Formation of medical information model for rehabilitation of highly qualified athletes

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Summary

Introduction: Each development stage of the healthcare system and medicine is associated not only with the emergence of new integrated areas of knowledge, but also with radical changes in the technology of the doctor's work with the patient, algorithms, methods for collecting, processing information, and making decisions. Also, many postulates need revision, activation of existing reserves, certain concepts also require a new interpretation.
Objective: To form a high-quality medical model for the rehabilitation of highly qualified athletes.
Material and method: The paper proposes a model for constructing a quality assessment of rehabilitation of athletes based on probabilistic methods. The novelty of the study underlies the transition from a qualitative to a quantitative assessment of health, which has become a new direction in the assessment and management of health.
Results: The authors present a model of a qualitative increase in the managerial process by the rehabilitation of highly qualified athletes. The paper proves that it is necessary to determine the ability to measure and express the basic properties of any organism in conditionally qualitative proportions – the ability to withstand various stressful effects and adverse environmental influences.
Conclusion: The practical significance of the study is determined by the fact that it is necessary to search for evaluative health criteria, and in the individual's ability to carry out biological and social functions. The perfection of these functions in humans can also be described quantitatively, by reserves of energy, plastic, and regulatory support of functions.

Key words:
Rehabilitation. Athlete. Model. Dynamics. Information.

Formación de modelo de información médica para la rehabilitación de atletas altamente calificados

Resumen

Introducción: Cada etapa de desarrollo del sistema de salud y de la medicina está asociada no solo al surgimiento de nuevas áreas integradas del conocimiento, sino también a cambios radicales en la tecnología del trabajo del médico con el paciente, algoritmos, métodos de recolección, procesamiento de información, y tomando decisiones. Asimismo, muchos postulados necesitan revisión, activación de las reservas existentes, ciertos conceptos también requieren una nueva interpretación.
Objetivo: Formar un modelo médico de alta calidad para la rehabilitación de atletas altamente calificados.
Material y método: El artículo propone un modelo para la construcción de una evaluación de la calidad de la rehabilitación de deportistas basado en métodos probabilísticos. La novedad del estudio subyace en la transición de una evaluación cualitativa a una cuantitativa de la salud, que se ha convertido en una nueva dirección en la evaluación y gestión de la salud.
Resultados: Los autores presentan un modelo de incremento cualitativo en el proceso gerencial por la rehabilitación de atletas altamente calificados. El documento demuestra que es necesario determinar la capacidad de medir y expresar las propiedades básicas de cualquier organismo en proporciones condicionalmente cualitativas: la capacidad de resistir diversos efectos estresantes e influencias ambientales adversas.
Conclusión: La importancia práctica del estudio está determinada por el hecho de que es necesario buscar criterios evaluativos de la salud, y en la capacidad del individuo para realizar funciones biológicas y sociales. La perfección de estas funciones en humanos también se puede describir cuantitativamente, por reservas de energía, plástico y soporte regulador de funciones.

Palabras clave:
Rehabilitación. Atleta. Modelo. Dinámica. Información.

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Introduction

Rehabilitation in medicine is a system of state, socio-economic, psychological, medical, professional, pedagogical measures aimed at restoring a person's health, ability to work, and social status. It is based on biological, socio-economic, psychological, moral, ethical and scientific method foundations[1]. The main objectives of rehabilitation are: maximum possible restoration of health; functional recovery (full or compensation in case of insufficiency or lack of recovery); return to everyday life; involvement in the labour process. Rehabilitation is based on the use of biological and social mechanisms of adaptation, compensation, and is conditionally combined into three interrelated types: medical, social, and professional[2]. They are aimed at eliminating the three main consequences of disease: deviation from the norm in morphological status; decreased performance; social maladaptation.

Medical rehabilitation is the main type of rehabilitation treatment of the patient, the effectiveness of which depends on the use of other types of rehabilitation, their duration and scope[3]. The leading methods of medical rehabilitation are restorative therapy and reconstructive surgery with subsequent prosthetics (if necessary)[4]. Restorative therapy is carried out, first of all, with the help of medical treatment, physical activation (remedial gymnastic, massage, physiotherapy, occupational therapy), psychological methods (group and individual psychotherapy). The ultimate purpose of rehabilitation treatment is the elimination or reduction of the manifestations of the disease, including prevention of its complications[5].

Medical rehabilitation aims to restore the physical, psychological, and social status of a person after serious illnesses, injuries, complex surgical interventions so as to avoid disability or have the least degree of disability, to ensure integration into society with the achievement of maximum possible social and economic independence[6]. In the rehabilitation of patients, priority is given to medical rehabilitation. Experts, educators, psychologists, sociologists, lawyers, representatives of social welfare agencies, trade unions, and enterprises actively take part in this process together with medical workers[7]. There is much concern about training of rehabilitation specialists, rehabilitation therapists, and paramedical workers who have the scientific foundations and practical skills of complex rehabilitation treatment: methods of physiotherapy, massage, remedial gymnastic, mechanotherapy, occupational therapy, and other rehabilitation means[8]. Their importance especially increases during the modern pharmacological boom[9].

The means used in medical rehabilitation are diverse and unequal at various stages of rehabilitation. Rehabilitation most often begins with active treatment, where pathogenetic drug therapy or surgical treatment is predominant, aimed at eliminating or reducing the activity of the pathological process[10]. It is gradually being replaced by supportive pharmacotherapy and various non-drug therapies[11]. The role of non-drug rehabilitation means gradually increases in the subsequent stages of rehabilitation and is appointed with the aim of accelerating recovery, achieving long-term remission, recovery of disability, preventing disability, returning the patient to society[12].

The most common non-pharmacological means of medical rehabilitation are: protective regime; medical nutrition; physical rehabilitation: physiotherapy, natural physical factors, cold water treatment; physical therapy, massage, mechanotherapy, traction therapy, manual therapy, occupational therapy; reflexology, phytotherapy, aromatherapy; psychotherapy: general and special psychotherapy, psychotherapeutic measures, bioethics, music therapy, vocal therapy, dance therapy; disease prevention, health education, healthy lifestyle[13].

The purpose of the presented article is to form a high-quality medical model for the rehabilitation of highly qualified athletes. The study was conducted according to the classical scheme of evidence-based medicine, multicenter, randomized, controlled trials were organized, and experiments were conducted.

Literature review

A living organism is a multi-level, self-regulating system with a dynamic control hierarchy. The reaction of the body in the process of interaction with environmental factors proceeds in different ways: depending on the strength, duration of exposure and the adaptive capacity of the body[14]. Adaptation of the body to the effects of inadequate environmental factors occurs through the mobilization and expenditure of functional reserves. Assessment of the adaptive capabilities of the body is considered as one of the important criteria of health. The stock of functional reserves is information, energy and metabolic resources, the costs of which are accompanied by constant recovery[15].

Adaptation as one of the fundamental properties of living matter is the result and means of resolving internal and external contradictions, it exists and is formed on the verge of life and death, health and disease due to their collision and adoption of the transition. Adaptation costs depend on the body's reserve capacity[16]. The cost that goes beyond the biosocial budget, requires new efforts from the body, leading to the breakdown of the adaptation mechanism[17]. This is not only biological, but also social in nature and is sometimes achieved at the cost of certain injuries, a certain disharmony as against the norm[18].

The problem of assessing the level of health is primarily associated with the development of methods for prenosological diagnostics[19]. The decrease in the adaptive capacity of the body is an almost unfavourable sign and one of the leading causes of the onset and development of diseases[20]. This condition occurs gradually, long before the first signs of the disease are detected, and is difficult to diagnose[21]. Medicine is not able to predict and prevent diseases, but only passively expects a healthy person to become a patient[22]. The main task of the health problem is its prognostic direction – the need to predict an individual trajectory of movement from health to disease, which, in accordance with the health criteria of highly qualified athletes, relates to strategic ones[23]. There are various opinions regarding the application of preventive rehabilitation. It necessitates early diagnosis of health deviations and the use of means to prevent and eliminate them.

Material and method

The research methodology was based on the analysis, systematization, identification of general patterns and factors influencing physical rehabilitation, the development of additional diagnostic methods, monitoring and evaluation of the effectiveness of rehabilitation measures. When conducting research, the requirements of the experiment were adhered. To register studies, a special map was created, which was characterized by uniformity and maximum preparedness for subsequent computer processing. The registration cards presented research areas, analysed indicators and data processing methods.

Creation of the information system involved over 1,680 blood pressure measurements, followed by recording and analysis of waveforms. The experiment was attended by 566 people (235 men and 331 women) who were practically healthy and with health deviations. Patients were examined using a clinical, instrumental, laboratory, or special examination. Homogeneous material was selected for the analysis. To form the control and main groups, a table of random numbers was used for each group of patients.

To assess the state of adaptive reserves of the body, we used the determination of the level indicator of regulation of individual mechanisms with correlation; we used methods of correlation and cluster analysis. The quantitative component of the experimental part of the study is presented in Table 1.

For the preparation of information technologies to assess the state of the cardiovascular system by peripheral blood circulation, about 1,600 measurements of blood pressure were carried out, followed by recording and analysis of oscillograms. The experiment involved 566 people (235 men and 331 women) aged 11 to 75 years, almost healthy and with deviations in health status. Upon research, the requirements of the experiment were adhered to. Oscillograms were recorded:

- at rest: 446 people aged 18-75,
- before and after physical load (Ruthier test 75 people, physical exercises according to the Qigong method – 46 people),
- before and after exposure to thermal factors (dry and wet baths – 42 people, "winter swimming" – 25 people),
- before and after psychological audiovisual influences – 31 people,
- before and after the massage procedure (manual – 47 people, Nuga Best – 19 people, Reiki session – 65 people).

The oscillograms were subjected to morphological, temporal, spectral analysis according to the methods introduced for the analysis of electrocardiograms. A cluster analysis of the obtained indicators is carried out. Norm indicators were selected based on the analysis of oscillograms of 127 healthy individuals.

To prepare the information system for the physical rehabilitation process, literary sources were studied and our personal practical experience in organizing and conducting physical rehabilitation were generalized. Algorithmic modelling of the general process of prescribing and conducting remedial gymnastic and massage was carried out, along with their use in some of the most socially significant diseases (myo-

Table 1. The quantitative component of the experimental part of the study.

Research area	Research objectives	Research methods
The rationale for the analysis of arterial oscillograms	To study the reaction of the cardiovascular system to compression of the vessels of the shoulder at rest and under the influence of physical, thermal, audio-visual factors	Methods of morphological, temporal, spectral, fractal analysis of oscillograms
Analysis of the adaptive response of the cardiovascular system to the load	To develop an information technology for constructing and evaluating correlation portraits of CVS indices in healthy people and in some pathological conditions at rest and after various influences	Methods of correlation and cluster analysis
The state of the cardiovascular system	Comparative analysis of synchronously recorded electrocardiograms and arterial oscillogram	Methods of time, spectral, fractal analysis
Analysis of the impact of differential massage	To investigate the degree of the target control procedure	Methods of time, spectral, autocorrelation analysis of an electrocardiogram and arterial oscillogram
The effectiveness of remedial gymnastic algorithm	To study the effectiveness of the algorithm of remedial gymnastic in patients who suffered a violation of blood supply in the middle cerebral artery basin (stationary stage of treatment)	Methods of time, spectral, correlation analysis of an electrocardiogram and arterial oscillogram
Informational content of clinical indicators	Assessment of the information content of the Kerdo index in determining the level of autonomic regulation disorders in patients with osteochondrosis of the cervical spine	Statistical and experimental research methods
The information content of the Ruthier test	The information content of the Ruthier test in assessing the physical condition	Oscillography methods and statistical research methods
Informational content of clinical indicators	To study the informativeness of the indicators of fractal dimension of the ECG to assess the effects of massage	Fractal analysis method
Justification for the use of multimedia tools in rehabilitation	System-analytical justification for the use of a multimedia environment for the prevention and rehabilitation of various diseases	T. Saati hierarchy analysis method
Optimality assessment in the branching of microvascular nodes	To assess the optimality in the branches of microvascular nodes, which is compared with the data of studies of literary sources	Mathematical modelling methods

cardial infarction, cerebrovascular accident, neurological syndromes of cervical spine osteochondrosis, osteoporosis).

The existing information technology were applied. Electrocardiogram was analysed with the following purposes:

- to determine the impact of rehabilitation on the physical condition of individual athletes after unsuccessful medical treatment;
- to investigate the informative value of the fractal portrait of patients with neurological syndromes of cervical spine osteochondrosis.

The information content of the Kerdo index for patients with neurological manifestations of cervical spine osteochondrosis was analysed (based on literature and analysis of the results of scientific studies of other authors). The fractal dimension of rheoencephalograms was analysed (based on literature and analysis of the results of scientific studies of other authors). To this end, a correlation approach was developed to justify the optimal branching patterns of microvascular nodes and an expert diagnostics system was applied to analyse the patient's condition and choose a set of treatment methods using the approaches of traditional Chinese medicine.

The result of research was the creation of information systems in medical (physical) rehabilitation, a software environment for data analysis; diagnostic and treatment information system in the Wuxing health improvement system; psychomodulating multimedia environment. The instrumental examination method involved a typical electrocardiograph with an additional program to study the effect of differential massage on the state of the autonomic nervous system, and to assess the information content of the Kerdo index and evaluate the information content of fractal dimension values. The study of changes in the state of the cardiovascular system at large and peripheral vessels in particular under the influence of various factors was carried out with the use of an electronic blood pressure meter that can record cuff pressure values during the compression growth period and export the obtained values for further analysis of the arterial oscillogram. The results of laboratory research methods were applied to assess the objectivity of the Kerdo index in patients with cervical spine osteochondrosis (containing adrenaline and noradrenaline in daily urine and acetylcholinesterase activity in capillary blood).

Results and discussion

To analyse the biosignals in the frequency spectrum, methods of fast Fourier transformation (FFT) were used. The discrete Fourier transformation for a vector x consisting of N elements has the form:

$$\vec{X} = \hat{A}x,$$

the $\hat{A}$ matrix elements have the form:

$$a_N^{mn} = exp\left(-2\pi i\frac{mn}{N}\right).$$

If N is paired, then FFT can be rewritten as follows:

$$X_m = \sum_{n=0}^{N-1} x_n a_N^{mn} = \sum x_{2n} a_N^{2nm} + \sum_{n=0}^{\frac{N}{2-1}} x_{2n+1} a_N^{(2n+1)m}.$$

Coefficients a_N^{mn} and $a_N^{(2n+1)m}$ can be rewritten as follows:

$$M = N/2: a_N^{mn} = exp\left(-2\pi i\frac{mn}{N}\right) = exp\left(-2\pi i\frac{mn}{N/2}\right) = a_M^{mn},$$

$$a_N^{(2n+1)m} = exp\left(-2\pi i\frac{m}{N}\right)a_M^{mn}.$$

As the result, we shall get:

$$X_m = \sum_{n=0}^{M-1} x_{2n} a_M^{mn} + exp\left(-2\pi i\frac{m}{N}\right)\sum_{n=0}^{M-1} x_{2n+1} a_N^{nm}.$$

That is, the discrete Fourier transformation of a vector consisting of N samples are reduced to a linear composition of two FFTs of $N/2$ samples, and if N^2 operations are required for the initial task, then for the resulting composition - $N^2/2$. If M is a power of two, then this separation can be recursively continued until we reach the two-point Fourier transformation, which is calculated according to the following formulas:

$$X_0 = x_0 + x_1 X_1 = x_0 - x_1.$$

To study the local indicators of the frequency and phase in the spectrum of biosignals, we used the Hilbert-Huang transformations (HHT), understood as the method of empirical mode decomposition (EMD) for nonlinear and non-stationary processes and Hilbert spectral analysis (HAS). HHT is a time-frequency data analysis and does not require an a priori functional transformation basis. Instantaneous frequencies (Ifs) are calculated from the derivatives of the Hilbert phase functions by transforming the basic functions.

The next step of the Hilbert-Huang transformation is the Hilbert transformation. Conversion for each IMF allows to obtain the value of the instantaneous frequency and amplitude for each point in time. We shall describe the application of the Hilbert transformation in more detail. It is applied to every IMF $c_j(t)$ to get $H[c_j(t)]$:

$$H\left[c_j(t)\right] = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{c_j(\tau)}{t-\tau}d\tau,$$

and we can build an analytical signal $Z_j(t)$

$$Z_j(t) = c_j(t) + iH\left[c_j(t)\right] = a_j(t)exp\left(i\theta_j(t)\right).$$

This is how the amplitude function $a_j(t)$ and the phase function $\theta j(t)$ change in time:

$$\alpha_j(t) = \sqrt{c_j^2(t) + H^2\left[c_j(t)\right]},$$

$$\theta_j(t) = arctan\frac{H\left[c_j(t)\right]}{c_j(t)}.$$

The instantaneous value of the frequency of a non-stationary signal can be calculated as follows:

$$\omega_j(t) = \frac{d\theta_j(t)}{dt}.$$

The spectral methods for the analysis of arterial oscillograms are used directly for the values of the pressure change in the cuff upon shoulder compression, without the pressure component that the compressor creates in the cuff. For a curve that reflects the mechanical activity of the arterial wall upon shoulder compression, a visual analysis is applied for quantitative characteristics, localization, and the presence of small fluctuations. Also, these methods are applied for electrocardiograms, pulsograms, and rheograms, the signal itself and the intervalograms between various extrema. In the above-described biosignals and intervals calculated from them, the methods of spectral analysis are applied in the following aspects:

- The fast Fourier transformation of the oscillogram is used to estimate the spectrum power according to the spectral analysis criteria adopted in the ECG in the range from 0 to 0.4 Hz (HF: 0.15-0.40 Hz; LF: 0.04-0.15 Hz; k = LF/HF; VLF: 0.003-0.04 Hz; Total <0.40 Hz; <0.003 Hz) and in the following ranges: Delta – 0-4 Hz, Theta – 4-8 Hz, Alpha – 8-13 Hz, Beta – 13-25 Hz, 25 Hz and more. For analysis, the arterial oscillogram itself is used, and not the intervals between the waves, as in the spectral analysis of the ECG.
- Application of the Hilbert-Huang (S-Hil) method to analyse the oscillogram in order to estimate the local frequency by determining the areas (Delta (S-Hil-Delta) 0-4 Hz, Theta (S-Hil-Theta) 4-8 Hz, Alpha (S-Hil-Alpha) 8-13 Hz, Beta (S-Hil-Beta) 13-25 Hz, (S-Hil-25-60Hz) 25-60 Hz, (S-Hil-60 Hz) 60 Hz or more). The same frequency intervals were used to calculate the area of the instantaneous phase.

In the arterial oscillogram, depending on the degree of compression, five of its parts are distinguished (until the diastolic pressure is reached, from the moment of appearance of diastolic pressure – up to 70% of the amplitude, from 70% to 100% of the amplitude, from 100% to the appearance of systolic pressure, from the appearance of systolic pressure until the end of measurement).

Spectral analysis is applied to the arterial oscillogram itself, and not to the intervals between the waves, as it is upon the spectral analysis of the ECG. The use of fast Fourier transformation of the oscillogram for assessing the spectrum power according to the criteria of the CVS functional state assessment method by the heart rhythm registered in the ECG in the range from 0 to 0.4 Hz and in the following ranges: Delta 0-4 Hz, Theta 4-8 Hz, Alpha 8-13 Hz, Beta 13-25 Hz, 25 Hz or more.

The Hilbert-Huang method was used to analyse the oscillogram for estimating the instantaneous frequency by determining the areas (Delta 0-4 Hz, Theta 4-8 Hz, Alpha 8-13 Hz, Beta 13-25 Hz, 25-60 Hz, 60 Hz and more). The instantaneous phase is also calculated in the above time intervals of the arterial oscillogram in frequency intervals up to 15 Hz and more than 15 Hz.

Fractal analysis was used to create a fractal portrait of the subject based on an analysis of the modulation levels of the recorded biosignal and intervalogram. A fractal provides an opportunity to study and evaluate the degree of harmonization of biorhythms of the entire organism and individual organs and systems that have an effect on the systems, organs or tissues under study. The use of fractal analysis methods allows to identify functional and pathological changes, assess the immune status, energy resources, level of psychoemotional and physical activity, the prognosis of changes in the patient's health status for the next day and a relatively long period (up to 10 days). Research in the mode of dynamic observation allow to monitor the functional state of the patient and evaluate the effectiveness of various methods of therapy in application of therapeutic and preventive measures.

To determine the fractal dimension, the Hurst exponent was calculated as follows:

$$\frac{R}{S} = (\alpha N)^H,$$

from which

$$H = \frac{\log(R/S)}{\log(\alpha N)},$$

where H is the Hurst indicator; S root mean square deviation of a series of observations; R is the size of an accumulated deviation; N is the number of observation periods; α constant of correlation and cluster analysis of oscillograms and assessment of the state of the cardiovascular system and peripheral vessels.

The method for determining the level of interaction of regulatory mechanisms and the correlation portrait (for marking loads and pathological processes) was based on methods of linear correlation and cluster analysis (k-means method). In probability theory and mathematical statistics, correlation is the dependence of two random values. With that, a change in one or several of these values leads to a systematic change in one or several other values. The correlation coefficient is a mathematical measure of the correlation of two random values.

The correlation can be positive and negative (a situation of the absence of a statistical relationship is also possible – for example, for independent random values). Negative correlation is a correlation where an increase in one value is associated with a decrease in another, while the correlation coefficient is negative. A positive correlation is a correlation where an increase in one value is associated with an increase in another, while the correlation coefficient is positive. We shall consider the algorithm for determining the correlation coefficient. If X, Y are random values with mathematical expectation μ_X and μ_Y. Their correlation coefficient is designated $as\rho(X, Y)$ and equates to:

$$\rho(X,Y) = \frac{Cov(X,Y)}{\sigma_X,\sigma_Y} = \frac{E\big((X-\mu_X)(Y-\mu_Y)\big)}{\sigma_X,\sigma_Y},$$

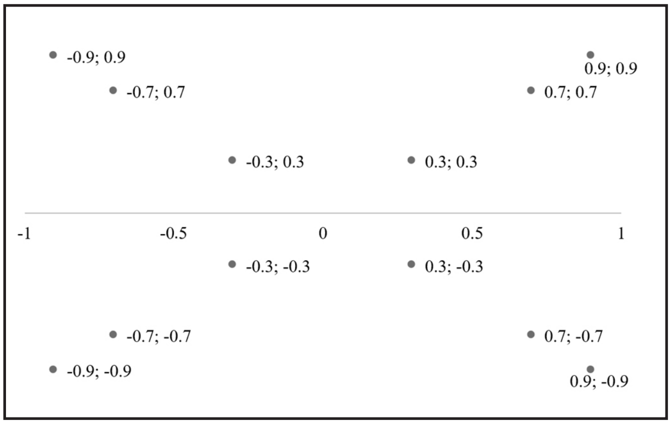
where $Cov(X, Y)$ is a covariation of X, Y values, σ_X, σ_Y is a standard deviation of X, Y values, E is a mathematical expectation operator.

Cluster analysis is the task of splitting a given sample of objects (situations) into subsets called clusters, so that each cluster consists of similar objects, and objects of different clusters differ significantly. Formal definition of clustering. Let X be the set of objects, Y – the set of numbers (names, marks) of clusters. The distance function between objects ρ(x,x') is set. There is a finite selection of objects $X^m = \{x_1, \ldots, x_m\}$. It is necessary to break the sample into extraordinary subsets called clusters, so that each cluster consists of objects similar in matrixρ, and the objects of different clusters are significantly different. With that, the cluster number y_i is assigned to each object $x_i \in X^m$.

The clustering algorithm is a function $a\colon X \rightarrow Y$, which associates a cluster number y ∈ Y with any object $x \in X$. The set Y in some cases is known in advance, but more often the task is to determine the optimal number of clusters from the standpoint of a certain clustering quality criterion. The selected correlation values were subjected to cluster analysis (k-means method), where the calculated correlation values were grouped separately within one experiment and between all indicators before and after the experiment in 12 clusters with the following centroid coordinates (Figure 1).

Data analysis was carried out for grouped data, by type of experiment, or its stage, between persons without complaints on health status and persons who had various diseases. The proposed algorithm was used to determine the level of interaction of regulatory mechanisms and a correlation portrait for marking loads and pathological processes for analysing the adaptation mechanisms of patient groups. In turn, clustered correlates, which were in the range from 0.85 to 1 and

Figure 1. Centroid forms of correlation values.



-0.85 to -1 (significant), were sorted by the following criteria – components of the correlation portrait:

- In the experiments that were carried out, the values of correlations in the cluster did not go beyond the limits of one cluster and were not sensitive to acting factors.
- In the experiment, the cluster values were unique (specific) up to a certain factor from the entire list of experiments.
- In the study of certain types of effect, the general and unique correlates were studied at various stages of research.
- The number of significant correlates before and after the experiment.
- The number of direct and inverse correlates.
- Comparison of the correlation portrait of an individual measurement grouped by certain attributes (weighting factors).
- The study of general correlates for experiments.

To identify the mechanisms involved in the adaptation process in a single study, the following algorithm was used. To evaluate and identify a single recorded biosignal, the following algorithms were implemented in the program "biosignal analysis":

- Evaluation of mechanisms and the strength of interrelations upon adaptation (correlation and cluster analysis) in a single analysis in the middle of the signal.
- Between synchronously (conditionally synchronously) registered signals of the same nature (ECG, pulsograms, rheograms, etc.).
- Between synchronously (conditionally synchronously) registered signals of various nature (ECG, pulsograms, rheograms, etc.).

Mathematical models (to study the effect of differential massage on a patient, a massage therapist, and upon constructing an algorithm for a massage procedure and its dosage). Mathematical modelling is a method of researching processes or phenomena by creating their mathematical models and researching these models. To build a mathematical model of differential massage, we used a system of linear differential equations. A differential equation is an equation connecting the independent variable X, the unknown function y and the derivatives of the unknown function $y`y''y\ (n)$. The general form of the differential equation is

$$F\left(x, y, y`, Y`, y(n) = 0.\right.$$

The solution of the differential equation is the function $Y = y(x)$, which, when substituted into the equation, turns it into an identical equation.

Pontryagin's maximum principle (PMP) for solving problems with phase constraints to optimize the process of bone tissue reconstruction. A correlation expressing the necessary conditions for a strong extremum for the nonclassical variational problem of optimal control of a mathematical theory was formulated in 1956 by L. S. Pontryagin. The accepted assertion of PMP relates to the following optimal control problem. A system of ordinary differential equations

$$x = f(x,u),$$

is given where $x \in R^n$ is a phase vector, $u \in R^p$ is a control parameter, f is a vector function, continuous in the aggregate of variables and continuously differentiable in x.

In the space, the set of admissible values U of the control parameter i is given; in phase space points x_0 and x_1 are given; fixed initial moment of time t_0. Let us assume that control is carried out by any continuous function $u(t), t_0 \leq t \leq t_1$ with values in the set U. It is said that an admissible control $u = u(t)$ transfers the phase point from position x^0 to position x^1 ($x^0 \rightarrow x^1$). Among all admissible controls that transfer the phase point from position x^0 to position x^1, we need to find the optimal control – the function $u^*(t)$, minimizing the functional:

$$j = \int_{t_0}^{t_1} f^0\left(x(t), u(t)\right) dt .$$

here $f^0(x,u)$ is a given function in the same class as the components $f^0(x,i)$, $x(t)$ is the solution of system[1] with the initial condition $x(t_0) = x^0$, which corresponds to the control $u(t), t_1$ – the time of passage of this solution through the point x_1.

By solving the problem, we mean a pair consisting of the optimal control $u^*(t)$ and the corresponding optimal trajectory $u^*(t)$. It follows from the above system, that

$$H(\psi,x,u) = (\psi, f(x,u)),$$

scalar (Hamiltonian) function of variables y,x,u

$$\psi = (\psi_0, \psi^1) \in R^{n+1},\ \psi_0\ R^1,\ \varphi^1 \in R^n, = (f^0, f).$$

Functions $H(y, x, u)$ are assigned to the canonical (Hamiltonian) system (relative to y, x)

$$\frac{dx}{dt} = \frac{\partial H}{\partial \psi}, \frac{d\psi}{dt} = -\frac{\partial H}{\partial x}.$$

The first of these equations is a system. Let

$$M(\psi, x) = sup\{u \in U\}.$$

Pontryagin's maximum principle: if $uu^*(t)$, $x^*(t)$ $(t \in [t_0,t_1])$ is a solution of the optimal control problem, ($x^0 \rightarrow x^1$, $u \in U$), then there exists such a nonzero absolutely continuous function $y(t)$, while the triple of functions $y(t)$, $x^*(t)$, $u^*(t)$, satisfies the system on $[t_0, t_1]$ and for almost all the maximum condition is performed.

$$H(\psi(t), x^*(t), u^*(t)) = M(\psi(t), x^*(t)),$$

and at the final moment t_1, the conditions

$$M(\psi(t_1), x^*(t_1)) = 0, \psi_0(t_1) \leq 0$$

If the functions $y(t)$, $x(t)$, $u(t)$ satisfy the correlations, (that is, $x(t)$, $u(t)$), form an extremum of S.M. Pontryagin, then the condition

$$M(t) = M(\psi(t), x(t)) \equiv const;\ \psi_0(t_1) \equiv const.$$

This statement implies the maximum principle for the performance problem $f^0 = 1$, $j = t_1 - t_0$, this statement can be naturally generalized to non-autonomous systems, problems with moving ends of trajectories, and problems with a restriction on phase coordinates (condition $x(t) \in X$, where X is a closed set of phase space R^n, satisfying some additional restrictions).

Saati hierarchy analysis method (to justify the use of a psycho-moderating multimedia environment for the prevention and rehabilitation of various diseases). The hierarchy analysis method contains a procedure for synthesizing priorities calculated on the basis of subjective judgments of experts (in our work, in connection with the need to construct a complex multi-criteria problem that requires judgments from different areas of knowledge, judgments from different branches were involved, with a weighted assessment of judgments from directly professional branch, related, and remote field of expertise). The number of opinions can be measured in dozens or even hundreds. Mathematical calculations for tasks of small dimension can be performed manually or using a calculator, however it is much more convenient to use software for entering and processing judgments. The procedure for applying the hierarchy analysis method:

The construction of a qualitative model of the problem in the form of a hierarchy that includes a purpose, alternative options for achieving the goal and criteria for assessing the quality of alternatives:

- prioritization of all elements of the hierarchy using the method of pairwise comparisons;
- synthesis of global priorities of alternatives by linearly convolving the priorities of elements in the hierarchy;
- verification of judgments for consistency;
- making decisions based on the results.

Methods of variational and alternative statistics (methods for testing statistical hypotheses were used to analyse changes in the indicators of an experimental study). The experiments were carried out by comparing the measured parameters before and after the experiment. The number of participants in one type of experiment ranged from 10 to 96, the number of experiments is 23.

The choice of the law of distribution. To determine the type of distribution law according to statistical data, a histogram is built. Histogram is a graph of statistical density of a random value in the form of a stepped polygon. It is constructed as follows: on the abscissa axis, the intervals χ_i are plotted. A rectangle with an ordinate is constructed on each of them, which is equal to the value of the studied quantity x. By combining the ordinates of the centres of the intervals χ_i, we obtain the polygon of the corresponding indicator (statistical density curve). Comparing these curves in appearance with the corresponding theoretical curves, factoring in the nature of the occurrence of failures, the hypothesis on this law of probability distribution is accepted.

The validity of the selected theoretical law (the consistency of the experimental and theoretical curves) is verified according to the matching criteria, of which the most common are Kolmogorov's and Pearson's χ^2 criteria. Kolmogorov's criteria are used when the distribution parameters are known prior to the experiment and after the experiment it is necessary to verify the consistency of the theoretical and experimental distributions. Pearson's χ^2 criterion is used when the distribution parameters are unknown. The algorithm for using χ^2 in assessing the consistency of theoretical and statistical distributions taking into account the statistical values of the frequencies χ^2 (Table 2) provides for:

Definition of discrepancy:

$$x^2 = m \sum_{i=1}^{k} \frac{(v_i^* - v_i)^2}{v_i},$$

where χ_1 is a theoretical frequency; χ_1^* is a statistical frequency of a random variable in ith interval; k is the number of intervals into which the observation time is divided; m is the sample size.

Finding the number of degrees of freedom:

$$r = k - (s + 1),$$

where s is the number of parameters of theoretical distribution.

The theoretical frequency and the number of degrees of freedom depend on the type of theoretical distribution law (Table 2). A decision was made on the consistency of experimental and theoretical distribution laws.

The calculated value of χ^2 is compared with the tabular value (Critical values of the statistics of χ^2 criterion), which correspond to the selected confidence probability χ = (0,9; 0,95; 0,99). If the tabular values are greater than the calculated ones, then the hypothesis of the correctness of the selected distribution law is accepted, otherwise they are rejected. Statistical hypotheses are hypotheses related to the type or individual distribution parameters of a random variable.

We shall describe the terminology used in this case. Let $f(X,\theta)$ be the distribution law of a random variable X with a certain parameter θ. Then:

– H_0 (null hypothesis) – $\theta = \theta_0$,

– H_1 (alternative or competing hypothesis) – $\theta = \theta_1$.

Table 2. The number of degrees of freedom and theoretical frequency when calculating the χ^2 criterion.

Theoretical distribution law	Number of degrees of freedom	Theoretical frequency
Normal law: $f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} exp[-(x-\bar{x})^2/(2\sigma_x^2)]$	$r = k - 3$	$v_i = \Phi\left(\frac{x_i - \bar{x}}{\sigma_x}\right) - \Phi\left(\frac{x_{i+1} - \bar{x}}{\sigma_x}\right)$
Exponential law: $f(x) = \lambda e^{-\lambda x}$	$r = k - 2$	$v_i = e^{-\lambda x_i} - e^{-\lambda x_{i+1}}$
Weibull's Law: $f(x) = \frac{\beta}{z_x} x^{\beta-1} e^{-\left(\frac{x}{z_x}\right)^\beta}$	$r = k - 3$	$v_i = e^{-\left(\frac{x_i}{z_x}\right)^\beta} - e^{-\left(\frac{x_{i+1}}{z_x}\right)^\beta}$

Φ – Laplace's function; χ_i – initial value of a random variable in the ith sample; χ_{i+1} – ultimate value of a random variable in the i^{th} sample.

H_0 is rejected when the probability that it is true falls below a certain level called the significance level. When analysing hypotheses, two kinds of errors are possible:

- H_0 is rejected when it is true.
- H_0 is accepted when H_1 is true.

Reducing the significance level, we reduce the probability of an error of the first kind, but at the same time, the probability of an error of the second kind increases. Therefore, the concept of the power of a criterion is introduced, which represents the probability of a deviation of H_0. Since this probability changes when the parameters of the population change (for example, the sample size), a power curve is usually considered.

Hypothesis testing usually goes through the following steps.

- Definition of the used statistical model. Here, a certain set of prerequisites is put forward regarding the law of distribution of a random variable and its parameters. For example, the distribution law is normal, the values are independent.
- H_0 and H_1 are formulated.
- A criterion (criterial statistics) is selected suitable for the advanced statistical model.
- A significance level is selected, depending on the required reliability of the findings.
- The critical area for testing H_0 is determined. If the value of the criterion falls into this area, then H_0 is rejected. Provided that H_0 is correct, the probability of falling into the critical area equals a. The type of this area (one-sided or two-sided) depends on the adopted H_0.
- The value of the selected statistical criterion for the available data is calculated.
- The calculated value of the criterion is compared with the critical (sometimes called tabular) value and then a decision is made to accept or reject H_0.

When choosing a criterion, it is always necessary to proceed from the applied statement of the problem and the nature of the data. The sequence of operations when choosing a criterion:

- Formulation of the problem. Possible classes of problems are given above. In this part, we consider problems associated with verification of any parameters of the distribution law.
- Definition of the class of criteria used. A choice must be made between parametric and nonparametric criteria for testing hypotheses.
- Definition of additional conditions for the selection of criteria. Many criteria require the performance of additional conditions, without which their use would be incorrect.
- The choice of a specific criterion. For many situations, there are several roughly equivalent criteria suitable for testing a hypothesis.

Student's statistical hypothesis test for normally distributed data. The boundaries of the confidence interval for small samples (n≥30 is limited by the coefficient tα, which was proposed in 1908 by the English mathematician and chemist V. S. Gosset, who published his work under the pseudonym "Student". Later this coefficient was called the Student's coefficient – specially designed tables with consideration of the sample size). It is advisable to adhere to such a sequence of preliminary processing of the observation results at n≥30:

- The observation results are recorded in a table.
- The average value of $\bar{X}$ is calculated fromn observations:

$$– \quad \overline{X = \frac{1}{n}\sum_{i=1}^{n} X}.$$

- The errors of individual observations are determined:

$$– \quad \Delta X_i = \bar{X} - X_i \text{ and their squares } (\Delta X_i)^2.$$

- The observations that are sharply different from others are filtered out. For this, the following are found:
- Mean square error:

$$- \quad \Delta\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} \Delta x_i^2}{n}}.$$

- The error value α = 0,95 is set.
- The student coefficient t_α=(n) is determined for a given reliability P and the number of observations n.
- The boundaries of the confidence interval (errors of the observation results) are found:

$$\Delta X = t_\alpha(n)\Delta\sigma_x, X = \bar{X} \pm \Delta X.$$

- Relative error of sampled data is calculated:

$$\varepsilon = \frac{\Delta x}{x} * 100\%.$$

The Wilcoxon criterion is one of the most famous tools for nonparametric statistics (along with such statistics as Kolmogorov-Smirnov and rank correlation coefficients). The properties of this criterion and the tables of its critical values are addressed in many monographs on mathematical and applied statistics. We shall introduce some notation. Let the button be the function inverted to the distribution function $F(x)$. It is defined on the segment [0; 1]. Let us assume that

$$L(t) = G(F - 1(t)).$$

Since $F(x)$ is continuous and strictly increasing, $F^{-1}(t)$ and $L(t)$ have the same properties. An important role in the subsequent presentation will play the value of unused $a = P(X<Y)$. As it is easy to show,

$$a = P(X < Y) = \int_0^1 t dL(t).$$

We shall also introduce:

$$b^2 = \int_0^1 L^2(t)dt - (1-a)^2, g^2 = \int_0^1 t^2 dL(t) - a^2.$$

Then the mathematical expectations and variances of the Wilcoxon and Mann-Whitney statistics are expressed in terms of the introduced values:

$$E(U) = mna, E\left(S = mn + \frac{m(m+1)}{2} - E(U) = mn(1-a) + \frac{m(m+1)}{2}\right),$$

$$D(S) = D(U = mn[(n-1)b^2 + (m-1)g^2 + a(1-a)]).$$

When the volumes of both samples grow infinitely, the distributions of the Wilcoxon and Mann-Whitney statistics are asymptotically normal with the parameters given by formulas[33]. If the samples are completely homogeneous, that is, their distribution functions coincide, the following hypothesis is fair:

$$if\ H_0: F(x) = G(x)\ for\ all\ x,$$

then $L(t) = t$ and $a = 1/2$.

Substituting into formula[37], we obtain:

$$E(S) = m(m+n+1)/2, D(S) = mn(m+n+1)/12.$$

Consequently, the distribution of normalized and centred Wilcoxon statistics:

$$T = (S - m(m+n+1)/2)(mn(m+n+1)/12) - 1/2,$$

as sample sizes increase, it approaches the standard normal distribution (with a mathematical expectation of 0 and a variance of 1).

Conclusions

The decision rules and the table of critical values for the Wilcoxon criterion are constructed under the assumption that the hypothesis of complete homogeneity described by the formula is valid. To implement the information system of medical (physical) rehabilitation and the software environment for the analysis of biosignals of athletes during rehabilitation. We have proposed a decision-making methodology for choosing a set of patient treatment methods. This approach provides the choice of a set of physiotherapeutic methods, which is optimal in efficiency and balanced in time of application and load on the patient. The proposed structure will allow doctors to determine supportive treatment plans for patients receiving drug therapy or recovering from surgery.

Ethical standards

The article does not contain experiments conducted with the participation of humans or animals.

Conflict of interest

The authors do not declare a conflict of interest.

Bibliography

1. Dmytriiev D. Assessment and treatment of postoperative pain in children. *Anaesth, Pain Intensive Care.* 2018;22:392-400.
2. Puk AL, De Luigi AJ. *Rehabilitation of the adaptive athlete*. Cham: Springer International Publishing; 2018.
3. Silfverskiold JP, Steadman JR, Higgins RW, Hagerman T, Atkins JA. Rehabilitation of the anterior cruciate ligament in the athlete. *Sports Med.* 1988;6:308-19.
4. Standaert, CJ, Herring SA, Pratt TW. Rehabilitation of the athlete with low back pain. *Curr Sports Med Rep.* 2004;3:35-40.
5. Watkins R, Kordecki M. Rehabilitation of the athlete's spine. In: Hsu WK, Jenkins TJ. *Spinal conditions in the athlete: A clinical guide to evaluation, management and controversies.* Cham: Springer International Publishing; 2020.
6. Wilk KE, Arrigo CA. *Principles of rehabilitation in the overhead athlete.* Cham, Switzerland: Springer International Publishing; 2019.
7. Zhanaidarova G, Nauryzov N, Nurseitova K, Arystan L, Dyussembekov R, Turdunova G, Zhanbyrbaeva S, Akhmetova G. Development of the Heart Muscle after Antenatal Ethanol Intoxication during the Neonatal Period. *Bangladesh J Med Sci.* 2022;21:344-53.
8. Sultonov NN, Sabirov MO, Tashpulatova MH, Maksudova LI. Evaluating the effectiveness of antiplatelet therapy of the patients with kidney disease. *Int J Res Pharm Sci.* 2020;11:6033-8.
9. Carli D. *Functional recovery of the combat sport athlete: wrist and hand injury – from post-rehabilitation to the competition*. Cham: Springer International Publishing; 2018.
10. Cohen C, Leme L, Barbosa G, Ejnisman B. *Postoperative rehabilitation: Return to Sport in the noncompetitive athlete*. Heidelberg: Springer Berlin Heidelberg; 2019.
11. Cools AM, Borms D, Castelein B, Vanderstukken F, Johansson FR. Evidence-based rehabilitation of athletes with glenohumeral instability. *Knee Surg, Sports Traumatol, Arthros.* 2016;24:382-9.
12. Coronado RA, Herzberg S, Archer KR. *Identification and management of psychosocial issues in the athlete for return to sport.* Cham: Springer International Publishing; 2019.
13. Cassella MC, Richards K. *Principles of rehabilitation*. New York: Springer New York; 2007.
14. Zhanaidarova G, Arystan L, Nauryzov N, Syzdykova A, Dyussembekov R, Zhanbyrbaeva S, Turdunova G, Shaimerdenova D. The effect of ethanol on the fetal heart muscle. *J Global Pharma Technol.* 2020;12:501-10.
15. Medvecky MJ, Zazulak BT, Hewett TE. A multidisciplinary approach to the evaluation, reconstruction and rehabilitation of the multi-ligament injured athlete. *Sports Med.* 2007;37:169-87.
16. Saroglia I, Pompili G. *Rehabilitation in the athletes.* Cham: Springer International Publishing; 2018.
17. Tilley D, James DA. *Rehabilitation of gymnasts.* Cham: Springer International Publishing; 2020.
18. Wayman K, Pintar J. *Evaluation and treatment of the swimming athlete*. Cham: Springer International Publishing; 2016.
19. Wheatley WB, Krome J, Martin DF. Rehabilitation programmes following arthroscopic meniscectomy in athletes. *Sports Med.* 1996;21:447-56.
20. Beitzel K, Imhoff AB. *Accelerated rehabilitation of shoulder injuries in athletes*. Heidelberg: Springer Berlin Heidelberg; 2015.
21. Kiuchukov I, Yanev I, Petrov L, Kolimechkov S, Alexandrova A, Zaykova D, Stoimenov E. Impact of gymnastics training on the health-related physical fitness of young female and male artistic gymnasts. *Science of Gymnast J.* 2019;11:175-88.
22. Lundblad M, Hägglund M, Thomeé C, Hamrin Senorski E, Ekstrand J, Karlsson J, Waldén M. Medial collateral ligament injuries of the knee in male professional football players: A prospective three-season study of 130 cases from the UEFA Elite Club Injury Study. *Knee Surg, Sports Traum, Arthros.* 2019;27:3692-8.
23. Zhou S, Tan B. Electrocardiogram soft computing using hybrid deep learning CNN-ELM. *Appl Soft Comp J.* 2020;86:105778.