Analytical complex for study of the oxygen status of tissues of the human organism

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Abstract. An automated complex for the study of the oxygen status of human body tissues using an artificial trained analytical system is presented. It includes sensory, electronic and computer modules for measuring and analyzing data. System training is implemented according to the principle of dividing the subjects into groups using mathematical methods of data processing and comparing them with data on the degree of adaptive responses obtained in the course of independent biomedical research. After analytical system training, subsequent recognition of the “image” of the test subject and its assignment to one or another group of the type of reaction to the functional load was possible.

1. Introduction
Successful resolution of issues related to maintaining the working capacity of the population is possible only with the organization of highly informative, rapid, regular and mass diagnostics of individual physical health and the functional state of physiological systems that determine the state of the body. It is essential for predicting, treatment, and rehabilitating the health of a large contingent of people [1-5]. Modern pulse oximeters, especially mobile ones, are inaccurate in the rapid diagnosis of human health [3-7]. Many people have limited access to high-resolution diagnostic equipment (tomographs, etc.). In addition, this equipment requires specially equipped facilities [8-11]. For an optimal solution to this problem, relatively cheap, high-speed diagnostic complexes of a new generation based on the implementation of modern biomedical methods of monitoring health by the catabolism and anabolism, determined by the key physiological and biochemical parameters of the cardiorespiratory and metabolic systems, are needed [12,13]. To solve the above-mentioned problem of mass, economically affordable diagnosis of individual physical health, an automated complex was developed using a sensor analyzer for determination of the oxygen status by the content of the main hemoglobin fractions (oxyhemoglobin, deoxyhemoglobin and methemoglobin) and the formation of “images” of the studied object in the learning process for their subsequent recognition in the diagnostic process.

2. Optical spectrum analyzer and methods
The analyzer is a computerized research diagnostic system consisting of a measuring optical module, a microprocessor control module, connected to a general computer control and analysis module for received data and the corresponding sample preparation module. The optical measuring module of
hemoglobin forms is represented by a set of miniature sensors and is based on recording of the absorption and reflection spectra in the range 450 - 650 nm. The sample preparation module provides measurements under specified conditions of temperature maintenance. The measuring module provides the conversion and output of the information received from the sensors with settable time intervals (0.01-2.0 seconds) into a microprocessor control module for the procedure of parallel multi-parameter measurements. It performs the processing and transmission of this information to a personal computer, which is a module for general control and data analysis. The computing module processes the received data. For each subject, the research results are presented in the form of an individual table of six registered potentials, which are displayed visually in the form of a hexagon and characterize the individual “image” of the oxygen status of the subjects’ tissues. The procedure for comparing the “images” of the subjects is carried out using an algorithm for processing of experimental data using the principal components analysis. This method allows you to classify the "images" of the subjects to different groups [14].

To assess the functionality of the developed diagnostic system and determine its capabilities, an experimental study was conducted, during which measurements were made using an analyzer, which are numerical values in arbitrary units, the relative change of which reflects the oxygen status of tissues in a sample of subjects exposed to hypoxic dose. The study involved 31 male subjects, each of whom was offered a functional load consisting in breath holding for at least 45 seconds. The measurements were recorded in continuous mode for 3 selected periods of time: at rest before the functional load, during breath holding, during the recovery period after the functional load. The primary results of all measurements were recorded in a tabular data structure, the final array of which contains information about the status of oxygen supply to the tissues of the body of each subject and the dynamics of its change throughout the experiment.

3. Results and discussion
Data processing was carried out using a software package for data analysis with the aim of visual presentation of information about each subject obtained using the diagnostic system in graphical form. For each subject, radial diagrams were constructed, which are a set of line segments, one ends of which converge in the center of the diagram, and the opposite ends are the vertices of the hexagon. The line segments are the coordinate axes for each of the six sensors, along which the coordinates of the vertex of the angles equal to the values of the sensors in arbitrary units at a certain point in time are laid off. The constructed diagrams, which are the “images” of the subjects, were used for a comparative analysis of trends in the status of oxygen supply of tissues at different phases of the experiment relative to the resting state. A typical image of the oxygen status of the test tissue is shown in figure 1.

Figure 1. Visual representation of typical images of test subjects in the form of hexagons, characterizing various adaptive responses to functional load. The numerical values of the readings of each of the six sensors in arbitrary units are plotted along the chart axes.
In addition, using the relation (1) a response index (RI) was calculated for each subject, which is equal to the ratio of the heart rate before the load and the heart rate after the load.

\[ RI = \frac{\text{Heart rate in 30 seconds after the load}}{\text{Heart rate 30 seconds before the load}} \] (1)

The calculated response index should not be greater than the value of \( RI = 1.2 \), exceeding this value indicates an unsatisfactory reaction of the functional systems of the body to the load.

Based on the obtained results, all subjects were divided into three characteristic groups having opposite main trends in the dynamics of the resulting images and different average indicators of the RI reaction. The averaged normalized images of the three selected groups with an indication of the average RI group are presented in figure 2 (a, b, c).

![Figure 2 (a, b, c). Visual representation of the averaged normalized images of subjects in three groups with an indication of the average RI group.](image)

Studies have shown that the "images" of the subjects have common and individual characteristics. Using the principal components analysis, the subjects were divided into three groups, presented in figure 3 and consisting of 6, 10 and 15 people of various levels of adaptive responses.
Figure 3. Images of the oxygen status of the test subjects in the space of the first two main components, found by 6 variables for 31 subjects. Variables are the numerical readings of each of the six sensors 4 minutes after the functional load, normalized to readings obtained at state of rest.

The subjects’ predisposition to one of the three groups was independently confirmed by biomedical studies carried out by the S.M. Kirov Military Medical Academy. Thus, an algorithm for training of the analytical system was implemented for the subsequent creation of software capable of recognizing adaptive response of subjects.

4. Conclusion
The results of the studies indicate the efficiency of the created complex and the prospect of studying of the oxygen status of human tissues using the methods of optical learning systems in order to assess adaptive responses, the functional state and human performance.

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