ORIGINAL ARTICLE

Interrelations of physical state parameters and biological age of students in the process of physical education

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim The objective of the study is to investigate the relationships of students' biological age (BA) with the parameters of functional and physical fitness (PF) in the process of adaptation to standard (university) and experimental physical education programs.

Material and Methods The studies were conducted at the National University of Telecommunications of Ukraine and involved 140 students aged 17-18 years old, comprising 80 boys and 60 girls. We recorded 55 indices of students' functional state and physical fitness, and determined their Body Mass Index (BMI). The experimental data were processed using methods of correlation, dispersion, and regression analysis. Mathematical models describing the relationships between BMI and key indicators of students' physical well-being were developed.

Results The impact of the program on 17-18-year-old students is marked by a decrease in BMI, an increase in the levels of physical fitness and overall well-being among both the experimental group of girls and boys. Additionally, there is a reduced correlation between BMI and the parameters of their physical health. The key indices of functional state and physical fitness determining the BMI of male and female students were identified. Multiple regression models were developed to illustrate the dependence of male and female BMI on somatic and functional indices. Quantitative characteristics of the degree of partial and total impact of key indices on male and female BMI were provided. It was found that the key indicators of students' physical state (PS) structure, which exerted the most significant influence on BMI, differ between young men and women. In young men, the key indicators influencing BMI include the following: Vital capacity (VC) accounts for 51.9% of BMI variation; self-perceived health status (SPHS) contributes 15.3%; static balancing (SB) affects 8.5%; inspiration breath-hold time (IBH) influences 8.4%; expiration breath-hold time (EBH) has a 0.8% impact; systolic blood pressure (SBP) plays a role with 4.6%; the number of sit-ups in 30 seconds (SU30s) is associated with 0.9%; and left hand muscle strength has a 0.6% influence. In girls, the key indicators are VC (34.5% of BMI variation), SBP (23.1%), and SB (7.9%).

Conclusions The experimental program of increased motor activity leads to an increase in the functional and motor capabilities of students, while simultaneously decreasing their BMI. Among the parameters studied, changes in vegetative parameters have the greatest impact on reducing students' BMI during the annual cycle of long-term adaptation to physical loads. In contrast, changes in somatic parameters and physical fitness parameters have a lesser influence on students' BMI. The calculated equations of multiple regression serve as model characteristics that reflect the relationships between BMI and the key indicators of functional state and physical fitness in 17-18-year-old students. These equations can be utilized to estimate, model, and predict the BMI of 17-18-year-old students of different genders when altering the parameters of their physical state in various conditions of daily life and activity.

Keywords: students, biological age, interrelations, functional state, physical fitness, models.

Introduction

The biological age (BA) of students serves as an integral marker of their physical state (PS) and plays a crucial role in assessing body ontogenetic maturity, individual development, aging rates, and overall health status [1, 2, 3]. Numerous studies by various authors have highlighted the interconnectedness of BA with aerobic physical work capacity [4, 5, 6], somatic health [7, 8], adaptation potential, and functional reserves of the human body [6, 9, 10]. Additionally, BA is influenced by physical development [11, 12] and regular physical activity [8], both of which are integral components of human functional state (FS).

Studies by a number of authors have established that regular motor activity reduces BA [5, 7, 13], slows down the aging processes [5, 14, 15], and increases the level of somatic health [7, 8, 16], and human life expectancy [17, 18]. There is a variety of material in the literature, in which researchers note

doi:10.15561/20755279.2024.0102

the dependence of the rate of biological maturation and aging on genetic factors, lifestyle, nutrition, the presence of bad habits, stress, chronic diseases, environmental situations, and many other reasons [9].

The variety of factors affecting BA envisages the development of adequate methods of its diagnosis, evaluation criteria, determination of the key factors, interrelations, and dependencies.

Most researchers assessed the biological maturity of an individual mainly by a set of individual indices or individual integral parameters of FS: according to the level of physical development [11, 12], indices of functional state [7, 19, 20] and component body composition [8, 21], genetic markers [22, 23, 24].

The correlations of BA with anthropometric, morphological, functional, genetic, and other indices indicate the diversity of factors, mechanisms, and criteria that determine human BA as an integral marker of PS.

This implies the necessity of using the methods of complex and systemic approaches to reveal the mechanisms that determine the biological maturity of an individual. In this regard, when defining and assessing BA, it is important to analyze its interrelationships with both individual and generalized parameters of students' FS, with subsequent determination of the degree of their influence on BA. In accordance with the principles of the system approach and, in particular, the principle of interaction, when investigating the mechanisms that determine BA, it is reasonable to study its interrelations with both individual human FS indices (based on pair correlation analysis) and with their set (on the basis of multiple correlation analysis).

It is equally important to assess the extent of their partial and overall impact on BA, as well as the relationship between BV and the ratios and interrelations of the complex set of key parameters of human FS [6, 8]. This necessitates the utilization of complex mathematical processing and analysis methods, such as multiple stepwise regression and analysis of variance [25]. Despite the fact that most authors have employed a combination of morphological, somatic, vegetative, and anthropometric indices to calculate individual biological maturity [5, 8, 19, 21, 26], their exploration of the relationships and dependencies of BA has often relied on a limited mathematical framework. This limitation has hindered the ability to determine the partial, cumulative, and interactive influences of various FS parameters on the BA of individuals with differing genders, ages, levels of physical fitness, and other factors.

In order to reveal the mechanisms of BA interaction, it is important to use, along with complex diagnostic methods, various methods of mathematical processing of multimodal information: multiple correlation, regression, factor, dispersion, and other statistical methods [6, 25]. To determine BA, in the works of the majority of researchers relatively simple methods of biological parameters statistical processing were used [8, 27]. In a number of works, methods of correlation and regression analysis of relationships between BA and somatic and vegetative parameters of the human body PS were used [2, 5, 19, 20, 26]. Having calculated relatively simple linear regression equations that enable to determine and predict BA by vegetative and somatic indices of human body FS, the authors recommend using the calculated level of BA as an index for assessing health status and aging, as well as for predicting mortality and morbidity of major age-related diseases in various conditions of life activity [2, 19, 20].

However, most of the regression models recommended by the authors for determining BA have been derived on middle-aged or older individuals. Therefore, the criteria for estimating and predicting BA, aging, or mortality cannot be used to assess and predict BA and health status in young adults [5, 9, 20].

The accuracy of linear regressions and correlations used for estimating and predicting BA in middle-aged, older, or representatives wider age ranges decreases when they are applied for estimating and predicting BA in young adults. Other factors affecting the accuracy of BA estimation and prediction are gender, occupation, motor activity, environment, etc. [9]. This necessitates taking into account the variety of influencing factors to improve the accuracy of estimating and predicting BA.

One of our previous publications presents experimental material reflecting the interrelations of BA with the level of somatic health, physical work capacity, adaptation potential, i.e., integral parameters of the FS of the students' body [6]. However, both in our publication and those of a number of authors [2, 5], the partial and total influence of individual FS parameters on students' BA is inadequately treated. The dependence of BA on the ratios and interrelations of students' PS parameters in the process of their adaptation to physical loads in higher education institutions is incompletely disclosed. The impact of different forms of motor activity, including sports activities, on BA, health status, aging, and life expectancy of an individual has been underinvestigated in the publications of researchers who have dealt with this problem [2, 5]. Even though many publications confirm the important role of regular motor activity in reducing BA, improving somatic health, and increasing functional reserves of young people [5, 6], they neither adequately treated the interrelationships of BA with somatic and vegetative parameters, nor identified the key FS indices and their interrelationships that determine the BA of men and women of different, including student, ages.

Determination of the key parameters of the FS structure, their correlations, and interrelations with the BA of students in the process of short- and long-term adaptation to physical loads, although being a pressing issue is insufficiently covered.

Insufficient coverage and relevance of the problem of BA interrelations with the parameters of students' PS structure determined the objective of the present study: to study the interrelations of students' biological age with the parameters of functional and physical fitness in the process of adaptation to standard (university) and experimental physical education programs.

Materials and Methods

Participants

The experiment included 17-18-year-old students from the State University of Telecommunications (Ukraine), consisting of 80 males and 60 females. The study protocol received approval from the Ethical Committee of the National Aviation University in Kyiv (Ukraine). Was conducted in accordance with the WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects [28].

Research Design

In the process of organizing the pedagogical experiment, students were divided into experimental (EG) and control (CG) groups. Students were surveyed during physical education classes in the first year of study. In the control group (CG), classes were conducted once a week for 2 hours, following the widely accepted methodology. In the experimental group (EG), classes were conducted using the experimental method, which included exercises incorporating elements of athletic gymnastics, track and field, and sports games. The program involved controlled physical loads of moderate intensity with a significant emphasis on various motor activities.

The difference of the experimental method from the traditional form of teaching was as follows:

- Along with the physical education classes stipulated by the schedule (once a week), additional independent classes were held 3 times a week at the stadium of the University, as well as classes in the landscape park including recreational running and physical exercises performed by the circuit training method;
- The circuit method was used during classes in the gym;
- The individual method was applied using exercise complexes of the basic CrossFit program;
- During theoretical classes specially developed physical exercises complexes of small forms of active rest were performed;
- EG students actively participated in physical training and sports activities of the University followed by taking part in district and city competitions;

Assessment of students' physical state was carried out in the forms of: a) stage control - at the beginning and the end of the academic year; b) current control - during several classes for a certain period; c) operational control - during a separate class.

The following methods and tests were used *to assess the level of physical fitness* (PF) of students:

a) dynamometry (DM) the maximum strength of the hand muscles - Fmax, kg was registered;

b) 60 m running (the quality of quickness was evaluated by the running time);

c) standing long jump (the explosive strength of the leg muscles was evaluated by the result);

d) push-ups (PUs) for 30 s (the strength endurance was evaluated by the number of performed movements);

e) sit-ups, hands behind the head (by the number of performed movements within 30 s strength endurance was evaluated) (SUs30s);

f) static balancing (SB) on the left leg (by the time of keeping balance (sec) motor coordination was evaluated).

To assess the students' level of functional fitness, activity indices of their cardiovascular and respiratory systems were recorded. These indices included heart rate (HR), systolic (SBP), and diastolic (DBP) blood pressure, vital capacity (VC in ml), inspiration breath-hold time (IBH - Stange's test in seconds), and expiration breath-hold time (EBH - Genchi's test in seconds). The vital index (VC/MT, where MT is body mass in kg), Skibinski index (0.01 VC·IBH/HR), vegetative Kerdo index ((1-DBP/HR)·100), and Robinson index (HR·SBP/100) [29] were also considered.

The students' biological age (BA) was calculated using a method developed by Professor Voitenko [26]. This method relied on commonly accepted techniques for recording activity indices of the cardiovascular, respiratory, and central nervous systems. The values of students' BA were determined using specific formulas [25]:

For men: $BA = 27.0 + 0.22 \times SBP - 0.15 \times IBH + 0.72 \times SPHS - 0.15 \times SB.$

For women: $BA = 1.46 + 0.42 \times PP + 0.25 \times BM + 0.7 \times SPHS - 0.14 \times SB,$

where: *SBP* – systolic blood pressure in mmHg, *IBH* - inspiration breath-hold in sec, *SPHS* – self-perceived health status in c.u., *SB* - static balancing on the left leg in sec, *PP* - pulse pressure in mmHg, *BM* - body mass in kg,

The physical development of students was assessed using measurements of body length (cm), body mass (BM, kg), and body mass index (BMI, kg/m²).

Statistical Analysis

The experimental data were statistically processed using the STATISTICA 14.01.25 software package [25]. Various statistical methods were applied, including correlation analysis, regression analysis, and dispersion analysis. We calculated the mean values of the parameters under study, multiple correlation coefficients, coefficients of determination, and performed linear stepwise regressions.

To assess the significance of differences between the recorded indices during the experiment, we computed the Student's t-criterion. Additionally, we employed the Fisher's criterion to evaluate the reliability of correlation, determination, and regression coefficients.

Results

The results of the biological age studies of the first-year students of higher education institutions indicate that it is 17.3-35.5 years ahead of the chronological age. The values of biological age and the difference between the chronological and biological age indicate accelerated rates of aging of 17–18-year-olds (Fig. 1).

Realization of the developed complex methodology in the process of students' education led to the decrease of girls' and boys' BA by the end of the academic year in the experimental groups and its insignificant change in the control ones.

In EG girls, BA decreased from 39.43±0.9 to 35.3±0.09 years (t=3.8 <0.001), whereas *in those of CG*, it remained virtually unchanged and constituted 39.2±1.2 years and 38.97±0.9 years at the beginning and the end of the academic year, respectively.

In EG boys BA decreased from 47.1±0.69 to 45.21±0.65 years by the end of the school year (t=2.0 <0.05), whereas *in CG boys* it decreased from 52.8±0.9 years at the beginning to 51.5±0.8 years (R=0.05) at the end of the year. A slight BA decrease in young men of CG by the end of the experiment indicates a less pronounced than in EG, but positive influence of the generally accepted PE program in higher school on their BA.

Changes of functional state indices. Changes in functional indices during the experiment were most pronounced in EG girls.

Decrease in BA of EG girls by the end of the year by 10.4%, (4.13±1.1 years, t=3.8 <0.001) was accompanied by an increase in their functional capabilities. This was characterized by a 56.3% increase in SB time (t=2.35 <0.05), 13.5% (t=4.98 <0.001) increase in VC, 31.0% increase in right hand strength (t=3. 12 <0.05), 38.2% increase in left hand strength (t=2.80 <0.05), 13.4% increase in inspiration breath-hold time (t=2.19 <0.05), and 37.1% increase in expiration breath-hold time (t=4.59 <0.001).

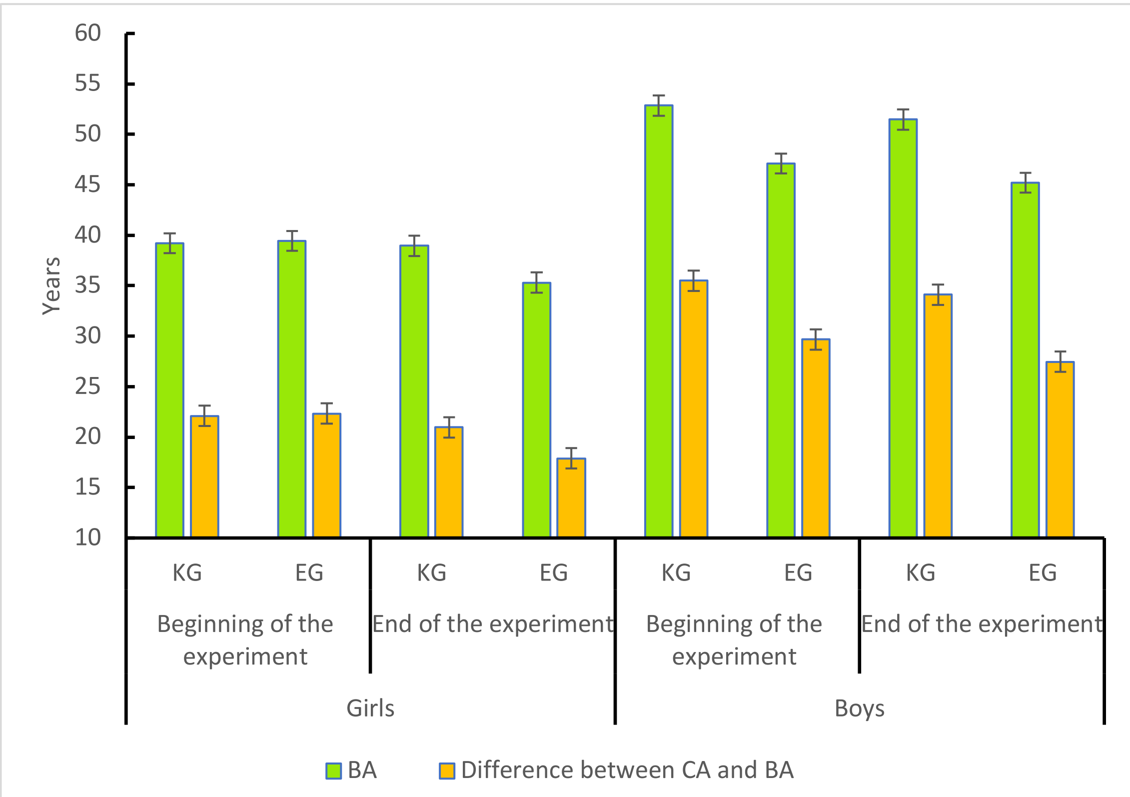

Figure 1. The values of biological age and the difference between the calendar and biological age in students of the experimental and control groups at the beginning and the end of the academic year

At the end of the experiment, the CG girls, with unchanged BA, showed positive changes in functional indices: SB time increased by 48.3% (t=2.6<0.02), the strength of the right hand increased by 26.8% (t=2.72<0.01), and that of the left hand by 31.1% (t=2.90<0.01). In the course of the experiment, some indices (VC, Genchi's test) demonstrated only a tendency to improve.

In EG young men the positive tendency to the improvement of the majority of the studied *functional indices* was observed in the course of the experiment (HR, IBH, EBH, right and left hand strength). Statistically reliable positive changes occurred only in SB indices (t=4.8, p<0.001).

In CG young men, the values of most functional indices practically did not change, and when performing the Genchi's test (EBH) a statistically significant deterioration of the result was observed (t=2.6, p<0.01).

Changes in physical fitness (PF) indices. In the process of the experiment, the greatest changes in students' physical fitness parameters occurred in both experimental groups.

In EG girls along with a decrease in their BA (by 10%) positive changes in PF parameters occurred: the time of 60 m running decreased by 5.2% (p<0.05), the number of pull-ups and sit-ups increased by 64.9 % (p<0.001)and 19.2% (p<0.001), respectively, and the time of shuttle run decreased by 2.8% (p<0.01) (Table 1).

In the CG of girls, changes in the majority of PP indices in the course of the experiment were less pronounced, their shifts showed only a tendency to improvement of the results. Only the indices of strength (sit-ups) and general (500 m running) endurance in the CG improved statistically significantly - by 4.4% (t=2.0, p < 0.05) and 8.7% (t=2.3, p < 0.05), respectively.

If before the experiment the differences in most indices between the girls of the experimental and control groups were statistically insignificant, at the end of the experiment the EG girls had an advantage in all the studied indices (Table 1).

The obtained results confirm the effectiveness of the influence of the developed complex PE methodology both on BA and PF level of female students of the experimental group.

The young men of both groups (EG and CG) had reliable changes in all the studied PF indices (Table 2).

In both groups, the highest increase in the results was in pull-ups - 29.6% (t=3.7, p<0.001) and 30.7% (t=2.97, <0.01) in young men of the CG and EG, respectively.

The least increase in both groups was observed in speed tests: 60 m running and 4 x 9 m shuttle run.

While at the beginning of the study, the differences between the two groups of young men

Table 1. Physical fitness indices of EG (n=30) and CG (n=30) girls at the beginning and the end of the experiment

Girls		Statistic parameters	60 m running, s	500 m running, s	Pull-ups, number	Sit-ups in 30 s, number	Standing long jump, cm	4x9 m shuttle run, s
Experimental group (EG)	Beginning of the experiment (1)	$\bar{x}$	10.68	2.26	11.1	21.9	167.7	10.9
		± m	0.21	0.04	0.67	0.67	2.61	0.12
	End of the experiment (2)	$\bar{x}$	10.13	2.16	18.3	26.1	172.3	10.5
		± m	0.06	0.05	0.87	0.59	2.90	0.09
	t_{1-2}		2.46	2.02	6.55	4.75	1.18	3.96
	p		<0.05	<0.05	<0.001	<0.001	>0.05	<0.001
Control group (CG)	Beginning of the experiment (1)	$\bar{x}$	11.04	2.37	8.6	18.6	162.5	11.4
		± m	0.09	0.06	0.66	0.55	1.74	0.11
	End of the experiment (2)	$\bar{x}$	10.88	2.29	10.0	20.3	164.0	11.3
		± m	0.05	0.04	0.52	0.46	2.04	0.12
	$\mathbf{t_{1-2}}$		1.58	2.00	0.86	2.28	0.56	1.09
	p		>0.05	<0.05	>0.05	<0.05	>0.05	>0.05
t-Student's	Beginning of the experiment	t_{EG-CG}	1.56	1.20	1.71	3.75	1.65	1.65
		p	>0.05	>0.05	>0.05	<0.001	>0.05	>0.05
	End of the experiment	t_{EG-CG}	9.28	2.23	8.03	7.86	-2.33	4.72
		p	<0.001	<0.05	<0.001	<0.001	<0.05	<0.001

Table 2. Physical fitness indices of young men of CG (n=39) and EG (n=40) at the beginning and end of the experiment

Young men		Statistic parameters	60 m running, s	1000 m running, s	Pull-ups, number	Sit-ups in 30 s, number	Standing long jump, cm	4x9 m shuttle run, s
Experimental group (EG)	Beginning of the experiment (1)	X̄	8.84	3.87	8.91	24.7	213.3	9.7
		± m	0.08	0.10	0.70	0.44	2.84	0.10
	End of the experiment (2)	X̄	8.44	3.61	11.64	27.4	239.4	9.2
		± m	0.07	0.06	0.60	0.44	2.43	0.06
	t_{1-2}		3.66	2.22	2.97	4.36	6.97	4.44
	p		<0.01	<0.05	<0.01	<0.01	<0.01	<0.01
Control group (CG)	Beginning of the experiment (1)	X̄	9.04	4.38	7.7	23.5	205.3	9.8
		± m	0.09	0.05	0.44	0.66	3.71	0.10
	End of the experiment (2)	X̄	8.53	3.88	10.0	25.2	228.8	9.5
		± m	0.09	0.06	0.43	0.47	2.88	0.06
	t_{1-2}		4.00	6.46	3.71	2.10	4.99	2.69
	p		<0.01	<0.01	<0.01	<0.05	<0.01	<0.01
t-Student's	Beginning of the experiment	t_{EG-CG}	1.95	4.43	1.43	1.61	1.71	-0.82
		p	<0.05	<0.01	>0.05	>0.05	>0.05	>0.05
	End of the experiment	t_{EG-CG}	-0.76	-3.14	2.19	3.44	2.82	-3.78
		p	>0.05	<0.01	<0.05	<0.01	<0.01	<0.01

in most PF indices were statistically insignificant, at the end of the experiment, the EG boys had an advantage over the CG boys in all of them.

The results point out that boys of both groups (EG and CG) improved their physical condition in all the indices of PF, characterizing general (aerobic) endurance, speed, speed-strength, strength, and coordination qualities.

By the end of the academic year, EG girls increased their physical conditions in speed, strength, and coordination qualities, whereas the CG girls showed positive expressed results only in the indices of strength and general endurance.

In general, the findings demonstrate that the decrease in the BA of girls and boys in the experimental groups was accompanied by more pronounced positive changes in their physical state by the end of the academic year compared to the students of the control groups.

These differences indicate the effectiveness of the experimental program impact on the BA, the level of functional and physical fitness of boys and girls of the EG.

The subsequent analysis was focused on studying the interrelations of BA with the indices of functional state and PF of students during the experiment.

For that purpose, pair and multiple correlation analysis of interrelations between the studied indices and BA was made, linear regression models of BA dependencies on the key indices of functional and physical fitness of students at the beginning and the end of the experiment were calculated.

Table 3 presents pair correlation coefficients reflecting the relationships of BA with individual indices of functional state and self-perceived health status of girls and boys of EG and CG.

The values of correlation coefficients in each of the examined groups of students indicate low correlations of BA with the majority of individual functional indices, both before and after the experiment. Only some correlations are medium and high.

In EG girls, the highest statistically reliable correlations of BA are observed with indices of SBP, VC, SPHS, whereas in CG girls - with those of SBP, SB, VC, SPHS in EG boys the highest reliable correlation of BA are noted with indices of SB, VC, IBH, SPHS, left and right hand strength, whereas in CG boys - with those of SB, VC, IBH, and SPHS (Tab. 3).

Despite the fact that most of these functional indices are used by researchers to calculate BA [26, 3], the low values of pair correlation and determination coefficients prevent revealing the variability mechanisms of most of the BA variance during the experiment.

Table 4 presents the correlations of BA with individual indices of physical fitness of EG and CG boys and girls.

The values of correlation coefficients in each of the examined groups of students indicate low interrelations of BA and the majority of PF individual indices both before and after the experiment. They reflect the low correlation of BA with the level of development of individual motor qualities such as speed, general (aerobic) and strength endurance, explosive strength, and agility.

We made an assumption that, at relatively low pair interrelations with the indices of students' physical state (PS), BA shows a higher dependence on the total influence of a group of individual indices, their intragroup ratio, and interaction.

To verify this assumption, multiple correlation and regression stepwise analysis of BA interrelations with indices of students' functional state and PF was performed.

At first, the interrelations of BA in groups of girls and boys were analyzed without dividing them into EG and CG, and later in each of the studied groups separately (before and at the end of the study).

Table 5 presents regression models of BA dependence on morphofunctional and PF indices of students of different sexes.

The use of the stepwise regression method permitted to select in the model indices with coefficients reflecting the degree of each parameter impact on the subjects' BA at a certain ratio and the influence of other model parameters.

The coefficients of multiple correlation and determination reflect the degree of BA dependence on the cumulative and interacting influence of the indices included in each mathematical model in the process of stepwise regression analysis.

The calculations presented in Table 5 imply that the physical state indices in the regression models determine with a high degree of reliability the BA of boys and girls. In addition, it was revealed that 81.4% ($p<0.0000$) of BA variance in boys is determined mainly by somatic and vegetative parameters of the model ($p<0.0000$), whereas in girls - 82.1% ($p<0.0000$). These values are indicative of the high prognostic significance of regression equations. The partial role of individual indices in the determination of BA is unequal. It is determined by the partial coefficient of each parameter in each regression model.

The calculations show that in young men, of all the parameters of the regression model, vegetative

Table 3. Correlation of BA with separate indices of physical state of girls and boys of EG and CG at the beginning and the end of the experiment

Groups. Conditions			SBP*	DBP	HR	SB	VC	IBH	EBH Fmax right	SPHS Fmax left	Dynamometry Fmax right	Dynamometry Fmax left
Girls	Before the experiment	EG	0.531*	0.179	0.137	-0.248	-0.370*	0.009	0.168	0.410*	-0.391*	-0.282
		CG	0.724*	0.078	-0.037	-0.491*	-0.578*	-0.162	0.339*	0.490*	-0.012	0.009
	After the experiment	EG	0.679*	0.590*	0.265	0.165	-0.086	0.122	0.062	0.470*	0.261	-0.027
		CG	0.651*	0.164	0.345*	-0.530*	-0.757*	-0.143	-0.550*	0.269	0.135	-0.051
Boys	Before the experiment	EG	0.092	-0.172	-0.065	-0.423*	-0.779*	-0.747*	-0.138	0.524*	-0.311	-0.336*
		CG	0.085	-0.136	-0.215	-0.483*	-0.610*	-0.453*	0.018	0.373*	-0.094	-0.149
	After the experiment	EG	0.155	0.061	-0.043	-0.444*	-0.424*	-0.600*	-0.047	0.360*	-0.438*	-0.456*
		CG	0.092	-0.136	-0.215	-0.437*	-0.610*	-0.097	0.016	0.399*	-0.046	-0.068

* Note: statistically reliable correlation coefficients are marked with an asterisk - *.

Table 4. Correlation of BA with physical fitness indices of girls and boys of EG and CG during the experiment

Groups. * Conditions			60 m running	500 m (girls), 1000 m (boys) running	Push-ups (PUs)	Sit-ups in 30 s	Standing long jump	4x9 m shuttle run
Girls	Before the experiment	EG	0.074	-0.291	-0.139	**-0.354**	0.156	-0.167
		CG	-0.079	-0.054	-0.065	0.075	0.075	0.081
	After the experiment	EG	-0.128	0.229	**-0.350**	-0.248	-0.018	-0.063
		CG	-0.216	0.060	0.144	0.026	-0.272	-0.153
Boys	Before the experiment	EG	**0.299**	0.226	**-0.387**	-0.041	-0.200	-0.003
		CG	0.063	0.184	**-0.398**	-0.126	-0.053	0.240
	After the experiment	EG	**0.363**	0.049	-0.171	-0.096	0.017	0.169
		CG	0.104	0.188	**-0.463**	-0.075	-0.037	0.163

* Note: Reliable correlation coefficients are highlighted in bold font

indices produce the greatest impact on BA. Their changes are responsible for 66.0% of the variability of the variance of young men BA ($p<0.0000$). Of the individual vegetative indices, the influence of VC can explain the variability of 51.9% ($p<0.0000$) of BA variance, that of breath hold during Stange's test - 8.4% ($p<0.0000$), that of breath hold during Genchi's test - 0.8% ($p<0.02$), and that of SBP - 4.6% ($p<0.0000$).

The total influence of somatic parameters determines the variability of 10.5 % of the variance of their BA. Of these, the following parameters have a statistically significant impact: SB (8.5%, $p<0.0000$), SU30c (0.9%, $p<0.0000$), left hand muscle strength 0.6% ($p<0.0000$). The indices of self-perceived health status (SPHS – 4.9 %, $p < 0.0000$) also produce a statistically significant effect on BA variability.

The total influence of other parameters of the regression model (right hand muscle strength, Shuttle run, PUs, HR) on the variability of BA variance was insignificant - 0.8% ($p>0.05$).

The vegetative indices have the greatest influence on BA (57.8%, $p<0.0000$) of girls and boys. Of these, 34.5 % ($p<0.0000$) of the BA variance is changed under the impact of VC, and 23.1 % ($p<0.0000$) under that of SBP.

The impact of somatic indices determines the variability of 9.1% of the BA variance of girls, of which statistically significant influence produces the SB index (7.9%, $p<0.0000$). and 15.3% ($p<0.0000$) of the BA variance is determined by the SPHS parameter.

The total effect of the other four parameters of the model (left hand muscle strength, 500 m running, breath-hold during Stange's test, BM) on BA constituted only 1.3% ($p>0.05$).

Table 6 presents regression models of BA dependence on individual morphofunctional indices of girls and boys of the control and experimental

Table 5. Regression models of biological age of girls and boys dependence on morphofunctional and physical fitness indices

Groups	Regression equations*	Coefficients**			
		r	d	F	P
Boys	$Y= (61.26+0.135x_1+0.528x_2+0.102x_3+0.048x_4-0.04x_5-0.115x_6-0.082x_7-0.154x_8-0.101x_9-0.731x_{10}-0.08x_{11}-0.022x_{12})\pm2.76$	0.902	0.814	49.9	<0.00000
Girls	$Y= (16.78+0.249x_1+0.639x_2+0.016x_7+0.036x_{13}-0.004x_5-0.106x_6-0.068x_3-1.01x_{14})\pm2.4$	0.906	0.821	63.8	<0.00000

* where: y – BA, years; x_1 – SBP, mm Hg; x_2 – SPHS; x_3 – DM left, kg; x_4 – Genchi's test, s; x_5 – VC, ml.; x_6 – SB, s; x_7 – Stange's test, s; x_8 – SU30s, number; x_9 – DM right, kg; x_{10} – Shuttle run, s; x_{11} – PUs, number; x_{12} –HR, bt/min; x_{13} – Body mass, kg; x_{14} - 500m running, s ** - correlation coefficient; d – determination coefficient; F - Fisher's coefficient.

Table 6. Mathematical models of dependence of biological age of EG and CG girls and boys on morphofunctional indices

Groups, conditions			Regression models*	Coefficients**			
				r	d	F	P
Girls	Before the experiment	EG	$Y= 25.9+(0.335x_1+0.794x_2-0.004x_3-0.120x_4-0.247x_5-0.116x_6-0.072x_7)\pm2.3$	0.906	0.821	13.3	<0.0000
		CG	$Y= 4.55+(0.372x_1+0.832x_2-0.003x_3-0.106x_4-0.153x_5+0.064x_8+0.02x_9)\pm1.1$	0.990	0.980	156.5	<0.0000
	After the experiment	EG	$Y= (11.15+0.150x_1+0.28x_2-0.05x_4+0.08x_5)\pm2.3$	0.765	0.585	8.8	<0.0001
		CG	$Y= 17.4+(0.341x_1+0.878x_2-0.04x_3-0.112x_4-0.178x_5-0.029x_7)\pm0.8$	0.990	0.980	188.1	<0.0000
Boys	Before the experiment	EG	$Y= 45.5+(0.175x_1+0.645x_2+0.086x_7+0.126x_{10}-0.04x_3-0.125x_4-0.056x_8-0.114x_{11})\pm0.5$	0.997	0.992	551.5	<0.0000
		CG	$Y= 42.9+(0.180x_1+0.782x_2+0.12x_7+0.023x_8-0.004x_3-0.152x_4-0.111x_{11}-0.023x_9)\pm1.5$	0.970	0.942	62.7	<0.0000
	After the experiment	EG	$Y= (66.02-0.1x_{10}-0.002x_7-0.06x_{11})\pm2.8$	0.779	0.606	16.4	<0.0000
		CG	$Y= 42.1+(0.18x_1+0.749x_2-0.13x_6-0.0006x_7)\pm3.3$	0.792	0.627	14.7	<0.0000

* where: y – BA, year; x_1 – SBP, mm Hg; x_2 – SPHS; x_3 – VC, ml; x_4 – SB, s; x_5 – DBP, mm Hg; x_6 – DM right, kg; x_7 – Genchi's test, s; x_8 – Body mass, kg; x_9 – HR, bt/min. x_{10} – Quetelet index, (BM,kg/ height^2); x_{11} – Stange's test; ** - r - correlation coefficient; d – determination coefficient; F - Fisher's coefficient.

Table 7. Regression models of biological age dependence on physical fitness indices in girls and boys of EG and CG

BA Groups, conditions			Regression models *	Coefficients**			
				r	d	F	P
Girls	Before the experiment	EG	$Y= 46.63+(0.758x_1-0241x_2-0.425x_3-4.334x_4)\pm4.1$	0.607	0.368	3.6	<0.02
		CG	$Y= (0.141+0.775x_1+0.08x_7+1.22x_8 -0.106x_3 -0.536x_4)\pm2.6$	0.313	0.099	0.5	>0.05
	After the experiment	EG	$Y= 60.0+(7.32x_4-3.67x_5-0.14x_6)\pm2.97$	0.575	0.254	4.3	<0.01
		CG	$Y= (63.0+5.65x_4+0.29x_6-3.79x_5)\pm5.0$	0.377	0.142	1.4	>0.05
Boys	Before the experiment	EG	$Y= (52.99+2.89x_5-0.25x_6-0.14x_2-0.14x_9)\pm5.4$	0.527	0.277	2.8	<0.03
		CG	$Y= (51.31+0.04x_7-0.66x_6-0.13x_2)\pm5.3$	0.470	0.221	3.3	<0.03
	After the experiment	EG	$Y= (4.1x_5+0.176x_7+0.314x_1-0.1x_9-0.118x_2-0.179x_6-14.4)\pm3.7$	0.635	0.404	3.3	<0.03
		CG	$Y= (30.2+0.22x_1+1.67x_5+1.44x_4+0.2x_6-0.68x_8)\pm5.3$	0.261	0.068	0.5	>0.05

* where: y – BA, years; x1 – Quetelet index, (BM,kg/ height^2); x_2 – DM right, kg; x_3 – SU30s, number; x_4 – 500(1000) m running, min; x_5 – 60m running, s; x_6 – PUs, number; x_7 – Standing long jump, cm; x_8 – Shuttle run, s; x_9 – Height, cm; ** - r - correlation coefficient; d – determination coefficient; F - Fisher's coefficient.

groups at the beginning and the end of the experiment.

Most of the models are characterized by high multiple correlation and determination coefficients, which are indicative of the adequacy and high predictive value of the developed models for each studied group of students.

The degree of BA dependence on the model parameters is slightly higher in CG girls than in EG girls, both before and after the experiment.

High coefficients of multiple correlation and determination are observed in boys of CG and EG before the experiment reflecting a high degree of BA dependence on model parameters in both groups before the experiment: in EG boys 99.2 % ($p<0.0000$) of BA dispersion before the experiment are determined by the impact of model parameters, whereas in those of CG - 94.2 % ($p<0.0000$) (Table 6)

After the experiment, the prediction of male BA according to the model parameters in CG decreased by 31.5 % and constituted 62.7 % ($p<0.0000$), whereas in EG - by 38.7 % and amounted to 60.6 % ($p<0.00001$). This reflects a significant decrease in BA dependence of young men of both groups on the studied morphofunctional indices by the end of the experiment.

The data indicate that the experimental physical education program resulted in the decrease of BA and its dependence on functional indices in boys and girls of EG.

Table 7 presents regression models of BA dependence on physical fitness indices of EG and CG students at the beginning and at the end of the experiment.

The models presented in Table 7 are characterized by average or low multiple correlation and determination coefficients. They indicate a relatively low predictive value of the presented equations in each studied group of students compared to the indices of functional fitness.

At the same time, low multiple correlation coefficients and determination coefficients in the experimental groups of boys and girls are statistically reliable both at the beginning and the end of the study (Table 7). This allows us to explain the variability of a certain part of the BA dispersion by the influence of the PF parameters in the experimental groups of boys and girls.

The coefficients of determination imply that in EG boys 27.7% ($p<0.03$) of the total variance of BA at the beginning of the study and 40.4% ($p<0.03$) at the end are determined by their PF indices.

In the EG of girls 36.8% ($p<0.02$) of the variance of BA at the beginning of the studies and 25.4% ($p<0.01$) at the end are also determined by their PF indices.

In the CG of boys, the influence of FP parameters on BV decreased from 22.1% ($p<0.03$) at the beginning of the studies to 6.8% at the end ($p>0.05$). In the CG of girls, the influence of FP parameters on BP was low and statistically unreliable both at the beginning (9.9%, $p>0.05$) and at the end (14.2%, $p>0.05$) of the study.

In the CG of boys, the impact of PF parameters on BA decreased from 22.1% ($p<0.03$) at the beginning of the study to 6.8% at the end ($p>0.05$). In the CG of girls, the influence of PF parameters on BA was low and statistically unreliable both at the beginning (9.9%, $p>0.05$) and the end (14.2%, $p>0.05$) of the study.

Discussion

Analysis of publications concerning human biological age indicates that most researchers consider it as one of the integral parameters of the human physical state, determined by vegetative, somatic, anthropometric, anthropometric, genetic, and other indices, the level of physical fitness and health [2, 8, 19, 24, 30].

The diversity of factors affecting human BW implies a variety of interrelationships, dependencies, and mechanisms that determine the biological maturity of an individual. This necessitates a complex approach to studying the mechanisms determining the body's BA, aging processes, health status, and life expectancy of an individual.

Despite numerous publications addressing the influence of various factors on BA, most of them do not fully disclose its interrelations with functional characteristics of the human body at different stages of ontogenetic development and in different conditions of life activity, and the key indices and interrelations determining BA are not defined.

The mechanisms of BA interrelations with the parameters of physical development and physical fitness in the process of adaptation to different forms of motor activity by people of different ages and sexes [3, 8], including in the process of long-term adaptation to sports physical loads [5, 31, 32], are understudied.

Increasing the efficiency of complex BA studies is possible on the basis of methodological principles of the system approach in biology [33], according to which human BA should be considered as an integral final result of partial and total influence of separate indices, their ratios, and interrelations in the structure of the individual's FS. The complex and systemic approaches are necessary for increasing the efficiency of studies with the registration of a large number of heterogeneous indices of the human FS structure.

Numerous publications devoted to the problem of biological maturation and aging of an individual present heterogeneous experimental material indicating the increase in BA and accelerated rates of aging of modern youth [2, 7, 34]. According to the researchers' views, one of the main reasons for the increase in BA and aging of modern youth is the insufficient level of their motor activity [4, 8, 19, 35].

Insufficient coverage of the impact of motor activity different forms on BA and its interrelation with FS parameters prompted us to conduct clarifying studies. They were aimed at establishing interrelationships of BA with the indices of functional and physical fitness of 17-18-year-old students in the process of their adaptation to the standard university and experimental programs on physical education.

With this end in view, a PE program was developed and implemented in the experimental group of girls and boys. It is a modification of the experimental program developed by Prisyazhnyuk et al. [7] for 17-18-year-old students of a technical university.

The principles of the system approach in biological research became the methodological basis for the selection of complex methods of registration, processing, and analysis of indices determining human BA [33].

The results of complex studies obtained at the end of the academic year confirmed the effectiveness of the experimental physical education program, as well as the applied methods of mathematical processing.

The experimental program caused a decrease in BA and an increase in the functional capacities and physical fitness of the experimental group students. The influence of the standard university program on the above parameters of control group students was less pronounced.

The application of methods of correlation, regression, and dispersion analysis of research materials allowed us to obtain statistically significant results indicating that the developed motor program through the increase in the level of functional state and physical fitness significantly reduces BA and slows down the aging processes of students' body.

The findings are in agreement with studies demonstrating the positive impact of increased physical activity on BA in young individuals [3, 8, 13, 16, 37]. The new results were also obtained, which are an addition to our previous studies [6, 7], and those of a number of authors who dealt with the problem of interrelations of BA, functional reserves, and health [2, 9].

The obtained results reflect the effectiveness of the experimental physical education program (its volume, content, aerobic orientation) on the functional state, PF, and BA of 17-18-year-old students.

The use of multiple correlation, regression and, variance analysis methods for the processing of research materials allowed us to determine the key indices of functional state and FP, affecting the BA of boys and girls aged 17-18 years old.

Regression models calculated in the process of research reflect approximately equal degrees of BA dependence on indices of functional state and PF of students of different sexes. In boys, 81.4% ($p<0.0000$) of the BA dispersion is determined by the key parameters of their FS, whereas in girls - 82.1% ($p<0.0000$).

At the approximately equal degree of total impact of the key physical state indices on the BA of boys and girls, differences in the influence of both individual and group somatic and vegetative parameters were revealed.

In the process of dispersion analysis, it was revealed that vegetative parameters have the greatest impact on the BA of students of both sexes. The variability of vegetative parameters in the course of the experiment was accompanied by 66.0% ($p<0.0000$) and 57.8% ($p<0.0000$) of the BA variance in boys and girls, respectively. The variability of 10.5% ($p<0.0000$) and 9.1% ($p<0.0000$)

of BA dispersion in boys and girls, respectively is determined by the impact of somatic indices.

The degree of partial influence of some somatovegetative parameters on students' BA was manifested in the share of total dispersion (expressed in percent) determined by each parameter: a) in boys - VC - 51,9 %, SB - 8,5 %, Stange's test - 8,4 %, SPHS - 4,9 %, SBP - 4,6 %, Genchi's test - 0,8 %; b) in girls - VC - 34,5 %, SBP - 23,1 %, SPHS - 15,3 %, SB - 7,9 %.

Under the influence of the developed physical education program, a decrease in BA and an increase in functional abilities occurred in the experimental groups of students. In EG girls the most pronounced decrease in BA and increase in functional abilities by the end of the experiment was observed as compared to other groups. In EG boys a lower decrease in their BA was observed by the end of the experiment as well as only a weakly expressed positive tendency to their functional capacity improvement. In both CG functional abilities and BA changed insignificantly.

The highest positive changes occurred in PF indices in the course of the experiment in students of both experimental groups, as well as young men of the CG.

While before the experiment the differences in the level of PF between the EG and CG students were insignificant, then at the end of the experiment the boys and girls of the experimental groups surpassed the CG students in all indices characterizing their general (aerobic) endurance, speed, speed-strength, strength and coordination capacities.

The decrease of BA in girls (by 4.13 years) and boys (by 1.9 years) of experimental groups by the end of the academic year was accompanied by more pronounced positive changes in their PF in comparison with CG students. In boys of CG, along with a slight decrease in their BA (1.3 years), a statistically significant improvement of PF indices occurred.

In general, the results confirm the effectiveness of the influence of the experimental physical education program on the motor capabilities and BA of 17-18-year-old students.

The novelty of the research results consists in the following: a) the key indices of functional and physical fitness determining the BA of students of different sexes were revealed; b) linear multiple regression models of BA dependence of boys and girls on somatic and functional parameters of their FS structure were developed and analyzed; c) quantitative characteristics of the degree of partial and total influence of the studied indices on BA of boys and girls was given; d) regression equations can be used for modeling, estimation, and prediction of BA of 17-18 years old students of different genders by the key indices of their physical state.

In addition, the novelty of the results of the present study lies in the fact that the influence of a complex experimental physical education program on the level and interrelations of BA, its dependence on the indices of functional and physical fitness was studied for the first time in students aged 17-18 years old in the process of training.

Conclusions

As a result of the conducted studies, the effectiveness of the experimental program of increased motor activity impact on the body of students aged 17-18 years old was confirmed. Implementation of the motor program in the educational process is accompanied by a decrease in BA, an increase in the level of functional and physical fitness of girls and boys of the experimental groups, a decrease in the BA dependence on the parameters of their physical state.

The coefficients of multiple correlations, determinations and parameters of regression equations reflect the variety of mechanisms determining the biological maturity of students, which are based on partial, total, and interacting influence of physical state key parameters on the BA of girls and boys.

Vegetative parameters of the physical state structure produce the highest impact on the decrease of students' BA within a one-year cycle of long-term adaptation to physical loads during the implementation of the experimental program. Somatic and PF parameters cause less influence on the BA of students.

The influence of the key vegetative, somatic, speed, speed-strength, and coordination parameters of the students' physical state structure on the BA was determined by the share of its dispersion (in %), changing under the impact of each of the determinants in the course of the experiment.

The key parameters of students' FS structure, which had the highest influence on BA, include: in boys - VC (determines 51,9 % of BA dispersion), SPHS (15,3 %), SB (8,5 %), IBH (8,4 %), SBP (4,6 %), EBH (0,8 %), SU30s (0,9 %), left hand muscle strength 0,6 %); in females - VC (34,5 % of BA dispersion), SBP (23,1 %), SB (7,9 %).

The multiple regression equations are model characteristics of BA dependence on the functional state and physical fitness of students aged 17-18 years old. They can be used to assess, model, and predict the BA of boys and girls when changing the parameters of their physical state in different conditions of life activity.

Conflict of interests

The authors declare that there is no conflict of interests.

References

1. Sirotin AB, Belozerova LM, Shchepina GM. Motor activity impact on aging of middle-aged men. *Remedial Gymnastics and Sports Medicine*, 2009;6:21–24.
2. Kang YG, Suh E, Lee JW, Kim DW, Cho KH, Bae CY. Biological age as a health index for mortality and major age-related disease incidence in Koreans: National Health Insurance Service - Health screening 11-year follow-up study. *Clin Interv Aging*. 2018;13:429-436. https://doi.org/10.2147/CIA.S157014
3. Prysiazhniuk S, Tolubko V, Oleniev D, Parczevskyy Y, Prontenko K, Griban G, Zhyrnov O. The influence of physical activities on biological age parameters of the first-year female students from the special medical department. *Journal of Physical Education and Sport*, 2018;18(2):561-564. https://doi.org/10.7752/jpes.2018.02081
4. Belozerova LM. Method of determining biological age according to work capacity. *Clinical Gerontology,* 1998;2:34-38. [In Russian].
5. Chainikov PN, Cherkasova VG. Biological age and age changes rate in athletes of playing kinds of sport and untrained persons. *Perm Medical Journal*. 2017;34(1):95-99. https://doi.org/10.17816/pmj34195-99
6. Pryimakov O, Sawczuk M, Tymoshenko O, Mazurok N. Model characteristics of the structure and interrelations of integral parameters of students' physical condition. *Physical Education of Students*, 2023;27(5):279–293. https://doi.org/10.15561/20755279.2023.0508
7. Prysiazhniuk S, Pryimakov O, Iermakov S, Oleniev D, Eider J, Mazurok N. Influence of weekly physical exercises on indicators of biological age of student's youth. *Physical Education of Students,* 2021;25(1):58-66. https://doi.org/10.15561/20755279.2021.0108.
8. Kolokoltsev M, Romanova E, Vorozheikin A, Bocharin I, Karuzin K, Martusevich A, Prikhodov D, Aganov S. The effect of physical activity on biological age and body composition in 18–19-year-old girls. *Journal of Physical Education and Sport,* 2022;22(4):981–987. https://doi.org/10.7752/jpes.2022.04125
9. Kutakova NS, Shushkova TS, Yudina TV. Methodology of assessing the pace of biological aging in hygienic research (literature review). *Vestnik RGMU,* 2013;5:59-63.
10. Razmahova SY, Timofeeva OV, Epp TI. Assessment of the biological age of full-time and part-time students. *Tomsk State University Journal*. 2023;(486): 221–227. https://doi.org/10.17223/15617793/486/24
11. Tzemah-Shahar R, Hochner H, Iktilat K, Agmon M. What can we learn from physical capacity about biological age? A systematic review. *Ageing Research Reviews*. 2022;77: 101609. https://doi.org/10.1016/j.arr.2022.101609
12. Sinkovic F, Novak D, Foretic N, Zemkova E. The Effects of Biological Age on Speed-Explosive Properties in Young Tennis Players. *Journal of Functional Morphology and Kinesiology,* 2023;8(2): 48. https://doi.org/10.3390/jfmk8020048
13. Gallo LA, Gallo TF, Young SL, Moritz KM, Akison LK. The Impact of Isolation Measures Due to COVID-19 on Energy Intake and Physical Activity Levels in Australian University Students. *Nutrients,* 2020;12(6):1865-1879. https://doi.org/10.3390/nu12061865
14. Parsons N, Griffin XL, Achten J, Chesser TJ, Lamb SE, Costa ML. Modelling and estimation of health-related quality of life after hip fracture: A re-analysis of data from a prospective cohort study. *Bone Joint Res*. 2018;7(1):1-5. https://doi.org/10.1302/2046-3758.71.BJR-2017-0199
15. Rebelo-Marques A, De Sousa Lages A, Andrade R, Ribeiro CF, Mota-Pinto A, Carrilho F and Espregueira-Mendes J Aging Hallmarks: The Benefits of Physical Exercise. *Front. Endocrinol*. 2018;9:258. https://doi.org/10.3389/fendo.2018.00258
16. Pavanello, Campisi, Tona, Lin, Iliceto (2019). Exploring epigenetic age in response to intensive relaxing training: a pilot study to slow down biological age. *International Journal of Environmental Research and Public Health,* 2019;16(17): 3074. https://doi.org/10.3390/ijerph16173074
17. Moore SC, Patel AV, Matthews CE, et al. Leisure Time Physical Activity of Moderate to Vigorous Intensity and Mortality: a large pooled cohort analysis. *PLoS Med*. 2012;9(11):e1001335. https://doi.org/10.1371/journal.pmed.1001335
18. Garatachea N, Pareja-Galeano H, Sanchis-Gomar F, Santos-Lozano A, Fiuza-Luces C, Morán M, et al. Exercise Attenuates the Major Hallmarks of Aging. *Rejuvenation Research*. 2015;18(1): 57–89. https://doi.org/10.1089/rej.2014.1623
19. Husted KLS, Fogelstrøm M, Hulst P, Brink-Kjær A, Henneberg KÅ, Sorensen HBD, et al. A Biological Age Model Designed for Health Promotion Interventions: Protocol for an Interdisciplinary Study for Model Development. *JMIR Research Protocols*. 2020;9(10): e19209. https://doi.org/10.2196/19209
20. Zhong X, Lu Y, Gao Q, Nyunt MSZ, Fulop T, Monterola CP, et al. Estimating Biological Age in the Singapore Longitudinal Aging Study. *The Journals of Gerontology: Series A,* 2020;75(10):1913-1920. https://doi.org/10.1093/gerona/glz146
21. Sindeeva LB, Nikolaev VG, Kochetova TF, Kovrigina OA. Component composition of the body as a criteria of biological age. *Siberian Medical Review*. 2015;5:61-65. https://doi.org/10.20333/25000136-2015-5-61-66
22. Prinzinger R. Programmed ageing: the theory of maximal metabolic scope. *European Molecular Biology Organization*, 2005;6:14-19. https://doi.org/10.20333/25000136-2015-5-61-66
23. Munoz-Espin D, Serrano M. Cellular senescence: from physiology to pathology. *Molecular Cell Biology*, 2014;15:482-496. https://doi.org/10.1038/sj.embor.7400425
24. Belsky DW, Moffitt TE, Cohen AA, Corcoran DL, Levine ME, Prinz JA, et al. Eleven Telomere, Epigenetic Clock, and Biomarker-Composite Quantifications of Biological Aging: Do They Measure the Same Thing?

American Journal of Epidemiology. 2017; https://doi.org/10.1093/aje/kwx346
25. Borovikov VP. A popular introduction to modern data analysis in STATISTICA. Methodology and technology of modern data analysis. Moscow: Goryachaya Liniya-Telecom; 2018.
26. Voitenko VP. *Health of the healthy. Introduction to Sanology*. Kyiv: Health; 1991. [In Russian].
27. Rahman SA, Adjeroh DA. Estimating Biological Age from Physical Activity using Deep Learning with 3D CNN. In: Yoo IH, Bi JB, Hu X, editors. Ieee International Conference on Bioinformatics and Biomedicine. *IEEE International Conference on Bioinformatics and Biomedicine–BIBM*, 2019:1100–1103. https://doi.org/10.1109/BIBM47256.2019.8983251
28. World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects. *JAMA*, 2013;310:2191. https://doi.org/10.1001/jama.2013.281053
29. Golyaka SK, Glukhov IG. *Physiological bases of physical culture and sports*. Kherson: Vyshemyrskyi VS, 2019. (In Ukrainian).
30. Sereda I, Lavrin H, Kucher T, Grygus I, Napierała M, Muszkieta R, et al. Effect of yoga exercises on the senior schoolchildren's biological age during physical education. *J Phys Educ Sport*. 2021;21(5):2782–2789. https://doi.org/10.7752/jpes.2021.s5370
31. Ajman H, Tomac Z. Differences in biological age of the best U11 and U13 teams in Croatia. *J Hum Sport Exerc*. 2019;14:2375-2379. https://doi.org/10.14198/jhse.2019.14.Proc5.52
32. Goto H, Morris JG, Nevill ME. Influence of biological maturity on the match performance of 8-to 16-year-old, elite, male, youth soccer players. *J Strength Cond Res*. 2019;33(11):3078-3084. https://doi.org/10.1519/jsc.0000000000002510
33. Sudakov KV. Informational features of functional systems: theoretical aspects. *RAMS Herald*. 1997;12:3-21.
34. Dao Chanh Thuc. The influence of physical activities on biological age parameters of females from 17 to 18 years old. J Sports Med Ther. 2018;3:75-79. https://doi.org/10.29328/journal.jsmt.1001030
35. Bacil E, Mazzardo Junior O, Rech C, Legnani R, Campos W. Physical activity and biological maturation: a systematic review. *Rev Paul Pediatr*. 2015;33(1):114–121. (In Portuguese). https://doi.org/10.1016/j.rpped.2014.11.003
36. Belsky DW, Caspi A, Houts R, Cohen HJ, Corcoran DL, Danese A, Harrington H, Israel S, Levine ME, Schaefer JD, Sugden K, Williams B, Yashin AI, Poulton R, Moffitt TE. Quantification of biological aging in young adults. *Proc Natl Acad Sci USA*. 2015;112(E4):104–110. https://doi.org/10.1073/pnas.1506264112
37. Gumenyuk S, Sereda I, Hulka O, Lavrin H, Ladyka P, Kuz Y. Effect of yoga on biological age indicators of 14-15-year-old girls. *J Phys Educ Sport*. 2021;21(5):2956-2962. https://doi.org/10.7752/jpes.2021.s5392

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Cite this article as:
Pryimakov O, Sawczuk M, Prysiazhniuk S, Mazurok N, Petrachkov O. Interrelations of physical state parameters and biological age of students in the process of physical education. *Physical Education of Students,* 2024;28(1):16–28.
https://doi.org/10.15561/20755279.2024.0102

Received: 25.12.2023

Accepted: 29.01.2024; **Published**: 28.02.2024