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Improvement of students' physical fitness in physical education classes using CrossFit means

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Abstract

Background and Study Aim The purpose of the study is to develop and experimentally substantiate the efficiency of methods to improve the physical fitness (PF) of students in physical education classes using CrossFit means.

Material and Methods The studies were conducted at the University with first-year students and involved 44 students of the control group and 52 students of the experimental group aged 17 to 19 years. Three versions of the experimental program to improve the students' PF in physical education classes using CrossFit means were developed. The students' PF level was determined according to the results of performing the State tests of the Ministry of Education and Science of Ukraine: 100 m running (s), standing long jump (cm), pull-ups and cross bar dips (number); hanging leg raises to the crossbar (number); 1000 m running (min, s); shuttle run 4x9 m and 10x10 m (s); trunk forward bending (cm). The level of students' functional fitness was determined according to the indices of heart rate (HR), blood pressure, time of breath-holding while performing Stange's test, lung vital capacity.

Results In the process of the pedagogical experiment more pronounced positive changes in the indices of physical and functional fitness were observed in students of the experimental group as compared to those of the control group, the functional reserves of the heart and motor system of students increased by the end of the experiment. The efficiency of four-hour classes a week according to the experimental program manifested itself in the increase of strength, strength endurance, speed and agility during a performance of motor tests; a decrease in resting heart rate, an increase of the degree of HR increment under load (relative to the resting level), an increase of HR recovery at the first minute after the load. Mathematical models of interrelations of separate somatic and vegetative parameters in the process of development and improvement of motor skills under the influence of the experimental program of physical education with the use of CrossFit means were developed and specified. Mathematical models reflect mechanisms of increase of functional reserves of heart and motor system of students, their interrelation in the process of improving the results in motor tests under the influence of CrossFit means.

Conclusions The results of the research confirm the higher efficiency of the physical education experimental method with the use of specially developed complexes of CrossFit® physical exercises in comparison with the generally accepted program of the Ministry of Education and Science of Ukraine. The efficiency of the experimental program's impact on the physical state of the students is confirmed by an increase in the level of development of motor qualities, an increase in the economy of the body functioning at rest, an increase in the functional reserves of the heart and the motor system.

Keywords: students, motor qualities, functional state, CrossFit, models.

Introduction

The efficiency of the educational process increases in higher education institutions, the intensification of students' independent work, and an increase in mental stress have acutely raised the question of introducing new means of physical education and sports in the daily life of students. Studies [1, 2, 3, 4] have shown a decrease in the physical health levels of students and graduates of higher education institution. Almost half of the studied students do not meet the average standard of physical fitness, which guarantees stable health [4].

The negative role in reducing the level of physical health, functional state and adaptive capacities of students is played by such factors as hypodynamia and hypokinesia, excessive emotional stress, irrational nutrition, decreased motivation

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to systematic physical activity and other reasons [5, 6, 7, 8]. The improvement of physical education efficiency of students necessitates the solution of several scientific problems associated with the substantiation of more rational forms, means, and methods to optimize physical fitness, work capacity, and health of different population categories [1, 5, 9, 10].

Nowadays, traditional forms of physical exercise sessions are no longer satisfying people to the full extent. That is why, many new, popular and effective forms are emerging. One such modern technology is the high-intensity functional training CrossFit®, founded by Greg Glassman in 2000 [9, 11, 12], which has spread around the world.

Initially, CrossFit was considered an exercise system to improve physical condition, but soon it turned into a “fitness sport”, representing a complex synthesis of several sports events or sports games [9, 12, 13, 14]. CrossFit is a powerful motivation means for high-intensity functional training of young people [15, 16, 17], a means of increasing strength, aerobic and anaerobic capacities [17, 18, 19] and strengthening youth health [13, 14]. Despite a sufficient number of works confirming the effectiveness of the CrossFit® system impact on the body of students [2, 17, 18, 19], the studies of foreign and national (Ukrainian) authors lack a comparison of the efficiency of different youth physical training programs. The published works present scattered information on the impact of CrossFit means upon the components of the physical condition of the trainees - physical development, motor qualities, functional state, and health status [13, 14, 20].

At the same time, not only the specificity but the direction of changes in the key components of physical condition as well are incompletely disclosed in the dynamics of long-term adaptation to CrossFit training [13, 14, 21]. The systemic mechanisms of integration and interaction of physical condition components determining the motor capacities of young people in the process of adaptation to physical loads during the CrossFit® program realization in the dynamics of the learning experiences of physical education have been the least analyzed in the scientific literature [4, 14, 18, 22]. Therefore, a deeper differentiated study and experimental testing of the impact of CrossFit® classes on the physical condition of higher education institution students of different gender, age, and fitness levels is of great current interest.

These unresolved questions reduce the efficiency of control, assessment, management, correction, and prediction of the physical condition, or its individual components in the dynamics of the development of students’ motor capacities [18]. In this regard, the problem of developing effective methods for the improvement of students’ physical fitness (PF) and revealing the mechanisms and principles underlying the improvement of their motor capacities, an increase of functional reserves, and health promotion is quite topical. The solution of this problem would further optimize the learning process of students and increase the efficiency of their professional activities in the future.

The purpose of the study is to develop and experimentally substantiate the efficiency of methods to improve the physical fitness of students in physical education classes using CrossFit® means.

Materials and Methods

Participants

The experiment involved 96 students of the National University of Life and Environmental Sciences of Ukraine aged 17-19 years. All students agreed to participate in the experiment. Study protocol was approved by Ethic Committee of the National University of Life and Environmental Sciences of Ukraine (Kyiv, Ukraine). The research was fulfilled in compliance with WMA Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects [23].

Research Design

We developed a method to improve physical qualities [1] and a targeted program of physical training using the CrossFit® method to increase the effectiveness of the pedagogical process of physical education in higher education institutions. The pedagogical experiment envisaged determining the efficiency of the developed method to improve the motor qualities and functional fitness of students. The boys of the experimental group (EG) had classes according to the experimental method, which included the use of CrossFit® means. The boys of the control group (CG) had practical classes once a week conducted according to the generally accepted program.

Practical classes for the boys of the EG were conducted twice a week (one pair of exercises according to the schedule, and the second – independent sessions under the guidance of the teacher). The main purpose of the former was to adapt the students’ bodies to physical loads and master the correct technique for performing basic exercises. The experimental methods consisted of three variants of CrossFit® workouts.

The first version was conducted in the gym and included jogging, rope skipping, arm flexion and extension in a supine position, sit-ups, squatting, pull-ups, and 10-15 kg barbell bent-over rows. Each exercise was performed for one minute using the circuit training method. *The second version was conducted in the gym* and included jogging, rope skipping, arm flexion and extension in supine position (legs on a gymnastic bench), sit-ups with hands behind the head, 10 kg barbell bent-over rows, 15-20 kg barbell squats, 20-30 kg bench press. Each exercise was performed for 2 minutes. Each student performed this set of exercises in two rounds. After the first round, the students had a two-minute rest, after which the set of exercises was performed again.

The third version was conducted in the stadium and included 400 (800) m jogging, lunges – 10 (15) reps of each leg, throwing 8 kg weights with back to the throwing section – 10 (15) reps, leg raises in the supine position - 30 to 60 repetitions, pull-ups – 8 to 12 repetitions, 24 kg kettlebell shot put – 8-15 repetitions. The number of each exercise repetitions was determined by the students themselves depending on their level of physical fitness. The intensity of classes in the experimental group constituted 60-70% of the maximum allowable HR at the beginning of the academic year. The volume and intensity of physical load increased steadily up to 75-95%. The duration of the training session was 80 minutes, of which 15 minutes were allocated for the CrossFit® physical training program.

Each version of CrossFit® was performed for two months with a gradual increase in the number of rounds depending on the stage of the version execution (from one at the beginning to three at the end of the academic year). The level of physical fitness (PF) of students was determined according to the State tests. The following test exercises were used to determine the level of motor skills development: 100 m (s) running for, standing long jump (cm), pull-ups and cross bar dips (number); leg raises to the bar from the hang position (number); 1000 m (min, s) running; shuttle run 4 x 9 m (s) and 10x10 m; trunk forward-downward bending (cm).

The level of student's functional fitness was determined according to heart rate (HR), blood pressure, breath holding time during the performance of Stange's tests [24] and vital capacity (VC). HR was recorded in different physiological states of the student's body during muscular activity: at rest, during the warm-up, during and after exercise.

Indices of functional fitness were recorded before, during, and at the end of the experiment, those of physical fitness - before and at the end of the experiment.

Statistical Analysis

Data were analysed by using STATISTICA 13.5 software package. During experimental material processing the methods of variation statistics, correlation, regression, and dispersion analysis were used. Mean values of the studied indices (X±m), correlation (r) and determination coefficients (r^2, d) were determined, parameters of regression and dispersion analysis were calculated. In the process of regression and dispersion analysis mathematical models of interrelations of physical fitness and functional state indices of students were developed in the dynamics of the experiment.

Results

Below are presented PF indices of the boys of CG and EG before and after the pedagogical experiment (Table 1).

Table 1. Comparative characteristics of physical fitness indices of the 1st year young men of CG and EG before and after the pedagogical experiment

Conditions		**Physical fitness indices**											
		100 m running, s (Speed)		**1000 m running, min., s (Endurance)**		**Standing long jump, cm (Speed-strength qualities)**		**Pull-ups, number (Strength)**		**4x9 m shuttle running, s (Agility)**		**Standing trunk bending, cm (Flexibility)**	
Groups		EG	CG	EG	CG	EG	CG	EG	CG	EG	CG	EG	CG
n		52	44	52	44	52	44	52	44	52	44	52	44
Before experiment	M	14.0	13.7	3.53	3.56	227.3	221.5	9.8	10.1	9.2	9.5	6.7	5.9
	± m	0.19	0.21	0.11	0.13	1.17	1.75	0.69	0.83	0.05	0.08	0.38	0.47
After experiment	M	13.3	13.4	3.25	3.41	249.4	238.7	12.3	10.9	8.9	9.3	9.1	7.3
	± m	0.12	0.17	0.07	0.15	2.09	2.67	0.46	0.71	0.07	0.12	0.72	0.83
Changes	%	-5	-2.2	-6.8	-4.5	9.7	7.8	25.5	7.9	-3.3	-2.1	35.8	23.7
t Student's		3.11	1.11	2.15	0.76	9.23	5.39	3.01	0.73	3.49	1.39	3.30	2.02
P		< 0.001	> 0.01	< 0.01	> 0.05	< 0.001	< 0.001	< 0.001	> 0.05	< 0.001	< 0.05	< 0.001	< 0.05

Note: The values are expressed as mean (M), standard error (±m), experimental group (EG), control group (CG).

The analysis of the experimental data revealed that by the end of the academic year, the classes with the use of CrossFit® means contributed to the improvement of the PF level of the EG students. Statistically significant positive changes were observed in all PF indices (Table 1).

The most pronounced positive changes in the EG students occurred in the results of 100 m running, long jump, pull-ups, standing trunk bending, and 4x9 m shuttle running. This is confirmed by the difference between the indices and the level of statistical significance ($p<0.001$).

In students of the CG, statistically significant positive changes occurred in the results of standing long jump ($p<0.001$), 4x9 m shuttle running, and standing trunk bending ($p<0.05$). However, these changes in the PF indices were less pronounced in the boys of CG than in those of EG.

Only a tendency to the improvement of the results in 100 and 1000 m running and pull-ups was noted in the CG students by the end of the experiment (Table 1).

In general, the changes in the studied PF indices of students in the course of the experiment indicate that the influence of the traditional university program of physical education on the body of CG students is less efficient than that of the experimental program on the body of EG students.

Below is presented the analysis of materials of research on the functional fitness of CG and EG young men (Table 2) during the academic year (before and after the experiment).

Changes in functional indices as well as those of PF indicate that the experimental program is more effective than the generally accepted university program of physical education.

The experimental program significantly improved the functional state of the body of the EG students by the end of the academic year. The most pronounced changes occurred in such physiological indices as HR, VC, breath holding time during the Stange's and Genche's tests. The CG students, on the other hand, showed only a tendency to their functional state improvement.

It is characteristic that blood pressure indices changed insignificantly in both groups.

In general, the impact of the experimental program on the physical state of the EG students turned out to be more effective than the influence of the generally accepted program on the CG students.

Further analysis was aimed at determining the specifics of interrelations between functional indices and the level of development of individual motor qualities in the process of their improvement during the implementation of the CrossFit® program.

To that end, the changes of HR in different physiological states during muscular activity and its interrelation with the level of individual motor qualities manifestation in the beginning and at the end of the experiment were analyzed in some of the CG subjects.

Figure 1 shows changes in resting heart rate, during the warm-up, during the main part of the CrossFit® session, and in the recovery period after exercise in the dynamics of the pedagogical experiment (Fig. 1).

The changes in heart rate shown in Figure1 reflect its statistically significant decrease in each part of the session under the influence of the experimental program. This indicates the efficiency of the CrossFit® program impact on the functional state of students' cardiovascular systems.

Table 2. Comparative characteristics of functional fitness indices of the 1st year students of CG and EG before and after the pedagogical experiment

Indices of body system functional activity	Initial indices	Groups	n	Before experiment	After experiment	Changes	P
				M ± m	M ± m	%	
Systolic blood pressure, mm Hg.	111.6 ±1.37	EG	52	113.0±3.43	113.8±3.34	-0.7	> 0.05
		CG	44	118.3±4.13	121.2±3.51	-2.5	> 0.05
Diastolic blood pressure, mm Hg	69.5±0.80	EG	52	70.7±2.20	71.5±2.52	-1.1	> 0.05
		CG	44	71.6±2.10	73.0±2.14	-2.0	> 0.05
Heart rate bt/min	77.6 ±1.05	EG	52	83.5±2.31	76.2±2.73	8.7	< 0.01
		CG	44	82.7±2.38	80.5±2.30	2.7	> 0.05
Vital capacity, ml	3377.0±87.2	EG	52	3260.7±119.3	3571.4±89.5	-9.5	< 0.01
		CG	44	3312.5±134.9	3004.2±129.5	9.3	> 0.05
Stange's test, s	57.3±2.36	EG	52	55.6±4.09	69.9±3.54	-25.7	< 0.01
		CG	44	52.6±4.19	48.4±3.82	8.0	> 0.05
Genche's test, s	38.8±1.62	EG	52	37.7±3.04	44.1±2.74	-17.0	< 0.05
		CG	44	35.8±4.22	34.7±2.56	3.1	> 0.05

To clarify the adaptive mechanisms underlying the increase in PF level of the subjects during CrossFit® training, the correlations of HR with the level of developing individual motor qualities during the experiment were analyzed (Fig. 2).

Figure 2 shows correlation coefficients reflecting the interrelations of students' PF parameters with HR recorded before, during, and in the recovery period after physical loads (Fig. 2).

Values of paired correlation coefficients and their direction reflect a different degree of HR interrelations during different physiological states with PF indices of students in the process of the experiment.

Statistically significant pair correlations served as the basis for further graphical, regression, and variance analysis of the identified interrelations. The purpose of this analysis is to examine the physiological mechanisms providing the development and improvement of motor qualities

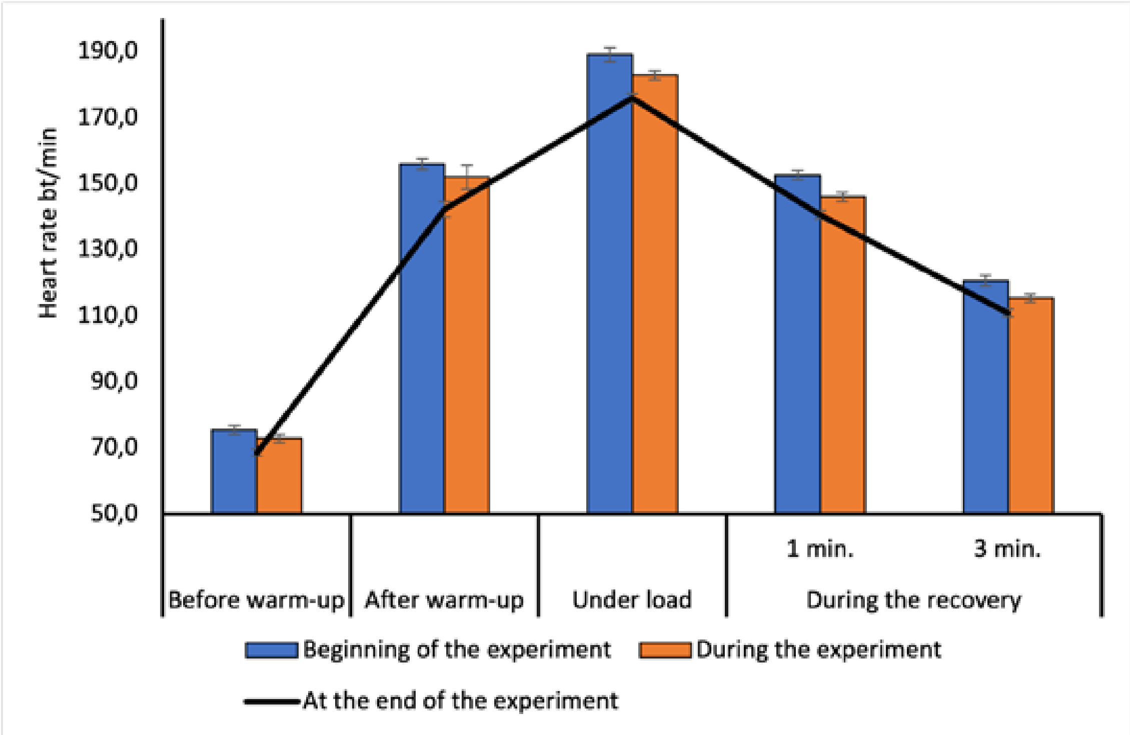

Figure 1. Changes of HR in different physiological states during muscular activity – at the beginning, during, and at the end of the experiment

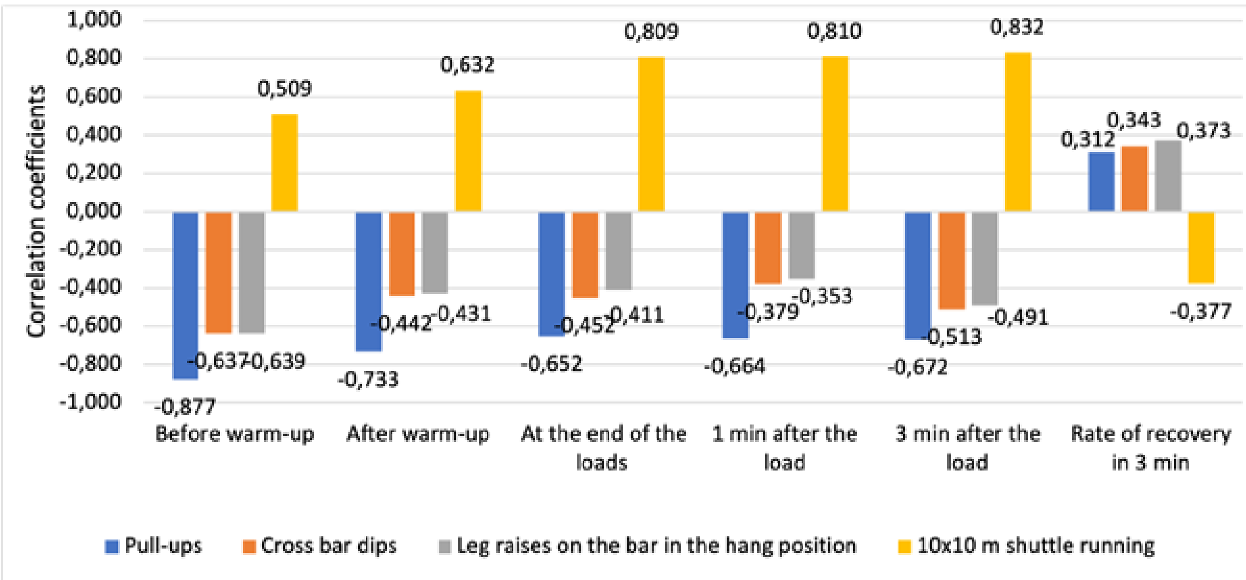

Figure 2. Interrelations of physical fitness parameters of students with HR recorded before, during and in the recovery period after physical load. Note: statistically significant correlations r⩾0.377.

(MQs) during CrossFit® training.

The results of the graphical and regression analysis presented in Figure 3 demonstrate that a decrease in resting HR during the experiment is accompanied by an increase in the degree of its increment (Fig. 3a), a decrease of its maximum values during CrossFit® physical loads (Fig. 3b), and an increase in the number of pull-ups (Fig. 3c).

An increase in resting heart rate, on the other hand, is accompanied by a decrease in the degree of its increment under loads (Fig. 3a), an increase in its maximum values (Fig. 3b), and a decrease in the number of pull-ups (Fig. 3c).

It is characteristic that an increase in HR increment during exercise in relation to resting heart rate is accompanied by an increase in the number of pull-ups (Fig. 3d).

Changes and correlations of the studied indices indicate that the result in the motor test depends both on the value of HR at rest, and the degree of its increment under load in relation to the HR recorded before physical load.

The analysis of variance showed that the 4-hour physical education program implemented in the EG is the key factor changing both resting heart rate values and its increment during the experiment (Fig.4a). The average HR values grouped according to the experiment stages in Figure 4a, reflect a linear decrease in resting HR and an increase of its increment under loads in the dynamics of the experiment.

It was found that the resting heart rate decreased under the influence of the CrossFit program. The coefficient of determination (d = 0.691 F=29.6; p < 0.00001) indicates that 69.1% of the total variability of resting HR is due to the influence of the experimental program (Fig. 4a). 37.5% of resting HR variability is determined by factors not accounted for in this experiment.

40.6% of the total variation of HR increment under load was due to the direct impact of the CrossFit® program used (d=0.406; F=7.18; p=0.002).

Analysis of variance revealed that the increase in HR increment under load also depends on the initial values of resting HR: the lower the resting HR, the greater its increment during exercise and vice versa (r=-0.712, p<0.001) (Fig. 4b). The sample coefficient of determination (d=0.506. F=20.0, p=.00000) indicates that 50.6% of the total variation of HR increment during exercise is determined by

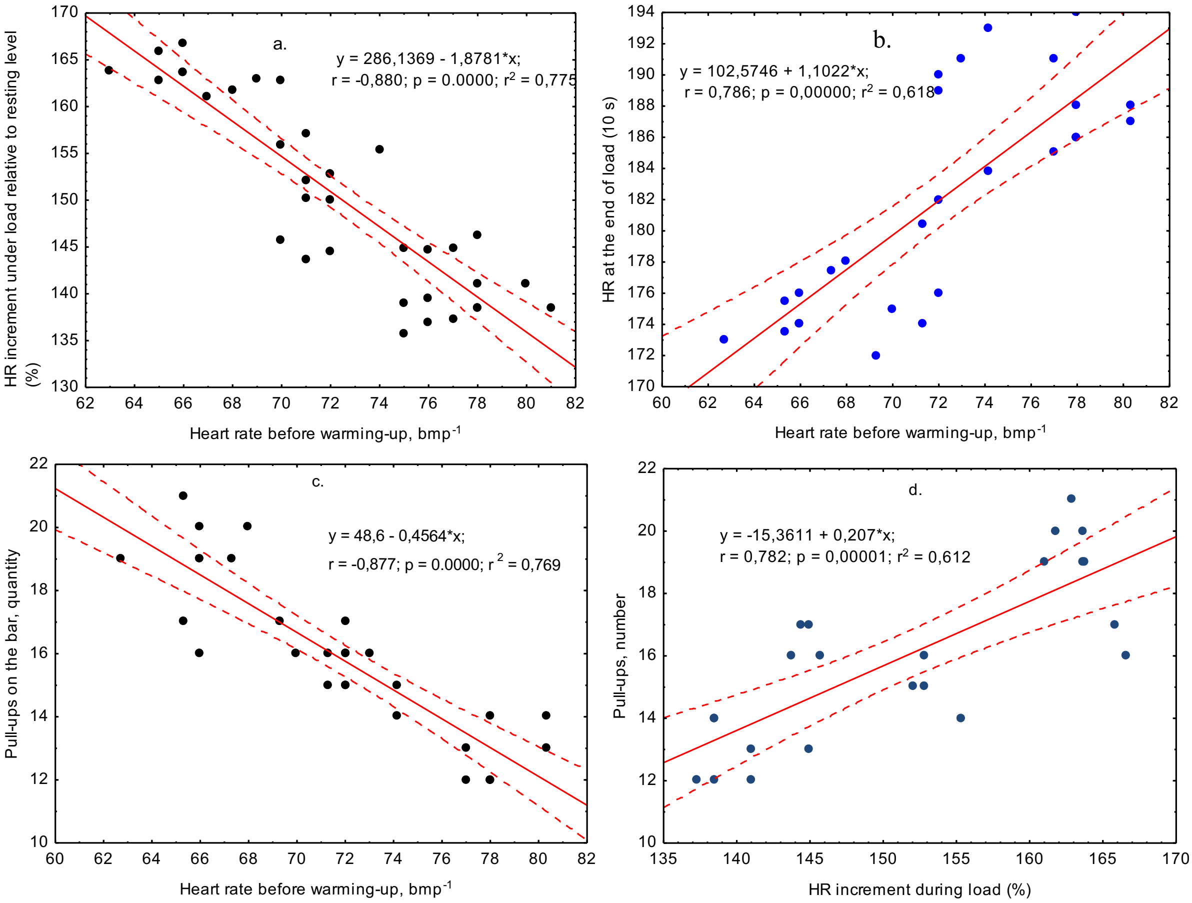

Figure 3. Correlations of HR in different states during muscular activity with each other and the number of pull-ups.

the influence of resting HR.

It is noteworthy that the rate of HR recovery increased at the first minute after load under the influence of the experimental program (Fig. 4c). The impact of the CrossFit® program can explain the variability of only 40.6% of the total variance in HR rate recovery after load (d = 0.406; F=12.6, p=0.00007).

The revealed dependencies indicate that the experimental program influences the HR increment both directly, through activation of motor-cardiac reflexes during exercise, and through enhancement of vagus nerve tone, which slows the heart performance and economizes body functions at rest. This reflects one of the mechanisms of increasing the functional reserves of the cardiovascular system.

The following step-by-step regression analysis allowed determining the key (out of the recorded) functional parameters and their interrelations, which to the greatest extent determine the PF of the subjects during the execution of individual motor tests.

Mathematical models of the result in motor test dependence on the HR values recorded in different physiological states of students' bodies during muscular activity are presented in Table 3.

Equation 1 (Y_1), presented in Table 2, shows that the strength training of students, assessed by the maximum number of pull-ups manifests dependence on the degree of HR increment during physical activity and the value of maximum HR under the load.

Analysis of the variance of this model parameters demonstrated that 79.8% of the total variation of the number of pull-ups is associated with the degree of HR increment (in %) and the value of HR maximum during exercise (F = 51.7, p<0.00001).

However, the effect of each of these parameters on the result in the motor test tends to manifest differently.

An increase in HR increment during exercise, relative to the resting state, contributes to an increase in the number of pull-ups (r = 0.782, p = 0.00001). 61.2% of the total variance of the number of pull-ups was determined by HR increment during exercise (d = 0.612, p = 0.00001).

Modeling with Equation 1 showed that a 2% increase in HR increment during exercise at its steady maximal values was accompanied by a 3.10.05 increase in the number of pull-ups (t=4.7, p<0.001), whereas a 2% increase in HR maximal during exercise at its stability at rest was accompanied by

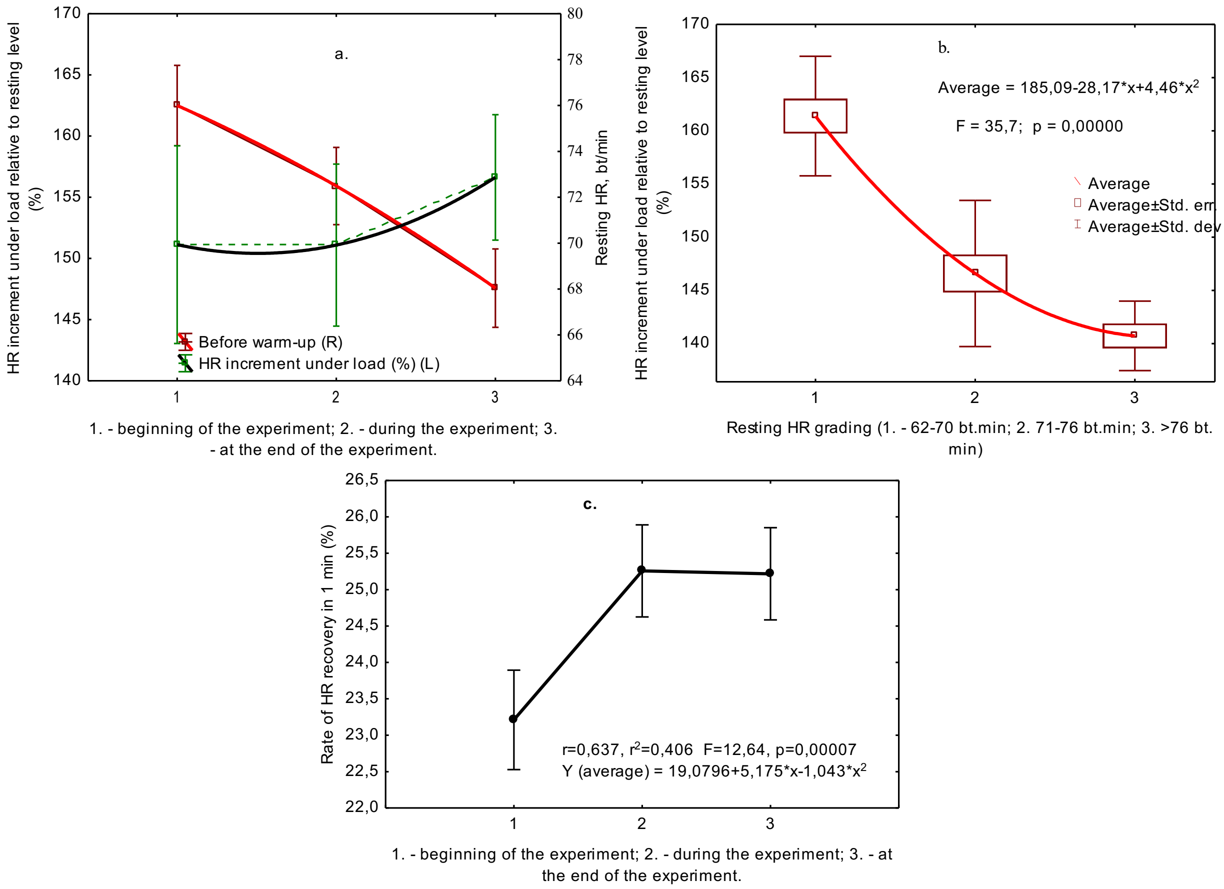

Figure 4. Analysis of variance of HR variation at rest and during muscular activity in the dynamics of the pedagogical experiment.

Table 3. Mathematical models of the result in motor test dependence on the HR values recorded in different physiological states of the body during muscular activity

№	Regression models	Determination coefficient, P
1.	Y_1= (33.71+0.137$\mathbf{x}_1$–0.214$\mathbf{x}_2$)±1.26	F=45.3, r = 0.893, d = 0.798, p < 0.0001
2.	Y_2= (61.8–0.6053 x_3)±3.74	F=17.7, r=-0.637, d=0.405, p<0.0003
3.	Y_3 = (62.1–0.6178x_4)±3.43	r = -0.685, p = 0.00002, d = 0.469
4.	Y_4 = (0.1747x_5 + 0.0766$\mathbf{x}_6$ – 10.195)±0.9	r= 0.842, d= 0.709, F=29.2 p<.00000

Notes: Y1 - maximal number of pull-ups; x1 – HR increment (%) under load, %; x2 - maximal values of HR under load; Y2 - number of cross bar dips; x3 - HR before warm-up; Y3 - leg raises on the bar in the hang position, x4 - HR before the warm-up. Y4 - 10 x 10 shuttle running, sec; - x5 - HR at the end of load; x6 - % of HR under-recovery in 3 min.

a 3.60.03 decrease in the number of pull-ups (t=5.6, p<0.001).

Equation 2 (Y_2) presented in Table 2 reflects the dependence of the number of cross bar dips on the value of pulse recorded at rest.

Parameters of this model show that the lower the pulse at rest (before the warm-up), the greater the number of dips the subject performs. However, only 40,5% of the total variation of the result during the execution of dips is due to the influence of resting HR (d=0,405, F = 17,7, p<0.0003). The remaining 59.5% of variations of dips are determined by the impact of factors not taken into account in this regression model.

Regression model 3 (Y_3), presented in Table 2 (Y3), reflects the dependence of the result in maximal leg raises in the hang position on resting HR.

Parameters of this model are indicative that the higher the resting HR (before the warm-up), the lower the strength endurance of the subjects, and vice versa - the lower the resting HR, the higher the number of performed movements (r = -0.685, p = 0.00002).

The dependence reflected in this model indicates that only 46.9% of variations in the strength endurance index (d=0.469; F = 22.05, p<0.0003) are due to a decrease in resting HR by the end of the experiment. The remaining 53.1% of strength test values were determined by other factors.

Equation 4 (Table 2, Y_4) reflects manifested in the experiment dependence of shuttle run result on HR at the end of the exercise during CrossFit® training and the degree of HR under-recovery (in %) within 3 minutes after load. The parameters of this model show that the higher the increase in HR during CrossFit® sessions and the greater the degree of HR under-recovery at the third minute after load, the greater the time of performing a shuttle run (r= 0.842 d= 0.709, F=29.2, p<.00000) and vice versa. That is, the worse the result in the coordination test used to assess agility. The impact of these two factors, which are physiological markers of the functional fitness of the students' bodies, is responsible for the variability of 70.9% of the total variance of the result in shuttle running (d= 0.709, F=29.2 p<.00000).

Discussion

The research materials presented in this article are a continuation of our earlier studies on the impact of PE means, CrossFit including, on the physical state of students [1, 18].

Part of our findings confirm the results of the studies of foreign and Ukrainian authors, who dealt with this problem, and part is completely new and complements them.

In particular, the positive impact of physical education classes using CrossFit® means on the functional fitness of students [13, 14, 20], the level of development of motor qualities [4, 14, 17], and physical work capacity has been confirmed [19, 21].

As a result of the implementation of our experimental program (using CrossFit® means), a positive impact of 4 hours per week of educational and specially organized physical education classes was revealed.

The results of studies in the CG are indicative that 2 hours of physical education classes per week, envisaged by the curriculum in higher education institutions of Ukraine, cause significantly less positive changes. They also fail to stimulate students' motivation to increase the level of PF and health promotion [3, 4, 6, 25].

More pronounced positive changes in the indices of functional and physical fitness occurred in the EG as compared to CG during the experiment.

The efficiency of four-hour classes a week according to the experimental program was manifested in the decrease of resting HR, the increase in HR increment under the load (in relation to the resting level), the increase in the rate of HR recovery in the first minute after the load, and the improvement of results in motor tests of the EG students.

The increase in the results in individual motor tests obtained in the course of the experiment reflects both an increase in the level of development of individual motor qualities (dynamic and explosive strength, speed, strength and general endurance, agility, flexibility), and an improvement of individual forms of physical work capacity manifestation: strength – pull-ups and dips to exhaustion; general (aerobic-anaerobic) - 1000 m running.

The revealed changes indicate the improvement of physical and functional fitness levels, an increase of heart functional reserves, and the motor system of students in the course of the experimental program realization.

Correlation and determination coefficients, developed regression models reflect both the specifics of interrelation between cardiovascular and motor systems, and mechanisms of improvement of students' functional reserves ensuring improvement of results during the performance of motor tests under the influence of CrossFit® means.

The experimental material analysis showed that the main mechanism of *HR increment increase* during exercise at relative stability of its maximum values is the decrease in resting HR by the end of the experiment. This is also evidence of an increase in the economy of the body functioning as one of the criteria for improving functional reserves in the process of EG students' adaptation to experimental program loads [18].

The phenomenon of resting HR decrease can be considered as one of the mechanisms for increasing the functional reserves of the cardiovascular system, which contributes to a greater HR increment, as well as the strength endurance increase during the execution of pull-ups and dips.

The novelty of the materials obtained in the process of research consists of clarification, specification and supplement of the results of studies both our earlier ones [1, 18, 22], and those of Ukrainian [3, 4, 26, 27] and foreign [13, 14, 20] authors.

In particular, the advantage of the influence of circuit training, its specificity, and the number of classes per week on the development of motor qualities and functional state of students was substantiated in the process of pedagogical experiment.

The novelty of the performed work also includes the development and refinement of mathematical models specifying mechanisms of interaction of somatic and vegetative systems in the process of development and improvement of aerobic-anaerobic endurance (1000 m running), speed (100 m running), dynamic (pull-ups) and explosive (standing long jumps) power, agility (shuttle running), and flexibility.

Presented models are the basis for the development of a system of physical fitness evaluation and prediction, differentiated according to various criteria (training period, a functional state during muscular activity, etc.). However, this requires additional clarifying studies.

The CrossFit method allows optimizing the training process in accordance with the main objective of the training period or stage. It can also provide optimal load dynamics, expedient combinations of various means and methods of training. In addition, it enables to comply with pedagogical effect factors and to achieve the necessary continuity in the development of various abilities.

Conclusions

The results of the studies confirm the higher efficiency of the experimental method of physical education using specially designed complexes of CrossFit® physical exercises in comparison with the generally accepted program of the Ministry of Education and Science of Ukraine.

The CrossFit® method of circuit training increases the motor and emotional density of classes, makes them more diverse and effective for students, improves their functional state and physical fitness, and enhances the functional reserves of the heart and motor system.

The efficiency of the experimental physical education program using CrossFit® means is confirmed by: a) improved strength, strength endurance, speed, and agility during motor test execution; b) decreased resting HR; c) increased degree of HR increment during exercise (relative to the resting level); d) increased rate of HR recovery in the first minute after physical load.

The revealed dependencies between the indices of functional state and physical fitness of students show that the lower the resting HR, the higher its increment under the load, and the higher the recovery rate in the first minute after the load, the higher the result in motor tests and the level of development of physical qualities. These shifts are the criteria of students' functional fitness.

The developed mathematical and graphical models, formalizing the role, correlation, and interrelation of the key physical fitness indices, reflect the mechanisms of improving the economy of functioning and increasing the body functional reserves in the process of adaptation to the means of the experimental program. The developed models can be used for designing estimation scales of the students' physical state and predicting the level of their physical fitness in the process of physical education classes using CrossFit® means.

HR in different physiological states during muscular activity is one of the most accessible and informative biological markers of students' functional fitness during PE classes.

Conflict of interests

The authors declare that there is no conflict of interests.

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