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Original Article

Cluster analysis of adaptation reserves of the body in the post-load period

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Abstract:
Improving the methods of medical and pedagogical control over persons engaged in physical culture and sports is an urgent problem. *Purpose:* using cluster analysis to carry out the distribution of students into groups of the body adaptive reserves levels in the post-loading period. *Materials and methods*. 75 students studying at universities in Nizhny Novgorod (Russia) took part in the research. Generally accepted motor tests were used as physical activity. The adaptive reserves level was studied in the post-loading period for 10 minutes after the load, according to heart rate variability (HRV). Statistical and spectral indicators of HRV, stress index level, heart rate, as well as systolic and diastolic blood pressure were analyzed. To determine the number of clusters, the method of hierarchical clustering was used with a Dendrogram construction. Cluster analysis was performed using the K-means method using Euclidean distances between cluster centroids. *Results*. There have been cases of cardiac rhythm adjustment inability to the effect of physical activity, a tendency to arrhythmogenic events, which indicates the lack of satisfactory adaptation of the heart rhythm in some group of young men. Cases of body overstrain with the presence of heart rhythm centralization in the post-loading period were revealed. During the hierarchical clustering, the presence of three separate clusters was revealed. At the same time, one cluster stands out significantly relative to the other groups of subjects. *Conclusions.* The obtained reliable differences of cluster groups indicate the different status of groups of young men. This fact provides the basis for a possible correction of physical activity in a separate category of persons and a personalized approach to students' physical training.
Key Words*:* **students, physical activity, heart rate variability (HRV), adaptive reserves, cluster analysis**

Introduction

It is known from the scientific literature that the physiological state of the human cardiovascular system adaptive reserves makes it possible to ensure the volume and intensity of physical performance using compensatory regulatory mechanisms (Guzii et al., 2020). A person's regular physical activity leads to the development of a functional state of economical work at rest, which is manifested by slowing down the pulse and significant mobilization of all functional systems during exercise and the ability to quickly complete recovery (Dupuy & Dugué, 2018). In this regard, special control over the body functional systems state and the persons' engaged in physical culture and sports physical health is required. The emergence of modern methods for studying the persons' performing regular physical activity functional state of the body significantly increase the effectiveness of determining and evaluating the body reserve capabilities. In order to achieve this aim, the method of studying heart rate variability has become widely used in sports practice (Shlyk, 2016; Guzii et al., 2020; Christiani et al., 2021). According to these researchers, a sufficiently high efficiency and reliability of this method has been established to assess the state of the observed persons' engaged in physical education or sports vegetative status. When using the heart rate variability method in the medical control of persons performing physical loads, the evaluation of the physical exertion impact effectiveness is carried out by studying the nature of changes in individual parameters within their statistical indicators measurement, which are processed by traditional methods of mathematical statistics (Eskov et al., 2012; Duncker, Bache, 2008). At the same time, according to data from Butakova et al. (2019), Bocharin et al. (2022), Martusevich et al. (2022) an important and

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practically significant task is the integral assessment of the body functional state and its adaptive reserves to various influences, including physical loads. In this regard, it seems important and timely to introduce into practice monitoring observations of persons performing physical activity modern systematic methods of studying and assessing their body functional state. Some integrative methods are used to monitor the autonomic nervous system (Balyklov et al., 2017; Suchomel, et al., 2021; Nedyalkova et al., 2021), which makes it possible to predict not only athletic performance, but also the prospects for the fitness development. Therefore, it is relevant to study the relationship of the functional systems of the body at rest, during exercise and during the recovery of the body in persons having different physical fitness and health status in the field of physical culture and sports (Adams et al., 2018; Aparecida Maria Catai et al., 2020; Kolokoltsev et al., 2022). To do this, it is necessary to monitor the adaptive reserves of the body to prevent prenosological conditions development (Eskov et al., 2012; Bocharin et al., 2022; Kolokoltsev et al., 2021), which is especially important among students (Sokolovskaya et al., 2021). When organizing and conducting mass non-invasive screening examinations of young people in educational institutions, it becomes difficult to distribute the subjects into different classes of individual levels, taking into account their functional reserves. The use of traditional statistical methods is laborious and insufficiently effective. Therefore, the research participants' distribution by reserve capabilities levels using cluster analysis is an actual and promising method of scientific research.

Purpose: using cluster analysis to carry out the distribution of students into groups of the body adaptive reserves levels in the post-loading period.

Material & methods

The study involved 75 male students of 1st, 2nd and 3rd courses studying at the Privolzhsky Research Medical University, the Nizhny Novgorod State Agricultural Academy and the National Research State University names after Lobachevsky of Nizhni Novgorod, aged 18-21-years-old, who, according to the results of a periodic medical examination, have the main group for physical education and sports. As functional tests, five exercises of the fitness and recreation complex "Ready for Labor and Defense" were used: long jump from a place in the amount of three repetitions in a row, flexion and extension of the torso from a prone position, shuttle run in the amount of three segments of 10 meters, running on maximum speed for a distance of 60 meters, pull-ups from the hang on the bar until the maximum possible number of repetitions is reached. To standardize physical performance data, the test was performed without a preliminary warm-up so that the results were not underestimated. The state of physiological rest before exercise testing served as a control. The level of adaptive reserves was studied in the post-exercise period, at the end of 10 minutes of rest after exercise, in terms of heart rate variability. To do this, the subjects recorded a five-minute interval cardiogram using the "Poly-Spectrum-12" device (Neurosoft, Russia). Statistical indicators of HRV were taken into the analysis - the standard deviation of NN intervals (SDNN), the proportion of NN intervals that differ from each other by 50 ms or more (pNN50), spectral indicators - the total power of the spectrum (TP), the power of the spectrum in the low region (LF, %), high (HF %), and very low (VLF %) frequencies, the ratio of the power of the spectrum in the low and high frequencies (LF/HF), the level of the stress index (SI) and the heart rate (HR). In addition, systolic and diastolic blood pressure (SBP, DBP) was analyzed using the Omron M2 Basic automatic tonometer. The study was conducted in a quiet, calm room at an air temperature of no more than 22 degrees, as well as in the complete absence of extraneous stimuli. All subjects signed an informed consent to the study.

Statistical processing of the study results was carried out using the Statistica 10.1 and Excel for Windows software package. The results are presented as mean (M) and standard deviation (σ). The absence of differences in the parameters obtained at rest and in the post-exercise period was determined using the parametric Student's t-test. Significance of differences was recorded at $p<0.05$. The normality of the distribution was tested using the Kolmogorov-Smirnov test with the Lilliefors correction. To determine the number of clusters, the method of hierarchical clustering with the construction of a Dendrogram was used. Cluster analysis was performed using the K-means method using Euclidean distances between cluster centroids.

Results

The results of the study of the students' adaptive reserves level in a state of physiological rest and in the post-loading period are presented in Table 1.

Table 1. The level of the students' adaptation reserves at rest and in the post-loading period, M±m

Parameter	Rest state	Post-loading state	P
SBP mmHg	129.4±9.7	132.3±7.9	0.032
DBP, mmHg	78.5±7.2	81.5±8.7	0.028
HR, bpm	77.2±10.4	74.9±6.3	0.011
SDNN, ms	54.6±11.3	47.2±10.6	0.045
pNN50, %	24.1±4.5	18.6±4.9	0.026
LF/HF, cu	1.6±0.5	1.8±0.4	0.031
TP, ms^2	1684.2±133.8	159.6±115.7	0.038
LF, %	33.3±4.2	35.4±5.3	0.042
HF, %	30.9±4.1	27.7±5.6	0.017
VLF,%	35.8±4.4	36.9±3.9	0.015
SI, cu.	112.3±4.7	119.5±5.6	0.009

It was found that during the recovery period, the analysis of the young men's functional indicators obtained by the heart rate parameter showed that students with a tendency to moderate tachycardia were detected. In the study of heart rate variability (SDNN, pNN50), cases of inability to adjust the heart rate to the action of various external stimuli (too low value of indicators), as well as a tendency to arrhythmogenic events (high value of pNN50) were recorded, which may indicate a lack of ability to satisfactorily adapt the heart rate in a separate category of examined young men, Table 1. At the same time, attention is drawn to the low-frequency and high-frequency powers ratio deviation of the spectrum, the increase of which in some students characterized the dominance of the sympathetic department of the autonomic nervous system with the suppression of parasympathetic inervation of cardiac activity. In addition, according to the VLF indicator, cases of the body overstrain with the presence of heart rate centralization in the post-loading period were revealed. This is further indicated by the level of the stress index, which characterized the tension of regulatory mechanisms in some subjects.

To determine the number of clusters, the method of hierarchical clustering with adendrogram construction was used. Here, an object is attached to a cluster only if the similarity between the candidate for inclusion and any of the cluster elements was not less than a certain threshold. To do this, the method of full communication was used in the current version of clustering. As a result, a distance matrix and a dendrogram graph are formed, where it becomes possible to determine the most rational number of clusters in the partition is shown in Figure 1.

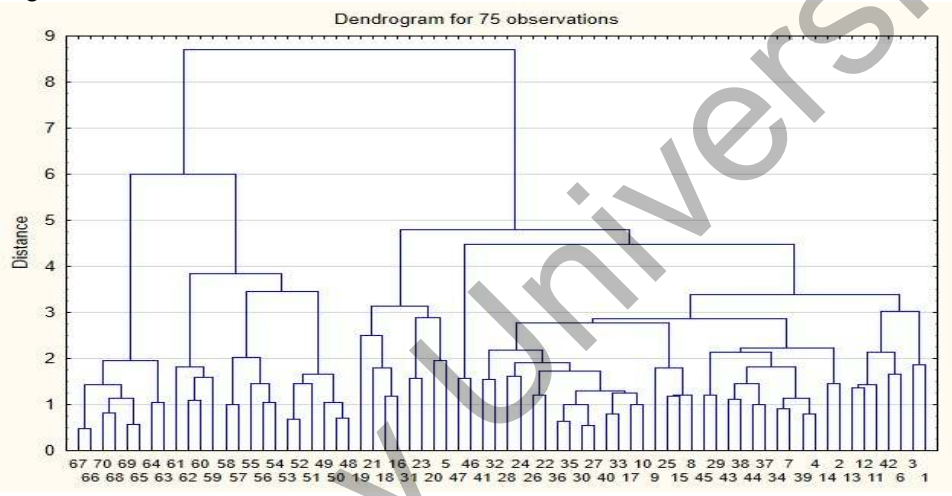

Fig. 1. Hierarchical clustering dendrogram for 75 observations

3 separate clusters are clearly defined on it. Then the standardization of indicators was performed to eliminate the possible influence of aggregates on the compared intensive indicators value. To do this, the compositions of the aggregates were equalized with the calculation of standardized coefficients for each indicator for their close location around zero. This made it possible to prepare the data for further cluster analysis and to assume multidirectional changes in regulatory mechanisms during the post-loading period, Table 2.

Table 2. Average values of standardized blood pressure and heart rate variability in each cluster, M±m

Parameter/Cluster	1st cluster (n=39)	2nd cluster (n=12)	3rd cluster (n=24)
LF (%)	0.68±0.52	0.16±0.63*	-1.13±0.57*
HF (%)	-0.44±0.47	0.12±0.68*	0.63±1,3*
VLF (%)	0.39±0.43	0.34±0.25*	-0.75±1.23*
SDNN	0.49±0.46	0.92±0.61*	-1.16±0.52*
pNN50	0.52±0.5	0.64±0.47*	-1.26±0.63*
TP	0.14±0.33	1.72±0.66*	-1.06±0.35*
LF/HF	-0.52±0.38	-0.65±0.97*	1.18±0.48*
SBP	0.64±0.42	0.49±0.64*	-1.25±0.52*
DBP	-0.58±0.34	-0.48±0.24*	1.13±0.2*
HR	-0.56±0.25	-0.7±0.28*	1.17±0.92*
SI	0.51±0.16	0.11±0.37*	-1.04±0.43*

Note. * - differences between cluster elements are statistically significant, p<0,05

At the next stage, cluster analysis of K-means methods was used. The research results analysis found that the average values of the third cluster stand out significantly among the other groups of subjects. When comparing the standardized coefficients with the initial indicators in cluster 3, it was found that this particular group of students has the tension of regulatory mechanisms during the recovery period after physical activity. It is manifested in an increase in heart rate, cardiac rhythm centralization according to statistical and spectral parameters HRV, a decrease in functional reserves and tension of regulatory mechanisms, despite the ten-minute rest time after performing a functional test. Table 3 shows the Euclidean distances between each cluster.

Table 3. Euclidean distances between each cluster

Cluster number	Cluster 1	Cluster 2	Cluster 3
Cluster 1	0.00	0.33	2.56
Cluster 2	0.58	0.00	3.01
Cluster 3	1.59	1.76	0.00

The first cluster consisted of 39 subjects who had sufficient adaptive reserves after performing physical exercises. In the second cluster there were 12 subjects whose indicators are on the border of adaptation-maladaptation. The third cluster consisted of 24 students who were close to the state of maladaptation in the post-loading period.

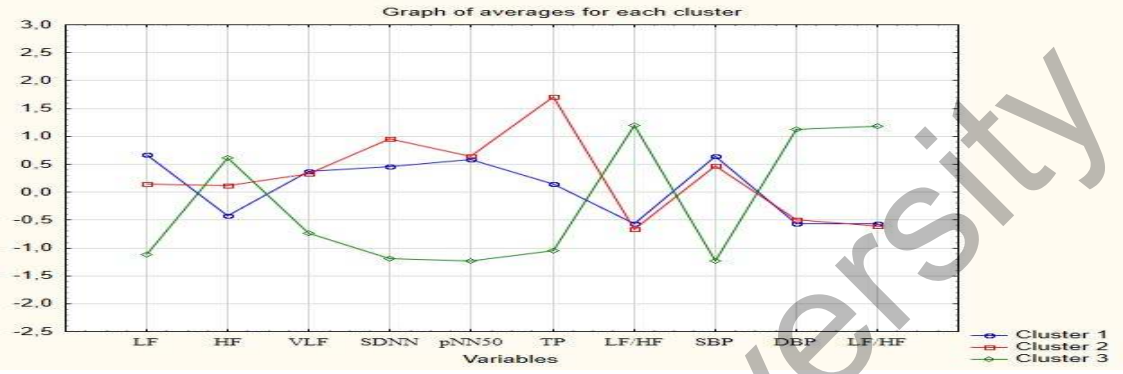

Fig. 2. Graph of averages for each cluster

The average graph for each cluster is shown in Figure 2, and the scattering diagram of cluster analysis by the K-means method is shown in Figure 3.

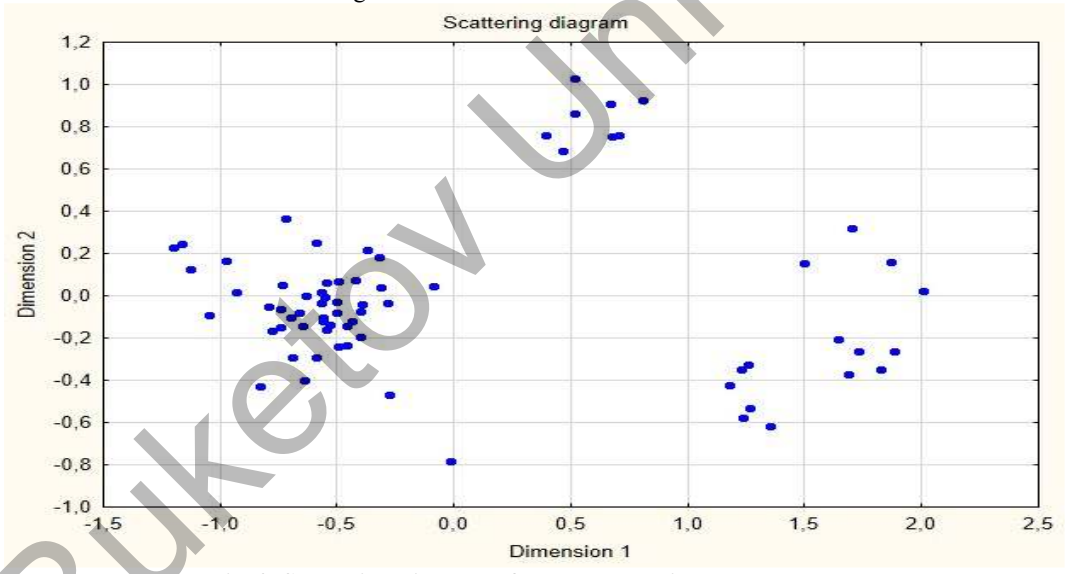

Fig. 3. Scattering diagram of cluster analysis by the K-means method

Thus, cluster analysis makes it possible to determine the groups of subjects, in accordance with the level of their adaptive reserves to physical exertion with high reliability. It allows the researcher to obtain information about the different status of cluster groups and provides a basis for possible correction of physical activity in a separate category of persons and a personalized approach to students' physical training.

Dicussion

Pphysical activity performance by a person causes significant functional changes in their body (Dupuy & Dugué, 2018). Therefore, there is a need to exercise control over the functional systems of the body to prevent undesirable consequences caused by physical loading (Gryaznykh et al., 2021; Dugnist, & Romanova, 2016). In recent years, the method of studying heart rate variability has become widely used in the medical and pedagogical control of persons engaged in physical culture and sports (Shlyk, 2016; Guzii et al., 2020; Christiani et al., 2021). The scientific literature provides information indicating the existence of a relationship between students' academic performance and their level of physical performance according to their HRV parameters (Wu et al., 2019). The authors point out that it is important to consider the possibility of diagnosing negative cardiovascular incidents during and after physical loadings. It determines the need for a detailed HRV state study

under the influence of standard physical activity and in the near future after it (Hadartsev et al., 2013). Evaluation of the physical activity impact results, as a rule, is carried out within the measurement of generally accepted statistical indicators (Eskov et al., 2012; Duncker, & Bache, 2008). However, a more effective analysis of the results of HRV testing can be obtained using an integral assessment of indicators (Butakova et al., 2019; Bocharin et al., 2022; Martusevich et al., 2022). At the same time, it is necessary to standardize the methodology for studying adaptive reserves during HRV testing. It can be implemented using cluster analysis, which considers the entire data set at once, and splits objects into different groups (Nedyalkova et al., 2021).

We studied the indicators of maximum and minimum blood pressure, heart rate, statistical and spectral parameters of heart rate variability in a state of physiological rest before performing stress tests, as well as during the recovery period of the body. During the recovery period of the body, students having functional indicators of cardiovascular and vegetative innervation were found; they were close to the state of maladaptation. This fact is confirmed when conducting cluster analysis by calculating K-means. We have recorded the division of students into 3 cluster groups. At the same time, one group of students in the number of 24 people had significant differences from the rest ones. Students of this group have a significantly low level of reserve capabilities of the body and there is tension of regulatory mechanisms, despite sufficient time for the body recovery after physical exertion. Our data do not contradict the research of the autonomic nervous system using integrative observation methods results (Balyklov et al., 2017; Suchomel et al., 2021; Nedyalkova et al., 2021). Our research results can be used in the practice of persons' performing physical activities medical supervision. It allows predicting the results of the physical loading impact on the student's body and make adjustments to the training process.

Conclusions

The analysis of our research results allowed us establishing that the use of the heart rate variability method in students performing standard physical activity makes it possible to diagnose the state of the reserve capabilities of the human body.

The use of cluster analysis makes it possible to diagnose the state level of students' reserve capabilities and distribute them into groups. We recorded 3 groups of young men with different levels of adaptive reserves during the post-loading period. Identification by means of cluster analysis of a group of young men with low reserve capabilities makes it possible to personify the specifics of students' physical training using the optimal program of physical activity. Such a medical and pedagogical approach makes it possible to prevent the occurrence of undesirable cardiovascular consequences in persons engaged in physical culture and sports.

Conflicts of interest. The authors declare no conflict of interest.

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