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MATHEMATICAL MODEL FOR RESEARCH OF ORGANISM RESTORING FOR OPERATORS OF CONTINUOUSLY INTERACTED SYSTEM

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Abstract*—The complex of information support is suggested for the research of organism compensatory and defense reactions for aircrew members under extreme perturbations of internal and external environments as well as pharmacological correction of organism restoring process.*

Index Terms—Mathematic modeling; information support; extreme conditions; compensatory and defense reactions; pharmacological correction.

I. INTRODUCTION

Maintaining of pilot health and work ability at high level is a priority problem for the increase of flight safety and high level of pilot fight readiness. Constant tension of organism compensatory and protective mechanisms of aircrew persons requires development of a special approach to a flight medical support [1]. Therefore the search of the ways to restore their psychophysical and physical state during the work process is ever actual.

II. PROBLEM STATEMENT

Pilot work may be seen as specific kind of operator activity, probably the most complicated among all types of human activities. Aviation contemporary high level, diversity of aviation technique increases the complexity of tasks solved by aircrews' professionals. This causes the increasing of requirements for pilots physical and psychophysical states. It is known that 65% of pilot flight activity is provided by his organism functional state and only 35% of its depends on aircraft technical characteristics [1], [2]. Regulation of pilot activity based on information about his individual characteristics is a widely spread method that used for of his work ability maintenance [1]. According to such approach for pilot work and relaxation organization, planning of flight loading, it is necessary to take into account pilot's health state, his age, level of physical fitness, phychophysiological peculiarities, and professional skills trainings [3]. The purpose of these measures is in necessity to provide perfection of pilot skills through the flight training intensity, functional organism trainings, and high motivation of tasks performing. All these contribute to the prevention of fatigue and accumulation of unfavorable influence of flight factors, as well as full and fast crews' member organisms normal state restoring. This happens due to the fact that effectiveness of pilot professional activity is provided only under the conditions of his balanced skills, his physiological characteristics, and technical condition of aircraft, work hygienic conditions. Pilot work may be seen as operator's work in conditions with continuous interaction [3]. Such type of the work assumes the solution of large complex of problems in limited time intervals and information deficiency, very often – in complex environmental conditions causing pressure increase on pilot's organism with consequence fatigue. Fulfillment of operator's activity needs combination of perception processes, information converting, and decision making of various complexities. It also needs the realization of defined behavioral algorithms.

The term "general fatigue" [5] means temporary functional changes that characterize the decreasing of work ability. Fatigue is a reversible process. It plays security role for the life of organism, for preservation of human health as well as in supporting of proper level of work efficiency. Fatigue may be understood as decrease of human muscle strength and work capacity, increase of number of erroneous actions, very often as increase of heartbeats and breath frequencies, blood pressure, time of received information processing, as well as increase of sensomotoric reactions time interval. Fatigue is revealed also in weakening of resistance concentration and switching of attention, in decrease of operative memory functions and thinking, in reducing of endurance, perseverance, and etc. The scheme of transformation of some fatigue and tension forms in others was demonstrated in [6] from the standpoint of system unity motion of human physiological processes; their relationship with the typical physiological and pathological processes was revealed. We propose the hypothesis of difference between phenomena “fatigue” and "over-fatigue" according to the rate of decrease of organism functional reserves.

From other side, any human activity (physical or mental) causes losses of energy. It is known that released energy is the result of dissolving and oxidation of carbohydrates, especially glucose (glycogen) and catabolism of free fatty acids. Their catabolism needs more oxygen for synthesis of equivalent number of adenosine three phosphates (ATP) molecules in comparison with glycolysis. With sufficient cells supply by oxygen both systems – "glucose" and "fatty acid" energy supply systems - are in state of dynamic equilibrium. In conditions of hypoxia (oxygen deficiency) that happens during the heavy work in conditions of "hypobaric" hypoxia at high altitudes or during high situational stress, the amount of received oxygen is insufficient for the oxidation of fatty acids. This causes accumulation of non-oxidized products, suppression of ATP transport in mitochondria, and consequently, damage of cell membranes. Analysis and evaluation of organism energy resources are rather important for planning of the works with intensive energy depletion, for example for the work of operators of systems with continuous, non-interrupted interactions in conditions of "hypobaric" hypoxia, during organism overloading and changes of environment temperature conditions [4], [7].

III. The Purpose of the Research

Development of mathematical model with further its implementation for theoretical study of possibility of pharmacological preparations use for correction of operator organism functions for those, who work with continuous interactive systems; and for further their organisms recovery after extreme disturbances of external and internal environment.

IV. Problem Solution

A. Theoretical basis of the approach

Hypoxia is defined as misbalance between energy consumption and energy production in the cell system of mitochondrial oxidative phosphorylation [8]. Basic characteristic of this misbalance in the most pathological conditions is a reducing of oxygen delivery to mitochondria. In result of this the reducing of mitochondrial oxidative phosphorylation happens. Energy deficiency at hypoxia leads to Ca^{2+} accumulation in cell cytoplasm because energy-depended Ca^{2+} pumps are blocked (ones that released Ca^{2+} from the cell or input Ca^{2+} to endoplasmic reticulum cavities); also Ca^{2+} accumulation activates Ca^{2+}-dependent phospholipases. One of cell defense mechanisms that prevent Ca^{2+} accumulation in cytoplasm is Ca^{2+} uptake by mitochondria. This increases the metabolic activity of mitochondria, aimed at stability maintenance of intra-mitochondrial charge and proton pump, causing ATP consumption increase. In such a way "defective circle" appears: the lack of oxygen blocks energy metabolism and stimulates free radical oxidation, from other side – free radical processes activation increases energy deficiency through modification of membrane and liposome functions. As the result the irreversible cell damages may appear.

According to some biochemical research [8-10] an improvement of cell energy status may be achieved by:

– improving of the efficiency of deficient oxygen consumption by mitochondria through the separation of oxidation and phosphorylation, by mitochondrial membrane stabilization;

– weakening of Krebs cycle inhibitory reactions by supporting of succinate dehydrohynase activity level;

– restoring of lost components of the respiratory chain;

– economization of oxygen consumption and by reduction of tissues oxygen request;

– production of ATP increasing during glycolysis without increasing of lactate production;

– input of outside high energy substrates.

Our special attention was paid to pharmacological agents with specific influence on metabolism at hypoxia – “antihypoxants”.

B. Supposed role of antihypoxants in health maintenance and recovery

All human activities associated with the depletion of energy resources (sport, intensive work in extreme conditions of hypoxybaric hypoxia, operator activity, and etc.) with the formation of health threatening conditions require pharmacological corrections of organism functions. There are many medical preparations that can make this being non-harmful to human health. Their descriptions and effects are beyond of this our publication.

Antihypoxants are pharmaceutical preparations for enhancing of oxygen absorption by organism and reducing of organs and tissues needs in it, thereby such preparations increase organism resistance in oxygen deficiency conditions.

Production of pharmaceutical preparations is quite expensive. Such pharmaceutical preparations have to be tested carefully on large number of animals, than they need further study in clinical practice, need multi-central wide-ranging studying in different world clinics; all these requires great financial resources. Therefore, previously it would be reasonable to use mathematical models and computer experiments for the demonstration of preparation ability to compensate hypoxic states of any etiology. Basing on hypoxia definitions [8], the mathematical models reflect metabolic biochemical reactions of Krebs cycle in cells, and mitochondria as well.

It is rather important to note the following. These preparations occur multidirectional effect and can be administered in various ways – by inhalation, per or, intramuscularly, intravenously. In addition, different people may demonstrate different reactions on different preparations. So for a quick recovery of organism in extreme conditions it is necessary to choose the best preparation according to its influence and performance in time. Applications of imitation simulation methods are the ways for this problem solution.

V. Results

A. Mathematical model of pharmacological correction of organism damage at hypoxia

With contemporary development of mathematical modeling methods in biology and medicine, an opportunity for the theoretical study of dynamics of organism energy resource changes and resources distribution during the work appears. For the achievement of previously defined results and their quality we suggest mathematical models given below. Some another models were represented in other scientific publications [12] in recent decades, their type depend on the goals and objectives of physiological research for which they were developed.

In our previous publications were proposed the model for evaluating of the reliability of operator work in system of continuous interaction at high situational pressure and environment temperature fluctuations for further rehabilitation of operator [4], [7]. So, this model has to be complemented by the equations for pharmacological preparations transport in organism structures considering their effects on metabolism in tissues.

In basement were lied our results in [13], [14]. Model of pharmacological correction given below was developed to restore organism oxygen regimes by imitation of medical preparation administration by one of three possible ways: intramuscular, intravenous injection, inhalation. If C^f is concentration of any antihypoxants, its dynamic in organism structures may be represented by following system of ordinary differential equations:

$$\frac{dC_D^f}{d\tau} = \frac{\dot{V}}{V_D}\left[\tilde{C}_D^f - \tilde{C}_A^f\right], \qquad (1)$$

$$\tilde{C}_D^f = \begin{cases} \xi d^f, & \begin{array}{ll} \xi = 1 & \text{for inhalation } (\dot{V} > 0), \\ \xi = 0 & \text{for inhalation absence } (\dot{V} > 0), \end{array} \\ C_D^f, & \dot{V} \le 0, \end{cases} \qquad (2)$$

$$\frac{dC_{LC}^f}{d\tau} = \frac{1}{V_{LC}}\left[(Q - Q_{sh})\left(C_{\bar{V}}^f - C_{LC}^f\right) + G_A^f\right], \qquad (3)$$

$$\frac{dC_a^f}{d\tau} = \frac{1}{V_a}\left[(Q - Q_{sh})C_{LC}^f + Q_{sh}C_{\bar{V}}^f - QC_A^f\right], \qquad (4)$$

$$\frac{dC_{ct_i}^f}{d\tau} = \frac{1}{V_{ct_i}}\left[Q_{ct_i}\left(C_a^f - C_{ct_i}^f\right) - G_{t_i}^f\right], \qquad (5)$$

$$\frac{dC_{t_i}^f}{d\tau} = \frac{1}{V_{t_i}}G_{t_i}^f, \quad i = \overline{1,m}, \qquad (6)$$

$$G_{t_i}^f = K\left(C_{ct_i}^f\right)S_{t_i}^f\left(C_{ct_i}^f - C_{t_i}^f\right), \quad i = \overline{1,m}. \qquad (7)$$

For the imitation of the preparation injection intramuscularly with the bulk velocity $Q_{t_i}^f$ at the right side of equation (6) has to be added the member $\frac{1}{V_{t_i}}d_1^f Q_{t_i}^f$. For intravenous injection the equation for mixed venous blood may be represented as:

$$\frac{dC_{\bar{V}}^f}{d\tau} = \frac{1}{V_{\bar{V}}}\left(\sum_{t_i} Q_{ct_i}C_{ct_i}^f + Q_{\bar{V}}^f d_{\bar{V}}^f - QC_{\bar{V}}^f\right). \qquad (8)$$

Output of pharmacological preparation from organism is a function of kidneys, so

$$\frac{dC_{t_i}^f}{d\tau} = \frac{1}{V_{t_i}}\left(G_{t_i}^f - Q_{t_i}^f C_{ct_i}^f\right), \qquad (9)$$

where t_i is the kidney; $Q_{t_i}^f$ is the volume velocity of excrete output (filtration) from kidneys.

B. Complex of program support for pharmacological correction research and algorithm of its work

Complex of software for research purposes of operator's (pilot) organism is following (Fig. 1).

Coefficients in equations (2) – (8) were taken for average person; also they may be identified as results of organism study in its life conditions. These coefficients have to be used for the construction of computer analogue of represented mathematical models for estimation of organism functional state during operator (pilot) intensive work in extreme conditions and his further restoring.

Iterative work procedure of proposed program complex is following.

1) Operator organism is studied instrumentally; data model based on the results of laboratory tests is made.

2) Data of these studies are introduced in the model of oxygen modes of organism; this model permits to obtain the dataset about operator functional state and input data for dynamics model functioning.

3) Basing on static model the integral estimation of operator cardio- respiratory system is made.

4) The data obtained during physiological studies and calculated as results in static model are introduced as input data into dynamic model; therefore the model is individualized; than imitation of loading may be done.

5) Obtained data are analyzed.

6) Different types of operator organism rehabilitation using pharmacological preparations are made; computer analysis of obtained data is done.

7) The decision about the best way of organism recovery is done.

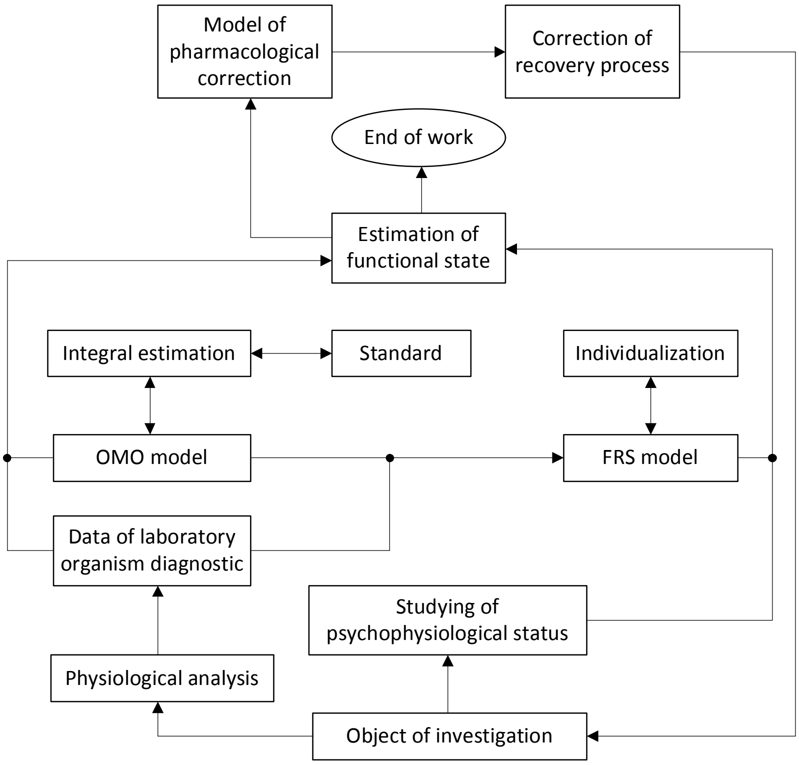

Fig. 1. Complex of software for purposes of operator's (pilot's) organism research: OMO is the oxygen mode of organism; FRS is the functional respiratory system

VI. CONCLUSIONS

Suggested approach may be useful for studying of operator (pilot) organism functional state during the work in extreme external and internal environmental conditions for professional selection, training and restoring of persons for the work in aviation and other respective professional fields.

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Н. І. Аралова, О. М. Ключко, В. Й. Машкін, І. В. Машкіна. Математична модель дослідження відновлення організму оператора систем неперервної взаємодії

Запропоновано комплекс інформаційної підтримки для дослідження компенсаторних і захисних реакцій організму осіб льотного складу у разі екстремального збурення внутрішнього та зовнішнього середовища і фармакологічної корекції процесу відновлення.

Ключові слова: математичне моделювання; інформаційна підтримка; екстремальні умови; компенсаторні та захисні реакції; фармакологічна корекція.

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Предложен комплекс информационной поддержки для исследования компенсаторных и защитных реакций организма для лиц летного состава при экстремальных возмущениях внутренней и внешней среды и фармакологической коррекции процесса восстановления.

Ключевые слова: математическое моделирование; информационная підтримка; экстремальные условия; компенсаторные и защитные реакции; фармакологическая коррекция.

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