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Model characteristics of the structure and interrelations of integral parameters of students' physical condition

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Abstract

Background and Study Aim Understanding the physical condition parameters of students during physical education classes is essential in the context of modern education. This understanding contributes to the development of effective teaching strategies tailored to the specific needs of this demographic. The aim of the study is to investigate the structure and interrelations of physical condition (PC) parameters of students aged 17-19 years in the process of physical education classes.

Material and Methods The study involved 153 students aged 17-19 years old, and their physical development, functional, and physical fitness indices were recorded. The study analyzed intra- and intergroup correlations among 55 physical condition (PC) indices. It examined the correlations among integral components of students' structure, including somatic health (SH), adaptation potential (AP), aerobic physical work capacity (APWC), and biological age (BA). The study utilized factor analysis, correlation analysis, dispersion analysis, and regression analysis to examine the relationships and patterns within the collected data.

Results The analysis of intra- and intergroup relationships among the studied parameters revealed that the structure of physical condition (PC) is consistent between girls and boys. There are close linear dependencies, similarities, and differences in the interrelations of integral PC parameters, including somatic health (SH), adaptation potential (AP), aerobic physical work capacity (APWC), and biological age (BA), between boys and girls. The regression model coefficients indicate that for both genders, SH is influenced by APWC and AP. In girls, AP is dependent on SH and BA, while in boys, AP depends on SH, BA, and APWC.
A strong relationship between APWC and resting heart rate (HR) was identified during testing, with boys demonstrating higher levels of APWC at lower initial HR values compared to girls.

Conclusions The study has provided valuable insights into the key components of the physical condition (PC) structure among 1st-year students. These components encompass physical development, adaptation potential, health, cardiorespiratory system functional capacities, speed-strength fitness, biological age, and degree of aging. Findings emphasize the significance of resting bradycardia as an informative marker and criterion for assessing APWC during moderate-intensity muscle activity. The developed mathematical models have proven effective in modeling and predicting students' PC, including the individual integral components (SH, AP, APWC, and BA). These models provide valuable tools for anticipating potential changes in these parameters.

Keywords: students, physical condition, somatic health, work capacity, adaptive potential, models.

Introduction

Physical development, physical fitness, biological age, and somatic health of a person are integral components of physical condition (PC) that determine functional reserves, mental and physical work capacity, and lifespan of an individual [1, 2, 3, 4]. The effectiveness of PC control and management depends to a large extent on the knowledge of the structure and interrelations of its components, mechanisms of their improvement in the process of growth and development, human adaptation to different conditions of vital activity, including physical loads. Despite the fact that researchers note the importance of mechanisms of interaction of human PC structure parameters in the process of implementing various motor tasks, the interrelations of its integral parameters are insufficiently studied. The partial role and interrelations of individual morphofunctional and metabolic indices of the human body PC in the process of ensuring the functional effect of a separate integral parameter are also under-explored. The coverage of these issues requires comprehensive studies based on the methodological principles of the system approach [5], methods of mathematical analysis, and modeling.

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The material presented in the publications of the majority of authors is mainly devoted to the characterization of individual integral parameters of the human body's physical condition (PC) [6, 7]. It also explores the interrelations of their individual morphofunctional and metabolic components in various conditions of motor activity, including during the practice of various kinds of sports [8, 9, 10]. At the same time, the publications of different authors have noted positive effects of regular motor activity and sports on some integral components of the human PC structure. In particular, positive adaptation effects were characterized by:

a) an increase in functional reserves [4, 11];

b) an increase in physical and mental work capacity [6];

c) a slowing down of the processes of body aging [10, 12, 13, 14]

d) a decrease in biological age [10, 15];

e) a decrease in mortality rate due to cardiovascular diseases [16, 7] and all other causes [13, 17, 18]; an increase in human lifespan [1, 19, 20].

Garatachea et al. [20] noted that regular physical loads in endurance sports events have a multisystem rejuvenating effect on the body of athletes - they had a longer average life expectancy than the average population. A comparative analysis of the impact of physical loads of moderate and relatively high intensity on human PC indicates that moderate intensity physical loads are the most efficient for reducing the intensity of aging and the risk of mortality due to cardiovascular diseases [7, 20, 21].

The health-related impact of aerobic physical loads on PC was noted in several studies [6, 12, 22]. These studies demonstrated a close relationship between the level of health and motor activity of moderate intensity, which is characterized by an aerobic mechanism of energy supply. According to the findings of these studies, aerobic physical work capacity is considered an integral parameter of PC and serves as one of the key biological markers and criteria for assessing an individual's health and lifespan [23, 20]. A similar point of view on the relationship between regular motor activity, health, and longevity may be found in the works of other authors [1, 10, 13]. According to the findings of Parsons et al. [13], moderate motor activity of middle-aged and elderly people improves their health and reduces mortality due to all causes by 20-30%. It has been noted in a number of studies that the index of physical work capacity is an objective, integral characteristic of adaptation functional reserves of the body of athletes [8, 11]. This index is interrelated with many cardiometabolic, inflammatory, endothelial, and adipokine biomarkers [6, 16, 13]. Additionally, it is often used as a criterion of individual health, aging, and lifespan [4, 6].

Insufficient level of motor activity is one of the factors of decreased health level [20], functional reserves [4], physical and mental work capacity [6], increased intensity of aging [13, 15, 24] and decreased lifespan [1, 21].

A number of studies present objective signs of the negative impact of insufficient motor activity on the PC of young people [15, 25, 26]. Materials published by different authors show that the insufficient number of physical education classes in universities is associated with a decrease in physical and mental work capacity, somatic health, functional status, and adaptive capacities, increase in biological age and aging of students [15, 27, 28].

Boiarska and Dotsenko [29] conducted research to determine biological age, adaptive potential, and the level of physical condition. The results have proven to be informative for diagnosing the health level of students. The identified biological age of the students can serve as a baseline for adjusting work functions and body systems.

In the studies of Repalova and Avdeeva [30] it was noted that in foreign students of a Medical University not engaged in motor activity under conditions of pre-examination stress, the tension of adaptation mechanisms is increased along with the decrease of the cardiovascular system functions.

In general, the analysis indicates that the issues of motor activity, health, adaptation potential, lifespan, and physical work capacity are closely interrelated. Therefore, the comprehensive understanding of the structure of human PC necessitates considering the interrelationships of each of its integral components with other components.

The majority of researchers studied mainly pairwise interrelations of integral components of the human body PC. These pairs included adaptation potential and biological age, somatic health and biological age, somatic health and physical work capacity, as well as other pairwise interactions. This did not allow researchers to fully describe the structure of the PC and the interrelations of its integral components, as well as the interrelations of the components of each individual integral parameter in different conditions of the body vital activity. Insufficient state of knowledge of the issues under consideration, their theoretical and practical significance served as a basis for conducting comprehensive research to study the structure and interrelationships of the PC parameters of the bodies of University students.

The objective of this work is to study the structure and interrelations of physical condition key parameters of students aged 17-19 years in the process of physical education classes.

Materials and methods

Participants

The experiment involved 153 students of the National Aviation University of Ukraine aged 17-

19 years old, including 79 boys and 74 girls. Study protocol was approved by Ethical Committee of the National Aviation University [Kyiv, Ukraine]. The research was fulfilled in compliance with WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects [31].

Research Design

An experimental study of the physical condition of the students was carried out in physical education classes, which were conducted once a week according to the generally accepted university program in accordance with the schedule for the first year of study. A set of methods of pedagogical testing, instrumental methods, and mathematical statistics was used.

To assess the structure of students' physical condition, the indices of physical development, functional state, and physical fitness were recorded.

In the process of research, the following integral indices of students' physical condition were determined: the level of somatic health, biological age, the value of adaptation potential, the level of aerobic physical work capacity.

The physical development of students was assessed according to body mass (BM, kg) and length (cm), body mass index (kg/height^2, cm), Quetelet index, body fat and water volume, chest circumference at rest, on inhalation and exhalation, and chest excursion.

Functional state of students was assessed using a range of parameters related to the cardiovascular and respiratory systems, including:

1) Heart rate (HR).
2) Systolic blood pressure (SBP) and diastolic blood pressure (DBP).
3) Vital capacity (VC).
4) Respiratory pause measured during Stange-Hench tests (sec.).
5) Pulmonary capacity-body mass index (VC(ml)/BM(kg)).
6) Skibinsky index (calculated as 0.01 VC × BH/HR, where BH represents the time of inspiration breath hold in seconds).
7) Kerdo autonomic index (calculated as (1-DBP/HR) × 100).
8) Robinson index (calculated as HR × SBP/100).
9) Autonomic reactivity measured during an orthostatic test (bt/min).
10) Index of economic functioning of the body, represented by the HR/Ruffier index [32].

The level of physical fitness was assessed using various parameters, including:

1) Wrist strength, measured during dynamometry (kg).
2) Strength index, calculated as the ratio of wrist strength to body mass (kg).
3) Speed, determined by the result of a 60 m running test (sec).
4) Explosive strength, evaluated based on the result of performing a standing long jump (cm).
5) Strength endurance, assessed by the number of push-ups to exhaustion and the number of sit-ups.
6) Motor coordination, measured while balancing on the left leg (sec).

The level of somatic health was assessed using the express method developed by Prof. Apanasenko [2, 3]. This method involved recording various anthropometric and functional parameters, including:

– Body length and mass.
– Vital capacity (VC).
– Muscle strength of the dominant wrist.
– Systolic blood pressure (SBP).
– Heart rate (HR).

These measurements were conducted following established and widely accepted methods [32].

Rapid assessment of physical health level was conducted through the calculation of the following parameters:

a) Physical development indices, including:

– Body mass index (BMI) calculated as BMI = BM(kg)/height^2(m^2).
– Pulmonary capacity-body mass index (PC-BMI) calculated as PC-BMI = VC(ml)/BM(kg).
– Strength index (SI) calculated as SI = wrist strength(kg)/BM(kg) × 100%.
– Robinson index (RI) as a measure of systolic work of the heart, calculated as RI = HR × SBP/100.

b) Characteristics of cardiovascular system functioning at rest and after dosed physical load, determined through Martinet's test.

Somatic health was assessed based on the total points corresponding to the calculated indices [2]."

Biological age (BA) was determined using the method developed by Voitenko [33] and following the recommendations of Prysiazhniuk et al. [15]. The assessment involved recording indices related to the functional state of the cardiovascular system (HR, SBP, and DBP), respiratory system (VC, breath-holding time during Stange-Hench tests), and central nervous system (static balancing) using established methods.

The calculation of BA was based on the following formulas:

For males: BA = 27.0 + 0.22 × SBP - 0.15 × IBH + 0.72 × SHA - 0.15 × SB.

For females: BA = 1.46 + 0.42 × PP + 0.25 × BM + 0.7 × SHA - 0.14 × SB.

Where: SBP - systolic blood pressure in mm Hg; IBH - inspiration breath-hold time in seconds; SHA - subjective health assessment (in arbitrary units); SB - static balancing on the left leg in seconds; PP - pulse pressure in mm Hg; BM - body mass in kg.

The assessment of adaptation potential was conducted using the method developed by Baevsky and Berseneva [34]. According to this methodology, various indices of the circulatory system, which play a significant role in the formation and consolidation of the body's adaptation to different environmental influences, were recorded. These indices included HR, BP, age, BM, and height. The calculation of adaptation potential (AP) was based on the formula by Baevsky:

$$AP = (0.011 \times HR + 0.014 \times SBP + 0.008 \times DBP + 0.014 \times A + 0.009 \times BM - 0.009 \times H) - 0.27,$$

Where: SBP - systolic blood pressure in mm Hg; DBP - diastolic blood pressure in mm Hg; A - age in years; BM - body mass in kg; H - height in cm.

The assessment was carried out according to the following criteria:

– ≤2.1: 4 points - satisfactory adaptation, indicating sufficient reserves of the circulatory system.
– 2.11-3.20: 3 points - satisfactory adaptation with functional tension of adaptation mechanisms.
– 3.21-4.30: 2 points - unsatisfactory adaptation to loads, indicating a decrease in functional reserves of the circulatory system.
– More than 4.30: 1 point - failure of adaptation, signifying a sharp decrease in functional reserves of the circulatory system with signs of failure of adaptation mechanisms of the whole body.

The level of aerobic physical work capacity was assessed during the performance of Rufier-Dickson test (c.u.) [35].

Statistical Analysis

The STATISTICA 13.5 statistical software package was used for statistical processing of the experimental material [36]. The methods of correlation, factor, regression, and dispersion analysis were used to process and analyze the structure and interrelations of PC parameters of students of different genders, biological age, somatic health, and adaptive potential.

Results

In order to characterize the structure of the students' body PC, factor analysis of experimental data with varimax rotation of 55 indices of physical development, speed-strength fitness, functional state, biological age, and somatic health was performed.

This allowed the identification of 5 generalized factors of students' physical condition structure in each experimental group (Fig. 1).

The comparison of the key factors indicates that the structure of students' PC in both groups is identical. The key integral components of the PC structure of both the boys and the girls include:

1) physical development;
2) level of adaptation potential and health;
3) cardiorespiratory system reserves;
4) speed-strength fitness;
5) biological age and degree of aging (Fig. 1).

The identified factors, as a whole, determined the variability of the most part of the variance of students' PC indices: in girls - 61.73 % of the total variance, in boys - 61.25 %.

The greatest influence on the variability of the total variance of PC structure indices in both groups is exerted by the *factor of physical development*: in girls - 19.75% of the total variance, in boys - 21.47%. The indices of body mass, body fat and water volume have the greatest load in this factor.

The second factor that we called *the factor of adaptation potential and somatic health level*, also exerts a significant impact on the variability of the total variance of students' PC structure indices: in girls, the degree of variability constitutes 15.78 % of the total variance, whereas in boys - 13.42 %.

The third factor according to the degree of influence on the variability of the total dispersion of the PC structure indices in girls is the factor that we called the factor of *the cardiorespiratory system* functional capacities (11.07 %), whereas in boys - *the factor of biological age and aging of the body* (11.36 %).

The fourth factor in girls included the indices of speed-strength fitness (8.47 % of the total variance), and in boys - those of the cardiorespiratory system (8.83 %).

The least contribution to the variability of the total variance of PC structure indices in girls is made by *the factor of biological age and degree of aging* (6.66 %), whereas in boys – *the factor of strength fitness (6.17 %)*.

The averaged values of individual integral parameters of students' PC structure are presented in Table 1.

Comparison of averaged values of individual integral parameters of the PC structure of boys and girls indicates that boys have a slight advantage in the level of somatic health and physical work capacity, whereas girls have a slight advantage in the level of adaptation potential and lower values of BA, which is indicative of their less pronounced degree of aging.

In general, according to the data presented in Table 1, students of both groups are characterized by a low health level (below average), sufficient reserves of the circulatory system (according to the values of adaptation potential), and average values of physical work capacity.

As for BA, it is significantly ahead of the chronologic age in boys as compared to girls.

Table 2 presents the averaged values of correlation coefficients reflecting intragroup and intergroup interrelations of the parameters of

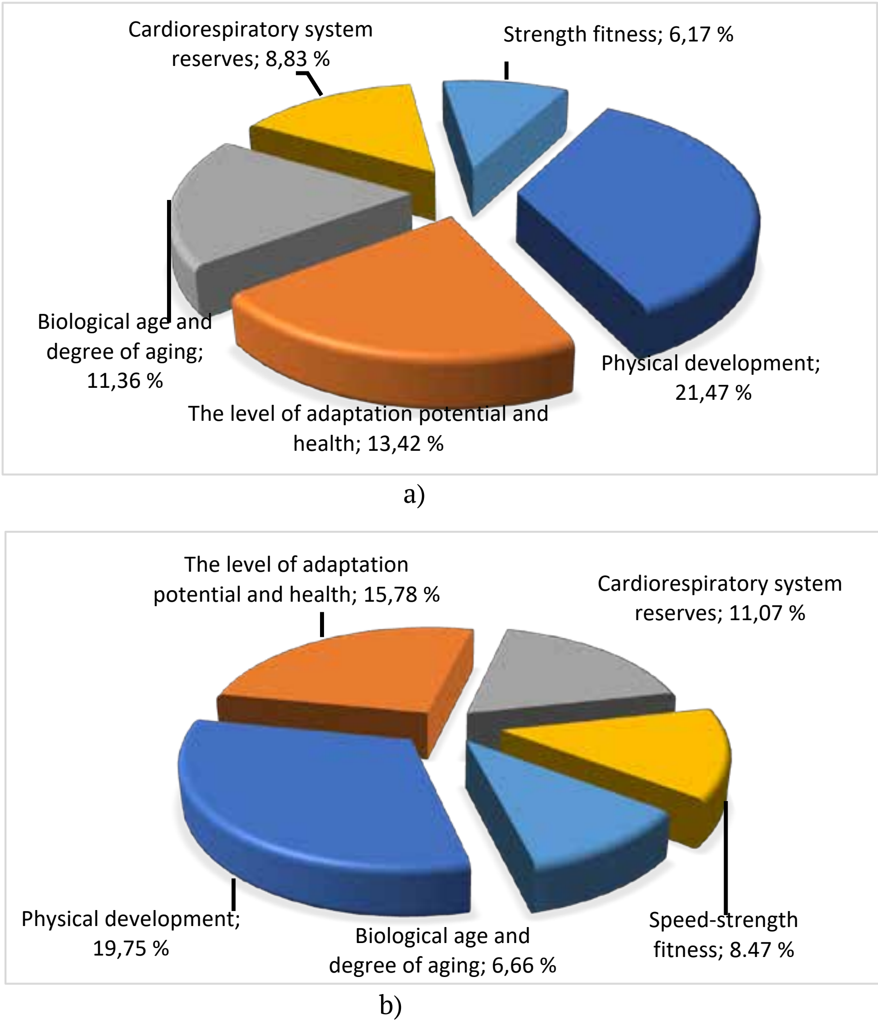

Figure 1. Key factors of physical condition structure of Technical University students (a – boys, b - girls)

Table 1. Integral parameters of the structure of students' physical condition (somatic health, level of adaptive potential, biological age, physical work capacity).

Groups	Statistical parameters	Somatic health level, points	Physical work capacity (Ruffier test) points	Adaptation potential, points	Chronologic age, years	Biological age, years
boys	$\bar{x}$	**4.89**	**9.5**	**2.03**	**18.56**	**59.44**
	±m	0.33	0.4	0.04	0.17	0.74
	n	79	79	79	79	79
girls	$\bar{x}$	**2.50**	**10.9**	**1.86**	**17.32**	**28.74**
	±m	0.31	0.5	0.03	0.09	0.83
	n	74	74	74	74	74
t Student's		**5.27**	**2.19**	**3.40**	**6.58**	**4.83**
P		<0.001	<0.05	<0.001	<0.001	<0.001

students' PC structure: physical development, physical fitness, and functional state.

The values of correlation coefficients presented in Table 2 indicate that the degree of interrelations between the studied indices is relatively low in both groups. Students of both sexes have the most integrated indices of physical development; lesser interrelations are manifested between the indices of physical fitness and functional state. The differences in the average values of correlation coefficients between boys and girls in each group of indices are statistically insignificant.

At the same time, the level of intragroup interrelations in both groups of students is higher than that of intergroup interrelations. Differences between the mean values of intra- and

Table 2. Intra- and intergroup interrelations of indices of students' physical condition structure (average values of correlation coefficients)

		Intragroup interrelations			Intergroup interrelations				
Groups	**Statistical parameters**	**Physical development**	**Physical fitness**	**Functional state**	**Physical development-functional state**	**Functional state – Physical fitness**	**Physical development - physical fitness**	**Intragroup interrelations**	**Intergroup interrelations**
boys	$\bar{X}$	0.496	**0.243**	**0.243**	**0.190**	**0.131**	**0.217**	**0.298**	**0.177**
	±m	0.043	0.054	0.020	0.014	0.009	0.020	0.019	0.008
	n	45	28	130	130	104	80	203	314
girls	$\bar{X}$	**0.479**	**0.351**	**0.270**	**0.193**	**0.117**	**0.194**	**0.327**	**0.168**
	±m	0.04	0.04	0.24	0.016	0.009	0.013	0.018	0.008
	n	45	28	130	130	104	80	203	314
t Student's		**0.29**	**1.61**	**0.11**	**0.14**	**1.10**	**0.96**	**1.08**	**-1.08**
P		>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

intergroup interrelations in each group of students are statistically significant: in boys t-Student's coefficient = 5.8 ($p<0.01$), in girls -7.94 ($p<0.01$).

The data presented in Table 2 suggest that the structure of girls' and boys' PC, according to the average values of intra- and intergroup interrelations, is identical.

Factor analysis allowed us to determine the generalized factors and key indices of students' PC that determine the structure of individual integral parameters.

To identify specific features in the PC structure of students of different genders, the analysis of experimental material was continued using dispersion and stepwise regression methods.

The regression equations presented below reflect the interrelations of integral parameters of students' PC structure: the level of somatic health, adaptive potential, biological age, and physical work capacity.

Table 3 presents regression models, multiple correlation and determination coefficients reflecting statistically significant dependencies of individual PC integral parameters on the combined and interacting influence of other integral parameters (Table 3):

1] the level of somatic health on the level of aerobic physical work capacity and the level of adaptation potential - Y_1;

2] the level of adaptation potential on the level of somatic health and the level of aerobic physical work capacity - Y_2;

3] the level of aerobic physical work capacity on the level of somatic health and the level of adaptation potential - Y_3;

4] biological age on the level of somatic health and the level of adaptation potential - Y_4.

As a result of the analysis performed, the total and partial impact of individual integral parameters on the dependent integral parameter (Y_1 - Y_4 in Table 3) was determined.

Somatic health level (Y1). The parameters of the regression model Y_1, presented in Table 3, suggest that in girls 53.6% ($F = 43.1$, $p<0.00001$) of the total variance of *somatic health* indices are determined by the value of aerobic physical work capacity (x_1) and the level of adaptive potential (x_2). Of these, the factor of aerobic physical work capacity (x_1) determines the variability of 45.0 % of the variance of somatic health indices ($F = 58.8$, $p<0.0001$), whereas the factor of adaptation potential (x_2) - 9.91 % ($F = 15.6$, $p<0.0001$). The remaining 46.4 % of the total variance of somatic health indices is due to factors not taken into account in this experiment.

In boys, 67.5% (Table 3, Y_1) of the total variance of *somatic health* indices is also determined by two parameters. Of these, aerobic physical work capacity (x_1) accounts for 43.1% ($F = 58.4$, $p<0.0001$) of the variance of somatic health indices, and adaptive potential (x_2) accounts for 23.1% ($F = 52.01$, $p<0.00001$).

The results of modeling using equation Y_1, (Table 3, equation Y_1) suggest that in girls the increase in aerobic physical work capacity by 10%, at the unchanged parameter of adaptation potential (the second parameter of the model), is accompanied by an increase in their somatic health level by 7%.

A 10 % increase in the adaptation potential of girls at the stability of the physical work capacity parameter is accompanied by an increase in somatic health level by 10.8 %. The simultaneous increase in physical work capacity and adaptation potential

Table 3. Model characteristics of interrelations of physical condition integral parameters of students of different genders

Integral parameters	Groups of students	Regression equation	Coefficients		
			Correlation, r	Determination, d	Fisher's [F], p
Somatic health level Y_1	Girls	$(4.182–0.096x_1-0.875x_2)$ ±0.52*	0.741	0.536	43.1 <0.00000
	Boys	$(21.096–0.54312x_1-7.165x_2)$±1.9	0.881	0.777	120.4 <0.00000
Adaptation potential level Y_2	Girls	$(1.782–0.185x_4+0.012x_3)$±0,24	0.600	0.359	19.9 <0.00000
	Boys	$(1.635+0.02x_3-0.294x_4-0.0218x_1)$ ±0.25	0.754	0.569	33.0 <0.00000
Level of aerobic physical work capacity Y_3	Girls	$(16.584–3.82x_4)$±3.2	0.671	0.450	58.8 <0.00000
	Boys	$(22.128–3.114x_4-3.157x_2)$±0.27	0.698	0.488	35.6 <0,00000
Biological age Y_4	Girls	$(16.584–3.82x_4)$±3.2	0.671	0.450	58.8 <0.00000
	Boys	$(22.128–3.114x_4-3.157x_2)$±0.27	0.698	0.488	35.6 <0.00000

* where: x_1 - level of physical work capacity (when performing the Ruffier test), c.u.; x_2 - level of adaptation potential, c.u.; x_3 - biological age, years; x_4 - level of somatic health, points; r - correlation coefficient; d – determination coefficient.

of female students by 10% results in somatic health improvement by 17.7%.

An increase in physical work capacity by 10% (x_1) in boys at unchanged adaptation potential parameters (x_2) is accompanied by somatic health level improvement by 7.07% (Table 3, equation Y_1). In addition, the increase of adaptation potential by 10 % at the unchanged physical work capacity parameter is accompanied by the level of somatic health improvement by 14.48 %. The simultaneous increase in physical work capacity and adaptation potential leads to a 21.56 % improvement in somatic health level.

Students were divided into 3 groups according to the level of physical performance and the corresponding level of somatic health (Fig.2).

Figure 2 illustrates the distribution of the number of students (in %) with different levels of somatic health (in points) by levels of aerobic physical work capacity (low, average, above average). The results indicate that the majority of students with low and average levels of physical work capacity have low (31.1% of boys and 52.8% of girls) and below average (55.4% of boys and 38.9% of girls) levels of somatic health.

Only a small number of examined boys (13.5 %) and girls (8.3 %) with above average level of physical work capacity have an average level of somatic health (boys - 11.2±0.86 points, girls - 8.83±1.24 points). However, the difference in the level of somatic health between boys and girls of this group is not statistically significant (t=1.9, p<0.05).

Figure 2 also presents pairwise regression equations of correlation and determination coefficients, reflecting the linear nature of the relationship between the two integral parameters - somatic health and the level of aerobic physical work capacity.

Modeling through the use of these equations demonstrated that in order to move from the group with a low somatic health level to the middle group, boys and girls need to increase their level of aerobic work capacity by 44% and 63%, respectively. To pass from the group with low to the group with average physical work capacity, boys and girls should increase their level of somatic health by 313.2%, and 321.1%, respectively.

According to Apanasenko [2], the level of somatic health of a person can vary from ≈1 to 15-20 points, which reflects the range of its percentage change - up to 1500-2000 %.

The level of adaptation potential (Y_2). The parameters of the regression model Y_2 (Table 3, Y_2) suggest that in girls the level of adaptation potential depends on the level of somatic health (x_4) and biological age (x_3). Of these, the influence of somatic health factor (x_4) accounts for 28.8% ($F = 29.14$, $p<0.00001$) of the total variance of adaptation potential, while the biological age factor [x_3] accounts for 7.1% ($F = 7.91$, $p<0.006$).

In boys, 56.9% of the total variance of adaptation potential is determined by three parameters (Table 2, Y_2). Of these, the impact of somatic health (x_4) accounts for 40.5% ($F = 52.5$, $p<0.00001$) of the total variance of adaptation potential, biological age (x_3] - 13.5% ($F = 22.2$, $p<0.00001$), and aerobic physical work capacity (x_1] - 2.9% ($F = 5.07$, $p<0.027$).

Level of aerobic physical work capacity (Y_3). The level of aerobic physical work capacity in girls is statistically significantly determined by the level of somatic health (Table 3, Y_3). Its influence can explain the variability of 45% of the total variance of the result in the aerobic test ($d= 0.450$; $F=58.8$ $p<0.00000$). The remaining 55.0% of the variation of the result in the Ruffier test is determined by the impact of factors not taken into consideration in this experiment.

In boys, 48.76% of the total variation in aerobic physical work capacity is determined by two parameters (Table 3, Y_3], of which, somatic health factor (x_4] accounts for 43.0% ($F = 57.3$, $p<0.00001$] of the total variance in physical work capacity, whereas adaptation potential (x_2] accounts for 5.8% ($F = 8.4$, $p<0.005$].

Figure 3 graphically depicts the level of physical work capacity (in points) of students in four groups differing in the level of somatic health (1-4], and also presents the number of students in percent (%] belonging to each group.

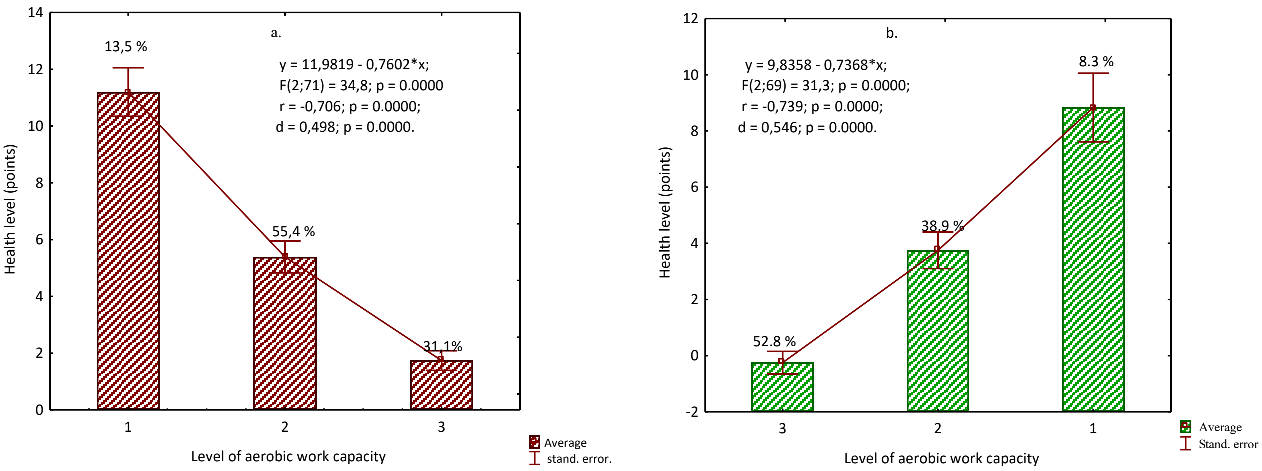

Figure 2. Model characteristics of somatic health level (in points) in students with different levels of physical work capacity; a. - boys; b. - girls; y - pairwise regression equations; F - Fisher's coefficient; r - correlation coefficient; d – determination coefficient. Level of aerobic work capacity: 1 - Above average; 2 – Average; 3 – Low.

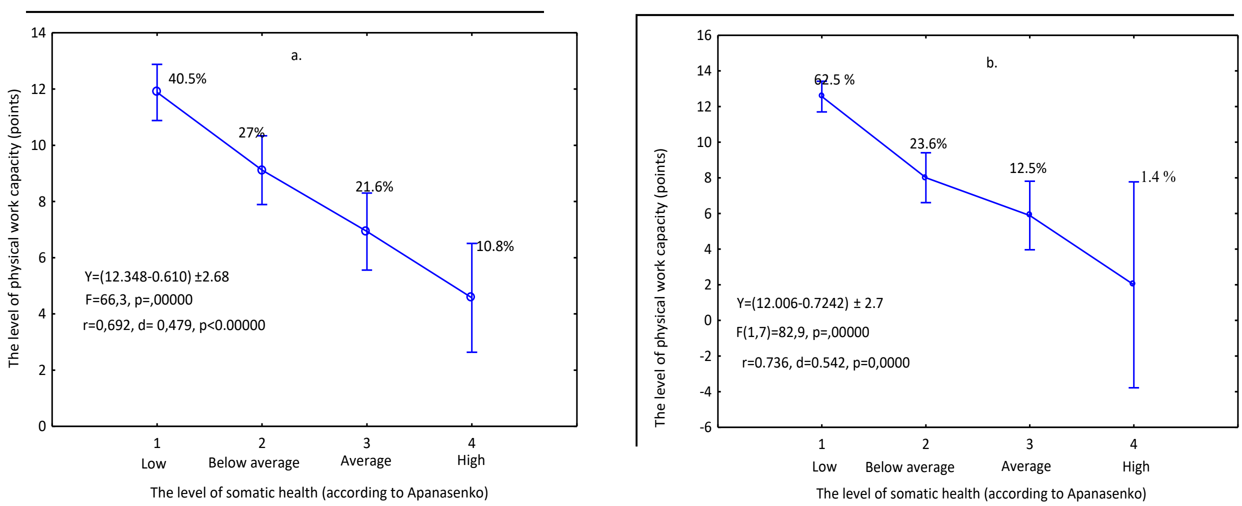

Figure 3. Physical work capacity of boys (a) and girls (b) in groups with different levels of somatic health (1-4 groups). The number of students in each group is presented in percentages; Y - pairwise regression equations; F - Fisher's coefficient; r - correlation coefficient; d – determination coefficient.

The data presented in Figure 3 shows that the majority of boys and girls have low and below average levels of somatic health and corresponding to them average and below average levels of physical work capacity. The low level of somatic health of students in both groups is characterized by a low level of physical work capacity. The majority of the examined students (40.5% of boys and 62.5% of girls) have both a low level of health and a low level of physical work capacity.

Students of the group with a high level of somatic health tend to manifest the highest level of physical work capacity. However, the group of a high level of somatic health and physical work capacity is the smallest: only 10.8% of boys and 1.4% of girls have simultaneously a high level of health and physical work capacity.

In general, the analyzed integral parameters demonstrate linear dependencies with relatively high and statistically significant correlation coefficients. The distribution of students by groups of somatic health and physical work capacity suggests that among boys there is a greater number of those with average (21.6%) and high (10.8%) levels of somatic health, who showed average and above average values of physical work capacity during testing, whereas among girls - 12.5% and 1.4%, respectively. 27.0% of boys and 23.6% of girls with below average health level have an average levels of physical work capacity.

The dependencies of each of the integral parameters of physical condition on the total and share influence of individual indices of physical development, physical fitness and functional state of boys and girls were determined in the process of step-by-step regression and variance analysis (Table 4). (Y_1 - Y_4). The interrelations of indices included in the regression models only with statistically significant coefficients were analyzed.

The level of somatic health (tab. 4). The coefficients presented in the first model (model Y_1) indicate that in girls the level of somatic health depends on vegetative parameters (Robinson index, pulmonary capacity-body mass index, VC) (d = 0.452, p<0.00000), to the greatest extent. The somatic parameters included in the model (strength index, strength endurance, body length, explosive power) have less impact on the level of health (d = 0.188, p<0.00000). Together, the somatic and vegetative parameters of the model determine the variability of 64% of the total variance of somatic health indices (p<0.00000).

The level of somatic health in boys also depends mainly on vegetative indices (Skibinsky index, resting HR, systolic blood pressure, the result of the Stange's test, VC). Their combined influence on the variability of the total variance of somatic health indices constitutes 57.3%. The impact of somatic parameters of the model (balancing on the left leg, expiratory chest circumference, body water content) is significantly less (16.5%).

The total effect of all model parameters on the level of somatic health constitutes 73.8% (p<0.00000).

The value of adaptation potential (Table 4, model Y_2). The coefficients presented in the second model (model Y_2) indicate that in girls *the value of adaptation potential* depends on vegetative and somatic parameters of the model by 98.1 % (p<0.00000). Of these, vegetative parameters determine 92.68 % of the variability of the total variance of adaptation potential, whereas somatic - 7.0 % (p<0.00000).

In boys, 99.18 % (p<0.00000) of adaptation potential is determined by both vegetative and somatic parameters of the model (Table 3, model Y_2). Of these, the degree of influence of vegetative parameters constitutes 92.5%, whereas that of somatic parameters - 6.71% (p<.00000).

The level of physical aerobic work capacity. According to the parameters of model 3 (Table 4, model Y_3), *the level of physical aerobic work capacity* depends on vegetative and somatic indices, which in boys determine the variability of 80.5% of its variance, and in girls - 68.5%. Of all the model parameters, the greatest influence on physical work capacity in both groups is exerted by HR recorded immediately before performing the Ruffier aerobic test.

The graphical and mathematical models of physical aerobic work capacity dependence on the initial values of HR recorded before performing the Ruffier aerobic test are presented below (Fig. 4).

The presented models suggest that a decrease in resting HR is associated with a decrease in the Ruffier index, indicating physical work capacity improvement. Conversely, an increase in resting HR is associated with an increase in the Ruffier index, indicating a decrease in physical work capacity [35]. High correlation and determination coefficients (in girls - r = 0.723, d=0.522, p<0.00001; in boys - r =0.864, d=0.747, p<0.00001) afford ground to consider resting bradycardia as an informative marker and criterion of physical work capacity at moderate intensity muscle activity (assessed by the results of the aerobic Ruffier test).

As compared with girls, boys had lower values of HR in the supine position and before the Ruffier test, and a higher level of physical work capacity. High values of correlation and determination coefficients reflect a more pronounced dependence of their aerobic work capacity on the initial values of HR - the lower the resting HR, the higher the work capacity.

In general, the correlations between resting HR and the Ruffier index in both groups are identical. Some advantage of boys is manifested in the average values of the result in the Ruffier test: in boys - 9.28±0.41, and in girls - 10.91±0.44 c.u.. The advantage of boys is small, but the differences are

Table 4. Model characteristics of integral parameters of students' PC (Y_1 - Y_4) dependence on individual indices of physical development, physical fitness and functional state

Integral parameters (Y_1 - Y_4)	Groups	Regression equations*	Coefficients**			
			r	d	F	p
Somatic health	Girls	$(0.019x_1+0.018x_2+0.059x_3-0{,}021x_4-0.021x_5-11.406x_6-0.008x_7)\pm0.48$	0.800	0.640	16.8	<0.00000
(Y_1)	Boys	$(10.36+0.065x_8-0.018x_9-0.02x_{10}-0.034x_{11}-0.033x_{12}-0.006x_{13}-0.348x_6)\pm0{,}57$	0.846	0.716	16.1	<0.00000
Adaptation potential	Girls	$(0.014x_{10}+0.018x_9+0.015x_{14}-0.013x_3-0.006x_{15}-0.248)\pm0.048$	0.991	0.981	1530. 3	<0.00000
(Y_2)	Boys	$(0.014x_{10}+0.019x_9+0.015x_{16}-0.007x_{15}-0.003x_5-1.948)\pm0.41$	0.994	0.987	1079.0	<0.00000
Physical work capacity	Girls	$(0.244x_{17}+0.053x_4+0.11x_8+0.462x_{18}-0.073x_2-0.531x_{19}-11.695)\pm2.5$	0.828	0.685	24.3	<0.00000
(Y_3)	Boys	$(0.215x_{17}+0.031x_{15}+0.054x_{20}-0.12x_{21}-0.027x_8-0.454x_{22}-3.594)\pm1.7$	0.897	0.805	46.1	<0.00000
Biological age	Girls	$(5.723+0{,}657x_{10}+0.237x_{23}+0.304x_{15}-0.206x_{13}-0.267x_4)\pm2.56$	0.927	0.859	83.3	<0.00000
(Y_4)	Boys	$(28.20+0{,}105x_{11}+0.209x_{10}+0.089x_{24}+0.062x_8-0.139x_{13})\pm1.8$	0.965	0.932	86.4	<0.00000

* where: x_1 - strength index; x_2 - trunk lifting in lying position, quantity; x_3 - height, cm; x_4 - Robinson index; x_5 – pulmonary capacity-body mass index; x_6 - VC; x_7 – standing long jump, cm; x_8 - Skibinsky index; x_9 - resting HR, bpm; x_{10} - systolic BP, mmHg; x_{11} – Stange's test, s; x_{12} - expiratory chest circumference; x_{13} - balancing on the left leg, s; x_{14} - water content in the body, l; x_{15} - Kerdo autonomic index; x_{16} - volume of adipose tissue, %; x_{17} - HR before Ruffier test, bpm; x_{18} - dynamic strength; x_{19} - right arm dynamometry, kg; x_{20} – chest circumference, cm; x_{21} - chest excursion, cm; x_{22} – 60 m running; x_{23} - body mass, kg; x24 - Hench test, s; ** - r - correlation coefficient; d – determination coefficient; F - Fisher's coefficient.

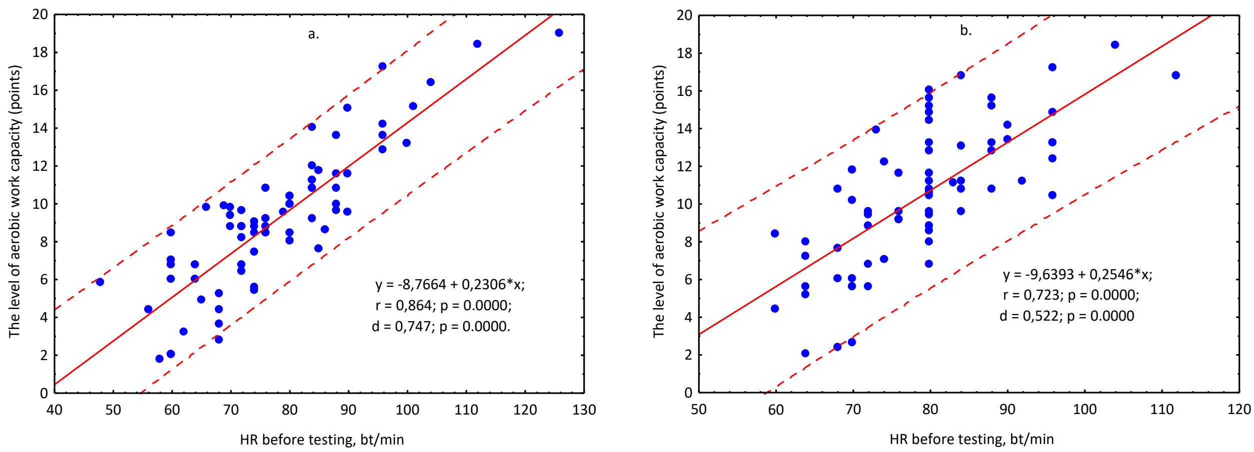

Figure 4. Graphical and mathematical models of aerobic physical work capacity dependence on initial HR values (a. - boys; b. - girls).

statistically significant (t=2.7<0.01). Higher values of correlation and determination coefficients also confirm some advantages of boys.

Biological age. In girls, the variance of biological age was 85.93 % (p<0.00000) determined by vegetative [Robinson index, systolic blood pressure, autonomic Kerdo index] and somatic [balancing on the left leg, body mass] parameters of the model (model Y_4). Of these, the former determined 39.2% of the variance of BA variance, whereas the latter - 46.7% (p<0.00000).

In boys, 93.2% (p<0.00000) of the variance of biological age was determined by vegetative [Skibinsky index, systolic blood pressure; Stange's test, Hench test) and somatic [balancing on the left leg] parameters of the model. Of these, the former determined 49.8% of the variance of biological age, and the latter - 43.4% (p<0.00000).

Discussion

As a result of processing and analyzing the experimental material the intra- and intergroup interrelations of parameters of physical development, physical fitness, and functional state of the body of the first-year students of the Technical University aged 17-19 years were studied. The use of methods of factor, dispersion, correlation, and regression analysis allowed to reveal the composition, ratio, and interrelations of the physical condition (PC) key indices of the students' bodies, determining its integral characteristics: the level of somatic health, aerobic physical work capacity, adaptation potential, and biological age. As a result, the corresponding mathematical models were constructed.

The analysis of publications on the problem under consideration shows that they present experimental material characterizing the physical condition of an individual mainly according to separate integral indices: physical work capacity [8, 37, 38], adaptation potential [34, 39, 30], level of somatic health [2, 3], morphofunctional and energy reserves [4, 8, 11, 40], biological age [15, 41, 42, 43], adaptation potential and biological age [29], and other parameters.

However, while studying the PC structure of the subjects, the interrelations of integral components in the process of their association to ensure the holistic activity of the human body were not addressed, as a rule. This reduced the possibilities of adequately interpreting the mechanisms of the body functioning as a system in the process of adaptation to various conditions of life activity.

A number of complex studies based on the methodological principles of the system approach were conducted on top-level athletes, whose body was adapted to the performance of specialized maximal or close to maximal physical loads [8, 37, 39, 44]. However, the criteria for assessing physical development, physical fitness, adaptation potential, and other integral characteristics of the PC of top-level athletes cannot be adequate benchmarks for evaluating the PC of non-athletes - students or middle-aged and elderly people.

The lack of analysis of ratios and interrelations of PC integral parameters of a person as fundamental principles of the system approach in biology is the main shortcoming of most complex studies. Such studies are necessary for system physiology at the present stage of its development and improvement.

Application of the methods of system approach, mathematical analysis, and modeling allowed us to determine the most informative indices and key components of the PC structure of the first-year students of the Technical University aged 17-19 years and to study their interrelations.

The following components of students' PC structure were investigated as the key ones:

1) level of physical development;
2) level of adaptation potential and health;
3) cardiorespiratory system capacities;
4) parameters of speed-strength fitness;
5) biological age and degree of aging;
6) physical work capacity.

Physical work capacity was also considered as one of the key integral parameters of students' PC, and its interrelations with other integral parameters were analyzed.

The novelty of the findings consists in the fact that the composition, ratios, and interrelations of the key integral factors of the PC structure have been studied for the first time in first-year students aged 17-19 years.

The factor analysis revealed that the general structure of PC in students of both sexes is identical. In both groups, the indices of physical development are the most integrated, whereas those of physical fitness and functional state - to a lesser extent.

In the process of stepwise regression analysis, statistically significant interrelations and dependencies of some integral parameters of the PC structure on others were revealed in students of both sexes; in addition, adequate mathematical models reflecting the specifics of their interaction were developed.

In particular, it was revealed that:

- *the level of somatic health,* in girls and boys, is primarily determined by the value of aerobic physical work capacity and the level of adaptation potential;

- *the level of adaptation potential* in girls depends mainly on somatic health and biological age, whereas in boys - on somatic health, biological age, and aerobic physical work capacity;

- the level of aerobic physical work capacity is determined mainly by the level of somatic health and the level of somatic health and the level of adaptation potential in girls and boys, respectively;

- *biological age* in girls is determined by the level of somatic health (45% of the variance), whereas in boys - by the level of somatic health and the level of adaptation potential.

The developed mathematical models can be used for modeling and predicting the dependence of individual integral parameters of students' PC on the cumulative and interacting impact of other integral parameters.

Different researchers analyzed mainly pairwise interrelations of physical condition integral parameters of a person: the level of health and motor activity [6, 45, 46]; motor activity and longevity [1, 13, 20]; motor activity and mortality [7, 17, 21]; motor activity and biological age [10, 15, 43]; motor activity and aging processes [1, 12], adaptation potential and health [30, 34], adaptation potential and biological age [29].

Of the pairwise dependencies in our study, the closest interrelation was observed between the level of somatic health and aerobic physical work capacity. This is consistent with the results of studies by Elhakeem et al. [6], Parsons et al. [13], Jennifer et al. [16], demonstrating the positive influence of physical exercises of moderate intensity on the health status of the subjects and vice versa - the impact of the health level on physical work capacity [27, 46].

However, the object of study in most works was, as a rule, middle-aged, elderly people or athletes [10, 14, 20].

In the present study, in contrast to the above-mentioned works, the object of study was 17-19-year-old students not engaged in sports. Their distribution by groups of somatic health and physical work capacity indicates that the majority of boys and girls of the Technical University have low and average levels of physical work capacity. According to these levels they have low and below average levels of health. Among boys there is a greater number of those with average and high levels of somatic health, manifesting average and above average values of aerobic PC.

The developed regression models and the modeling carried out on them showed that to move from the group with a low level of somatic health to the average group boys and girls need to increase the level of aerobic physical work capacity by 44% and 63%, respectively.

These data suggest that the modern university system of physical education (with two hours of physical education classes per week as envisaged by the curriculum) is not effective enough to strengthen and improve the level of somatic health, aerobic physical work capacity, and adaptation functional potential of students.

The results of assessing the PC of students of a Technical University obtained in the present study coincide with those observed in several other studies, in which a decrease in the level of physical health and adaptation potential of modern student youth and graduates of higher education institutions was noted [15, 30, 47].

According to the researchers, the key factors that exert a negative impact on student's physical condition are hypodynamia and hypokinesia, excessive emotional stress, decreased motivation for systematic physical exercise, insufficient number of physical education classes, etc. [25, 26, 30].

Improving the efficiency of physical education of students requires the solution of a number of scientific issues related to the substantiation of both more rational forms, means, and methods of g their physical fitness and health optimization [2, 43], and methods for assessing the integral parameters of the PC, the mechanisms of their interrelations and integration in providing holistic activity.

The novelty of the present study should also include the development of mathematical models containing PC indices that have the greatest partial, total, and interacting influence on integral parameters - somatic health, adaptation potential, biological age, physical work capacity of moderate intensity.

According to the developed models, in girls *somatic health and adaptation potential* are determined to the greatest extent by somatic indices, whereas *biological age* - by vegetative indices. In boys, *somatic health* is determined to the greatest extent by vegetative and somatic indices, *adaptation potential* - by somatic indices, and *biological age* - by vegetative indices.

It was found that among the individual vegetative indices of the PC structure of students' bodies, one of the most informative is resting HR - resting bradycardia. The data suggest that resting bradycardia is an informative marker of aerobic physical work capacity during moderate-intensity muscle activity.

The results of the present study are consistent with the studies we have conducted on combat athletes of the national team of Ukraine [44] and cadets of the National University of Bioresources and Nature Management of Ukraine aged 17-19 years [48], in which a statistically significant dependence of the level of aerobic-anaerobic work capacity on the initial values of HR was revealed. This allows considering resting bradycardia as a marker and criterion of physical work capacity.

Somatic indices of physical development and physical fitness analyzed in this work did not manifest themselves as important determinants of integral parameters of students' physical condition.

It may be explained by the fact that the methods developed by the authors to assess individual integral parameters of physical fitness were based mainly on the registration and analysis of vegetative indices [3, 34, 37, 41].

As far as vegetative parameters prevail in the experimental material of this article, the developed regression models should be considered as models of the influence, mainly, of the parameters of the vegetative component of the PC structure on the level of somatic health, aerobic physical work capacity, adaptation potential, and biological age of students.

The highest coefficients of multiple correlations, regressions, and determinations, reflecting, preferentially, the linear nature of the interrelations of the analyzed parameters give reason to recommend the developed models for modeling, inter- and extrapolation forecasting of students' PC depending on various factors analyzed in this work. They can also be used to design normative assessment scales.

Conclusions

1. The key components of the physical condition structure of the first-year students of the Technical University include: 1) physical development; 2) level of adaptation potential and health; 3) cardiorespiratory system functional capacities; 4) speed-strength fitness; 5) biological age and degree of aging.
2. Close linear interrelations and dependencies of student physical condition integral parameters: somatic health, physical work capacity, adaptation potential, biological age were revealed. The parameters of somatic health and physical work capacity are most closely interrelated. The level of somatic health is the key determinant of students' aerobic physical work capacity, whereas aerobic physical work capacity is a biological marker of the somatic health of boys and girls.
3. The majority of examined students are characterized by low and below average levels of somatic health, sufficient circulatory system reserves (according to AP values, average values of aerobic physical work capacity, and high values of biological age. Among boys, as compared to girls, there is a great number of those with average and high levels of somatic health and, accordingly, average and above average levels of physical work capacity.
4. Resting bradycardia is an informative marker and criterion of physical work capacity during moderate-intensity muscle activity: a decrease in resting HR is associated with an increase in aerobic physical work capacity. As compared to girls, boys tend to manifest a higher level of physical work capacity at lower values of initial resting HR.
5. Gender differentiated mathematical models allow modeling and predicting the physical condition of students or the level of manifestation of its individual integral components depending on possible changes in the parameters of each model.

Conflict of interests

The authors declare that there is no conflict of interests.

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