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ARALOVA N.I.[1]**,** DSc (Engineering), Senior Researcher,
Senior Researcher of Optimization of Controlled Processes Department,
ORCID 0000-0002-7246-2736, e-mail: aralova@ukr.net
BELOSHITSKIY P.V.[2]**,** DSc (Medicine), Professor
Professor of Biological Faculty
ORCID 0000-0002-6058-3602, e-mail: bilosh827@ukr.net
ZUBIETA-CALLEJA G.[3]**,** M.D. Professor
Director
ORCID: 0000-0002-4283-6514, e-mail: zubieta@altitudeclinic.com
ARALOVA A.A.[1]**,** PhD (Phys&Math)
Researcher of the Department of Methods for Discrete Optimization,
Mathematical Modelling and Analyses of Complex Systems
ORCID 0000-0001-7282-2036, email: aaaralova@gmail.com
[1] Glushkov Institute of Cybernetics of National Academy of Sciences of Ukraine,
40, Acad.Glushkov av., 03187, Kyiv, Ukraine
[2] Pavlo Tychyna Uman State Pedagogical University,
2, Sadova str, 20300 Uman . Chercassy distr., Ukraine
[3] High Altitude Pulmonary and Pathology Institute HAPPI-IPPA
Av. Copacabana, Prolongacion # 55, La Paz, Bolivia

AUTOMATED INFORMATION SYSTEM FOR THE EVALUATION OF CLIMBERS' PERFORMANCE UNDER CONDITIONS OF EXTREMELY LOW pO_2 OF INHALED AIR

Introduction. *Currently, as a result of ever-increasing intensity of human activity, unfavorable environment, the need to perform work in various extreme disturbances, significantly increase physical, mental and emotional stress on the human body, leading to pronounced changes in functional systems. Therefore, the task of studying the adaptation of the human body to work in extreme environments is urgent. The work of climbers is a fairly adequate model for studying the combined effects of hypobaric hypoxia and exercise hypoxia. The need to process large amounts of information necessitates the use of modern computer technology that allows the training process in the training of climbers, which would repeatedly, almost in real time to speed up the processing of survey data and accumulate for further use in determining current status and forecasting regulatory reactions of the body to external and internal disturbances.*

The purpose of the paper *is to develop an automated information system of functional diagnostics using the model of regulation of oxygen regimes of the body and its practical application in the study of highly qualified climbers.*

Methods. *Programming methods for creating an automated information system and methods of functional diagnostics.*

Results. *On the basis of the model of regulation of oxygen regimes of the organism the automated information system for functional diagnostics of the persons who are in the conditions of extreme disturbances is constructed. The results of approbation of the offered software for research of group of highly skilled climbers are resulted.*

Conclusions. *The proposed software allows you to use a model of oxygen regimes of the body in real time, i.e. repeatedly accelerates the processing of data obtained during the survey of athletes, allows centralized collection of information for its pre-processing, storage and collective use, allows you to compare the basic parameters characterizing the functional respiratory system during natural sports activities and obtained during ergometric loading.*

Keywords: *methods of functional diagnostics, highly qualified climbers, mathematical model of regulation of oxygen regimes of the organism, human adaptation to work in extreme environment, hypoxibritic hypoxia.*

INTRODUCTION

The urgency of the problem is caused by the social importance and practical relevance, connected with the necessity of human organism's adaptation to ever increasing requirements of extreme loads in the process of labor and sport activity. Mountain climbing is a vivid example of the combined effect of hypoxybaric and hypermetabolic hypoxia in conditions of increased environmental tension and could be considered as a model problem for research of human activity at high altitudes revealing latent organism's reserve capacities. Nowadays the number of publications on this subject is very insignificant and, unfortunately,most written by non-physiologists — one gets the impression that the authors are completely unaware of the studies, carried out since 1929 at the Institute of Physiology named after A.A. Bogomolets of the National Academy of Sciences of Ukraine and at its Elbrus Medical and Biological Station (EMBS) by a member of the Academy of Sciences N.N. Sirotinin, his students and followers, and in particular in the preparation of Soviet and Ukrainian expeditions to Everest, Manaslu, Kanchejunga, Lhotse, Annapurna, Akonkagua and so on.

Conducted by N.N. Sirotinin school long-term study of the problems of hypoxic states in comparative-physiological, evolutionary aspects, in onto- and phylogeny, at all levels of the organism, using adequate modern methods and mathematical modeling was a broad general biological approach to disclose mechanisms of adaptation, impaired functions, development of mountain sickness, reliability of body functioning in extreme conditions, changes in reactivity and resistance. These fundamental studies, which reveal destructive (pathogenic) and constructive (sanogenic) mechanisms of hypoxic conditions in the body, allowed for the first time in the history of the world to discover and substantiate a new highly effective direction — hypoxytherapy, implemented in the mountains, altitude chambers or with various hypoxicators for treatment, prevention, rehabilitation, increasing resistance and performance.

The concepts on the use of step adaptation to hypoxia, on the organism's oxygen regimes and their regulation, on the functional system of breathing were proposed and substantiated; their mathematical modeling was carried out, allowing not only qualitative but also quantitative characterization of various types of hypoxic states and evaluation of their degrees, forecasting changes in the organism's state under conditions of extreme factors, analyzing the role of certain physiological reactions in compensation of oxygen deficiency.

Naturally, there was a need to process large amounts of information obtained in the study of the body's adaptation to hypoxia, increased work capacity, resistance to the extreme factors of space flight, improved sports performance, which necessitated the introduction of information technology.

These works carried out under the leadership of A.Z. Kolchinskaya, P.V. Beloshitsky, Yu.I. Petunin received back in the seventies the support of a member of the Academy of Sciences V.M. Glushkov and this led in turn to the active introduction into practice the ideas of mathematization of medicine and biology, which initiated the transformation of the science of hypoxia from descriptive experimental to accurate and systematic and generalized results.

The conducted studies have been published in a number of monographs, journals and reported at many international congresses, conferences on mountain medicine and physiology [1–17], and Kyiv was considered the "capital of hypoxia" [6].

We should also note from foreign studies the works [18–30]. Separately, a completely unique study [31] related to the determination of blood gases taken from climbers directly on the peak of Mount Everest should be mentioned.

Nowadays the problems of adaptation to mountain conditions, life at high altitude under chronic hypoxia, respiratory physiology, and neurobiology are intensively studied at the High Altitude Pulmonary and Pathology Institute IPPA (La Paz, Bolivia) since 51 years ago. They initiated the World Congresses on High Altitude Medicine and Physiology in 1994. They established the prestigious international award for outstanding researchers of hypoxia problems (Science, Honor, and Truth) and multiple innovative achievements. Their focus with respect to life at high altitude is based on their observations of human physiology and successful life and exercise activities between 3,100m and 4,100m of altitude in the city of La Paz, with over 2.5 million inhabitants. One of their outstanding feats was to carry out a football (soccer) game on top of Mount Sajama at 6,542m in the highest mountain of Bolivia.

Among their most important scientific observations are:

1) The development of the high altitude adaptation formula [32]:

$$Adaptation = \frac{Time}{Altitude},$$

which states that upon arrival to a high altitude location like the city of La Paz (3.600m), it takes around 40 days for the hematocrit to increase to the maximum normal level for optimal life at high altitude. This is a logarithmic increase reaching a high plateau, the most efficient physiological oxygen transport system under chronic hypoxia. It is interesting to point out that going in a reverse way, there is a linear decrease of the hematocrit to the most optimal sea-level value in 20 days.

2) Another point of interest is the Tolerance to Hypoxia Formula [33]:

$$Tl = \frac{Hb}{p_a CO_2},$$

where Tl — tolerance to hypoxia, was developed based on the fact that hemoglobin increases and p_aCO_2 decreases at high altitude. Noteworthy is the fact that tolerance to hypoxia increase with altitude. On the summit of Mt. Everest, humans are six times more tolerant than at sea level. It is possible to conclude that the human organism carries the capability of survival at high altitude even in the highest point of the Earth.

The Acid-Base balance has also been studied where it was defined that a correction factor should be applied for the Van Slyke formula specific for each altitude [34]. They postulated that maintaining the acid-base balance is transcendental for optimal biochemical function at high altitude, where the pH should remain within normal physiologic values.

The Oxygen Transport Triad [35] is formed by 3 factors: 1) The Pneumo-dynamic pump (the lungs) that is a mechanical vacuum pump allowing ventilation for oxygen renewal in the alveoli and carbon dioxide excretion to the environment. 2) The Hemo-dynamic pump (The heart), which is a mechanical liquid pressure pump that moves blood to and from the tissues, and 3) Hemoglobin, the iron-based molecule that transports oxygen and carbon dioxide. The interrelation between these three mechanisms allows for a most energy-efficient system of survival at high altitude during acute and chronic hypoxic exposure. The Pneumo-dynamic pump plays the most important role of adaptation to acute hypoxia, along with the Hemo-dynamic pump. With adaptation to chronic hypoxia, hemoglobin releases the extra load upon the two pumps, as the energy consumption is high with their increased work.

The hypothesis that man can adapt to live in the hypoxic levels of Mt. Everest [36], continues to be proved with successful climbs. Initially, it was thought that man could not reach the summit without supplemental oxygen. Messner and Habeler were the first to climb Mount Everest breathing only ambient air without an oxygen mask. Messner then climbed all 14, + 8000m mountains without oxygen.

However, these studies, for obvious reasons, are connected with the study of blood: respiratory gas tension, acid-base balance, blood lactate. The works [37, 38] consider the limiting role of the respiratory system. At the same time, the information about the maximum oxygen consumption [39–44], as an index that characterizes the cardiorespiratory system capacity criterion of aerobic capacity, is still relevant when making decisions about the possibility of carrying out extreme loads by the organism. It is believed that the Maximum Oxygen Consumption (MOC) is the factor influencing and limiting the ability to perform in different sports; for climbers, such studies, in particular, were carried out by employees of the Bogomolets Institute of Physiology of the National Academy of Sciences of Ukraine, the National University of Physical Education and Sports of Ukraine and the Glushkov Institute of Cybernetics of the National Academy of Sciences of Ukraine [45, 46].

In this regard, the methodology of screening the climbers, which was used at the Elbrus medical-biological station when forming teams for climbing the Himalayan eight-thousanders, is of special interest [47–49].

A.Z. Kolchinskaya's concept of regulation of oxygen regimes of human organisms was the theoretical basis for research and decision-making on the formation of expedition composition [50]. According to this concept, two groups of parameters are interconnected in the organism: oxygen transport rates and its partial pressures and stresses at the main stages of its path (lungs, alveoli, arterial, and mixed venous blood). The analysis of combinations of these two groups of parameters allows us to objectively characterize the function of the body's supply system quantitatively and qualitatively.

This approach allows obtaining a general characteristic of gas homeostasis using a minimum of indicators: 1) to give its detailed analysis involving fundamental mechanisms providing respiratory gas transport, 2) to make a diagnosis of the main syndromes related to the disorder of gas transport function, 3) to give an oxygen "portrait" of the organism and its dynamics under various functional states, 4) to assess the organism's ability to recover after external and internal disturbing influences. Systematic accumulation of data, their systematization with subsequent processing and analysis provide discernibility and objectivity of characteristics of a large number of the examined athletes, making it possible to trace the dynamics of changes in the indicators during the annual training cycle by periods of training (transition, basic, competitive), long-term training, increase of sportsmanship, in the age aspect, allowing the establishment of relationships between individual indicators, conduct their differentiation by kinds of sports, trace the differentiation by kinds of sports, trace the dynamics of changes in the main indices in the period after the cessation of active sports activity.

In a healthy individual the oxygen parameters, indicators of efficiency and economy of oxygen regimes of the body, as well as parameters characterizing the production, accumulation, and transport of carbon dioxide, indicators of the internal environment of the body, its acid-base state, and others prove to be so representative that they can be used as normative for a given age, sex, training level, and type of sport. Deviations of oxygen parameters and indicators of economy and efficiency of oxygen regimes from these standards can be used to determine: 1) an objective characteristic of changes in the functional state of the organism, 2) trace the dynamics of this state in the process of athletes' preparation for competitive activity, 3) competitive activity itself and recovery period. It is likewise useful in the process of recovery and rehabilitation of athletes after injuries.

Estimation of general fitness level and adaptation degree of athletes to heavy loads and to oxygen deficiency requires detailed characterization of a complicated process of oxygen delivery to working muscles, the degree of compliance of oxygen delivery, and carbon dioxide excretion process with the metabolic demand of tissues. Such characteristics cannot be given without labor-consuming calculations of some oxygen parameters and functional indices. That was possible due to mathematical models of the respiratory system and computer software.

When analyzing the oxygen regimes of the organism and the criteria of its functional state, a synchronous determination of more than twenty separate indices characterizing the state of the respiratory system is assumed. These indicators include parameters of external respiration, oxygen-transport function of blood, hemodynamic system, and gas exchange. The calculation indices, obtained on their basis allow the characterization of the activity of functional systems of the organism and assess the function of oxygen supply of the organism from the point of view of economy, efficiency, tension, speed, intensity of oxygen delivery in separate sections of its transport within the organism, in a total amount of about one hundred indices.

The mathematical model of mass transfer of gases in human and animal organisms, which was based on the concept of regulation of oxygen regimes of the organism [50], was a reliable tool for characterizing the functional state of athletes in various activities. The role of load hypoxia in resolving the conflict situation between the cardiac and skeletal muscles in the fight for oxygen was investigated using a mathematical model of the breathing system with optimal control.

Calculations of oxygen parameters, carbon dioxide parameters, functional indices additionally allowed the characterization of the activity of functional systems of the organism, the evaluation of the state of oxygen supply system by the rate and intensity of its delivery to lungs and alveoli, the oxygen transport through arterial and venous blood, the tissue oxygen consumption, the efficiency of staged oxygen delivery, and the tension and economy of oxygen modes of the organism.

A sufficiently complete review and analysis of existing developments on this topic is given in [51]. Further development was presented in [52] the automated information system of functional diagnostics of athletes, which included software capabilities existing at that time and its modification for mountaineers [46]. Further development of works in this direction was the study of the dynamics of the parameters of self-organization of the respiratory system of mountain rescuers during short- and medium-term adaptation [53] in the conditions of the middle altitude

The purpose of the work is to create a modern automated information system for functional diagnostics of athletes using the organism oxygen regimes (OOR) model, which would allow:

1) to significantly accelerate the processing of data obtained during the examination of athletes;

2) to centralize the accumulation of information for its pre-processing, storage, and collective use;

3) to create an algorithmic apparatus to provide evidence of scientific provisions, development of options for optimization of decisions on the assessment of athletes' prospects;

4) to implement the diagnostic algorithm of functional state assessment of athletes developed earlier.

SOFTWARE PACKAGE STRUCTURE

For clarity of presentation of the data and their operative processing by means of the correlation analysis, the most informative twenty indicators characterizing the functional condition of the respiratory system were chosen. A computerized model of the respiratory system is constructed. The proposed software allows you to build these model characteristics on the basis of the calculated data. Accordingly, the data stored them in memory with output to external media to create model characteristics for athletes of different ages and training levels. It permits for specialization in certain disciplines of cyclic sports and strength martial arts.

The software works with the implementation of two workstations: a laboratory technician and a medical professional. Such a division was due to the fact that collecting data during the examination requires a set of specific knowledge and skills. Initially such data acquisition knowledge and skills are not necessary, however, the laboratory blood tests performed not directly at the workplace. Indicators characterizing the state of the external and alveolar respiration systems, cardiac activity, circulatory system are registered by devices directly in the process of examination and can be used immediately as initial data.

The system works as follows. After logging into the system at the Laboratory technician's workstation, general data about the subject is entered: such as last name, age, sex, sport, qualification, height, and weight. The system automatically forms groups according to age or qualification. Then, the requests for the examination of a certain group on a certain date are generated on the Automated Workplace (AWP) of the Medic (Fig. 1). Based on the survey requests, general environmental data is collected — barometric pressure, partial pressure of water vapor, altitude, ambient temperature etc. Blood samples are also taken for analysis. Then the respiratory, circulatory, and cardiac systems are examined at rest and under various loads (bicycle ergometry or step tests are possible), depending on the objective set for the researcher. After the examination of one person is completed, the information obtained by the laboratory and the information obtained after performing special performance tests is also entered into the database.

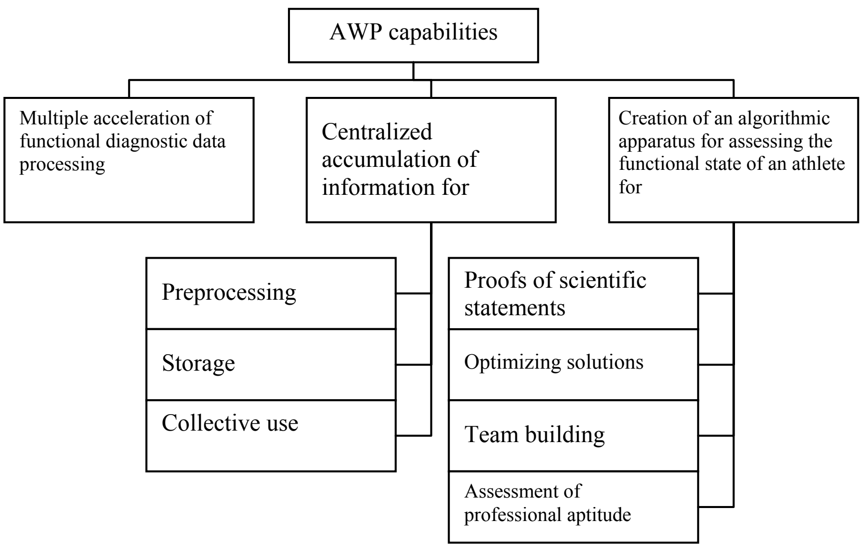

Fig. 1. AWP capabilities

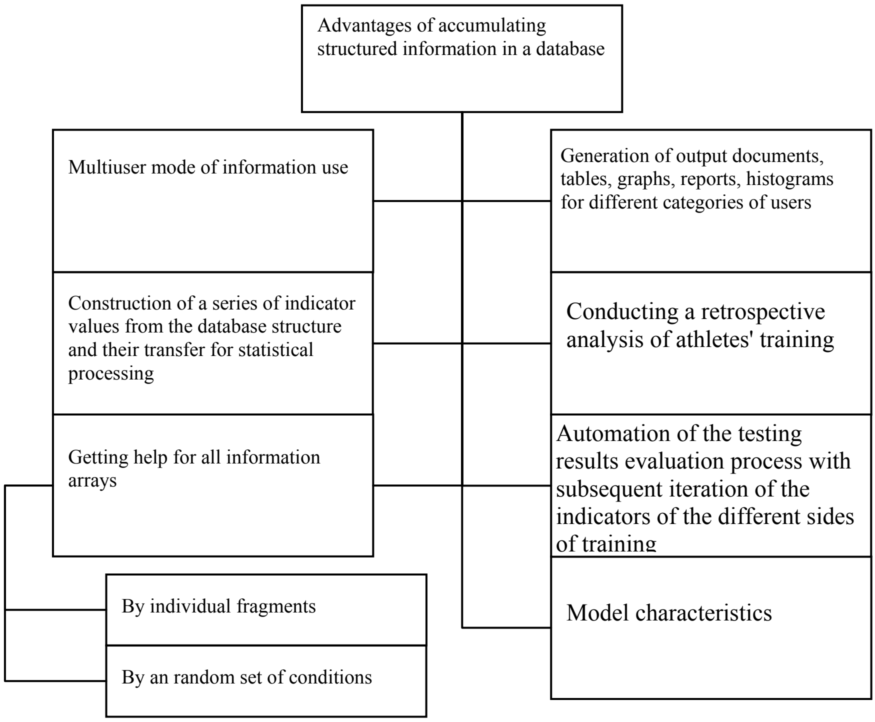

Fig. 2. Benefits of accumulating structured information in a database

Special performance tests were developed for different sports — speed and power, cyclic, technically difficult sports, martial arts, sports games, mountain climbers, and alpinists. This allows for a comparison of the main parameters characterizing the functional breathing system during natural sports activity and those obtained during ergometric bicycle exercise. When all the initial data necessary for the calculation are entered, the calculation of the indicators of oxygen regimes of the organism and their distribution into groups, which correspond to different parts of the respiratory system, takes place. These are functional indices of speed, intensity, the efficiency of staged oxygen delivery; indices characterizing the economy of the respiratory system and blood circulation, as well as parameters characterizing the hypoxic state of the organism. These operations can be repeated several times within one application. In this case, if the weight or height during a series of examinations has changed, the system allows you to enter the changed values in the database while maintaining the previous values. On Fig. 2 are shown benefits of accumulating structured information in a database.

The general scheme of the software package and the OOR algorithm is shown in Fig. 3.

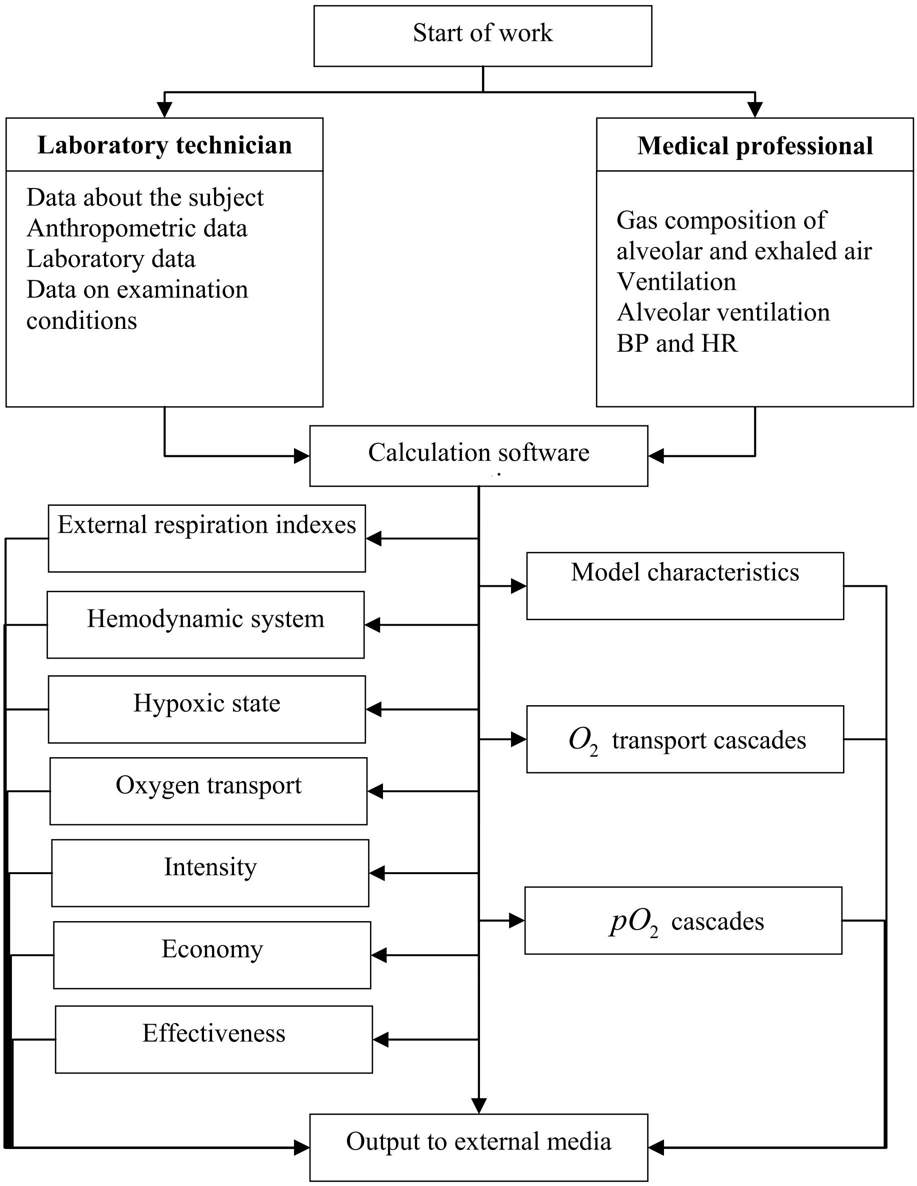

Fig. 3. General scheme of OOR operation

ALGORITHMS OF INDIVIDUAL AWP BLOCKS

The software is divided into separate blocks, each of which solves its own task. Let's describe each of them in detail.

The central block is the Main menu, which is defined by the tasks of the user's workstation. All the blocks of Help, Info and Signing Out are common for both workstations. In other blocks there is a division depending on the tasks, which are solved at this automated workstation. The functions of each block are grouped in Table 1.

Table 1. **Individual block functions**

Block name	Functions
Entering regular data	provides correct input of regular data (full name, sports type, qualification, height, weight). The results are recorded in the database (DB).
Entering personal data	provides correct input of personal data (heart rate, breathing rate etc.). The results are recorded in the database
Survey data entry	provides correct input of the examination data (barometric pressure, gas content in the air etc.). Results are recorded in the database
Entering initial data	provides the correct data input about the examined group, about the system of examination, about the organism state in different moments of examination, including checks on data compatibility. It is carried out both on the level of the software part of the system and on the level of the database management system. The results are recorded in the database and subsequently used to calculate the characteristics
Saving initial data	provides saving the data to the database. Saving takes place automatically and at the user's command. The input is a request to save the original data.
Solving a mathematical task	builds and performs calculations.
Result formation	provides graphical and tabular representation of the results of the work.
Saving a report:	if the user wishes, a report on the performed work can be made. The input is a request to save data about the person being examined, where to save it.
Help for the user	from any task of the system gives contextual help, instructions and advice to the users. The input is a request for help to the user.
Creator Info	from any system task outputs the creator information with contact information. Input is a request for information about the creators
Signing Out	Provides correct sign out, saving parameters, current data via a dialog with the user. The input is a request to sign out of the system.

Let's dwell in more detail on the possibilities of correction and additional data verification. Experience shows that the largest number of failures in calculations and system malfunctions occurs not because of incorrectly working program, but because of an error during data entry. In accordance with the above, the developers have created a robust mechanism for checking the correctness of data, both numeric and lowercase. To do this, various methods of interaction with the user, such as input error messages, convenient structuring, templates for entering string and numeric data, drop-down lists, switches etc are used.

Then, in the dialog box we enter data about the general environmental conditions in which the survey takes place. The given variant of the dialog box assumes entering the known reduction factors to the conditions $BTPS$ and $STPD$, but the variant of calculating these indicators is also provided.

The individual initial data from the examination (minute respiratory volume, alveolar ventilation, exhaled and alveolar gas composition, blood pressure, and heart rate) are then entered.

Further, after entering all the initial data for the group, the calculation of indices of speed, intensity, efficiency of stepwise oxygen delivery, indices characterizing economy of respiratory and circulatory system, parameters characterizing hypoxic state of the organism are made, transport by arterial and mixed venous blood and economy of the system of external respiration and hemodynamics.

RESULTS AND DISCUSSION

In order to study the adaptation of climbers to the reduced partial pressure of oxygen in the inhaled air, the group of 46 climbers was examined. According to the results, it was divided into two groups: sport masters (20 persons) and candidates to sport masters (26 persons). The examination was carried out in natural conditions at an altitude of 2100 m above sea level and in an altitude chamber at an "altitude" of 7500 m above sea level. Cycloergometric load with gradually increasing power was carried out. The minute respiratory volume, gas composition of exhaled and alveolar air, respiratory rate, heart rate, blood pressure, anthropometric parameters, hemoglobin and acidity of arterialized blood were measured.

Using the above-described AWP the indices characterizing the systems of external respiration, blood circulation, efficiency, intensity, economy of oxygen regimes of the body, the parameters of hypoxic state were calculated.

Physical performance of climbers was assessed by the work performed and power developed, the rate of oxygen consumption and carbon dioxide output, the rate of staged oxygen delivery, partial pressure and tension of respiratory gases in the alveolar space, arterial and mixed venous blood. The degree of tissue hypoxia was assessed by the presence of oxygen debt, shifts in the acid-base state of blood, changes in blood acidity, presence of lactate.

The test of special work capacity of climbers was also carried out. The obtained indices were also compared with similar indices obtained when examining these groups on the plain (lowlands) [49]. The results of the examinati on are presented in the Table 2.

Table 2. **The results of the examination**

Indicator	Load			
	1,7 Wt/kg		2,7 Wt/kg	
	2100 m	7500 m	2100 m	7500 m
Respiratory volume per minute, l/min	57,0±1,8	110,3±3,4	72,2±2,3	137,9±5,0
Respiratory rate, breath/min	22,7±2,1	34,25±3,2	28,6±1,9	49,96±4,1
Respiratory volume, l	2,51±0,1	3,22±0,12	2,52±0,23	2,74±0,14
Ventilatory equivalent,	28,57±1,6	76,39±2,9	29,76±1,9	83,37±1,8
Respiratory cycle oxygen effect, ml/r.c.	87,9±2,1	42,15±3,3	84,82±1,8	33,1±2,7
Partial pressure of oxygen in the alveolar space, mm Hg	76,13±2,0	36,94±1,6	75,47±1,6	38,83±2,1
Partial pressure of carbon dioxide in alveolar space, mm Hg	31,9±0,8	13,34±0,6	33,88±1,0	13,24±0,4
Oxygen consumption rate, l/min	1,995±0,093	1,444±0,106	2,426±0,104	1,654±0,141
Heart Rate, r/m	105,2±3,1	139,7±2,8	123,8±4,2	149,9±3,2
Systolic output, ml	133±9	119,13±2,0	134,9±5	118,8±1,8
Cardiac output, l/min	13,965±0,35	16,71±0,205	16,739±0,48	17,72±0,345
Hemodynamic equivalent	7,0±0,2	11,57±0,7	6,75±0,2	10,7±0,9
Cardial cycle oxygen effect, ml/c.c.	18,96±1,1	10,33±0,6	19,59±0,9	11,03±0,85
Hemoglobin content, g/l	154,2±3	159,2±2	154,2±3	159,2±2
Arterial blood oxygen content, ml/l	188,8±2,4	138,6±1,8	184,2±3,1	129,9±1,1
Arterial blood oxygen saturation, %	90,1±1,3	64,0±0,9	89,3±13	59,98±1,1

In order to find out the climbers' adaptability to extremely low partial pressure of oxygen in the inhaled air the performance and functional state of the organism were determined: at the "altitude " of 7500 meters there was carried out a cycloergometric examination in an altitude chamber. The loads were reduced. The first load was 0.85 W/kg, (we do not consider this load because there is nothing to compare it with), the second — 1.7 W/kg, the third — 2.7 W/kg, i.e. there was work that was not more intensive than moderate at sea level and at 2000 meters (oxygen consumption at these loads and at 2100 meters was less than 50% of MOC). More than half of the examined climbers carried a load of 2.7 W/kg. Those climbers who were able to withstand it performed it either at the AMT level (anaerobic metabolic threshold) or slightly to the right beyond it, i.e. third-degree load hypoxia was manifested.

The data obtained show that breathing and blood circulation at the "altitude" of 7500 m during low-intensity load at sea level becomes less economical. At the simulated altitude of 7500 m the second load 1.7 W/kg, (the first load at 2100m), was performed with an oxygen consumption 551 ml/min lower than at 2100m (differences are not significant, p>0.05). The climbers consumed on average 1444. ± 107 ml/min of oxygen. At the same time, each liter of consumed oxygen provided 76.4 ± 94.1 l/min of ventilated air, which is 47.81 l/min more than at 2100 m altitude. The consumption of 1 L of oxygen required 11.57±0.8 L of circulating blood, which was 4.57 L more than at 2100 m for the same workload. Systolic volume was lower than at 2100 m and was 119.13+3.4 ml, and cardiac output was 2.745 L/min higher than during the same work at 2100 m. At a load of 1.7 W/kg, the arterio-venous oxygen difference was quite high (132.5 ml/l ± 3.0 ml/l), the oxygen content in mixed venous blood decreased to 53.6 ml/l ± 2.3 ml / l, its saturation with oxygen up to 25% ± 1.6%, oxygen tension up to 13 mm Hg. At a load of 2.7 W/kg, the arteriovenous oxygen difference increased to 145.1 ml/l ± 4.2 ml/l, the oxygen content was 28.1 ml/l ± 0.9 ml/l, the saturation of mixed venous blood with oxygen was only 13.3% ± 0.6%, oxygen tension in mixed venous blood was 12.0 ± 0.4 mm Hg. At the "altitude" of 7500 m, the coefficient of oxygen utilization from the blood decreased, as evidenced by the decrease in the arterio-venous difference in oxygen to 86.4 ml/l ± 2.1 ml/l at a load of 1.7 W/kg and to 72.9 ml /l ± 1.0 ml/l. Note that at a load of 1.7 W/kg, the oxygen content in the mixed venous blood was 52.4 ml/l ± 2.4 ml/l, saturation 24.2% ± 0.6%. At a load of 2.7 W/kg, the oxygen content in the mixed venous blood was 36.7 ml/l ± 3.1 ml/l and 17.2% ± 0.9%, respectively. The oxygen tension in the mixed venous blood at loads of 1.7 W/kg and 2.7 W/kg was 12 ± 0.5 mm Hg, respectively and 13 ± 0.9 mm Hg.

In [49] the impossibility of maintaining a high rate of oxygen consumption in conditions of extremely low ambient air is explained, on the one hand, by the decreasing rate of oxygen diffusion from the blood capillaries into cells and mitochondria due to a significantly reduced gradient between the blood and the intracellular environment, on the other hand, oxygen tension in arterial and mixed venous blood below a critical level causes a significant decrease in tissues, which directly reduces the rate of oxidative processes.

During a load of 2.7 W/kg (the third load at an "altitude" of 7500 m and the second load at 2100 m), oxygen consumption decreased and the efficiency of external respiration decreased — each liter of oxygen at this load provided 84.02 ±4.1 l/min of ventilated air, 40 l/min more than at the same load at 2100 m. The respiratory volume did not increase significantly, but the respiratory rate increased, which was 43.79 ± 6 breath/min. Respiratory coefficient began to exceed unity, arterio-venous difference decreased markedly, and hemodynamic equivalent increased. Oxygen tension in arterial blood was the same as during lower intensity exercise performed at the same altitude, and oxygen tension in mixed venous blood was 2-4 mm higher than its values during previous exercise. Low arterio-venous difference and increased pO_2 in the mixed venous blood indicated the decrease of oxygen utilization from the blood, the reason of which was the decrease of its tension in the tissues to below the critical level. Metabolic acidosis became more expressed: at the "altitude" of 7500 m pH was 0.11 lower than at rest; while pO_2 in alveolar air was only 16.58±1.6 mm Hg, i.e. 30.57 mm Hg lower than at sea level.

Estimation of general physical fitness level and adaptation degree of athletes to heavy loads and to oxygen deficiency requires detailed characterization of the complex process of oxygen delivery to the working muscles, the degree of compliance of oxygen delivery and carbon dioxide excretion process with the metabolic demand of tissues. Such characterization cannot be given without labor-consuming calculations of some oxygen parameters and functional indices, which turned out to be possible due to created mathematical models of respiratory system and software for computer.

The mathematical model of mass transfer of gases in human and animal organisms, which was based on the concept of regulation of oxygen regimes of the organism [50], was a reliable tool for characterizing the functional state of athletes in various activities. The role of load hypoxia in resolving the conflict between the cardiac and skeletal muscles in the struggle for oxygen was investigated using a mathematical model of the respiratory system with optimal control.

Calculations of oxygen parameters, carbon dioxide parameters, functional indices additionally allowed to characterize the activity of functional systems of the organism, to estimate the state of oxygen supply system by the rate and intensity of its entrance into the lungs and alveoli, oxygen transport by arterial and venous blood, tissue consumption, efficiency of staged oxygen delivery, tension and economy of oxygen regimes of the organism.

Reduced oxygen consumption rate, decreased arterio-venous oxygen difference, increased oxygen debt and blood lactate content, decreased *pH*, increased respiratory coefficient, low O_2 stress in arterial and mixed venous blood indicated that that load hypoxia during work with 2.7 W/kg at the "altitude" of 7500 m became uncompensated, which made it impossible to perform heavy loads at this altitude, i.e. at 7500 m the load of 2.7 W/kg can be considered the limit for climbers. Out of 60 people who were examined at this altitude, nine climbers were not able to carry these loads for more than one minute. Large shifts of *pH* after loading at the "altitude" of 7500 m in the pressure chamber indicated insufficient function of compensatory mechanisms and insufficient adaptation of these climbers to strenuous muscular activity at high altitudes.

Let us also note the following. If we analyze separately the role of the external respiratory system and the circulatory system in adaptation to the combined effects of hypoxybaric hypoxia and load hypoxia (Figure 4, 5), it appears that adaptation is mainly due to the external respiratory system, both when the load increases and when the partial pressure of oxygen in the inhaled air decreases.

At the altitude of 2100 m when the load increased from 1.7 W/kg to 2.7 W/kg, respiratory volume increased by 26 %; at the "altitude" of 7500 m when the load increased from 1.7 W/kg to 2.7 W/kg, ventilation increased by 25 %. At the same time the main role in increasing ventilation was performed by 26 % and 45 % increase in respiratory rate, respiratory volume at the altitude of 2100 m increased by 28 %, at the "altitude" of 7500 m respiratory volume decreased by 17 %. If we compare the dynamics of the external respiratory system indices during the same load of 1.7 W/kg, it appears that the main role in the increase of MRV by 142 % was played by the increase of respiratory frequency by 120 %, while the respiratory volume increased by only 9 % (Figure 6–8).

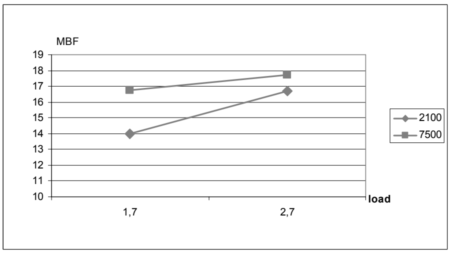

Fig. 4. The compensatory role of the external respiratory system in adaptation to the combined effects of hypoxybaric hypoxia and load hypoxia

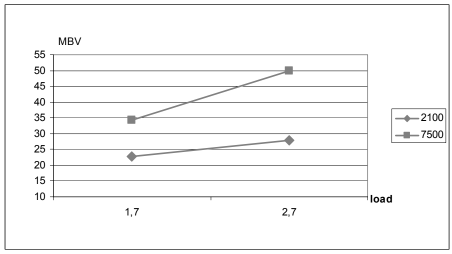

Fig. 5. The compensatory role of the circulatory system during adaptation to the combined effects of hypoxybaric hypoxia and load hypoxia

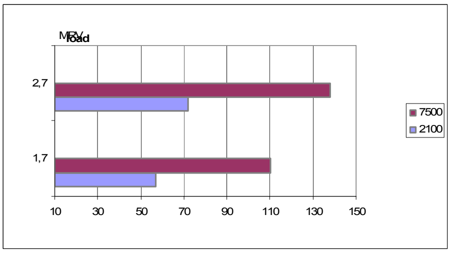

Fig. 6. Minute Respiratory Volume

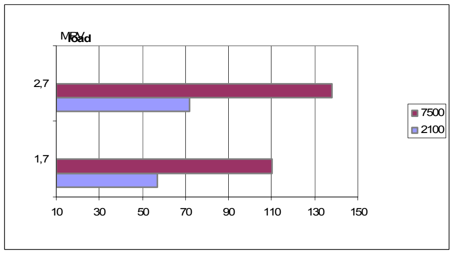

Fig. 7. Respiratory Erequency

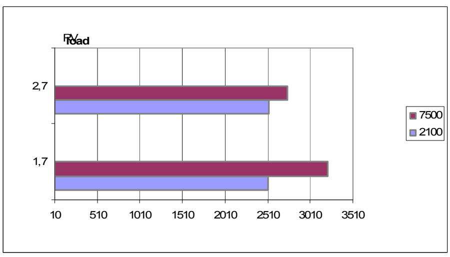

Fig. 8. Respiratory Volume

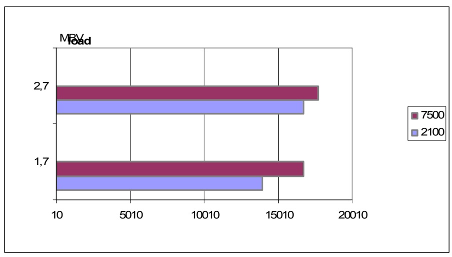

Fig. 9. Systemic Blood Flow

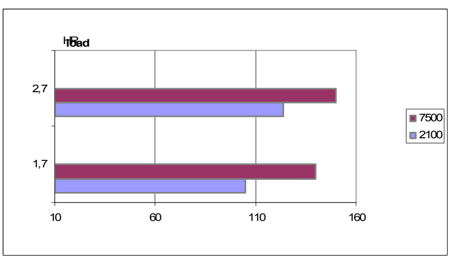

Fig. 10. Heart Rate

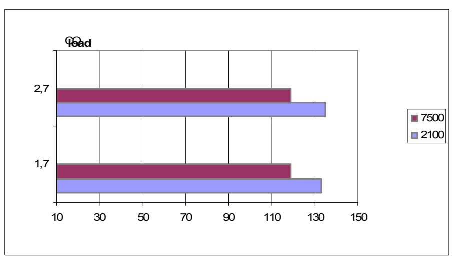

Fig. 11 Respiratory Erequency

If we consider the role of systemic blood flow (SBF) and its components — stroke volume and heart rate (Figure 9–11), we find that SBF increased insignificantly at the altitude of 2100 m when the load was increased from 1.7 W/kg to 2.7 W/kg, and at the first load at the "altitude" of 7500 m — only by 19 %, at the second load at 7500 m the increase was even less — only by 6 %. When performing the same load of 1.7 W/kg at 2100 and 7500 m, there was a 26% increase in blood flow. At the same time, the main role in the increase of the systemic blood flow is played by the increase of heart rate: by 17 % at the "altitude" of 7500 m compared to 2100 m, with the increase of load at the altitude of 2100 m the heart rate increased by 33 %, with the increase of load at the "altitude" of 7500 m there was an increase of heart rate by 21 %. As for the systolic output, the study showed that with increasing load, the value of this parameter decreased both at 2100 m altitude by 12 % and at 7500 m altitude by 13 %, with the values of these figures being practically equal.

CONCLUSION

The proposed software allows using the model of organism's oxygen regimes practically in real time, because it accelerates processing of the data obtained in the process of examination of sportsmen and allows centralized accumulation of information for its pre-processing, storage and collective use, allows to compare the main parameters characterizing the functional system of breathing during natural sports activity and those obtained during cycloergometric exercise, recovery, in the annual training cycle, during the Olympic cycle, during the whole sports activity and after it, during the recovery and rehabilitation after severe injuries when training activity was suspended, to study the processes of adaptation of the athlete's organism to training loads.

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Аралова Н.І.[1], д-р. техн. наук, старш .науч.співроб.,
старш .науч.співроб. відділу оптимізації керованих процесів
ORCID 0000-0002-7246-2736, e-mail: aralova@ukr.net
Білощицький П.В.[2], д-р. мед.наук, проф.,
Професор біологічного факультету
ORCID 0000-0002-6058-3602, e-mail: bilosh827@ukr.net
Зубієта-Калейа Г.[3], д-р. мед. наук, проф.,
директор
ORCID: 0000-0002-4283-6514, e-mail: zubieta@altitudeclinic.com
Аралова А.А.[1], канд. фіз.-мат. наук,
наук. співроб. відд. методів дискретної оптимізації,
математичного моделювання та аналізу складних систем
ORCID 0000-0001-7282-2036, email: aaaralova@gmail.com
[1]Інститут кібернетики імені В.М. Глушкова НАН України,
40, пр. Акад. Глушкова., 03187, Київ, Україна
[2]Уманьський державний педагогічний університет імені Павла Тичини,
2, вул.. Садова, 20300 Умань, Черкаська обл.., Україна
[3]Інститут високогірної мелицини та патології Ла Пас, Болівія

АВТОМАТИЗОВАНА ІНФОРМАЦІЙНА СИСТЕМА ДЛЯ ОЦІНЮВАННЯ ПРАЦЕЗДАТНОСТІ АЛЬПІНІСТІВ В УМОВАХ НИЗЬКОГО pO_2 У ВДИХУВАНОМУ ПОВІТРІ

Вступ. Наразі в результаті постійного зростання інтенсивності людської діяльності, несприятливого для довкілля, необхідності виконання роботи в різних екстремальних умовах значно посилюються фізичні, психічні та емоційні навантаження на організм людини, що призводять до виражених змін у функціональних системах. Тому актуальним є завдання вивчення адаптації організму людини до роботи в екстремальних умовах. Робота альпіністів є досить адекватною моделлю для вивчення комбінованих ефектів гіпобаричної гіпоксії та гіпоксії фізичного навантаження. Необхідність оброблення великих обсягів інформації зумовлює необхідність використання сучасних комп'ютерних технологій, що дає змогу в процесі підготовки альпіністів багаторазово, майже в режимі реального часу прискорювати оброблення даних і накопичувати їх для подальшого використання для визначення поточного стану та прогнозування регуляторних реакцій організму на зовнішні та внутрішні порушення.

Метою роботи є розроблення автоматизованої інформаційної системи функціональної діагностики з використанням моделі регулювання кисневих режимів організму та її практичне застосування для вивчення стану висококваліфікованих альпіністів.

Методи. Методи програмування, створення автоматизованої інформаційної системи та методи функціональної діагностики.

Результати. На основі моделі регулювання кисневих режимів організму побудовано автоматизовану інформаційну систему функціональної діагностики осіб, які перебувають в умовах екстремальних порушень. Наведено результати апробації запропонованого програмного забезпечення для дослідження групи висококваліфікованих альпіністів.

Висновки. Запропоноване програмне забезпечення дає змогу використовувати модель кисневих режимів організму в режимі реального часу, тобто, багаторазово прискорює оброблення даних, дає можливість централізовано збирати інформацію для її попереднього оброблення, зберігання та колективного використання, уможливлює порівнювняння основних параметрів, які характеризують функціональну дихальну систему під час природних спортивних занять та отримані під час ергометричного навантаження.

Ключові слова: *методи функціональної діагностики, стан альпіністів високої кваліфікації, математична модель регулювання кисневих режимів організму, адаптація людини до роботи в екстремальному середовищі, гіпоксібрична гіпоксія.*