

Interaction of integral parameters of physical state and biological age of students aged 17-19 years old in the process of adaptation to standard and experimental physical education programs

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Abstract

Background and Study Aim The process of adaptation to physical education programs is a critical factor influencing the health and physical development of students. Understanding how these programs affect both the physical state and biological age of students can significantly improve their effectiveness. The aim of the study is to investigate the interaction between integral parameters of physical state (PS) and biological age (BA) of students aged 17-19 years old in the process of adaptation to standard and experimental physical education (PE) programs.

Material and Methods The study involved 140 first-year students of the National University of Telecommunications - 80 males and 60 females. In the course of the research, the indices of functional state, physical fitness (PF) and physical development (PD), biological age (BA) were recorded in young men and women of the control (CG) and experimental (EG) groups. To process the experimental material, methods of dispersion and canonical analysis were used and multiple correlation and determination coefficients were calculated.

Results It was revealed that the impact of PS integral parameters on students' BA is stronger than the inverse influence of BA on PS parameters. The degree of BA reduction under the influence of the studied factors is most pronounced in the EG of girls and boys. The variability of the group of PD and PF indices is accompanied by the variability of most of the BA parameters' dispersion in all studied groups of students. The factor of gender has the greatest impact on the BA of students. Girls have lower initial values of BA and it's a more pronounced decrease by the end of the experiment. The effectiveness of the impact of an aerobically oriented experimental program on the improvement of students' PS and reduction of BA was confirmed. Under the influence of the experimental program, the BA of EG girls decreases to a greater extent in comparison with EG boys and students of both control groups. Changes and differences in BA of boys and girls of EG and CG are due to the combined impact of the factor of PE software and that of adaptation changes of students' PS in the annual process of PE. In the group of boys and girls more pronounced influence on BA in the course of the experiment was produced by the factor of software and adaptation changes, respectively.

Conclusions The gender factor has the strongest impact on students' BA - girls have lower initial values of BA and it's a more pronounced decrease by the end of the experiment in comparison with boys. Adaptation changes of PS in the process of software implementation are accompanied by a decrease in BA in the experimental groups. One of the criteria and confirmations of the effectiveness of the developed PE program is the degree of mutual influence of PS integral parameters, which is most pronounced in the reduction of BA in the experimental groups of girls and boys.

Keywords: students, gender, physical education, biological age, physical state, mutual influence.

Introduction

Accurately assessing the impact of physical education programs on student well-being and performance is increasingly recognized as a vital component of educational strategies. Understanding

the physiological adaptations of students to physical education programs is crucial for optimizing health and performance outcomes. In this context, biological age (BA) provides a unique lens through which these adaptations can be assessed, highlighting variations in physical development that are not evident from chronological age alone.

Biological age is an integral parameter of a

human's physical state, encompassing physical development (PD), functional and physical fitness (PF), somatic health, and physical work capacity. These factors together provide a comprehensive measure of an individual's health and capabilities relative to their age group [1, 2, 3]. It is noted in the publications of several authors that the BA of modern youth significantly exceeds the chronological age [4, 5, 6]. Researchers believe that one of the reasons for this phenomenon is the insufficient level of motor activity of modern youth. The motor activity deficit of modern youth is accompanied by the deterioration of somatic health and accelerated rates of aging [4, 7, 8]. On the other hand, regular motor activity and sports engagement improve the PS and somatic health of a person [5, 7, 9], reduce BA [3, 10, 11] of persons of different ages.

Experimental material presented in the publications of a number of authors indicates that the improvement of PS and somatic health as a result of regular motor activity leads to physical work capacity increase [12, 13, 14], a decrease in BA, and the rate of aging [3, 10, 11], and increase in human life expectancy [15, 16]. In publications on the motor activity of students, it is noted that the insufficient number of physical education (PE) classes in universities is associated with an increase in BA and the rate of aging of students, deterioration of their functional status, and a decrease in physical and mental work capacity [4, 6, 13]. Different values of BA in persons of different sexes, and ages, showing different motor activity and having different levels of somatic health are indicative of the variety of factors influencing BA [2, 10, 17].

The analysis of mechanisms and factors influencing BA is complicated by the fact that the authors of numerous publications used for this purpose more than 300 heterogeneous PS parameters in total. Despite the study of the interrelations of many individual and a number of integral parameters of the PS with BA, the presented material is heterogeneous, difficult to compare, and does not allow to offer insight into the key factors and mechanisms determining BA. The majority of researchers used a limited number of PS indices to determine BA: anthropometric, morphological, functional, genetic, physical work capacity [18, 19, 20, 21]. Despite the fact that the publications of many authors reflect the dependence of BA on individual and integral PS parameters [2, 10, 17, 22], the specifics of the mutual influence of integral PS parameters on BA and BA on individual and integral parameters of students' PSs is not adequately investigated. It is characteristic that based on the analysis of a relatively limited number of human PS indices, researchers have developed mathematical models of BA dependence on the individual, most informative, indices of PD, PF, and functional state [3, 10, 17, 23].

A relatively small set of informative indices in the developed models, available methods of their determination, and high coefficients of determination allowed the authors to recommend mathematical models for assessing, modeling, and predicting youth BA depending on the partial weight, ratio, and variability of regression model parameters [10, 17, 18]. It is noteworthy that the mathematical models recommended by most authors for assessing and predicting youth BA were based primarily on functional indices. In some models, PD and PF indices were also considered as components determining a person's BA: body mass and length, static balancing in an upright posture, hand muscle strength, speed, endurance, and other parameters [2, 17, 23].

However, the available publications do not sufficiently reflect the relationship of BA with individual key and integral indices of PD, functional and physical fitness of individuals of different ages and genders.

The issues of mutual influence of integral parameters of students' PS and BA represent one of the least covered aspects of the problem under consideration. Even though the majority of authors analyzed the interrelationships of BA with individual indices of PD, PF, and functional state, the issues of mutual influence of PS integral parameters on youth BA and BA on integral parameters of PS remain insufficiently covered. The impact of different PE programs on students' BA, causing specific adaptation changes in the PS in the annual cycle of university PE, should also be referred to as the insufficiently covered aspect of the problem.

The effective solution of the set tasks is possible on the basis of complex research using adequate mathematical apparatus and based on the methodological principles of the system approach. The system approach, as a methodological principle, necessitates the study of the structure and interrelationships of integral components of PS, mechanisms of their improvement, mutual influence and impact on students' BA in the process of adaptation to physical loads in the annual cycle of university PE.

Incomplete coverage and relevance of the problem of interaction and mutual influence of integral indices of PS and BA structure of students determined the *objective of this work*: the study of the interaction of physical state and biological age integral parameters of 17-19 years old students in the process of adaptation to the standard and experimental physical education programs.

Materials and Methods

Participants

The study involved first-year students of the State University of Telecommunications aged 17-

19 years old (80 males and 60 females). The study protocol was approved by Ethic Committee State University of Telecommunications (Kyiv, Ukraine). The research was fulfilled in compliance with WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects [24].

Research Design

The studies were conducted in physical education classes. To solve the tasks set in the study, students were divided into control (CG) and experimental (EG) groups of boys and girls. The teaching and learning process of physical education with students of the control and experimental groups was carried out in accordance with the schedule of classes - once a week for two academic hours. Classes in the CG were conducted according to the generally accepted methodology in conformity with the program of physical education in higher educational institutions of the Ministry of Education and Science of Ukraine [25].

In the EG, in addition to the physical education classes provided by the schedule (once a week), 3 times a week additional independent classes were held according to the experimental method developed by us [2, 4]. Additional classes were held at the stadium of the university, as well as in the landscape park during non-study time. They included recreational running and physical exercises performed by the method of circuit training. In accordance with the author's program, EG students performed dosed physical loads with a large number of physical exercises mainly of moderate intensity and different in coordination structure. The training process included exercises with elements of athletics, sports games, artistic gymnastics. In the gym, an individual method was applied using complexes of exercises of the basic CrossFit program. Besides, students performed specially selected complexes of physical exercises of small forms of active recreation in theoretical classes in other subjects.

Students' physical state (PS) was assessed by individual indices of physical development, functional and physical fitness. A total of 55 indices of PS and BA were recorded. Biological monitoring of PS was conducted in the forms of stage (at the beginning and the end of the academic year), current (during several classes in a certain period), and operational (during a single class) control.

The following methods, tests, and indices were used to assess the level of physical fitness (PF) of students: a) *dynamometry* - the maximum strength of the hand muscles was registered;

b) *60 m running with maximum speed* (the quality of quickness was evaluated according to the result);

c) *standing long jump* (the explosive power of the leg muscles was evaluated according to the result);

d) *arm flexion-extension in a supine position for 30 s* (the speed-strength endurance of the shoulder

girdle muscles was evaluated according to the number of performed movements);

e) *sit-ups* with hands behind the head for 30 s (speed-strength endurance of the abdominal muscles was assessed by the number of performed movements);

f) *4 x 9 m shuttle run* (to characterize the physical qualities of agility and coordination of movements);

h) *500 m (girls) and 1000 m (boys) running* (to characterize the motor quality of general (aerobic and anaerobic endurance).

The functional fitness level of students was assessed according to the indices of cardiovascular, respiratory, and central nervous system activity: systolic and diastolic pressure, heart rate, vital capacity, inspiration breath-hold time (Stange's test, sec.) and expiration breath-hold time (Genchi's test, sec), vital index (Vital Index (VL/MT, where MT - body mass, kg), Skibinski index (0.01 VC·IBH/ HR), vegetative Kerdo index (1-DBP/ HR)·100), Robinson index (HR·SBP/100), static balancing on the left leg (motor coordination was evaluated by the time of keeping balance (sec) [2].

The level of physical development (PD) of students was assessed by body mass (kg) and length (cm), as well as body mass index (BMI).

Students' BA was calculated according to the method developed by Voitenko [17]. This method was based on the generally accepted methods of recording the activity indices of the cardiovascular, respiratory, and central nervous systems, and a specially developed method of health subjective estimation. The values of students' BA were calculated according to the following formulas [17]:

For men:

$$BA = 44.3 + 0.68 \cdot HSE + 0.40 \cdot SBP - 0.22 \cdot DBP - 0.22 \cdot PP - 0.004 \cdot VC - 0.11 \cdot IBH + 0.08 \cdot EBH - 0.13 \cdot SB.$$

For women:

$$BA = 17.4 + 0.82 \cdot HSE + 0.005 \cdot SBP + 0.16 \cdot DBP + 0.35 \cdot PP - 0.004 \cdot VC + 0.04 \cdot IBH - 0.06 \cdot EBH - 0.11 \cdot SB.$$

where: *HSE* – health subjective estimation in c.u., *SBP* – systolic blood pressure in mm Hg, *DBP* – diastolic blood pressure in mm Hg, *PP* – pulse pressure in mm Hg, *VC* – vital capacity, *IBH* – inspiration breath-hold in sec, *EBH* – expiration breath-hold in sec, *SB* – static balancing on the left leg in sec.

Statistical Analysis

Processing of the experimental material was carried out using the statistical software package STATISTICA 14.01.25 and Excel. To determine the degree of mutual influence of various factors on students' BA and biological age on individual integral parameters of PS, methods of dispersion analysis of one-, two- and three-factor complexes, as well as canonical analysis were used. Multiple correlation

coefficients and coefficients of determination were calculated. To determine the significance of differences between the registered parameters in the dynamics of the experiment, Fisher's criterion was calculated between the studied groups.

The algorithm of research results processing was as follows: first, the research materials were processed in the combined group of students (n=140), then in the EG (n=70), and CG (n=70) of students participating in the implementation of the developed (experimental) and standard (university) PE programs. The processing was completed in 4 groups of students: in experimental (n=40) and control (n=40) groups of boys, and in experimental (n=30) and control (n=30) groups of girls.

Results

Dispersion analysis of research results

Dispersion analysis of the research results obtained on EG and CG students enabled determining the degree of influence of the following integral factors on BA:

- 1) students' gender;
- 2) specificity of the software;
- 3) adaptation changes of physical state in the one-year pedagogical process in PE.

Table 1 presents the results of the dispersion analysis of the influence of 3 integral factors on students' BA (Table 1).

Dispersion analysis coefficients presented in Table 1 reflect the different degrees of influence of the studied factors on the BA. Of the three factors under consideration, that of gender has the greatest impact on students' BA.

The gender factor determines the variability of 47.2% ($p < 0.0000$) of the BA dispersion. Gradations of the factor:

- 1) girls performing experimental and control programs;
- 2) boys performing experimental and control programs (Table 1).

The software specificity factor determines the variability of 6.84% ($p < 0.0000$) of the BA dispersion. Gradations of the factor:

- 1) the combined group of girls and boys

performing the experimental program (EP);

- 2) the combined group of girls and boys performing the standard (university) PE program.

The factor of adaptation changes of physical state in the annual cycle of the pedagogical process determines the variability of 1.45% ($p < 0.004$) of the BA dispersion. Gradations of the factor:

- 1) beginning of the experiment;
- 2) end of the experiment.

Figure 1 graphically presents the changes in BA under the influence of three factors taken into account in the experiment:

- 1) gender - regardless of the impact of software and adaptation changes of students' PS (Fig. 1a);
- 2) *specificity of software* - regardless of the influence of gender and adaptation changes of PS (Fig. 1b);

3) *adaptation changes of PS* in the annual cycle of the pedagogical process - regardless of the impact of gender and software (Fig. 1c).

The coefficients of multiple correlation ($r = 0.746$, $r < 0.00001$) and determination ($d = 0.555$, $p < 0.0000$) indicate that changes of 55.5% ($p < 0.0000$) of the total variation of students' BA are due to the influence of the above presented 3 factors, whereas 44.5% of variations in the BA dispersion are conditioned by factors not considered in this experiment.

The data presented in Figure 1 indicate that each of the factors under consideration has a statistically significant impact on students' BA. Among them, the strongest influence is exerted by the factor of gender ($d = 0.472$, $p < 0.0000$), determining the variability of 47.2% ($p < 0.0000$) of the dispersion of students' BA.

The graphical analysis of BA changes under the influence of adaptation changes in the physical state of boys (Fig. 2a) and girls (Fig. 2b) in the annual cycle of the PE process (without each group differentiation into CG and EG) is presented below.

The results presented in Figure 2 show the decrease in BA in boys (Fig. 2a) and girls (Fig. 2b) in the process of changes in their PS by the end of the academic year. The decrease in BA in both groups occurs regardless of the content of the software. This is explained by the fact that the students' BA was considered in this analysis in the combined group of

Table 1. Dispersion analysis of the influence of various factors on the biological age of students in the process of physical education in the first year of study

No.	Factors	Influence, %	F	p
1.	Gender (females – males)	47.2	243.8	<0.000000
2.	Specificity of PE software (content of EP and SP)	6.84	40.9	<0.000000
3.	Adaptation changes of physical state in the process of PE (<i>beginning – end of the experiment</i>)	1.45	8.7	<0.0035
4.	Factors not considered in the experiment	44.51		
	General	100.0		

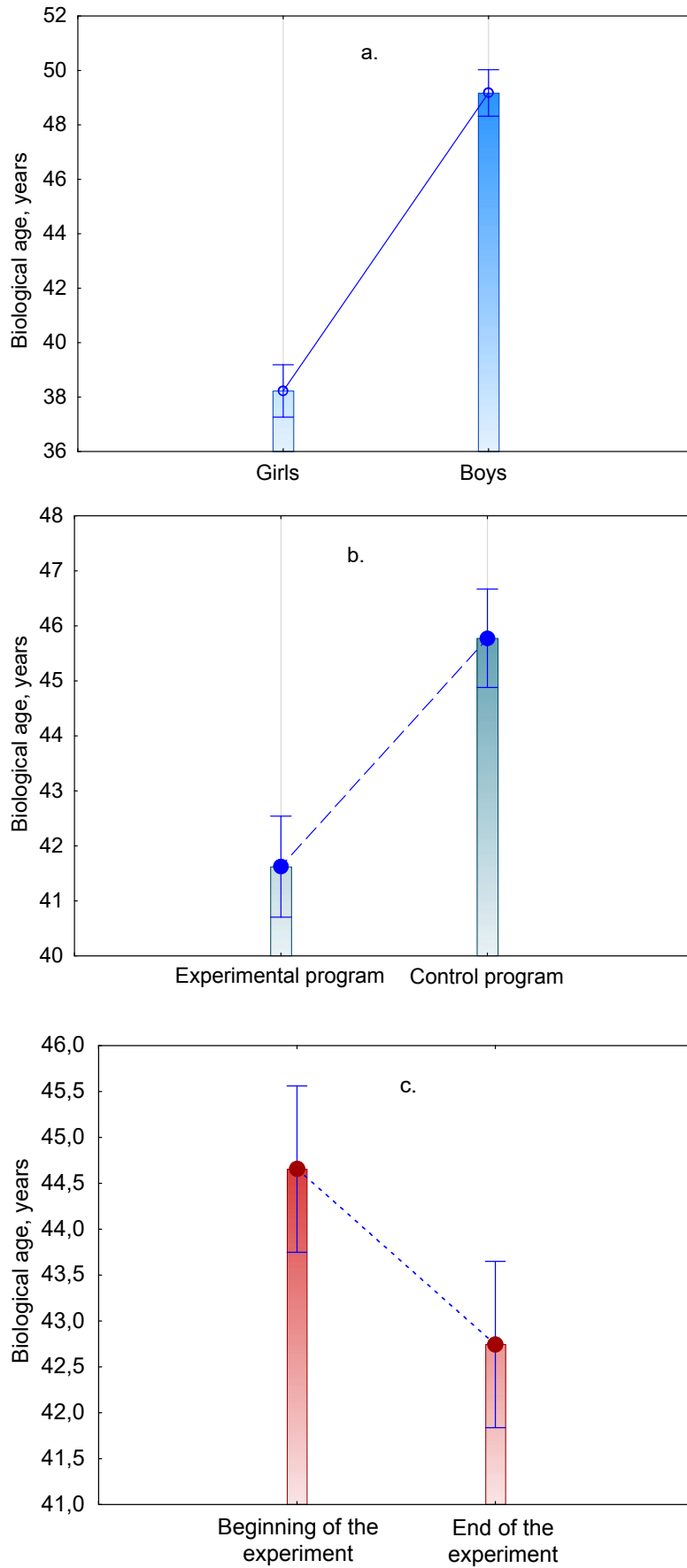


Figure 1. Changes in BA of students depending on gender (a), specificity of experimental (EP) and control (CP) PE programs (b), adaptation changes in PS during PE (c).

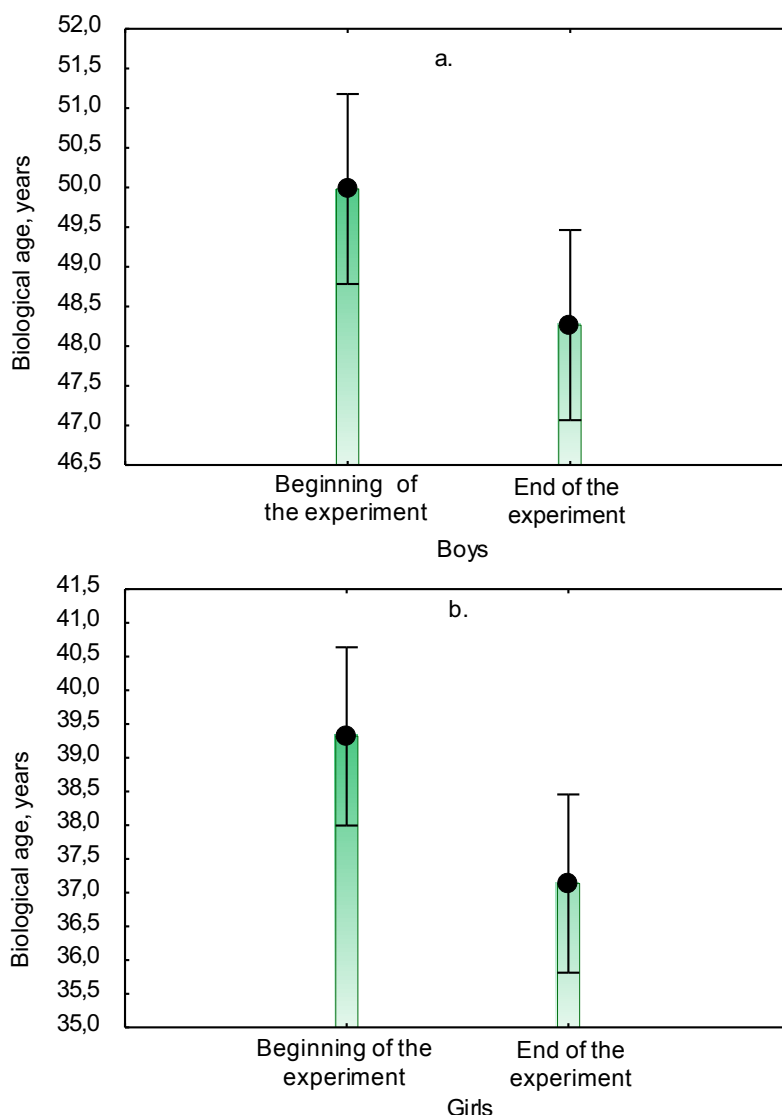


Figure 2. Changes in BA under the influence of adaptation changes of PS of boys (a) and girls (b) during the implementation of PE programs in the annual cycle of the pedagogical process.

boys (n=80) and girls (n=60) without differentiating them into EG and CG. The changes in the process of PE reflect the influence of adaptation changes of PS on the BA of students. Their impact determines the variability of 1.98 % ($p < 0.05$) and 4.15 % ($p < 0.02$) of BA dispersion in boys and girls, respectively.

The dispersion analysis allowed us to identify, quantify, and compare the impact of different factors on the BA of students of different genders (girls and boys) in the process of PE in the first year of study (Table 2).

The calculations presented in Table 2 and Fig. 1b indicate that software also contributes to a pronounced decrease in students' BA. The influence of the software factor of PE explains the variability of 24.83 % ($p < 0.0001$) and 6.03 % ($F = 11.0$, $p < 0.001$) of BA variation in boys and girls, respectively. The influence of the factor of physical state adaptation changes in the process of PE explains the variability of 1.98 % ($p < 0.0001$) and 24.11 % ($F = 43.8$, $p < 0.000000$)

of BA variation in boys and girls, respectively.

Fig. 3 graphically presents the changes in BA in girls and boys of EG and CG during the implementation of standard (in CG) and experimental (in EG) PE programs at the beginning and the end of the experiment. The specifics of the PE software in the CG and EG were considered as factors influencing the BA in the groups of boys and girls (Fig. 3).

The curves presented in Figure 3a, indicate that the differences in BA of the two groups of girls are due to the differences in the training programs during the experiment. In the experimental group of girls, a statistically significant decrease in BA ($p < 0.04$) is observed, whereas in the CG only a tendency to its decrease ($p > 0.05$) is noted. In the boys of EG and CG, a positive dynamics to the decrease of BA was revealed under the influence of the studied factors with the most pronounced in the boys of EG (Fig. 3).

The dispersion analysis showed that the influence of the software factor on BA was more pronounced

Table 2. Results of dispersion analysis of different factors impact on the BA of boys and girls in the process of pedagogical experiment

Group	Factors of impact	Impact, %	F	p
Boys	Specifics of PE software (content of EP and SP)	24.83	50.25	0.0000
	Adaptation changes in physical state in the process of PE (beginning - end of the experiment)	1.98	4.00	0.05
Girls	Specifics of PE software (content of EP and SP)	6.03	11.0	0.001
	Adaptation changes in physical state in the process of PE (beginning - end of the experiment)	24.11	43.8	0.000000

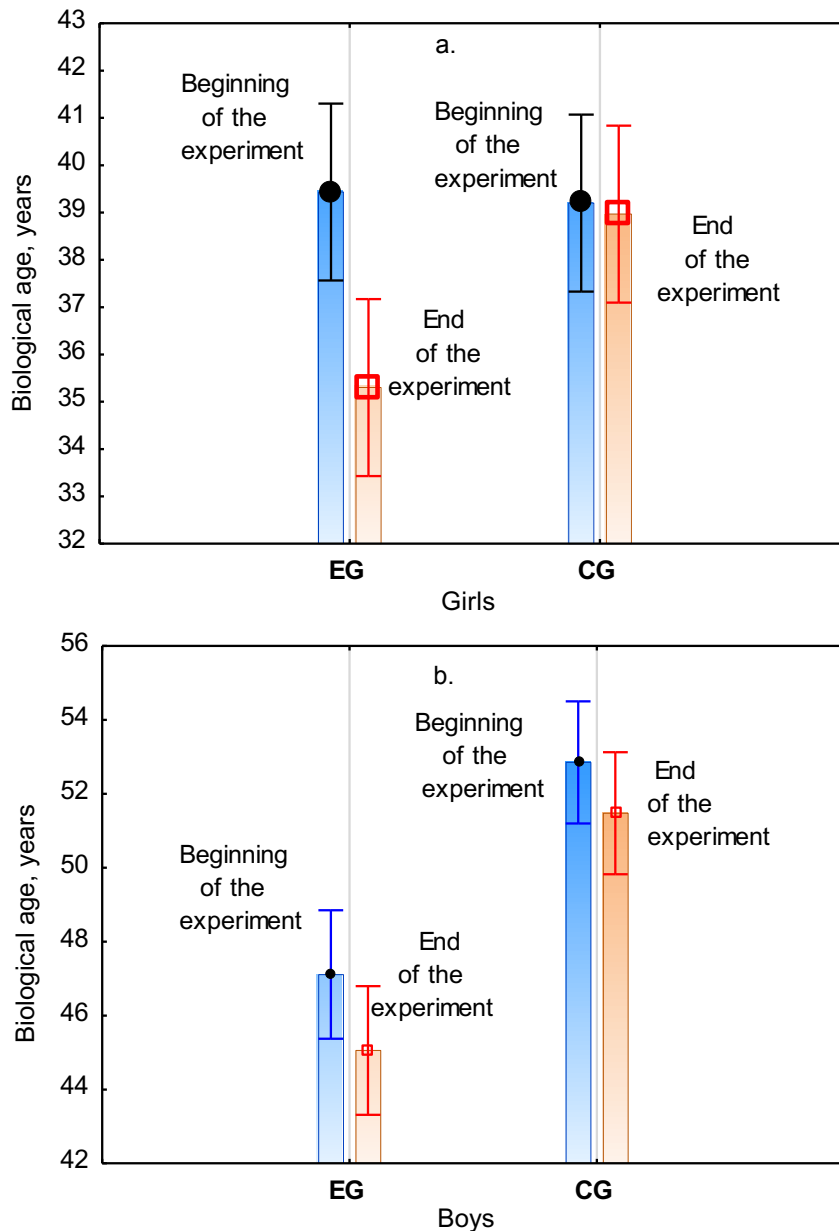


Figure 3. Change of biological age of girls and boys of the control (CG) and experimental (EG) groups in the pedagogical experiment. Gradations of the factor: beginning of the experiment, end of the experiment.

in the group of boys, whereas in girls the factor of adaptation to physical loads turned out to be more pronounced (tbl. 2).

Differences in the software of boys and girls of EG and CG caused differences in adaptation changes of their PS. The influence of the factor of PS adaptation

changes determines the variability of 24.11% ($P < 0.000$) and 1.98% ($P < 0.05$) of BA dispersion in girls and boys, respectively.

The coefficients presented in Table 2 indicate that the differences in the biological age of boys and girls of the EG and CG are due to the combined

influence of the factor of PE software and that of adaptation changes in the physical state in the process of PE. That is, the factors of software of PE classes, determining the specificity of PS adaptation changes of boys and girls, contribute to the reduction of their BA by the end of the experiment. The degree of cumulative impact of two analyzed factors on the BA variation constitutes 26.9% ($P < 0.000$) and 30.14% ($P < 0.000$) in boys and girls, respectively.

The relatively low percentage of BA variability in boys and girls under the influence of the studied factors indicates that most of the variability of the total dispersion of BA is determined by factors not taken into account in this analysis.

Differences in the BA of the students of EG and CG throughout the experiment, while characterizing the average biological age in each combined group (females and males), reflect the impact of the specifics of the experimental and standard programs in the process of physical education and adaptation changes in the physical state in the dynamics of the annual cycle in PE.

Canonical analysis of the research results. To determine the specificity of the mutual influence of the studied groups of indices and BA, *canonical analysis* was undertaken. The conducted *canonical analysis* showed the different character of interaction of the following groups of variables:

- 1) functional state (7 parameters);
- 2) physical development and physical fitness (11 parameters);
- 3) biological age (2 parameters);
- 4) the combined group of all parameters (18 indices) of students' physical state ($n=140$).

The correlations between the following sets of indicators were investigated:

- 1) between functional indices (7 indices) and PD

and PF indices (11 indices) (Table 3);

- 2) between BA variables (2 indices) and functional indices (7 indices) (Table 4);
- 3) between BA variables (2 indices) and PD and PF variables (11 indices) (Table 5);
- 4) between *all investigated parameters of physical state* (18 indices) and BA parameters (2 indices).

The analysis of the results of the mutual influence of the studied pairs of group indices is presented below.

The mutual influence of the group of functional indices and that of PD and PF indices. The parameters of the canonical analysis presented in Table 3 reflect different mutual variability of the group of functional indices and the combined group of PD and PF indices in the whole population of students.

The statistics presented in Table 3 reflect the proportions of dispersions determined by the canonical variables.

Sufficiently high values of the canonical correlation coefficient ($R=0.679$) and chi-square ($\chi^2=246.9$, $p=0.0000001$) between the two groups of PS variables in the combined group of students indicate a sufficiently high correlation between the group of functional indices and the group of PD and PF indices.

The data indicate that 14.68% of the dispersion of functional fitness indices is determined by the impact of canonical variables of PD and PF. Similarly, 23.18% of the dispersion of PD and PF indices is determined by the impact of the group of functional indices.

The results of interaction between two groups of physical state variables indicate that in EG boys and girls PD and PF indices have a stronger influence on functional indices than functional indices on PD and PF indices. In the control groups of boys and girls, on the contrary, the influence of functional

Table 3. Results of canonical correlation analysis of the relationship between the group of functional indices and the group of physical development and physical fitness indices

Groups		Statistical characteristics;	Functional indices (7)	Physical development and physical fitness indices (11)
All students	EG and CG (N=140)	Canonical correlation, χ^2	r=0.679 Chi2=246.9 p=0.0000	
		General variation	14.68%	23.18%
Girls	EG (N=30)	Canonical correlation, χ^2	r= 0.830 Chi2=123.0 p=0.0007	
		General variation	31.47%	26.18%
	CG (N=30)	Canonical correlation, χ^2	r= 0.586 Chi2=51.17 p=0.990	
		General variation	14.32%	8.55%
Boys	EG (N=40)	Canonical correlation, χ^2	r= 0.740 Chi2=133.73 p=0.00007	
		General variation	26.63%	15.32%
	CG (N=40)	Canonical correlation, χ^2	r= 0,647 Chi2=107,00 p=0,02	
		General variation	19,62%	14,87%

Table 4. Results of canonical correlation analysis of interaction between BA indices and functional indices

Groups		Statistical characteristics	BA indices (2)	Functional indices (8)
All students	EG and CG (N=140)	Canonical correlation, χ^2	r=0.795 Chi2=351.9 p=0.0000	
		General variation	34.4%	14.5%
Girls	EG (N=30)	Canonical correlation, χ^2	r= 0.827 Chi2=65.2 p=0.0000..	
		General variation	39.02%	11.9%
	CG (N=30)	Canonical correlation, χ^2	r= 0.989 Chi2=212.6 p=0.0000..	
		General variation	56.1%	17.7%
Boys	EG (N=40)	Canonical correlation, χ^2	r= 0.873 Chi2=104.7 p=0.0000..	
		General variation	48.02%	18.4%
	CG (N=40)	Canonical correlation, χ^2	r= 0.878 Chi2=133.7 p=0.0000..	
		General variation	19.62%	14.87%

Table 5. Results of canonical correlation analysis of interaction between the group of BA and the group of PD and PF indices

Group		Statistical characteristics	BA indices (2)	Physical development and physical fitness indices (10)
All students	EG and CG (N=272)	Canonical correlation, χ^2	r=0.881 Chi2=468.6 p=0.0000	
		General variation	65.6%	40.9%
Girls	EG (N=30)	Canonical correlation, χ^2	r= 0.641 Chi2=40.8 p=.004	
		General variation	31.47%	26.18%
	CG (N=30)	Canonical correlation, χ^2	r= 0.570 Chi2=37.3 p=0.01	
		General variation	29.22%	6.90%
Boys	EG (N=40)	Canonical correlation, χ^2	r= 0.645 Chi2=49.3 p=0.0003	
		General variation	29.0%	11.0%
	CG (N=40)	Canonical correlation, χ^2	r= 0.392 Chi2=17.6 p=0.61	
		General variation	11.8%	2.4%

indices on PD and PF indices is stronger than that of PD and PF indices on functional indices.

Interaction of the group of functional indices (8 indices) with those of BA (2 indices) (Table 4). The parameters of the canonical analysis presented in Table 4 indicate that the influence of functional indices on BA is stronger than the inverse impact of BA on functional indices. This specificity of interaction between the *two groups of variables* is characteristic of all examined groups (girls and boys of EG and CG). It is confirmed by high values of canonical correlation coefficients (0.827-0.989 (p=0.0000)), percentage of variability of indices, as well as chi-square values (χ^2) in all groups of students.

Table 5 presents canonical correlation coefficients, chi-square, and percentage of mutual influence of BA indices (2 indices) and PD and PF indices (11 indices) in all analyzed groups of students.

The results presented in Table 5 indicate that the variability of the group of PD and PF indices determines that of most of the dispersion of the group of BA indices in all groups of students. At the same time, the influence of the group of BA indices

on the dispersion of PD and PF indices is much smaller. It is characteristic that in the CG of girls and boys, the mutual influence of BA variables and those of PD and PF is low and statistically insignificant.

The canonical analysis of interacting all parameters of students' physical state (18 parameters) with BA parameters (2 parameters) in the combined group of students (n=140) showed that the variability of 79.5 % (p=0.0000...) of dispersion of students' BA variables is determined by the influence of all variables of students' PS (18 parameters). On the other hand, the impact of BA variables on the total dispersion of PS indices is significantly lower and amounts to 29.2 % (p=0.0000...).

This regularity significance in the interaction between the two groups of parameters is evidenced by the high values of the canonical correlation coefficient (R = 0.909, p=0.0000001) and chi-square ($\chi^2 = 728.4$, p=0.0000001). These calculations confirm the high dependence between PS indices and BA of students. At the same time, the combined effect of all PS indices on BA is higher than the BA effect on PS parameters.

The revealed interrelations reflect the presence of a certain positive cross-transfer between the groups of indices of functional state, PD, PF, and BA of students. The degree of mutual influence is most pronounced in the experimental groups of girls and boys, which is one of the confirmations of the positive influence of the experimental program on students' BA.

Therefore, the canonical analysis demonstrated that BA not only depends on the functional state, physical development, and physical fitness of students but also differently affects these components of the physical state of both boys and girls of EG and CG.

Discussion

Despite the fact that a large number of works have been devoted to the problem of BA and its interrelations with the indices of human physical state (PS), some aspects of the problem under consideration require more in-depth coverage.

The inadequately treated aspects of the problem under consideration include the issues of mutual influence of PS parameters and BA of persons of different ages. The analysis of works by various authors indicates that most of them are devoted to analyzing the influence of different PS parameters on BA and human aging [10, 13, 27]. At the same time, the inverse effect of BA on PS parameters has been studied comparatively less. Although specialists who have been dealing with the problem of human BA suggested using it as an index for assessing the general state of health and aging, as well as for predicting the main age-related diseases and mortality [21, 28, 29].

The object of study in the works of most authors addressing the relationships between BA and different forms of motor activity was middle-aged, elderly persons or athletes as a rule [3, 11, 16]. The authors studied mainly the relationships of BA with individual or integral indices of PF of individuals of different sex [10, 27, 30], somatic health [30], and motor activity levels [16, 23]. The influence of different forms of motor activity on the PS and BA of students has been studied to a much lesser extent, even though some studies have noted the low effectiveness of the impact of university physical education programs on the physical state, somatic health, and BA of students [2, 4, 23, 27, 30].

Insufficient study of the influence of different motor activity programs on students' BA, as well as the issue of the mutual influence of PS parameters and BA prompted us to conduct the present research. The research was aimed at studying the specifics of the mutual influence of BA parameters and 3 groups of PS parameters of boys and girls aged 17-19 years old in the process of their adaptation to standard [university] and experimental PE programs.

The experimental program of motor activity for students 17-19 years old was developed and published by us earlier [1, 2, 4, 23]. The diversity of factors affecting human BA, a large number of heterogeneous indices used by researchers to assess it, served as an argument for selecting methods of a complex approach and adequate mathematical apparatus to determine the factors and mechanisms influencing BA and its interrelationships.

To solve the tasks of the present research, standard methods of registration and estimation of students' PS parameters, as well as methods of dispersion and canonical analysis of experimental results were applied.

As a result of the conducted complex research, the effectiveness of the experimental PE program, as well as the used methods of mathematical processing and analysis - dispersion and canonical analysis - was confirmed.

The methods of dispersion and canonical analysis enabled to obtain material for analysis, which is an addition to our previously published results [2, 4, 23].

The dispersion and canonical analysis were used to determine the degree of influence of the following integral factors on students' BA:

- 1) PE software;
- 2) gender;
- 3) adaptation changes of students' body PS in the dynamics of the annual PE process;
- 4) group of PS functional parameters;
- 5) group of PD and PF parameters;
- 6) combined group of all studied PS parameters.

The canonical analysis also permitted to study the degree of mutual influence of integral parameters of students' PS and BA.

The dispersion analysis revealed that under the influence of the factors of PE software, gender, adaptation changes of students' body PS in the annual cycle of PE most part of students' BA dispersion changed (55.5%, $p < 0.0000$). A lesser part of BA dispersion changed due to the influence of factors not considered in this analysis. The influence of some other integral factors on students' BA was considered in one of the previous publications [2].

Of the factors analyzed in this article, the factor of gender had the greatest influence on the BA of students in the first year of study. As our research has shown, its influence determines 47.2 % ($p < 0.0000$) of BA variability in the studied students. Significantly lower values of BA are observed in girls as compared to boys.

It is noteworthy that the influence of the software factor on the BA is higher in the group of boys, whereas that of adaptation changes in the course of the experiment - in the group of girls. The results indicate that the difference between the BA of girls and boys in the EG and CG is due to the combined impact of the factor of software specificity and that

of adaptation changes in the PS in the course of the experiment.

This result can be explained in the following way: the specificity of the PE classes' software through adaptation changes of the body PS of boys and girls, determined BA decrease by the end of the experiment in both groups unevenly. The most pronounced changes in BA occurred in the EG of girls.

The findings suggest that the changes and differences in the BA of boys and girls in the EG and CG are caused by the combined influence of the factor of PE software and that of adaptation changes in the students' PS in the annual PE process.

Lower initial values of BA in girls compared to boys indicate an important role of genetic mechanisms in determining BA. It is safe to assume that genetic mechanisms, modulating the influence of software on BA, determine the specificity of adaptation rearrangements and changes in students' BA in the process of PE, which were most pronounced by the end of the experiment in EG girls.

Lower initial values of girls' BA and a more pronounced reliable decrease of BA by the end of the pedagogical experiment give grounds to conclude that aging processes in girls are slower in comparison with boys. Under the influence of the experimental program the BA of girls is more amenable to decrease compared to boys of EG and students of both control groups.

The novelty of the results of the present study is that for the first time interactions of BA indices of students aged 17-19 years old with different groups of their PS indices under the influence of experimental and university PE programs were studied.

The canonical analysis allowed us to study the peculiarities of mutual influence of several groups of variables of students' PS and BA:

- a) the group of functional indices and those of the combined group of PD and PF;
- b) the group of BA indices and the group of functional indices;
- c) the group of BA indices and the combined group of PD and PF indices;
- d) the group of BA indices and the combined group of all analyzed PS indices.

The results of the mutual influence of the group of functional variables and the group of PD and PF variables demonstrate that in EG boys and girls PD and PF indices exert a stronger impact on functional indices compared to that of functional indices on PD and PF indices. In the control groups, on the contrary, the influence of functional indices on PD and PF indices is stronger than that of PD and PF indices on functional indices. Explanation of the mechanisms of such mutual influence requires further more in-depth studies.

The values of canonical correlation coefficients,

percentage of variability of indices, and chi-square (χ^2) values in EG and CG of girls and boys afford ground to assert that the influence of the group of functional indices on BA is stronger than the inverse impact of BA on functional indices.

It was revealed that the influence of the combined group of PD and PF indices is responsible for the variability of most of the variance of the group of BA indices in all studied groups of students. The reverse impact of BA on the variability of PD and PF indices in EG and CG of students is significantly lower. In the control groups of students, the mutual influence of BA variables and PD, and PF variables is low and statistically insignificant.

The canonical analysis of the mutual influence of the most informative parameters of PS (18 out of 55 parameters) of students and BA parameters in the combined group of students indicates that under their combined influence 79.5 % ($p < 0.0000$) of the BA dispersion changes. At the same time, the impact of BA provides only 29.2% ($p < 0.0000$) of the dispersion of PS parameters' changes.

The revealed dependencies reflect the presence of a certain positive cross-transfer between the groups of studied indices:

- 1) functional state;
- 2) PD and PF;
- 3) all studied parameters of PS;
- 4) students' BA.

The degree of mutual influence of these groups of indices in students' BA decrease is most pronounced in the experimental groups of girls and boys. This can also be considered as one of the criteria and confirmations of the developed program's positive impact on the PS and BA of the experimental groups' students.

The conducted studies have shown an insignificant influence of the university (standard) program on the BA, functional and physical fitness of students in the control groups.

The insufficient efficiency of the university program impact on PS and BA of students, revealed by our research, is confirmed by the findings of other authors [19, 27, 30].

The results obtained are consistent with the findings of Prysiazniuk et al. [1], Kolokoltsev et al. [27], Pavanello et al. [31] on the positive effect of increased motor activity on BA and youth health.

The results substantiate the necessity of introducing additional PE programs into the system of pedagogical process in higher education institutions.

The obtained results are also an addition to our previous studies [2, 4, 23] and to the studies of a number of authors who dealt with the problem of interrelations of motor activity, health and BA and youth [10, 27, 31].

The experimental motor activity program caused a decrease in BA, an increase in functional

capabilities and physical fitness of students of the experimental groups, which were most pronounced in girls.

The novelty of the obtained results consists in the following:

a) the quantitative characterization of the influence of the following factors on students' BA is given: PE software, gender, adaptation changes of students' PS in the dynamics of PE, the group of PS functional parameters, the group of parameters of PD and PF, the combined group of all studied parameters of PS. Of the PS parameters, the combined group of functional and physical fitness parameters has the greatest influence on BA;

b) the effectiveness of the experimental motor program of predominantly aerobic orientation impact on the physical state and BA of students was confirmed. The efficiency of the developed PE software is characterized by a decrease in BA and slowing down the processes of aging of students' bodies, an increase in functional capabilities and physical fitness of boys and girls of the experimental groups in the annual cycle of training;

c) the degree of mutual influence of integral parameters of PS and BA of boys and girls aged 17-19 years old was determined for the first time. The degree of mutual impact of BA and the group of the most informative parameters of PS (18 indices) is most pronounced when BA decreases in the experimental groups of girls and boys.

Conclusions

1. The use of dispersion and canonical analysis methods allowed to confirm the effectiveness of physical education experimental program, to determine the degree of mutual influence of PS and BA integral parameters of boys and girls aged 17-19 years old.
2. BA and physical state changes of students of CG and EG in the dynamics of annual process

of physical education reflect the specificity of the influence of standard and experimental programs, as well as adaptation changes in the PS of boys and girls. More pronounced positive changes in PS parameters with a greater decrease in BA in the experimental groups confirm the efficiency of the developed program.

3. Adaptation changes of PS in the process of software implementation are accompanied by a decrease in BA in the experimental groups. The gender factor has the highest influence on students' BA - lower values of BA and its more pronounced decrease has been observed in girls by the end of the experiment in comparison with boys.
4. The canonical analysis showed that 79.5% ($p < 0.0000$) of students' BA dispersion changed under the influence of the key PS parameters (functional, physical development, and physical fitness), while only 29.2% ($p < 0.0000$) of students' PS parameters dispersion changed under the influence of BA. The degree of mutual impact of BA and all the studied PS parameters is most pronounced in the experimental groups of girls and boys.
5. The greatest impact on students' BA is exerted by the group of PD and PF indices: 65.6% ($p < 0.000...$) of the BA dispersion changes under their influence. At the same time, under the influence of BA, 40% ($p < 0.000...$) of the dispersion of PD and PF indices changes.
6. One of the criteria and confirmations of the developed physical education program efficiency is the degree of mutual influence of PS integral parameters, which is most pronounced during BA decrease in the experimental groups of girls and boys.

Conflict of interests

The authors declare that there is no conflict of interests.

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