or organ systems during physical exertion on MSS. During human physical activity, impulses from proprioceptors (receptors of muscles, tendons, joints) radiate along nerve fibers to internal organs, increasing their activity in accordance with the loads on MSS. This creates a training effect of both the MSS system, but also the vegetative systems and, first of all, the blood circulation system, the blood system, the respiratory system, i.e. functional respiratory system (FRS) This adaptation of body systems increases the efficiency of energy supply of working skeletal muscles, their physical capabilities, which in the process of training (repetition of optimal loads) leads to the efficiency of FSR functions.

The 5th chapter of the Military Medical Doctrine of Ukraine [2] deals with the issue of scientific support of the health care system of military personnel. Also, the NATO Medical Doctrine [3] considers various aspects of joint operations. Thus, when planning medical support for joint land operations, such extreme conditions as permafrost, deserts, mountainous terrain, and jungles should be taken into account. In the course of air operations, crews are subjected to extreme physical and psychological stress, which requires appropriate training. Complex technical and other features of military aviation and medicine must be taken into account when providing medical support for air operations. The same applies to the medical support of joint maritime operations, including submarines, when the crews also have to operate in extreme environmental conditions.

PROBLEM STATEMENT

It is quite obvious that the professional selection and training of military personnel, which make high demands on the adaptation of the personnel's body to work in extreme environmental conditions, must be scientifically based and objectified. Due to the fact that modern diagnostic methods give only a partial slice of the current state of the body, for the professional selection and assessment of the process of adaptation of the body of a military serviceman, it is proposed to use mathematical models of the functional systems of the body, which, subject to their personalization, allow simulating extreme disturbances on the body and predict the stationary state of the organism at a given level of disturbing influences and, thus, manage the process of professional training of military personnel.

All of the above justifies the need to adapt the body of a serviceman to professional activity in extreme environmental conditions, and this should also be taken into account when planning the physical training of servicemen.

Analysis of the latest research and publications. The creation of a modern system can only be possible under the condition of using scientific knowledge and new technologies based on it, capable of contributing to the solution of critically important problems. It should be noted that in Ukraine there is a significant development regarding the scientific support of the health care system of military personnel, which includes both a number of normative acts and a number of monographs [4–15].

One of the important components of modern military training is physical training, which will allow professional military activity in the conditions of a combination of extreme internal and external disturbances on the soldier's body. A person's work capacity depends on a number of factors, including aerobic productivity, its dependence on the level of development of the functional respiratory system (FRS), on such physical qualities as strength, speed and coordination capabilities, endurance, flexibility. The results of military training are also determined by the mental and moral qualities of a serviceman. On the other hand, military readiness depends on gender, age, and level of physical fitness. The development of physical qualities involves the application of various methodologies of a static and dynamic nature and, therefore, the development and improvement of neurohumoral regulation mechanisms not only of intra- and intermuscular coordination, but also the development of aerobic and anaerobic energy supply mechanisms for the functions of the musculoskeletal system [1].

Currently, in a number of publications, there is a trend [16] regarding the individualization of physical training of military personnel, which should be aimed at increasing the productivity of performance when performing basic professional and military tasks in military conditions that require physical effort, emphasizing an approach to training in which a smaller volume , but a higher intensity in combined training can be a possible and effective way to improve the military professional qualities of recruits and servicemen. In [17], the issue of the influence of non-traditional military physical training is considered. The review analyzes the effects of exercise on various domains of physical fitness (eg, aerobic fitness, flexibility, muscular endurance, muscular strength, muscular strength and work-related physical performance) that influence occupational performance.

The issue of optimization of modern physical training of military personnel is also considered in works [18–22]. A number of works are devoted to the state of health and the training process of female military personnel [23–28].

Some authors conduct a comparative analysis of the training of male and female military personnel, in particular their training load, gender differences in physical requirements [29–47] using the example of training in the armed forces of Great Britain, Australia and Israel. Another problem is the worldwide deterioration of physical fitness and the increase of fat deposits among young people. Therefore, knowledge about optimizing physical adaptation and performance through physical training is vital. Research has shown that military training requires a greater variety of training stimuli to induce more effective training adaptations, especially when considering the development of maximal or explosive strength and maximal aerobic capacity. In addition, some individual programming is required to avoid unnecessary injuries and overloads, as differences in soldiers' initial fitness can be very large. It is clear that a large number of works are devoted to the optimization of modern physical training of military personnel, including works on the health status and training process of female military personnel, a comparative analysis of the training of male and female military personnel, in particular, their training load, gender differences in physical requirements .

The purpose of the paper is to develop, on the basis of mathematical models of the body's functional systems, intelligent technology to support decision-making regarding the optimization of physical training of military personnel.

OUTLINE OF THE MAIN MATERIAL

Development of the theory of dynamic games, the theory of optimal control and computational methods of optimization [9]. We created the prerequisites for the creation of instrumental and software tools for computer analysis of the state of the organism in a disturbed environment. Mathematical models of functional body systems and their computer analysis definitely complement the system experimental and clinical data, which are obtained by traditional for methods of physiology and medicine. Over the past half century, cooperation allowed mathematicians, physicists and physiologists to build mathematical models almost all systems and processes studied by human physiology. These models are most fully presented in a number of monographs, the analysis of which is contained in particular in [48–50]. It is known that all physiological systems of the body are multifunctional; mathematical models, as a rule, are built to study one or, in the best case, several functions of a system. When studying the possibilities of adaptation of the organism to certain environmental disturbances, it is desirable to take into account the possibility of the participation of intersystem mechanisms in the process of stabilizing the state of the organism with taking into account both intra-system and inter-system conflicts situations that arise at the same time.

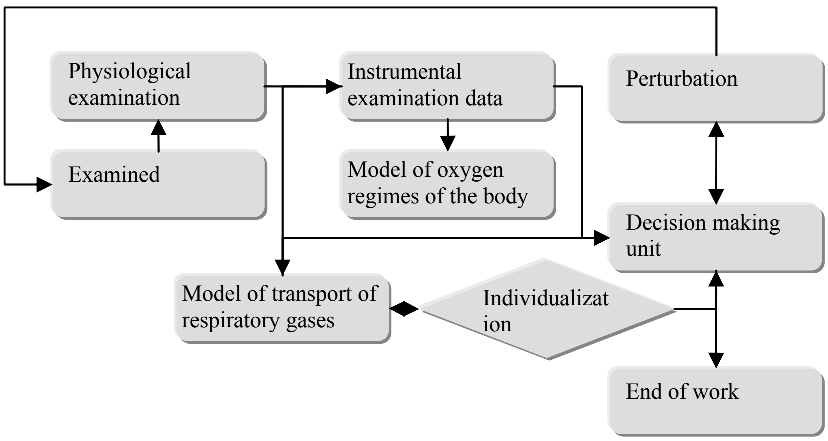

Fig. 1. Complex to support decision-making regarding the optimization of physical training of military personnel

The method of mathematical modeling is an important tool for studying the regularities underlying the functioning of complex systems of an arbitrary nature, including biomedical ones. The basic principle of mathematical modeling of complex systems is the principle of optimality. Mathematical analysis of physiological functions includes two types of models: data models and systems models.

Usually, the results of the analysis of a physiological experiment with the construction of a data model are the initial material for the next stage of research — a systematic analysis of these data models and the construction of a mathematical model of the functioning of the system being studied, aimed at elucidating the fundamental physiological mechanisms underlying its functioning. These principles were used to develop a complex of mathematical, algorithmic and software to support decision-making regarding the optimization of physical training of military personnel (Fig. 1).

MATHEMATICAL MODEL OF REGULATION OF OXYGEN REGIMES OF THE BODY

Aerobic performance, in particular, oxidative phosphorylation is the most efficient and economical process of ATP formation compared to glycolytic processes in the human body. The implementation of oxidative phosphorylation completely depends on the state and development of the FRS and its component — the system of regulation of the body's oxygen regime (KRO) [51].

Currently, one of the most effective and relatively simple ways to obtain information about the functional state of the respiratory system is the assessment of the body's oxygen regimes (OR) and the staged delivery of oxygen to the human body, which is based on the concept proposed in [51] regarding the regulation of the body's oxygen regimes, according to which in the body two groups of oxygen transport speed parameters and its partial pressures and stresses at the main stages of the path in the body (lungs, alveoli, arterial blood, mixed venous blood) are interconnected. Analysis of the combination of these two groups of parameters allows us to characterize the function of the body's oxygen supply system quantitatively and qualitatively.

This approach makes it possible to obtain a general characteristic of gas homeostasis with the help of a minimum of indicators, to provide a detailed analysis involving the fundamental mechanisms that ensure the transport of respiratory gases, to carry out a diagnosis of the main syndromes associated with disorders of the gas transport function, to provide an oxygen "portrait" of the organism and its dynamics in various functional states, assess the body's ability to recover from external and internal disturbances. The systematic accumulation of data, their systematization with subsequent processing and analysis provide the possibility of recognition and objectivity of the characteristics of a large number of persons who are examined, make it possible to track the dynamics of changes in the main indicators in the process of general physical training, which contributes to the health of the body and the development of general physical qualities and special physical training, which is professionally oriented and primarily aimed at increasing the body's stability, as well as tracking the dynamics of changes in the main parameters of the soldier's respiratory system and blood circulation. The working algorithm of the KRO model is shown in fig. 2.

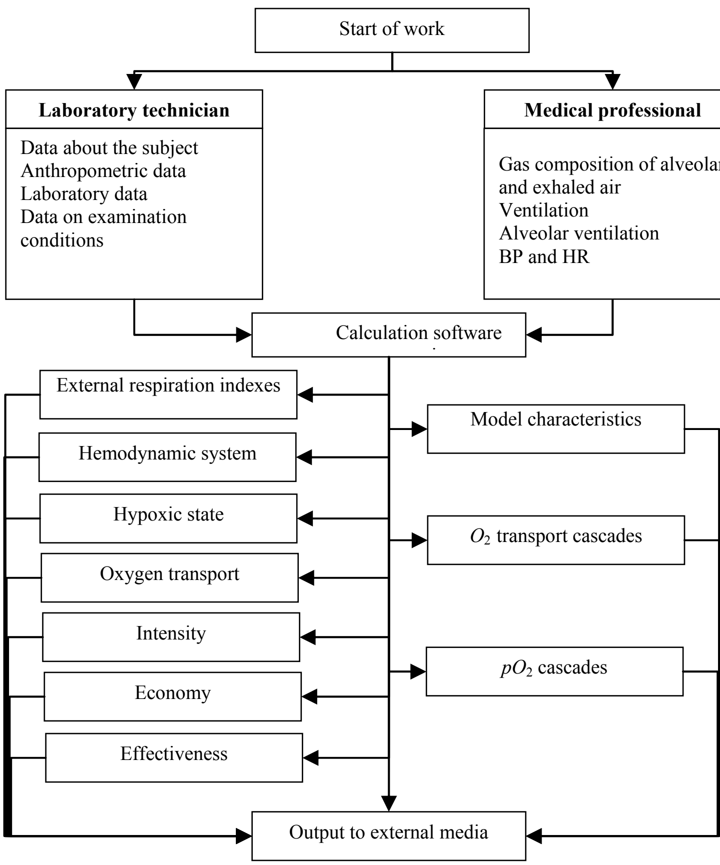

Fig. 2. General scheme of OOR operation

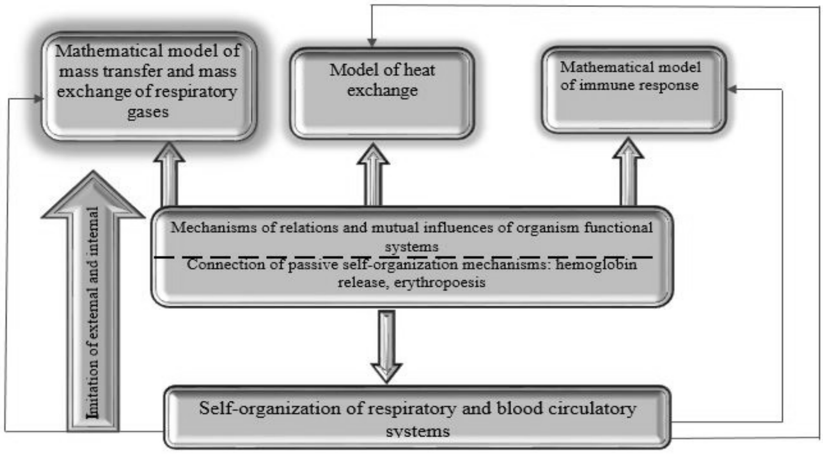

Fig. 3. Integrated model of the body's functional systems

Based on the given algorithm, an automated information system of functional diagnostics [52] was developed, which allows to speed up the processing of the data obtained during the examination many times over; implement a diagnostic algorithm for assessing the functional state of athletes; centrally accumulate information for its preliminary processing, storage and collective use; to create an algorithmic apparatus to ensure the possibility of proving scientific propositions, developing options for optimizing decisions when assessing professional suitability.

When studying the adaptation of the organism to certain disturbances, it is desirable to take into account the possibility of participation of intersystemic mechanisms in the process of stabilizing the state of the organism, taking into account both intrasystemic and intersystemic conflict situations. In response to the outrageous influence of the environment, external or internal, all functional systems of the organism, to one degree or another, react to it, trying to stabilize the state, despite the contradiction between goals and interests. The structural scheme of the complex mathematical model for the study of the main functional systems — breathing and blood circulation, heat exchange, the immune system and the mechanisms of their mutual influence and interconnection during the implementation of vital activities in extreme conditions of the external and internal environment is shown in fig. 3.

MATHEMATICAL MODEL OF THE FUNCTIONAL RESPIRATORY SYSTEM

Each of the specified models of functional systems is described inherent to it by a system of specific parameters that evaluate the condition of this system. The parameters of the mechanism model seem appropriate tie the interaction of the body's functional systems to the respiratory system and blood circulation, through which, first of all, all body systems are supplied with oxygen, and which carry out the transport of energy substances, heat, enzymes and other bioenergetic substances, without which the vital activity of the body is impossible. We also note that experimental data and theoretical studies make it possible to state that the nature of the dynamics of minute blood volume in a healthy body depends on the intensity of metabolic processes in tissues, the gas composition and other characteristics of the inhaled mixture, the temperature of the environment, other external and internal disturbances. The proposed model precisely takes into account the occurrence of such situations and their compromise solutions using the example of the interaction of the respiratory and circulatory systems, thermoregulation and the immune system, the construction of mathematical models, which have received the most attention in the world and domestic literature.

Note that the model is based on the principle of performing the main function of the respiratory and circulatory system, namely, timely and adequate delivery of oxygen to metabolizing tissues and the removal of carbon formed during tissue metabolism from tissue reservoirs. Oxygen during the respiratory cycle is transported through the respiratory tract into the alveolar space of the lungs, and then through the alveolar-capillary membranes it enters the blood of the pulmonary capillaries. Circulatory system — arterial blood, branching into the system of tissue capillaries, delivers oxygen to the organs and tissues of the body. Mass transfer of oxygen from the blood to the tissue reservoir is carried out, where tissue respiration takes place. Carbon dioxide, which is a product of metabolism in tissues, diffuses into the blood and is removed by venous blood to the lungs, where it is washed out of the body during exhalation. The partial pressure of respiratory gases of oxygen and carbon in the respiratory tract, alveolar space and their tension in the blood and fluid of tissue capillaries are considered phase variables, which are used to assess the state of the functional system of breathing and blood circulation.

Depending on the goals of mathematical modeling, the apparatus of the theory of differential equations with concentrated or distributed parameters is usually used to assess the functional state of the respiratory system [53, 54]. Since the mathematical model of the functional system of breathing and blood circulation was built to study the mechanisms of self-regulation and adaptation of the body to the disturbance of the external and/or internal environment, the dynamics of partial pressures and stresses of respiratory gases in the structures of the body is described by a system of ordinary differential equations. The principles of material balance and flow continuity were used for their construction.

Using a systematic approach to describe the process of mass transfer of respiratory gases in the body, we will present the respiratory system in the form of a controlled system in which the mass transfer of oxygen and carbon dioxide is carried out and a control system that produces certain effects that ensure the normal course of the gas mass transfer process [55]. The mathematical model of the controlled part of the respiratory system in [52, 53] is described by a system of ordinary differential equations that describe the dynamics of oxygen tension at all stages of its path in the body, in a brief form it looks like

$$\frac{dp_iO_2}{d\tau} = \varphi(p_iO_2, p_iCO_2, \eta_i, \dot{V}, Q, Q_{t_i}, G_{t_i}O_2, q_{t_i}O_2), \qquad (1)$$

$$\frac{dp_iCO_2}{d\tau} = \psi(p_iO_2, p_iCO_2, \eta_i, \dot{V}, Q, Q_{t_i}, G_{t_i}CO_2, q_{t_i}CO_2), \qquad (2)$$

where the functions φ and ψ are described in detail in [50, 53, 54]: $\dot{V}$ — ventilation, η — the degree of saturation of hemoglobin with oxygen, Q — the volumetric rate of systemic and Q_{t_i} — local blood circulation, $q_{t_i}O_2$ — the rate of oxygen consumption by the i-th tissue reservoir, $q_{t_i}CO_2$ the rate of release of carbon dioxide in the i-th tissue reservoir. The rate of flow of oxygen from the blood to the tissue $G_{t_i}O_2$ and carbon dioxide $G_{t_i}CO_2$ from the tissue to the blood is determined by the ratio

$$G_{t_i} = D_{t_i}S_{t_i}(p_{ct_i} - p_{t_i}), \qquad (3)$$

where D_{t_i} are gas permeability coefficients through the aerogematic barrier, S_{t_i} is the area of the gas exchange surface.

MATHEMATICAL MODEL OF THE MECHANISMS OF REGULATION OF THE MAIN FUNCTION OF THE RESPIRATORY SYSTEM

In [55] it was proposed to consider the breathing process described by equations (1) – (2) as a controlled dynamic system. There is a significant amount of experimental data on the reaction of the respiratory system to external and internal disturbances, namely: $\dot{V}$ the amount of alveolar ventilation changes significantly Q — volume velocity systemic blood circulation, vasodilatation (vasoconstriction) of tissue vessels and, as a result, changes in them. volume velocity of blood circulation Q_{t_i}. That is why, in mathematical modeling, the parameters $\dot{V}$, Q, Q_{t_i} are considered as controlling, respectively, respiratory muscles, cardiac muscles, and vascular smooth muscles, the work of which ensures the values of these vapor parameters necessary for the stabilization of the main function of breathing, as the executive organs of active regulation. The system of equations (1) – (2) is asymptotically stable, so it can be assumed that the goal of regulation is to bring the disturbed system to a relatively balanced state, which occurs when

$$\left|G_{t_i}O_2 - q_{t_i}O_2\right| \le \varepsilon_1, \ \left|G_{t_i}CO_2 + q_{t_i}CO_2\right| \le \varepsilon_2, \qquad (4)$$

where $\varepsilon_1, \varepsilon_2$ are arbitrarily small positive numbers. Metabolism in the body occurs at the tissue level in the fluid of the tissue capillary. The products of metabolism are carbon dioxide, which is released at a rapid rate $q_{t_i}CO_2$, and water. Oxygen is delivered to the cylinder by blood flow at a speed $G_{t_i}O_2$, carbon dioxide is removed at a speed $G_{t_i}CO_2$. Condition (4) is a requirement for the performance of the main function of the respiratory system — timely and adequate delivery of oxygen to the tissues of working organs and the same process of removing carbon dioxide, which was formed in the process of metabolism. The set of system states for which (4) is satisfied is defined as the terminal set M of the dynamic system control problem. Of course, the control parameters are limited, the limits are determined from experimental data

$$\dot{V}_{\min} \le V \le V_{\max}, \quad Q_{\min} \le Q \le Q_{\max}, \quad Q_{t_i \min} \le Q_{t_i} \le Q_{t_i \max}, \quad \sum_{t_i} Q_{t_i} = Q. \tag{5}$$

Since the conditions of Filipov's theorem [56] are fulfilled, the control problem — the derivation of a perturbed dynamic system into a set M under constraints (5) has the solution Of all the solutions of the control problem, the optimal parameters $\dot{V}_{onm}, Q_{onm}, Q_{t_i onm}$ will be those that ensure the minimum of the functional on the state change trajectory dynamic system

$$\dot{I} = \int_{\tau_0}^{T} \left[\rho_1 \sum_{t_i} \lambda_{t_i} \left(G_{t_i} O_2 - q_{t_i} O_2 \right)^2 + \rho_2 \sum_{t_i} \lambda_{t_i} \left(G_{t_i} CO_2 + q_{t_i} CO_2 \right)^2 \right] d\tau \tag{6}$$

on the set of all values $\dot{V}_{onm}, Q_{onm}, Q_{t_i onm}$, where ρ_1, ρ_2 are the coefficients of the body's sensitivity to hypoxia and hypercapnia, λ_{t_i} — coefficients characterizing the importance of this or that organ or tissue for life.

Coefficients λ_{t_i} are formed through evolution. It is known that damage to the heart muscle, brain tissue, liver, kidneys and some others leads to loss of life, and perhaps that is why the density of capillaries in them is quite high. In mathematical modeling, dependence is accepted

$$\lambda_{t_i} = \frac{V_{ct_i}}{V_{t_i}}. \tag{7}$$

Even with such a simple form of dependence, it becomes obvious what is what more blood in the tissues of the organ and the smaller its volume, the more acute tissues experience a lack of oxygen and hypercapnia.

MATHEMATICAL MODELS OF HEAT EXCHANGE AND THERMOREGULATION

The heat exchange system is most closely related to the functional respiratory and circulatory system, thermal energy is the result of tissue metabolism and receives additional heat from the environment. Heat is distributed in the body by circulating blood. But when building a mathematical model of heat exchange and thermoregulation, it is necessary to take into account the differences — if oxygen enters the body through the respiratory tract and carbon is removed in the same way, then the heat evaporates mainly through the skin and spreads not only through the blood, but also convectively, from one region to another. It is known that as a result of exchange processes that take place in body, a certain amount of heat is released, while the amount of heat that produced in the body should be equal to the amount of heat that discharged into the environment.

To assess the temperature distribution in the body, the most productive multicompartmental mathematical models of energy were revealed processes of heat exchange and thermoregulation developed in [57]. In this model, two processes are clearly distinguished — the process of passive heat transfer and the process of active transfer as a control process that ensures thermal homeostasis of the body under the influence of external disturbances. The passive transfer model describes the processes of heat generation, heat transfer, and heat exchange and is essentially a model of the thermophysical properties of the body. Therefore, this part of the model is built on the basis of well-studied physical laws. The mathematical model of heat transfer is based on the equation heat balance written for the elementary unit representing is a volume of cylindrical shape — a compartment. The geometric shape of the body and the structure is defined by a set of compartments and established connections between them. Depending on the goals of modeling, you can choose different ones structures included in some class of models. Difference of models consists in the degree of detailing of the display of heat generation processes, heat transfer and heat exchange, as well as human temperature topography.

Let T_i is the average temperature in the structural unit of the respiratory and circulatory system. We denote by c, ρ — the specific heat capacity and density of blood in individual structures, $c_{t_i}, v_{t_i}, \mu_{t_i}$ — the specific heat capacity, mass and rate of change of heat production for the t_i tissue reservoir, respectively, γ_{t_i} — the thermal conductivity coefficient between the volumes of blood and tissue, S_{t_i} — the surface area on which heat exchange is carried out in the "blood" system - tissues", $D_{t_i,t_i-1}(\tau), D_{t_i,t_i+1}(\tau)$ — heat flows forming heat transfer between t_i and t_{i+1} tissue volumes and adjacent along the length of the generalized capillary, and — Q_{t_i} volume speed of blood in tissue capillaries. In [57], a system of ordinary differential equations describing changes in the temperature of arterial blood, in the structures of tissue blood, mixed venous blood, and pulmonary capillary blood, which can be generally written as:

$$\frac{dT_i(\tau)}{d\tau} = \phi(T, T_{t_i}, Q, Q_{t_i}, v_t, \mu_t, c_t, V_i, G_{t_i}, D_{t_i}), \tag{8}$$

where $Q = \sum_{t_i} Q_{t_i} = Q_{Sh} + Q_{LC}$, G_{Res} -is the value of the heat flow, which represents heat loss to the environment through the respiratory pathway. The main heat exchange flows with the environment are carried out through the skin — therefore, the equation of temperature change in the skin should be present in the mathematical model of heat exchange. Like the functional respiratory system, the heat exchange system in the body is presented as a regulated system during modeling. In the proposed model, it is considered that the purpose of regulation is to bring the disturbed heat exchange system to some equilibrium state, in which the relation is fulfilled for all tissue regions

$$\theta(\tau) = \mu_{t_i} - G_{t_i}\left(T(\tau)\right) - D_{t_i,t_{i-1}}(\tau) + D_{t_i,t_{i+1}}(\tau) = 0 . \tag{9}$$

At the same time, the following effector physiological reactions of evaporation $G_{EV}(\tau)$ from the surface of the skin act as the parameters of regulation, as the main action of the body, which protects it from overheating; speed of heat production in muscles μ_{t_i} , taking into account the effect of thermal shivering; volume velocities of tissue blood circulation $Q_{t_i}, i = \overline{1,m}$.

The quality of heat exchange system regulation processes can be assessed by the ability of the system to provide a minimum of functionality

$$\dot{J} = \int_{\tau_0}^{\tau^*} \left[\sum_{t_i} \kappa_{t_i} \theta_{t_i}^2(\tau) + \sum_{t_i} \omega_{t_i} \left(\mu_{t_i}(\tau) - \mu_{t_i}^N \right)^2 \right] d\tau , \tag{10}$$

where the first term in the integrand characterizes the disturbance of the heat balance in all tissue regions under consideration, and the second term is the body's energy expenditure. In (10) κ_{t_i} are coefficients that determine the sensitivity of various tissues to thermal imbalance, and ω_{t_i} — sensitivity to imbalance and energy consumption.

As already mentioned, the main mechanism of heat production by working muscles, the excess of which must be removed to the environment to maintain the thermal balance of the body, is evaporation from the surface of the skin. Naturally, the function of the sweat glands intensifies. To maintain it, it is necessary to increase the volumetric velocity of blood circulation in the skin either due to the redistribution of systemic circulation, or due to the increase of the volumetric velocity of blood circulation in the arterial and venous channels. The first means that with an unchanged volume velocity of blood, it is necessary to reduce the volume velocity of tissue blood in other tissue reservoirs. Thus, a conflicting situation arises, since the decrease Q_{t_i} leads to the occurrence of hypoxia in this tissue reservoir and blood acidosis. In the second case, the increase Q is possible only with the intensification of the work of the heart muscle, which is completely impossible in the conditions of a compromise solution to the conflict situation. It is obvious that the establishment of thermal balance in the body depends significantly on the temperature of the external environment

MATHEMATICAL MODEL OF THE IMMUNE RESPONSE AND MECHANISMS OF ITS INTERACTION WITH MODELS OF RESPIRATORY, BLOOD CIRCULATION AND HEAT EXCHANGE SYSTEMS

The simplest model of immune response [58] is based on the fundamental principles of immune protection formulated in the clonal selection theory of F. Barnett and the basic principles of pathophysiology. The model considers the interaction of four components of the system: antigen, antibody, plasma cell and quantitative characteristics of the affected organ and is based on the following provisions of immunology: the antibody binds the antigen, forming an antibody-antigen complex; after some time, plasma cells that produce antibodies are formed in the body in proportion to the number of antibody-antigen complexes; the number of plasma cells formed as a result of antigenic stimulation depends on the viability of the affected organ: as the damage to the organ increases, the formation of plasma cells decreases, which, in turn, affects the activity of the immune system.

The dynamics of the damage process in [58] is described by a system of ordinary differential equations, which in abbreviated form can be presented as

$$\frac{dL(t)}{dt} = q(c, V, F, m), \tag{11}$$

where $L(t)$ — the rate of reproduction of the corresponding protein structures that participate in immune-reactive processes in the body, $V(t)$ — the concentration of proliferating pathogenic antigens, $C(t)$ the concentration of plasma cells of the population of carriers and antibody producers (immunocomponent cells and immunoglobulin producers), $F(t)$ — the concentration of antibodies (substrates of the immune system, which neutralize antigens (immunoglobulins, cell receptors)), $m(t)$ is a relative characteristic of the affected organ. If M is the characteristic of a healthy organ (mass or area), and M' is the corresponding characteristic of the healthy part of the affected organ, then the relative characteristic of damage to the target organ m can be written in the form

$$m = 1 - \frac{M'}{M}, \tag{12}$$

It is obvious that $m = 0$ for an unaffected organ and $m = 1$ for a completely affected organ. It is obvious that the pathological condition that develops in the body with damage to the body, which is controlled by the immune system, can be considered as a disturbance when considering and modeling the circulatory system. The other is also true — the change in volume velocity of blood through the affected organ should affect the course of recovery. It is natural to assume that the values σ and μ_m are functions of the volume velocity of regional blood circulation through the capillaries of the affected organ. But, based on the main function of the respiratory system, the dynamics of systemic and regional blood circulation is directly related to the change in the gas profile of the body and the intensity of exchange processes in individual tissue regions. When considering the joint modeling of the respiratory system, blood circulation and the immune system and their regulation, it is necessary to add to the regulation quality criterion (6) in the integral expression member

$$\rho_{\eta_k} f_k^2(m(\tau), V(\tau)), \tag{13}$$

where ρ_{η_k} is the coefficient characterizing the degree of influence of the modeled lesion type on the level of gas homeostasis. The function

$f_k\,(m(\tau),V(\tau))$ determines the degree of damage to the target organ at the current moment. At control points, this function is taken as

$$f_k\,(m,V)=a_k m+b_k \nu\,. \tag{14}$$

It is clear that there is an obvious influence of the immune system on the respiratory system and blood circulation. It can be assumed that the course of energy processes in tissues of the damaged organ is provided only thanks to its intact one parts. In this case, the mass of the part of the metabolizing organ will be determined by the formula

$$\nu_{t_k}(\tau)=\nu_{t_k}^0(1-m(\tau)), \tag{15}$$

where is $\nu_{t_k}^0$ the total mass (volume) of tissues of a healthy organ.

A more significant role in determining the mutual influence of these systems is played by $q_{t_k}O_2$ — the rate of oxygen consumption in the tissue reservoir. Change magnitude $q_{t_k}O_2$ leads to an instantaneous change in the magnitude of Q_{t_k}, and this, in turn, leads to a change in all input parameters in the immune response model. Let's consider two variants of the effect of damage on energy exchange in the target organ. The first one is related to the assumption that the rate of oxygen consumption $q_{t_k}O_2$ does not depend on the degree of damage to the cells, that is, the unaffected cells compensate for the metabolic functions of the damaged ones without additional energy expenditure. The second with the assumption that the unit mass of the intact part of the damaged organ is does not change its rate of oxygen consumption during metabolism and then

$$q_{t_k}O_2=q_{t_k}^0 O_2(1-m(\tau)), \tag{16}$$

where $q_{t_k}^0 O_2$ is the rate of oxygen consumption in a normally functioning organ. In accordance:

$$q_{t_k}CO_2(\tau)=\sigma_{t_k}q_{t_k}O_2(\tau), \tag{17}$$

where σ_{t_k} is the respiratory coefficient.

Taking into account the mutual influence of the immune system and the respiratory and circulatory systems in mathematical modeling allows you to predict the course of recovery after a lesion, taking into account possible reactions to this lesion of the respiratory and circulatory systems in the form of a change in the state of these systems and its necessary regulatory correction.

The quality criterion of self-organization is evaluated by the minimum functionality:

$$\int_{t^*}^{t^*+\Delta t}[\rho_1\sum_{i=1}^{n}\lambda_{t_i}(G_{t_k}O_2(\xi)-q_{t_k}O_2(\xi))^2+\rho_2\sum_{i=1}^{n}\lambda_{t_i}(G_{t_i}CO_2(\xi)+q_{t_i}\ CO_2(\xi))^2+ \\ +\rho_{3_k}f_k^2(m(\xi),V(\xi))]d\xi \qquad (18)$$
,

where $G_{t_i}O_2(\xi), G_{t_i}CO_2(\xi)$ — flows of O_2, CO_2 through the capillary-tissue membranes of that tissue at the moment of time ξ; $q_{t_i}O_2(\xi)$, $q_{t_i}CO_2(\xi)$ — rates of utilization of oxygen and release of carbon dioxide by the i -th tissue; $f_k(m(\xi),V(\xi))$ — an indicator characterizing the degree of organ damage (k — that tissue reservoir); λ_{1_i}, λ_{2_i} coefficients characterizing morphological and physiological features for each gas for the ith tissue; ρ_1, ρ_2, — coefficients of sensitivity of the entire organism to hypoxia, hypercapnia; ρ_{3_k} — coefficient characterizing the degree of influence of the modeled type of disease on the level of gas homeostasis; t^* — the point in time, starting from which the control quality criterion is evaluated; Δt — the time during which the dynamics of gases and parameters of the immune system are evaluated to determine the management quality indicator.

CONCLUSIONS

The proposed complex of mathematical, algorithmic and software in various modifications was widely used to solve a number of problems of occupational medicine and sports, including for the study of the process of adaptation of operators of continuous interaction systems, in particular, members of the flight crew to work under the combined effect of extreme conditions flight and increased situational stress [50], mountain rescuers under the combined influence of load hypoxia and hypoxic hypoxia [50], women to extreme loads during professional sports activities [59–61]. That is why it seems that the proposed complex of mathematical, algorithmic and software will be useful for supporting decision-making in the physical training of military personnel for professional activities in extreme environments in conditions of conflict and uncertainty.

REFERENCES

1. Platonov V.N. The system of training athletes in Olympic sports. The general theory and its practical applications: book for students of physics universities. education and sports. K.: Olympic literature, 2004, 808 p.
2. Military medical doctrine of Ukraine. Government courier. 07.11.2018. No. 209
3. NATO standard AJP-4.10 allied joint doctrine for medical support Edition C Version 1. September 2019. North Atlantic treaty organization. Allied Joint Publication. Published by the NATO standardization office (NSO), 124 p.
4. Shekera O.H. Views on reforming the system of medical support of the armed forces of Ukraine. Medical support of an anti-terrorist operation: scientific-organizational and medical-social aspects: a collection of scientific works / by General. ed. academicians of the National Academy of Sciences of Ukraine V. I. Tsimbalyuk and A. M. Serdyuk - K.: State Enterprise "Prioritety" Scientific Center, 2016, 316 p. ISBN 978-617-7288-43-4 P. 270–271.

5. Galushka A.M., Zahovskyi V.O., Livinskyi V.G. Medical support of the armed forces of Ukraine: experience, achievements, prospects. *Ukrainian Journal of Military Medicine.* 2021, 1, T.2/ DOI:10.46847/ujmm.2021.1(2)028
6. Decree of the President of Ukraine dated September 24, 2015 No. 555/2015 "On the decision of the National Security and Defense Council of Ukraine dated September 2, 2015 "On the new edition of the Military Doctrine of Ukraine".
7. Resolution of the Cabinet of Ministers of Ukraine dated October 1, 2018 o 910 "On approval of the Military Medical Doctrine of Ukraine".
8. Order of the General Staff of the Armed Forces of Ukraine dated March 12, 2020 No. 100 "On Approval of the Strategy for the Development of the Medical Forces of the Armed Forces of Ukraine until 2035"
9. The doctrine "Medical Forces of the Armed Forces of Ukraine" was approved by the Commander-in-Chief of the Armed Forces of Ukraine on November 13, 2020.
10. Verba A.V., Zhakovskyi V.O., Livinskyi V.G. Medical support of the Armed Forces of Ukraine: state and views on development prospects. Monograph. Kyiv: Lyudmila Publishing House. 2017, 420 p.
11. Khomenko I.P., Lurin I.A., Tsymbalyuk V.I., Zahovskyi V.O., Livinskyi V.G., Galushka A.M., Humenyuk K.V., Shvets A.V., Ivanko O. .M.Medical support of the Armed Forces of Ukraine during the anti-terrorist operation and the operation of the United Forces on the territory of Luhansk and Donetsk regions: a monograph in 3 parts. K.: Lyudmila Publishing House, 2020. Part I, 386 p.
12. Khomenko I.P., Lurin I.A., Tsymbalyuk V.I., Zahovskyi V.O., Livinskyi V.G., Galushka A.M., Humenyuk K.V., Shvets A.V., Ivanko O. M. Medical support of the Armed Forces of Ukraine during the anti-terrorist operation and the operation of the United Forces on the territory of Luhansk and Donetsk regions: a monograph in 3 parts. K.: Lyudmila Publishing House, 2020, Part II – 437 p.
13. Khomenko I.P., Lurin I.A., Tsymbalyuk V.I., Zahovskyi V.O., Livinskyi V.G., Galushka A.M., Humenyuk K.V., Shvets A.V., Ivanko O. M. Medical support of the Armed Forces of Ukraine during the anti-terrorist operation and the operation of the United Forces on the territory of Luhansk and Donetsk regions: a monograph in 3 parts. K.: Lyudmila Publishing House, 2020. Part III , 487 p.
14. Zahovskyi V.O., Livinskyi V.G. Unified medical space and military medicine. Monograph. Kyiv: “Lyudmila” Publishing House. 2018, 336 p.
15. Bilyi, V.Ya., Zhakhovskyi, V.O., & Aslanian S.A. (2021). Evoliutsiia systemy medychnoho zabezpechennia viisk pid chas boiovykh dii. Monohrafiia K. : «Vydavnytstvo Liudmyla». 348 p. (In Ukrainian)
16. Vaara J.P., Groeller H., Drain J., Kyröläinen H., Pihlainen K., Ojanen T., Connaboy C., Santtila M., Agostinelli P., Nindl B.C. Physical training considerations for optimizing performance in essential military tasks. *Eur J Sport Sci.* 2022 Jan;22(1):43–57. doi: 10.1080/17461391.2021.1930193. Epub 2021 Jun 3. PMID: 34006204.
17. Smith C., Doma K., Heilbronn B., Leicht A. Effect of Exercise Training Programs on Physical Fitness Domains in Military Personnel: A Systematic Review and Meta-Analysis. *Mil Med.* 2022, Aug 25;187(9-10):1065-1073. doi: 10.1093/milmed/usac040. PMID: 35247052
18. Vaara J.P., Kalliomaa R., Hynninen P., Kyröläinen H. Physical Fitness and Hormonal Profile During an 11-Week Paratroop Training Period. *J Strength Cond Res.* 2015, Nov;29 Suppl 11:S163-7. doi: 10.1519/JSC.0000000000001033. PMID: 26506182.
19. Santtila M., Pihlainen K., Viskari J., Kyröläinen H. Optimal Physical Training During Military Basic Training Period. *J Strength Cond Res.* 2015, Nov29, Suppl 11:S154-7. doi: 10.1519/JSC.0000000000001035. PMID: 26506180.
20. Haddock C.K., Poston W.S., Heinrich K.M., Jahnke S.Аю, Jitnarin N. The Benefits of High-Intensity Functional Training Fitness Programs for Military Personnel. *Mil Med.* 2016, Nov, 181(11):e1508-e1514. doi: 10.7205/MILMED-D-15-00503. PMID: 27849484; PMCID: PMC5119748

21. Poston W.S., Haddock C.K., Heinrich K.M., Jahnke S.A., Jitnarin N., Batchelor D.B. Is High-Intensity Functional Training (HIFT)/CrossFit Safe for Military Fitness Training? *Mil Med*. 2016, Jul, 181(7):627-37. doi: 10.7205/MILMED-D-15-00273. PMID: 27391615; PMCID: PMC4940118.
22. Gibala M.J., Gagnon P.J., Nindl B.C. Military Applicability of Interval Training for Health and Performance. *J Strength Cond Res.* 2015, Nov, 29 Suppl 11:S40-5. doi: 10.1519/JSC.0000000000001119. PMID: 26506197.
23. Gilchrist J., Jones B.H., Sleet D.A., Kimsey C.D; CDC. Exercise-related injuries among women: strategies for prevention from civilian and military studies. *MMWR Recomm Rep.* 2000, Mar, 31;49(RR-2):15-33. PMID: 15580730.
24. Givens A.C., Bernards J.R., Kelly K.R. Characterization of Female US Marine Recruits: Workload, Caloric Expenditure, Fitness, Injury Rates, and Menstrual Cycle Disruption during Bootcamp. *Nutrients.* 2023, Mar, 28;15(7):1639. doi: 10.3390/nu15071639. PMID: 37049480; PMCID: PMC10096956.
25. Moran D.S., Israeli E., Evans R.K., Yanovich R., Constantini N., Shabshin N., Merkel D., Luria O., Erlich T., Laor A., Finestone A. Prediction model for stress fracture in young female recruits during basic training. *Med Sci Sports Exerc*. 2008, Nov, 40(11 Suppl):S636-44. doi: 10.1249/MSS.0b013e3181893164. PMID: 18849871.
26. Yanovich R., Merkel D., Israeli E., Evans R.K., Erlich T., Moran D.S. Anemia, iron deficiency, and stress fractures in female combatants during 16 months. *J Strength Cond Res.* 2011, Dec, 25(12):3412-21. doi: 10.1519/JSC.0b013e
27. Greeves J. P. Physiological Implications, Performance Assessment and Risk Mitigation Strategies of Women in Combat-centric Occupations. *Journal of Strength and Conditioning Research* 29.11, Suppl. (2015): S. S94–S100.
28. Szivak T.K., Mala J., Kraemer W.J. Physical performance and integration strategies for women in combat arms. *Strength and conditioning journal*. 2015, 37(4), pp. 20-29. doi:10.1519/SSC.0000000000000137
29. O'Leary T.J., Saunders S.C., McGuire S.J., Venables M.C., Izard R.M. Sex Differences in Training Loads during British Army Basic Training. *Med Sci Sports Exerc.* 2018, Dec, 50(12):2565-2574. doi: 10.1249/MSS.0000000000001716. PMID: 30048410
30. Jurvelin H., Tanskanen-Tervo M., Kinnunen H., Santtila M., Kyröläinen H. Training Load and Energy Expenditure during Military Basic Training Period. *Med Sci Sports Exerc.* 2020, Jan, 52(1):86-93. doi: 10.1249/MSS.0000000000002092. PMID: 31343524.
31. Richmond V.L, Carter J.M., Wilkinson D.M., Homer F.E., Rayson M.P., Wright A., Bilzon J.L. Comparison of the physical demands of single-sex training for male and female recruits in the British Army. *Mil Med*. 2012, Jun, 177(6):709-15. doi: 10.7205/milmed-d-11-00416. PMID: 22730848.
32. Blacker S.D., Wilkinson D.M., Rayson M.P. Gender differences in the physical demands of British Army recruit training. *Mil Med.* 2009, Aug, 174(8):811-6. doi: 10.7205/milmed-d-01-3708. PMID: 19743735
33. Orme G.J., Kehoe E.J. Women and Men Together in Recruit Training. *Mil Med.* 2018, May, 1;183(5-6):e147-e152. doi: 10.1093/milmed/usx098. PMID: 29425352
34. Varley-Campbell J., Cooper C., Wilkerson D., Wardle S., Greeves J., Lorenc T. Sex-Specific Changes in Physical Performance Following Military Training: A Systematic Review. *Sports Med*. 2018, Nov, 48(11):2623-2640. doi: 10.1007/s40279-018-0983-4. PMID: 30232790; PMCID: PMC6182553.309. 30.
35. Gibala M.J., Gillen J.B., Percival M.E. Physiological and health-related adaptations to low-volume interval training: influences of nutrition and sex. *Sports Med.* 2014, Nov, 44 Suppl 2(Suppl 2):S127-37. doi: 10.1007/s40279-014-0259-6. PMID: 25355187; PMCID: PMC4213388.
36. Dada E.O., Anderson M.K., Grier T., Alemany J.A., Jones B.H. Sex and age differences in physical performance: A comparison of Army basic training and operational populations. *J Sci Med Sport*. 2017, Nov, 20 Suppl 4:S68-S73. doi: 10.1016/j.jsams.2017.10.002. Epub 2017 Oct 18. PMID: 29100826.

37. Santtila M., Pihlainen K., Vaara J., Tokola K., Kyröläinen H. Changes in physical fitness and anthropometrics differ between female and male recruits during the Finnish military service. *BMJ Mil Health.* 2022, Oct, 168(5):337-342. doi: 10.1136/bmjmilitary-2020-001513. Epub 2020 Sep 30. PMID: 32999088.
38. Santtila M., Pihlainen K., Vaara J., Nindl B.C., Heikkinen R., Kyröläinen H. Aerobic fitness predicted by demographics, anthropometrics, health behaviour, physical activity and muscle fitness in male and female recruits entering military service. *BMJ Mil Health.* 2022, Oct, 21:e002267. doi: 10.1136/military-2022-002267. Epub ahead of print. PMID: 36270735.
39. Wentz L, Liu P.Y., Haymes E., Ilich J.Z. Females have a greater incidence of stress fractures than males in both military and athletic populations: a systemic review. *Mil Med.* 2011, Apr, 176(4):420-30. doi: 10.7205/milmed-d-10-00322. PMID: 21539165.
40. Bell N.S., Mangione T.W., Hemenway D., Amoroso P.J., Jones B.H. High injury rates among female army trainees: a function of gender? *Am J Prev Med.* 2000, Apr, 18(3 Suppl):141-6. doi: 10.1016/s0749-3797(99)00173-7. PMID: 10736550.
41. Anderson M.K., Grier T., Dada E.O., Canham-Chervak M., Jones B.H. The Role of Gender and Physical Performance on Injuries: An Army Study. *Am J Prev Med.* 2017, May, 52(5):e131-e138. doi: 10.1016/j.amepre.2016.11.012. Epub 2016 Dec 21. PMID: 28012810.
42. Yanovich R., Evans R., Israeli E., Constantini N., Sharvit N., Merkel D., Epstein Y., Moran D.S. Differences in physical fitness of male and female recruits in gender-integrated army basic training. *Med Sci Sports Exerc*. 2008, Nov, 40(11 Suppl):S654-9. doi: 10.1249/MSS.0b013e3181893f30. PMID: 18849869.э
43. Daniels W.L., Wright J.E., Sharp D.S., Kowal D.M., Mello R.P., Stauffer R.S. The effect of two years' training on aerobic power and muscle strength in male and female cadets. *Aviat Space Environ Med*. 1982, Feb, 53(2):117-21. PMID: 7059326.
44. Daniels W.L., Kowal D.M., Vogel J.A., Stauffer R.M. Physiological effects of a military training program on male and female cadets. *Aviat Space Environ Med*. 1979, Jun, 50(6):562-6. PMID: 475702.
45. Jacobson I.G., Donoho C.J., Crum-Cianflone N.F., Maguen S. Longitudinal assessment of gender differences in the development of PTSD among US military personnel deployed in support of the operations in Iraq and Afghanistan. *J Psychiatr Res.* 2015, Sep, 68:30-6. doi: 10.1016/j.jpsychires.2015.05.015. Epub 2015 Jun 1. PMID: 26228397.
46. Blacker S.D., Wilkinson D.M., Rayson M.P. Gender differences in the physical demands of British Army recruit training. *Mil Med*. 2009, Aug, 174(8):811-6. doi: 10.7205/milmed-d-01-3708. PMID: 19743735.
47. Wood P.S., Grant C.C., du Toit P.J., Fletcher L. Effect of Mixed Basic Military Training on the Physical Fitness of Male and Female Soldiers. *Mil Med.* 2017, Jul, 182(7):e1771-e1779. doi: 10.7205/MILMED-D-16-00218. PMID: 28810971.
48. Chikrii A.A. Conflict controlled processes. Boston; London; Dordrecht: Springer Science and Business Media, 2013, 424 p.
49. Bobryakova I.L. Sensitivity of the mathematical model and optimal regulation of the functional respiratory system. diss. Candidate of Physics and Mathematics Nauk, Kyiv, 2000. 179 p.
50. Aralova N. I. Mathematical models of functional respiratory system for solving the applied problems in occupational medicine and sports. Saarbrücken: LAP LAMBERT Academic Publishing GmbH&Co, KG. 2019, 368 p. (In Russian)
51. Kolchinskaya A.Z., Lauer N.V., Shkabara. Ye.A.. About the regulation of body oxygen regimes. Oxygen organism regime and its regulation. K.: Nauk.Dumka, 1966. P. 157–200.
52. Aralova A.A., Aralova N.I., Klyuchko O.M., Mashkin V.I., Mashkina I.V. Information system for the examination of organism adaptation characteristics of flight crews' personnel. *Electronics and control systems.* 2018, 2, pp. 106-113. DOI: 10.18372/1990-5548.52.11882
53. Onopchuk Yu.N. Homeostasis of functional respiratory system as a result of intersystem and system-medium informational interaction. Bioecomedicine. Uniform information space. Ed. by V. I. Gritsenko. Kyiv. Naukova dumka, 2001, pp. 59–84.
54. Onopchuk Yu. N.Homeostasis of the functional circulatory system as a result of intersystem and system-medium informational interaction. Bioecomedicine. Uniform information space. Ed. by V. I. Gritsenko. Kyiv, Naukova dumka, 2001, pp. 85–104.

55. Polynkevich K.B., Onopchuk Yu.N. Conflict situations at regulating of the main function of organism respiratory system and mathematical models of their resolution. *Cybernetics.* 1986, 3, pp. 100-104. (In Russian)
56. Filippov A.F. Differentional equations with discontinuous right-hand sides. Mathematics and Its Applications. Springer Dordrecht, 1988, 304 p. DOI https://doi.org/10.1007/978-94-015-7793-9
57. Ermakova I.Y. Mathematical modeling of human thermoregulation processes. M.: BLAME, 1987, 134 p.
58. Marchuk G.I. Mathematical models in immunology. M.: Nauka, ch. Ed. Phys.-Math. Lit, 1991, 304 p.
59. Shakhlina L.J.G. Medizinisch-biologische Grunglagendes sportlichen Trainings von Frauen. Bundesinstitut für Sportwissenschaft. Bonn: 2010, 322 p.
60. Aralova N.I., Shakhlina L.Ya.-G. The mathematical models of functional self-organization of the human respiratory system with a change pf the hormonal states of organism. *Journal of Automation and Information Sciences.* 2018, 3: 132-141. DOI: 0.1615/JAutomatInfScien.v50.i5.50 pages 49–59
61. Aralova N.I. Shakhlina L.Ya.-G. Futornyi S.M. Mathematical Model of High-Skilled Athlete's Immune System. *Journal of Automation and Information Sciences*. 2019, pp. 56-67. DOI: 10.1615/JAutomatInfScien.v51.i3.60

Received 28.08.2023

Аралова Н.І. [1], д-р. техн. наук, старш. наук. співроб.,
старш. наук. співроб. відд. оптимізації керованих процесів
https://orcid.org/0000-0002-7246-2736, e-mail: aralova@ukr.ne
Радзійовський П.О. [2], д-р біол.наук, проф.,
проф. фак-ту фізіотерапії
https://orcid.org/0000-0001-8232-2705, e-mail: p.radziejowski@wseit.edu.pl
Радзійовська М.П. [3], д-р біол.наук, проф.,
проф. фак-ту менеджменту, відд. інновацій та систем безпеки керування
https://orcid.org/0000-0002-9845-390X, e-mail: maria.radziejowska@pcz.pl
Аралова А.А. [1], канд. фіз.-мат.наук,
наук. співроб. відд. методів дискретної оптимізації, математичного моделювання та аналізу складних систем
https://orcid.org/0000-0001-7282-2036, email: aaaralova@gmail.com
[1] Інститут кібернетики імені В.М. Глушкова НАН України,
40, пр. Глушкова, 03187, Київ, Україна
[2] Вища Школа Едюкації та Терапії ім. проф. Казімери Мілановської,
22, вул. Грабова, 61-473,Познань, Польща
[3] Честоховський Технічний Університет,
19b, вул. Армії Крайової, 42-200, Честохова, Польща

ІНТЕЛЕКТУАЛЬНІ ТЕХНОЛОГІЇ ПІДТРИМКИ ПРИЙНЯТТЯ РІШЕНЬ ЩОДО ОПТИМІЗАЦІЇ ФІЗИЧНОЇ ПІДГОТОВКИ ВІЙСЬКОВОСЛУЖБОВЦІВ

Вступ. *В Медичній доктрині НАТО та у Воєнно-медичній доктрині України наголошується на необхідності застосування наукових підходів до охорони здоров'я, фізичної підготовки та супроводження спеціальних операцій. Звичайно, екстремальні умови професійної діяльності вимагають від особового складу відповідної підготовки та здатності до адаптації. Професійний відбір та підготовка мають бути, з одного боку, науково обґрунтовані та об'єктивізовані, з іншого, застосовувати індивідуальний підхід, максимально ефективними. Наразі це неможливо без застосування інформаційних технологій.*

Мета статті. *Розробити на основі математичних моделей функціональних систем організму інтелектуальну технологію для підтримки прийняття рішень щодо оптимізації фізичної підготовки військовослужбовців.*

Методи. *Методи математичного моделювання, чисельні методи оптимізації.*

Результати. *Розроблено інтелектуальну технологію для підтримки прийняття рішень щодо оптимізації фізичної підготовки військовослужбовців, яка містить комплекс математичного, алгоритмічного та програмного забезпечення для оцінювання поточного стану та прогнозування функціонального стану військовослужбовців. Математичне забезпечення охоплює математичні моделі регулювання кисневих режимів організму людини, транспорту та масообміну респіраторних газів в організмі людини, функціональної самоорганізації системи дихання та кровообігу, теплообміну в організмі людини, імунного відклику взаємодії та взаємовпливу цих систем. За наявності відповідного масиву персональних даних технологія може застосовуватися для індивідуального планування фізичної підготовки особового складу.*

Ключові слова: *математичні моделі, інтелектуальна технологія, оптимізації фізичної підготовки військовослужбовців, функціональна система дихання, екстремальні умови професійної військової діяльності, адаптація організму військовослужбовця, чисельні методи оптимізації.*