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System Analysis of the Physiological and Psychophysiological Determinants of Purposeful Physical Activity and Prediction of its Effectiveness Among Students of a Medical University

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ABSTRACT

INTRODUCTION: In the field of sports physiology, the need to study the determinants of the effectiveness of various types of physical activity is quite urgent. A variety of physiological and psychophysiological parameters as potential predictors of purposeful physical activity determines the need to search for a new algorithm for system analysis carried out using modern methods of mathematical data processing. In this regard, it is relevant to use artificial neural networks and multifactorial regression analysis in order to solve the stated tasks.

AIM: To carry out a system analysis of the individual physiological and psychophysiological determinants of human physical activity in order to predict its effectiveness.

MATERIALS AND METHODS: One hundred twenty young men who did not have sports grades and did not regularly attend sports clubs voluntarily participated in the study. The subjects' motivational basis of behavior, basic physical qualities, physiological and psychophysiological parameters were evaluated. Forecasting the direction of performance was carried out using the constructed models of artificial neural network technology and multifactorial regression analysis.

RESULTS: Based on the statistical processing of the obtained parameters (division into clusters, rank correlation, neural network modeling, linear regression), an algorithm was created for the correct and reliable identification of the direction of the effectiveness of physical activity when the study participants realized the basic physical characteristics (strength, dexterity, endurance, speed). The study participants were divided into homogeneous clusters: 'effective in running disciplines' (70 boys) and 'effective in strength disciplines' (50 boys). The models constructed using artificial neural network technology with the involvement of various parameters, allowed identification of the determinants of the effectiveness of physical activity (ROC sensitivity: 75.7, 86.0 and 96.5%). According to the calculated parameters of the regression equation the result was predicted in high-speed quality with an accuracy of 87.9% ($p \leq 0.001$), and in power quality with an accuracy of 70.8% ($p \leq 0.004$).

CONCLUSION: The complex of mathematical and statistical methods of analysis selected in the work can be introduced for identification and system analysis of motor activity of individual physiological and psychophysiological determinants of physical activity to predict its effectiveness in young men.

Keywords: physical activity; physiological determinants; psychophysiological determinants; prognosis of effectiveness; neural network.

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Системный анализ физиологических и психофизиологических детерминант целенаправленной физической активности и прогнозирование ее результативности у студентов медицинского университета

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АННОТАЦИЯ

Введение. В области спортивной физиологии достаточно актуальной является необходимость изучения детерминант результативности различных видов физической деятельности. Множество физиологических и психофизиологических параметров как потенциальных предикторов целенаправленной физической активности (ФА) определяет необходимость поиска нового алгоритма системного анализа, осуществляемого с помощью современных методов математической обработки данных. В связи с этим актуальным является применение искусственных нейронных сетей и многофакторного регрессионного анализа с целью решения заявленных задач.

Цель. Провести системный анализ индивидуальных физиологических и психофизиологических детерминант ФА человека для прогнозирования ее результативности.

Материалы и методы. В исследовании добровольно приняли участие 120 юношей, не имеющих спортивных разрядов и не посещавших регулярно спортивные секции. У испытуемых была оценена мотивационная основа поведения, основные физические качества, физиологические и психофизиологические показатели. Прогнозирование направления результативности осуществлялось при помощи построенных моделей технологии искусственных нейросетей и многофакторного регрессионного анализа.

Результаты. Исходя из статистической обработки полученных параметров (деление на кластеры, ранговая корреляция, нейросетевое моделирование, линейная регрессия), получили алгоритм для корректного и надежного выявления направления результативности ФА при реализации участниками исследования основных физических качеств (сила, ловкость, выносливость, быстрота). Участники исследования были разделены на однородные кластеры: «результативные в беговых дисциплинах» (70 юношей) и «результативные в силовых дисциплинах» (50 юношей). Благодаря моделям, построенным с помощью технологии искусственной нейронной сети с различным вовлечением показателей, были выявлены детерминанты результативности ФА (чувствительность ROC: 75,7, 86,0 и 96,5%). По расчетным показателям уравнения регрессии спрогнозировали результат в скоростном качестве с точностью 87,9% ($p \leq 0{,}001$), а в силовом — с точностью 70,8% ($p \leq 0{,}004$).

Заключение. Подобранный в работе комплекс математических и статистических способов анализа может быть внедрен для выявления и системного анализа индивидуальных физиологических и психофизиологических детерминант ФА человека для прогнозирования ее результативности у юношей.

Ключевые слова: физическая активность; физиологические детерминанты; психофизиологические детерминанты; прогнозирование результативности; искусственная нейросеть.

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INTRODUCTION

In the field of sports physiology, it is important to study the determinants of the effectiveness of various types of physical activity (PA) [1, 2]. Literature data evidence the need to study various mathematical methods and procedures for predicting sports results [3]. In this regard, the formation of a reliable forecast of the effectiveness of physical purposeful activity based on a combination of individual physiological, psychological and motivational determinants is a relevant task in the field of sports physiology [4].

A variety of physiological and psychophysiological parameters as potential predictors of purposeful physical activity determines the need of searching for a new algorithm for system analysis carried out using modern methods of mathematical data processing [5, 6]. Modern IT technologies allow diagnosing and forecasting the effectiveness of various types of human motor activity [7]. The use of artificial intelligence (in particular, an artificial neural network (ANN)) and mathematical data analysis (linear regression) is relevant to solve the stated problems. In our opinion, this will permit timely adjustment of the training process that influences the results of the activity [5].

The **aim** of this study to analyzes individual physiological and psychophysiological determinants of human physical activity to predict its effectiveness.

MATERIALS AND METHODS

In 2022–2023 were examined 120 young men citizens of the Russian Federation studying at a medical university

Inclusion criteria: age 18–21 years, ability to follow the study instructions, belonging to the main physical education group (according to the results of a medical examination at the university clinic), noninvolvement in sports and regular physical activity. The study was approved by the Local Ethics Committee or Ryazan State Medical University (Protocol No. 14 of April 11, 2021).

The purposeful motor activity of subjects was considered a model of activity in identifying specific physical characteristics.

Table 1 presents the methods for studying the physiological and psychophysiological determinants of human PA. Bicycle ergometry (PWC_{170} test) was carried out on a Corival bicycle ergometer (Lode, Netherlands), neuroenergy mapping was carried out using the Neuroenergokartograph NEK-5 hardware and software complex (HSC) (Statokin, Russia). Psychophysiological characteristics were assessed using a questionnaire with subsequent computer processing using NS-Psychotest, version 1.6.7.7 (Neurosoft, Russia).

The passing of control standards for the assessment of students' physical qualities and simultaneous questionnaire testing of the motivational basis of this activity was carried out at the Lokomotiv stadium in Ryazan.

In Table 2 presents the methods of statistical processing of the results (Statistica Basic Academic 13.0 Ru, serial number AXA003J115213FAACD-X).

The equation for multiple regression analysis is:

$$y= B_0+B_1\times x_1+B_2\times x_2\ldots+B_n\times x_n$$

where B_0 is a free number, B_1, B_2 ... B_n are coefficients of the equation for independent factors, x_1, x_2 ... x_n are factors that do not depend on each other.

Based on the tasks set, the Neural Networks module created, trained and tested artificial neural networks. The study used MLP (*multi-layer perceptron*) neural networks, as well as RBF (*radial basis functions*). Training, control and test samples were obtained.

The study parameters that were entered into the body of the ANN program, included individual physiological and psychophysiological characteristics of the study participants. At the output, in the classification mode, the subjects were distributed into 2 clusters reflecting the *direction of the study participants' effectiveness*.

The neural network forecasting included three main stages. The first stage involved assessing the individual properties of the subjects and entering the obtained parameters into the body of the *Neural Networks* program, the second stage involved training and testing from the entered values based on the study aims, and the final stage involved determining the values of the subjects' individual parameters in forming the effectiveness of control tests of physical activity based on the constructed ANN model. Using *ROC* analysis, the reliability of the forecast was calculated (*ROC* analysis data for the control samples are presented). The samples were selected from the main group by random selection ('random creation of subsamples'): 35% of cases were training sample, 30% were control sample, and 35% were testing sample.

The determinants that had a more significant effect on the effectiveness of physical activity were identified by automatic sorting by significance and eliminating less important ones. The efficiency of the regression equation was assessed by variance analysis with a significance criterion of $p \leq 0.05$.

Study stages:

1) evaluation of the effectiveness of control tests;

2) selection of determinants and prediction of the success of the subjects' motor activity;

3) verification of the results of *ROC* analysis;

4) comparison of *ROC* curves with the involvement of a different number of predictors to form a prediction of the final result;

5) determination of the relationship between individual parameters determined in laboratory conditions (see Table 1) and the effectiveness of testing physical fitness using

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Table 1. Methods of assessment of physiological and psychophysiological determinants of human physical activity used in the study to predict its effectiveness

Examination method	Assessed parameters	Measurement units and assessment
Bicycle ergometry	general physical performance (PWC_{170})	W/kg
Neuroenergy mapping	initial level of constant potential of the brain and its dynamics in functional tests: hyperventilation, verbal fluency test, Schulte–Gorbov table	mV
Questionnaire and behavioral methods for assessing motor and sensory functional asymmetries	motor asymmetry (manual, leg asymmetry) sensory asymmetry (auditory and visual)	score
Ch.D. Spielberger — Yu.L. Khanin test (STAI)	personal and situational anxiety	score
Jenkins test (JAS)	behavior type (A, B, AB)	score
Teylor test (MAS)	personal anxiety	score
V.M. Rusalov test (TSQ)	temperament structure	score
V.K. Gerbachevsky test	motivational basis of behavior (15 scales)	score
Assessment of physical qualities when passing control standards	Physical activity: - running 100 meters - running 1000 meters - pull-ups on a high crossbar - long jump from a standing position	 sec sec number of times cm

Notes: STAI — State-Trait Anxiety Inventory; JAS — Jenkins Activity Survey;, MAS — Taylor Manifest Anxiety Scale; TSQ — temperament structure questionnaire

Table 2. Statistical methods of assessment of results

Examination method	Assessed parameters	Measurement units and assessment
Methods of nonparametric statistics: - Shapiro–Wilk test - Mann–Whitney test	 normality of distribution reliability of difference	Me [Q1; Q3] p <0,05
Cluster analysis method (hierarchical trees and k-means procedure)	differences between the parameters in two groups (classification of subjects), identification of elements included in clusters, while using the hierarchical tree method the number of clusters was estimated as 2, and the elements of 2 clusters were identified (k-means method) at the 3rd iteration	distance between clusters
Method of multivariate regression analysis	predicting the effectiveness of physical activity	regression coefficient
Method of variance analysis	reliability and efficiency of using the model	dispersion coefficient
Artificial Neural Network (ANN) Technology	determinants of successful passing of control standards	pcs

multivariate regression analysis in individuals of a certain cluster;

6) dispersion and regression analysis.

RESULTS

At the first stage of the system analysis of the determinants of purposeful physical activity, the differences in the performance of control tests were assessed (Table 3). Based on the results of the sports tests, the study participants were assigned to two homogeneous clusters that differed from each other:

1) young men 'effective in *running* disciplines' who successfully ran 100 and 1000 meter distances (n=70);

2) young men 'effective in *strength* disciplines' who successfully completed strength and agility exercises (n=50).

Before dividing into clusters, the subjects' parameters were checked using the hierarchical cluster analysis method, which initially identified two groups.

Table 3. Effectiveness of purposeful physical activity in the formed clusters, Me [Q1; Q3]

Parameters	Cluster 1, young men 'effective in running disciplines'	Cluster 2, young men 'effective in strength disciplines'	U (Z)	*p*
Running 100 m (sec)	13.0 [12.6; 14.5]	14.7 [14.2; 14.9]	867.4	0.05
Running 1000 m (sec)	245.2 [240.0; 248.4]	256.0 [247.0; 269.3]	734.0	0.05
Standing long jump, (cm)	259.0 [246.0; 267.0]	279.0 [267.0; 287.0]	716.9	0.05
High Bar Pull-Ups (times)	12.0 [10.0; 14.0]	15.0 [13.0; 19.0]	263.6	0.05

At the second stage, several models were constructed based on ANN with a *gradual increase in leading factors*, which included a different number of neurons at the input to the program body and neurons of the intermediate layer. Two output neurons were unnamed, since in the forecasting process the subjects were distributed into two clusters 'effective in running disciplines' and 'effective in strength disciplines'.

The next task of the study was checking the results of the *ROC* analysis, which indicate that the effectiveness of purposeful PA of the study participants depends not only on the parameter of general physical performance, but also on other individual physiological and psychophysiological characteristics. The most illustrative reflection of the results of including additional parameters in the neural network is shown in the changes in the area under the *ROC* curve (AUC), which reflects the specificity, sensitivity, and reliability of the forecast.

A comparison of *ROC* curves was carried out with the involvement of a different number of predictors to form a forecast of the final result. To begin with, only the *physical performance parameter* with various characteristics was used as a predictor. %. Based on the results of the ANN (MLP 1-5-2), the contribution of the physical performance parameter was identified, which has the greatest impact on determining the desired cluster with a certain performance, but with low reliability of the forecast.

Next, the list of leading factors was expanded, including *parameters of functional lateralization of the brain*. The added parameters served to increase the prediction reliability and the inclusion of study participants in the proper cluster to 86.0% (Figure 2). At the final stage, all the studied parameters were included and the prediction reliability was 96.0% (Figure 3).

Based on the results of the algorithm presented above and the work of the ANN (MLP 58-16-2) formed at the final stage, *twelve parameters were identified* that make the greatest contribution to determining the direction of the effectiveness of physical activity of the subjects. The ranking of determinants in descending order of their significance is presented in Table 4.

At the next stage of this study, the relationship between individual laboratory parameters determined in laboratory conditions (see Table 1) and effectiveness in physical fitness testing was determined using multivariate regression analysis in individuals of a particular cluster. The regression coefficients were obtained, which determine the success of the study participants in 100 meters running and pull-ups on a bar (Tables 5, 6).

The equation for predicting the leading factors and the result in 100-meter running is as follows:

$$y=11,442+0,246\times x_1-0,363\times x_2,$$

where x_1 is the motivation parameter (internal motive), x_2 is the PWC_{170} parameter.

Based on the analysis of variance and the resulting regression model, it was determined that the model with

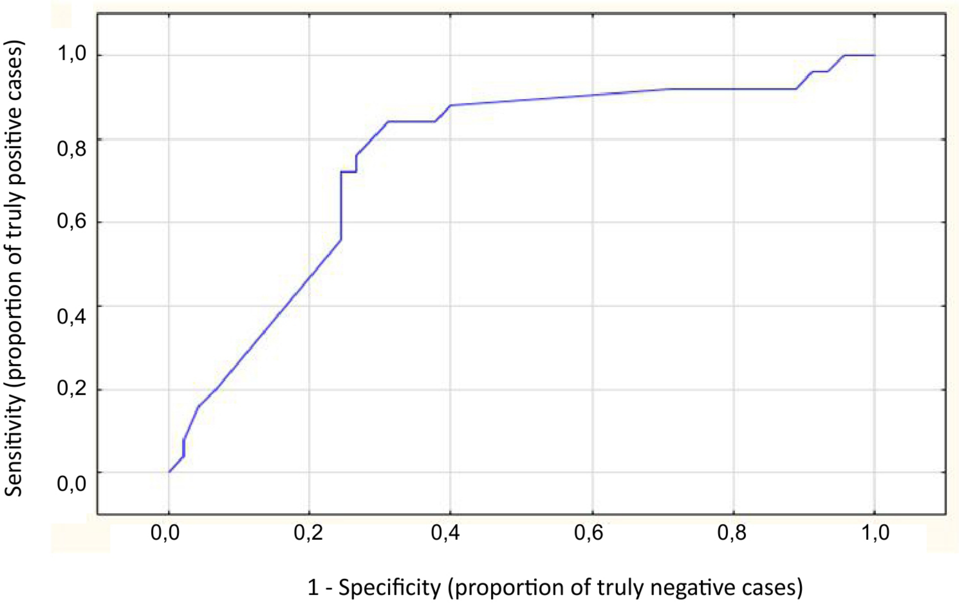

Fig. 1. Graphic presentation of the results of *ROC* analysis for a neural network using only the physical performance parameter as a predictor: training effectiveness — 71.1%, control effectiveness — 28.8%, test performance — 29.4%, prediction reliability — 75.7%.

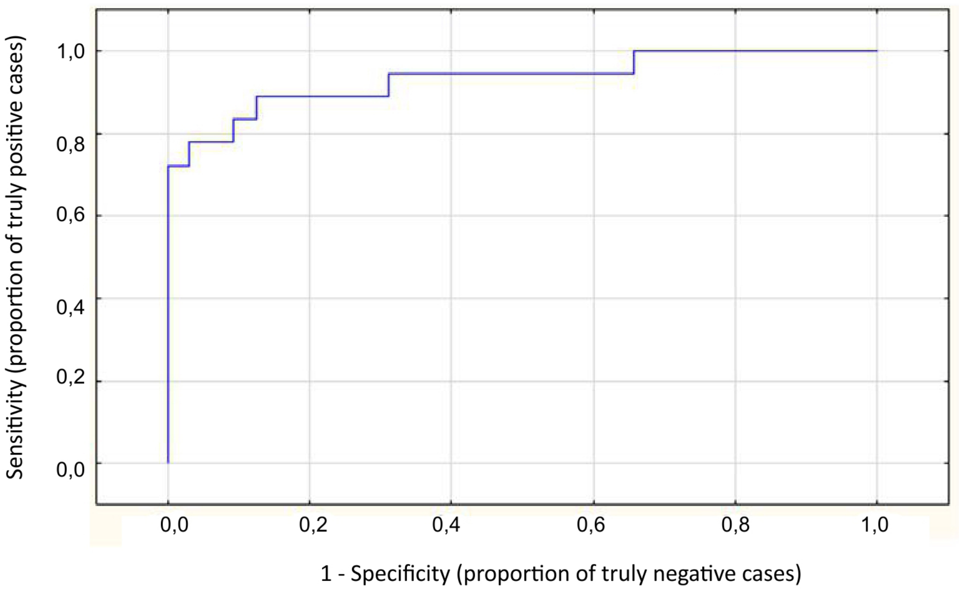

Fig. 2. Graphic presentation of the results of *ROC* analysis for a neural network using the parameter of physical performance and functional lateralization of the brain as predictors: training effectiveness — 84.1%, control effectiveness — 14.0%, test effectiveness — 15.5%, prediction reliability — 86.0%.

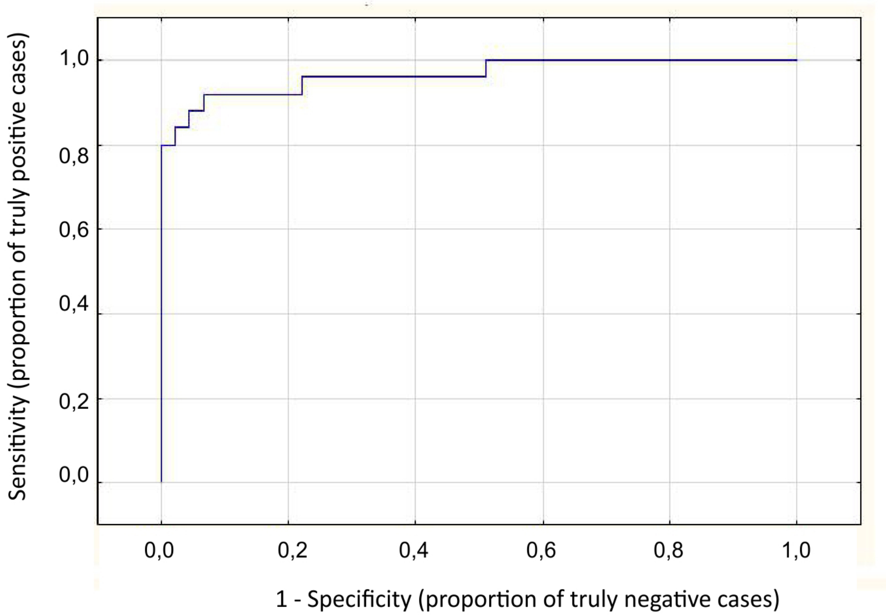

Fig. 3. Graphic presentation of the results of *ROC* analysis for the neural network (MLP 58-16-2) using all the studied parameters as predictors: training effectiveness — 88.9%, the control effectiveness — 92.8%, test effectiveness — 91.4%, prediction reliability — 96.0%.

Table 4. Ranked list of determinants used by the neural network to distribute subjects into clusters with different effectiveness of physical activity

Rank	Parameters
1	Motor asymmetry coefficient (leading leg) (according to N.N. Bragina, T.A. Dobrokhotova)
2	Sensory asymmetry coefficient (dominant eye) (according to N.N. Bragina, T.A. Dobrokhotova)
3	FMA coefficient (Annet questionnaire)
4	General physical performance (PWC170 test)
5	Lateral Organization Profile
6	Motor asymmetry coefficient (leading hand) (according to N.N. Bragina, T.A. Dobrokhotova)
7	Motive for changing activities
8	Level of constant potential during hyperventilation test, Td-Ts lead (neuroenergy mapping method)
9	Social tempo (V.M. Rusalov TSQ test)
10	Internal motif (V.K. Gerbachevsky test)
11	Speed and tempo (V.M. Rusalov TSQ test)
12	Personal anxiety (Spielberger-Khanin STAI test)

Notes: STAI — State-Trait Anxiety Inventory*;* TSQ — temperament structure all the leading factors is complete. To check the analysis of residuals, a standardized graph with a scatter of points on a plane was used, which shows the normal distribution residuals. The normal distribution of residuals, as well as the scatter of regression coefficients on the plane, is not very extensive, which indicates the correctness of constructing the equation for calculating the time interval in speed aspect and allows predicting the result (result in 100-meter running (s)) with accuracy of 87.9%, since the determination coefficient (R^2_a) is 0.879 (p ≤0.001, Figure 4).

Table 5. Regression analysis parameters for assessing success in running 100 meters in young men of the first cluster (n=70)

Parameters	Coefficients	Standard deviation of the regression coefficient	Standardized regression coefficient	*p*
Motivation (internal motif)	0.246	0.066	0.380	*0.001*
PWC_{170}	-0.363	0.081	-0.456	*0.001*

Table 6. Regression analysis parameters for assessing success in high bar pull-ups among young men of the second cluster (n=50)

Parameters	Coefficients	Standard deviation of the regression coefficient	Standardized regression coefficient	*p*
Lateralization profile coefficient	0.055	0.116	0.446	*0.004*
Visual asymmetry coefficient	-0.034	0.115	-0.336	*0.004*
Motivation (initiative)	-0.806	0.112	-0.405	*0.001*

The equation for predicting the leading factors and the result in pull-ups on a high bar has the form:

$$y=28,711+0,055\times x3-0,034\times x_4-0,806\times x_5,$$

where x_3 is the lateralization profile coefficient, x_4 is the visual asymmetry coefficient, x_5 is the motivation parameter (initiative).

Based on the analysis of variance and the resulting regression model, it was determined that the model with all leading factors is complete. An analysis of the model residuals was conducted, and a standardized regression graph with a scatter of points on the plane was presented, which shows the residuals of the distribution normality of the leading factors. Due to the fact that the scatter of points on the plane of regression coefficients is quite insignificant, it was considered that the constructed model for predicting effectiveness in strength aspect is acceptable. Therefore, the constructed equation allows us to determine the result in strength characteristics (number of times), with the manifestation of maximum efforts with accuracy of 70.8%, since the determination coefficient (R^2_a) is 0.708 (p ≤0.001, p ≤0.004) (Figure 5).

DISCUSSION

In the study by E.G. Kostenko and I.G. Pavel'ev (2021), the effectiveness of sports activities was predicted using the regression analysis method, including data on the height and weight of the subjects [8]. K.A. Ponomareva (2020) in her work describes the possibilities of using ANN technology to predict the success of studying at a university [9]. A number of studies are devoted to the use of ANN technology to predict results in sports competitions and modeling the training process. Thus, for example, E.N. Bobkova and E.V. Parfianovich (2018) in their work relied on data on the monthly volumes of training athletes to predict the results of a 400-meter run for 10 subjects with varying degrees of fitness [10]. S.T. Kasyuk and E.M. Vakhtomova (2013) used ANN to predict results, where the determinants were the results of the European national teams' games at the European Football Championship [11]. A.V. Azyabina and P.K. Petrov (2023) predicted results in weightlifting based on anthropometric data and athletes' data in the snatch exercise [12].

Thus, the analyzed literature data indicate that the effectiveness of sports activities is predicted without the use of ANN technology, and this technology is used to predict

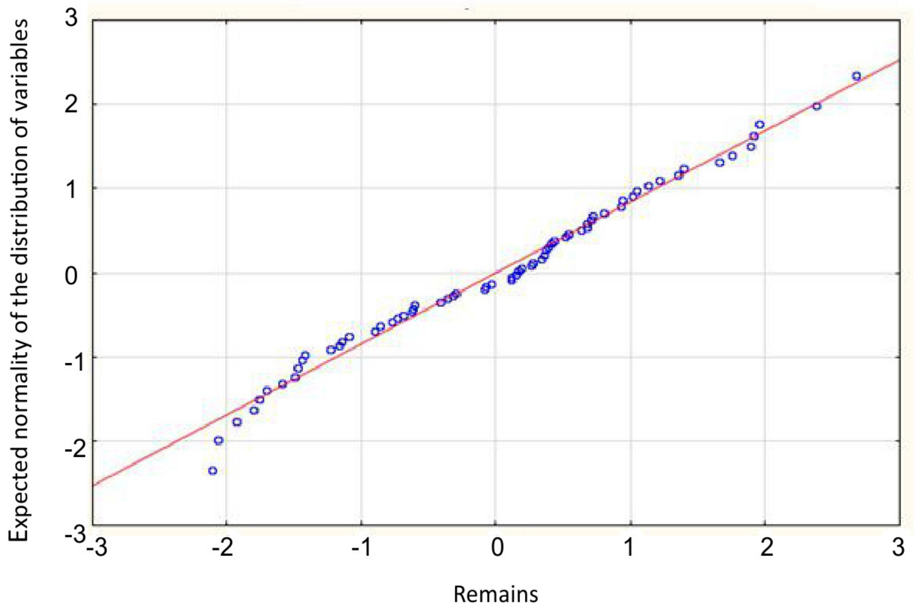

Fig. 4. Distribution of residuals and scatter of points on the plane of regression coefficients in strength quality among subjects of the first group (n=70).

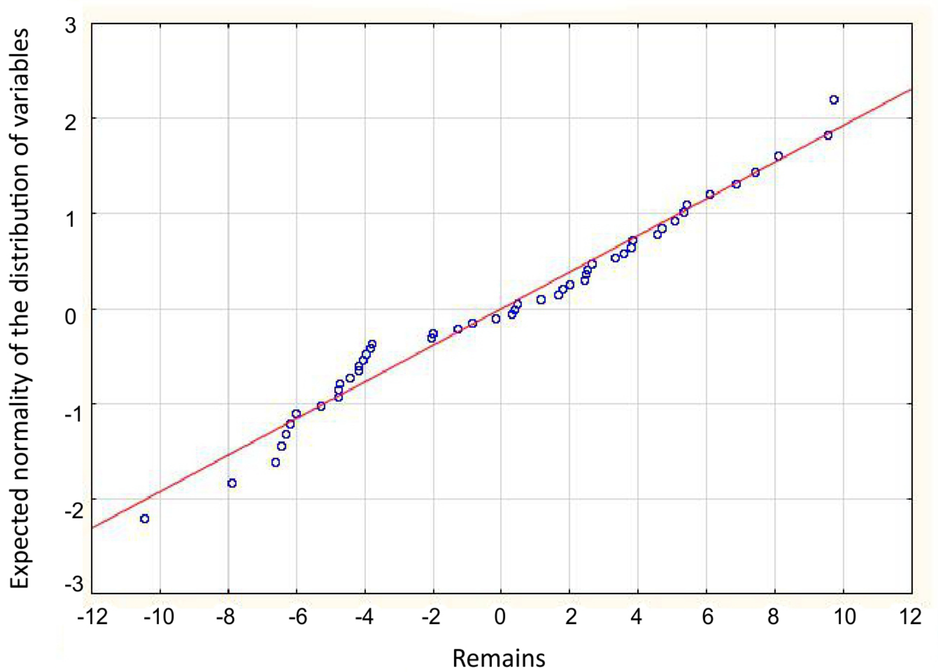

Fig. 5. Distribution of residuals and scatter of points on the plane of regression coefficients in strength quality among subjects of the second group (n=50).

the effectiveness of other types of activities. In addition, the results of activities in the works of other authors are forecast without taking into account psychophysiological predictors.

According to our study, the effectiveness of passing control tests in physical education among the participants in the study directly depends on the parameters of functional lateralization of the brain, general physical performance, temperament characteristics, as well as the motivation of the subjects during implementing specific physical characteristics. Based on the studies, one should speak about the possibility of using a multi-stage algorithm for predicting sports results in young men who are studying at a medical university. The use of clustering method as well as the hierarchical and the k-means methods made it possible to identify two groups of people with varying success in performing running and strength exercises in physical education classes. Based on various physiological and psychophysiological components identified in the participants of the study, ANN correct distribution of subjects into clusters with different effectiveness in various types of physical activity, and can also rank the studied parameters that have the greatest influence on the forecast of performance. In addition, based on the inclusion of the widest possible range of parameters, it becomes possible to form algorithms for predicting the effectiveness of purposeful activities using neural networks with a high degree of reliability.

Multiple regression analysis with the construction of a linear model helps to identify factors that ensure the successful implementation of physical characteristics in running or strength disciplines with testing hypotheses for the model. The efficiency and performance of the constructed equations were tested using variance analysis, which revealed the correctness of the formation of the model and construction of the equation for predicting the results of the study participants in speed and strength aspects.

The presented materials show that we have developed an effective, accessible algorithm for predicting the performance of passing control standards for students, created on the basis of neural network technology.

CONCLUSION

A reliable forecast of high performance of sports activities as a variant of physical activity manifestation in people with equal level of preparedness can be formed not only taking into account the organization of the training process, but also the psychophysiological characteristics, which, along with physical performance, determine the quality and effectiveness of activities in specific conditions.

Thus, the complex of mathematical and statistical methods of analysis selected in the work can be implemented for the system analysis of individual physiological and psychophysiological determinants of human physical activity to predict its effectiveness in young men.

ADDITIONAL INFORMATION

Author contributions. I.M. Mazikin — collection of data and processing of material, writing the text; M.M. Lapkin — concept and design of the study, editing; R.A. Zorin — statistical processing of data, writing the text; M.V. Akulina — design of the study, collection of data, editing, design of illustration; N.A. Kulikova — collection of data, editing. All authors approved the manuscript (the publication version), and also agreed to be responsible for all aspects of the work, ensuring proper consideration and resolution of issues related to the accuracy and integrity of any part of it.

Ethics approval. The study was approved from the Local Ethics Committee of the Ryazan State Medical University (Protocol No. 14 of April 11, 2021).

Consent for publication. All participants of study voluntarily signed an informed consent form before being included in the study.

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