FACTORS AND LEVEL OF PHYSICAL PERFORMANCE OF SCHOOLCHILDREN AGED 13–14 YEARS

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ABSTRACT

There is an insufficiency of data on the characteristics of physical performance of schoolchildren in the critical period of ontogenesis associated with pubertal development.
The aim of the study. *To determine the factors and level of physical performance of schoolchildren aged 13–14 years, taking into account pubertal development.*
Methodology. *The study involved healthy male adolescents aged 13–14 years (n = 165). Five stages of puberty were determined. To diagnose the level of physical performance, a complex of functional and ergometric tests and a battery of motor tests were used. The structure of performance was determined based on the factor analysis.*
Results and discussion. *We determined the factors characterizing physical performance: aerobic capacity; absolute aerobic power; anaerobic alactic performance; anaerobic glycolytic performance; relative aerobic power. The identified factors are associated with zones of relative power. It has been established that during puberty, changes in indicators combined into different factors occur non-linearly and non-simultaneously. The results of the study show that subjects of the same age with stages II, III and IV of puberty differ in the level of key bioenergetic performance criteria. Transition to higher stages of puberty is accompanied with progressive dynamics of most indicators associated with factors of anaerobic performance, while indicators of aerobic power and capacity change in different directions, showing in some cases a tendency to temporarily decrease.*
Conclusion. *It is advisable to use the results of the study when organizing various types of monitoring the functional state and regulation of aerobic and anaerobic physical activity in adolescents aged 13–14 years at different stages of puberty. The obtained materials can serve as a scientific basis for improving the physical education system in order to increase the functional capabilities of children's bodies during the critical period of ontogenesis associated with pubertal development.*

Key words: *factor analysis, physical performance and muscle energy, stages of puberty, adolescent boys*

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ФАКТОРЫ И УРОВЕНЬ ФИЗИЧЕСКОЙ РАБОТОСПОСОБНОСТИ ШКОЛЬНИКОВ 13–14 ЛЕТ

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РЕЗЮМЕ

Существует недостаток данных об особенностях физической работоспособности школьников в критический период онтогенеза, связанный с процессом полового созревания.

Цель исследования. *Выявить факторы и уровень физической работоспособности школьников 13–14 лет с учётом полового созревания.*

Методика. *В исследовании приняли участие здоровые подростки мужского пола 13–14 лет (n = 165). Определяли пять стадий полового созревания. Для диагностики уровня физической работоспособности использовали комплекс функциональных и эргометрических проб и батарею моторных тестов. Структуру работоспособности определяли на основе факторного анализа.*

Результаты и обсуждение. *Идентифицированы факторы, характеризующие физическую работоспособность: аэробная ёмкость; абсолютная аэробная мощность; анаэробная алактатная работоспособность; анаэробная гликолитическая работоспособность; относительная аэробная мощность. Выделенные факторы ассоциируются с зонами относительной мощности. Установлено, что в процессе полового созревания изменения показателей, объединённых в разные факторы, происходят нелинейно и неодновременно. Результаты исследования показывают, что испытуемые одного возраста со II, III и IV стадиями полового созревания отличаются по уровню ключевых биоэнергетических критериев работоспособности. С переходом на более высокие стадии полового созревания наблюдается прогрессивная динамика большинства показателей, связанных с факторами анаэробной работоспособности, тогда как показатели аэробной мощности и ёмкости изменяются разнонаправленно, проявляя в отдельных случаях тенденцию к временному снижению.*

Заключение. *Результаты исследования целесообразно использовать при организации различных видов контроля функционального состояния и нормирования физических нагрузок аэробной и анаэробной направленности у подростков 13–14 лет с разными стадиями полового созревания. Полученные материалы могут служить естественнонаучным основанием для совершенствования системы физического воспитания в целях повышения функциональных возможностей организма детей в критический период онтогенеза, связанный с процессом полового созревания.*

Ключевые слова: *факторный анализ, физическая работоспособность и мышечная энергетика, стадии полового созревания, мальчики-подростки*

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BACKGROUND

Physical performance is a reliable indicator of the functional state of a person, reflecting the level of his health, physiological and mental reserves of the body, efficiency, power and capacity of energy sources, the degree of adaptation to intensive muscular activity. Identification of patterns of formation of the muscular energy system and human performance during ontogenesis is one of the most important tasks of sports and age physiology, preventive medicine, health-improving physical culture, theory and methods of youth sports. This is largely determined by the fact that the transformation of individual elements of this system in the process of development occurs heterochronically and unevenly, determining the specificity of the body's adaptation to physical work of aerobic and anaerobic orientation [1-4]. Of particular importance is information about the state of muscular energy and human performance during the critical period of ontogenesis associated with the process of puberty. During puberty the activity of the hypothalamic-pituitary system, which mediates the restructuring of the functioning of the endocrine glands and key physiological systems, changes significantly [5–8].

Today, the question of the factors determining the physical performance of adolescents during puberty remains open. These factors are generally considered to be relatively independent aspects of performance, reflecting the activity of various functional systems integrated into the dominant functional system responsible for the implementation of muscular activity [9, 10]. To a large extent, this is due to the fact that during puberty, there are significant transformations in the mechanisms of energy supply for muscle activity [2, 4], which cannot but affect the change in the number and composition of factors characterizing physical performance, the boundaries of various power zones, the ratios of the development levels of aerobic and anaerobic capabilities and motor fitness. In this regard, there is a need to identify the factor structure and level of physical performance of adolescents, as well as to determine valid indicators for its assessment during puberty.

It is well known that during puberty, the functional state and reserve capacities of the body are determined not only by the passport age, but also by the biological age of children [5, 2, 4, 11]. At this stage of development, significant differences in the level of sexual maturity are observed among adolescents of the same passport age [12, 13], which must be taken into account when diagnosing the functional capabilities of the body, standardizing aerobic and anaerobic loads, and choosing adequate physical activity regimens.

THE AIM OF THE STUDY

To determine the factors and level of physical performance of schoolchildren aged 13–14 years, taking into account pubertal development.

METHODS

The study involved 13–14-year-old male adolescents who did not attend sports clubs (n = 165; average age 13.5 ± 0.03 years). The study was carried out in accordance with the principles of the World Medical Association Declaration of Helsinki and was approved by the Ethics Committee of the Institute of Child Development, Health and Adaptation (Protocol No. 1 dated February 02, 2023).

The study was conducted at an air temperature of 18–24°C, several hours after eating. The room where the testing was carried out provided conditions for providing emergency and first medical aid. A doctor with extensive experience in carrying out this type of functional research participated in the work. Exclusion criteria for testing physical performance were: acute illnesses 2 weeks before the start of the study; signs of acute respiratory infection at the time of examination. The study was conducted only on healthy adolescents with no medical contraindications for physical education and sports, on days of optimal performance between 9:00 and 12:00 a.m.

The factors of physical performance and informative indicators suitable for its diagnostics were determined. In adolescents with different stages of puberty, the values of informative indicators of physical condition characterizing each of the identified factors were compared.

The study used a heterogeneous battery of ergometric and functional tests that comprehensively assessed physical performance [10]. The maximum oxygen consumption (VO_2max) according to Dobeln, watt-pulse (WP), physical working capacity at a pulse of 170 beats/min (PWC_{170}), maximum strength (MS), pulse debt accumulation intensity (PDAI) and time for performing bicycle ergometric loads "to failure" of 3 and 5 W/kg were determined. Using the Muller equation, individual constants characterizing the capacity of the aerobic (b) source and the degree of heterogeneity of the working skeletal muscles (a), indicators of the work power with the retention time of 1, 40, 240 and 900 s (W_1, W_{40}, W_{240} and W_{900}) were found [2, 14].

The testing model assumed the use of bicycle ergometer loads. To calculate the parameters of the Mueller equation, two loads "to failure" of 3.0 and 5.0 W/kg were performed, VO_2max – one "standard" load of 2.5 W/kg body weight for 5 min, PWC_{170} - a load of increasing power with rest intervals. The load steps were 1.5, 2.5 and 3.5 W/kg body weight. The duration of work at each step was 5 min; the rest interval between steps was 3 min. The first two stages of work were implemented by all subjects. If the heart rate (HR) after the second stage of work did not reach 150 beats/min, the third stage was performed with a power of 2.5–3.5 W/kg [15]. Heart rate was recorded using a Polar heart rate monitor (Polar Electro, Finland). The interval between two tests for maintaining loads "to failure" was 7 days, in all other cases – 2 days. The pedaling speed was constant and amounted to 60 rpm. As a criterion for "failure to perform the work" a decrease in the pedaling frequency by more than 10% was considered. During the testing of adolescents' performance, no significant clinical signs indicating the need to stop work were detected, supporting the idea that the assessment of physical performance of adolescents through strenuous physical exercise is a safe procedure if precautions are taken [2, 15].

The battery of control exercises included: 6-minute run; 4 × 9 m shuttle run; 20 m standing start; standing long jump, torso lifting from a supine position in 1 min; forward bend. The overall physical fitness score (OPFS) was calculated by summing the points obtained for completing each motor test [10].

According to the method of D.V. Kolesov and N.B. Selverova, 5 stages of puberty were determined. All stages of puberty were identified in the sample under examination (stage I – 4 schoolchildren; stage II – 63 schoolchildren; stage III – 58 schoolchildren; stage IV – 37 schoolchildren; stage V – 3 schoolchildren). However, the results of testing adolescents with stage I and stage V were not analyzed due to their small number. It was found that the groups of adolescents with different stages of puberty did not statistically significantly differ in passport age.

Statistical data processing was performed using the Statistica software package (StatSoft Inc., USA). Factor analysis as the principal component method was used to study the structure of physical performance. The possibility of performing factor analysis was assessed using the Kaiser – Meyer – Olkin (KMO) criterion. The sample was considered acceptable if the value of this criterion exceeded 0.5. The statistical significance of differences was determined by applying parametric and nonparametric criteria of statistical significance of estimates for unrelated sample populations. The probability level $p < 0.05$ was used to assess the statistical significance of differences. The described research algorithm was also used to identify the structure of physical performance in children aged 7–8 and 9–10 years [10].

RESULTS AND DISCUSSION

Based on multivariate statistical analysis, factors characterizing the muscular energy and physical performance of students during puberty were identified. The factors were interpreted based on the analysis of the physiological content of the indicators included in them, taking into account the values of the weighting coefficients.

After factorization of the intercorrelation matrix, significant factors were identified that reflect the fundamental characteristics of muscle energy and physical performance of adolescent boys during puberty: I – aerobic capacity (oxidative system); II – absolute aerobic power (oxidative system); III – anaerobic alactic performance (phosphagen system); IV – anaerobic glycolytic performance (lactic system); V – relative aerobic power (oxidative system) (table 1).

The basis of the internal structure of the aerobic capacity factor (38% of the total variance) is created by its close relationships with the coefficients "b" and "a" of the Muller equation, the time of physical performing "to failure" of a load of 3 W/kg (t3 W/kg), W_{900}, W_{240}, $PDAI_{3\ W/kg}$ and the results of a 6-minute run (table 1).

All these physiological variables characterize to one degree or another volume of aerobic work performed. The exceptions are the W_{240} and 6-minute run indicators, which reflect the mixed aerobic-anaerobic nature of energy supply, also included in the factors of anaerobic glycolytic and anaerobic alactate performance. The greatest weight loads for the aerobic capacity factor were characterized by the coefficient "b" of the Mueller equation (r = 0.98) and $t_{3\ W/kg}$ (r = 0.97).

The absolute (17% of variance) and relative (5% of variance) aerobic power factors included VO_2 max, WP, and PWC_{170}. It should be noted that in the first case, these physiological indicators were characterized by high negative factor coefficients, and in the second case – by a high and medium degree of positive correlation. In both factors, VO_2max (r = –0.94 and r = 0.86) and WP (r = –0.94 and r = 0.85) had the maximum weight loads.

The performance factor associated with the phosphagen energy supply system (13% of variance) correlated with the PDAI after sprint running, motor fitness assessment (MFA), W_1, MS, results of shuttle running, long jump, 20 m standing start, 6-minute run. Most of the above mentioned indicators were characterized by a medium degree of correlation with the factor under review. The most significant statistical relationship with it was demonstrated by the PDAI after sprint running (r = –0.93) and MFA (r = 0.75).

The performance factor associated with the lactic acid energy supply system (8% of variance) combined $t_{5\ W/kg}$, W_{40}, W_{240}, $PDAI_{5\ W/kg}$, and the results of the torso lifting test. The maximum values of the factor coefficients were $t_{5\ W/kg}$ (r = 0.91) and W_{40} (r = 0.91).

Taking into account the results of multivariate statistical analysis, the influence of puberty on the performance indicators included in each factor was assessed. Differences due to the degree of puberty were identified (table 2).

Depending on the stage of puberty, statistically significant differences ($p < 0.05–0.001$) were found between most of the variables included in the aerobic capacity factor. Differences were observed for individual indicators between stages II and III on the one hand, and stage IV on the other (table 2). In this case, boys with stage III had higher values compared to stage II and especially stage IV. It is important to note that adolescents with stage III were characterized by a high generalized assessment of aerobic capacity (fig. 1).

Physiological variables associated with aerobic power factors also depended on the stage of puberty. The highest ($p < 0.05–0.001$) values of absolute aerobic performance indicators were observed at the stage IV,

TABLE 1

FACTOR STRUCTURE OF PHYSICAL PERFORMANCE OF MALE ADOLESCENTS AGED 13–14 YEARS

Indicators	Factors				
	I	II	III	IV	V
Coefficient «b», r.u.	0.981	-	-	-	-
$t_{3\,W/kg}$, s	0.966	-	-	-	-
W_{900}, W/kg	0.901	-	-	-	-
Coefficient «a», r.u.	0.871	-	-	-	-
W_{240}, W/kg	0.766	-	-	-	-
$PDAI_{3\,W/kg}$, bpc	-0.686	-	-	-	-
6-minute run, m	0.508	-	-	-	-
VO_2max, l/min	-	-0.938	-	-	-
WP, kgf-m/b	-	-0.937	-	-	-
PWC_{170}, kgm/min	-	-0.925	-	-	-
PDAI (sprint running), bpc	-	-	-0.926	-	-
MFA, score	-	-	0.746	-	-
Shuttle running, s	-	-	-0.710	-	-
Long jump, cm	-	-	0.675	-	-
W_1, W/kg	-	-	0.632	-	-
MS, kg/kg	-	-	0.632	-	-
20 m standing start, s	-	-	-0.603	-	-
6-minute run, m	-	-	0.515	-	-
$t_{5W/kg}$, s	-	-	-	0.913	-
W_{40}, W/kg	-	-	-	0.909	-
Torso lifting from a supine position in 1 min, time	-	-	-	0.782	-
W_{240}, W/kg	-	-	-	0.539	-
$PDAI_{5W/kg}$, bpc	-	-	-	-0.508	-
VO_2max, l/min*kg	-	-	-	-	0.856
WP, kgf-m/b*kg	-	-	-	-	0.845
PWC_{170}, kgm/min*kg	-	-	-	-	0.746
Variance, %	38	17	13	8	5

Note. MFA – motor fitness assessment.

and the lowest – at the stage II (table 2). In contrast, relative aerobic performance indicators showed a tendency to decrease as the transition from the stage II to the stage IV occurred, which in some cases was statistically significant (p < 0.05–0.001). Similar dynamics were demonstrated by the integral estimates of absolute and relative aerobic power.

Lower relative values of VO_2max in 13–14 year old adolescents with stage IV probably reflect a significant increase in body weight and a temporary decrease in the capacity of the oxygen transport system, which during this period can only be partially compensated for by improved functioning of the autonomic nervous system.

TABLE 2

PHYSICAL PERFORMANCE PARAMETERS (M ± M) RELATED TO DIFFERENT FACTORS IN ADOLESCENTS AGED 13–14 YEARS AT DIFFERENT STAGES OF PUBERTY

Indicators	Stages of puberty		
	II	III	IV
Factor 1 (aerobic capacity)			
Coefficient «b», r.u.	12.5 ± 0.3**	12.7 ± 0.3	11,5 ± 0,3^{x}
$t_{3 W/kg}$, s	838.5 ± 46.8*	988.3 ± 54.0^{+}	628,5 ± 80,3^{x}
Coefficient «a», r.u.	5.5 ± 0.2**	5.5 ± 0.2	4.8 ± 0.2^{x}
W_{900}, W/kg	2.8 ± 0.1	2.8 ± 0.1	2.6 ± 0.1^{x}
W_{240}, W/kg	3.6 ± 0.1	3.8 ± 0.1^{++}	3.5 ± 0.1^{xxx}
$PDAI_{3 W/kg}$, bpc	0.4 ± 0.1**	0.5 ± 0.1	0.7 ± 0.1
6-minute run, m	1261.9 ± 17.8*	1275.3 ± 18.7	1319.0 ± 13.9
Factor 2 (absolute aerobic power)			
VO_{2max}, l/min	2055.6 ± 38.1***	2184.5 ± 43.1^{+}	2539.0 ± 48.7^{xxx}
WP, kgf-m/b	7.8 ± 0.2***	9.8 ± 0.2^{+++}	10.7 ± 0.3^{x}
PWC_{170}, kgm/min	542.8 ± 18.5***	591.4 ± 15.8^{+}	755.1 ± 29.2^{xxx}
Factor 3 (anaerobic alactic capacity)			
PDAI (sprint running), bpc	14.5 ± 0.6*	14.3 ± 0.6	16.7 ± 0.7^{x}
Shuttle running 4 × 9 m, s	10.5 ± 0.1*	10.4 ± 0.1	10.3 ± 0.1
MFA, score	18.8 ± 0.4***	19.3 ± 0.4^{+++}	21,7 ± 0,4
Long jump, cm	173.0 ± 1.9***	176.7 ± 2.8	190.9 ± 1.6^{xxx}
W_{1}, W/kg	10.3 ± 0.4	10.5 ± 0.3	11.5 ± 0.4^{x}
MS, kg/kg	1.60 ± 0.03**	1.61 ± 0.03	1.74 ± 0.04^{x}
20 m standing start, s	3.78 ± 0.03***	3.74 ± 0.04	3.47 ± 0.02^{xxx}
6-minute run, m	1261.9 ± 17.8*	1275.3 ± 18.7	1319.0 ± 13.9
Factor 4 (anaerobic glycolytic capacity)			
$t_{5W/kg}$, s	42.4 ± 2.3	46.7 ± 2.8	46.3 ± 3.6
W_{40}, W/kg	5.0 ± 0.1	5.1 ± 0.1	5.1 ± 0.1
Torso lifting from a supine position in 1 min, time	45.4 ± 1.0**	44.6 ± 1.2	40.2 ± 1.5^{x}
W_{240}, W/kg	3.6 ± 0.1	3.8 ± 0.1^{++}	3.5 ± 0.1^{xxx}
$PDAI_{5W/kg}$, bpc	3.72 ± 0.27*	3.75 ± 0.26	4.59 ± 0.27^{x}
Factor 5 (relative aerobic power)			
VO_{2max}, l/min*kg	51.2 ± 1.0***	47.1 ± 0.9^{++}	44.4 ± 0.9
WP, kgf-m/b*kg	0.195 ± 0.004	0.212 ± 0.004^{++}	0.187 ± 0.005^{xxx}
PWC_{170}, kgm/min*kg	13.5 ± 0.5	12.8 ± 0.3	13.2 ± 0.5

Note. *, **, *** – statistical significance of differences between stages II and IV of puberty; +, ++, +++ – between stages II and III of puberty; x, xx, xxx – between stages III and IV of puberty at $p < 0.05$, 0.01 и 0.001, respectively.

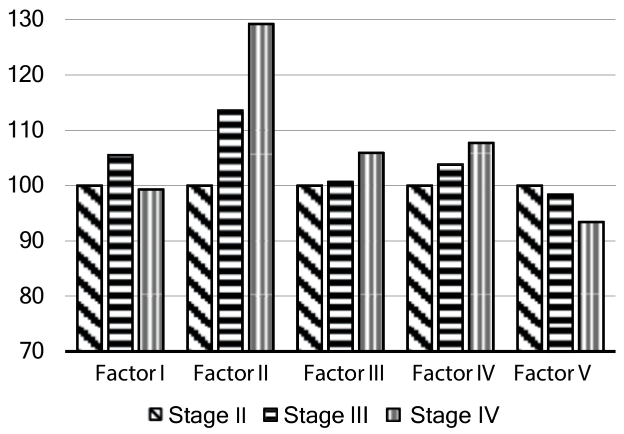

FIG. 1.
Integral physical performance parameters of adolescents with different stages of puberty: integral parameters for adolescents with II stages of puberty were taken as 100%»

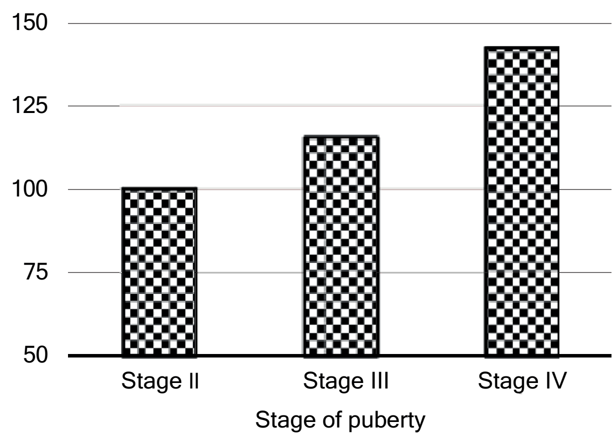

FIG. 2.
Body weight (%) in adolescents at different stages of puberty: the average values of body weight in adolescents with II stage of puberty were taken as 100%»

This conclusion is based in particular on the analysis of the data we obtained, showing that the average values of body weight in adolescents aged 13–14 years statistically significantly (p = 0.000) increase with the increase in the stage of puberty, with students with the stage II being characterized by below average and average, with stage III – above average, with stage IV – a high assessment of the indicator.

It is important to note that the average values in adolescents with stage II were close to the average values for 12 years of age, in adolescents with stage III – for 13 years of age, and in adolescents with stage IV – for 15 years of age [16]. The most pronounced differences were found when comparing stage III and stage IV (fig. 2).

Comparison of the indicators associated with the anaerobic alactic performance factor revealed a general trend of their improvement ($p < 0.05–0.001$) with an increase in the stage of puberty (table 2). Similar dynamics were also manifested in changes in the integral assessment of anaerobic alactic performance (fig. 1).

Analysis of the dynamics of the parameters included in the anaerobic glycolytic performance factor revealed a weak tendency for higher values of a number of physiological variables characterizing the capabilities of the lactic acid source in adolescents with stage IV compared to adolescents with stage II (table 2). However, statistically significant differences ($p < 0.05$) were found only in relation to the $PDAI_{5W/kg}$ anaerobic glycolytic performance factor. An exception is the oppositely directed dynamics of the results of the torso lifting test, which apparently reflects not the transformation of anaerobic energy during puberty, but the accelerated increase in torso mass and the increase in the muscle lever arm traction when performing this control exercise during the pubertal growth spurt.

In general, progressive changes in the anaerobic glycolytic capabilities of adolescents are well illustrated by the dynamics of integral indicators of physical performance during puberty (fig. 1). The obtained materials confirm the idea, established in age physiology, physiology of muscle activity and preventive medicine, that the development of anaerobic alactate and anaerobic glycolytic capabilities of the body is significantly accelerated in the final stages of puberty.

DISCUSSION

The study materials indicate that the greatest factor loads in the structure of physical performance of adolescents aged 13–14 years have the parameters of aerobic, anaerobic glycolytic, anaerobic alactate capabilities of the body and indicators of related motor abilities. The identified factors are associated with V.S. Farfel's relative power zones: the capacity and power of the oxidative system characterize the functional readiness to perform moderate and high-power muscle activity, anaerobic glycolytic capacity characterizes the effectiveness of implementing a submaximal power load, anaerobic alactate capacity characterizes the ability to perform work of maximum power. It is important to note that the factors considered are also interconnected with indicators of the development of students' conditioning motor abilities.

Three factors characterizing aerobic performance accounted for more than 60% of the total variance in the sample. These are aerobic capacity, absolute and relative aerobic power. Aerobic power, as is known, determines the intensity of work and reflects the highest rate of adenosine triphosphate (ATP) formation due to a given energy source, aerobic capacity limits the amount of work performed and characterizes the total amount of ATP that can be resynthesized due to available reserves of energy substrates [17]. The dynamics of the capacity indicators of aerobic and anaerobic processes, in contrast to the power indicators, in the ontogenetic aspect has been practically not studied [2]. At the same time, the obtained results determine the need to assess the aerobic performance of adolescents not only on the basis of traditional power indicators, but also metabolic capacity. The coefficient "b" of the Muller equation and the time of maintaining a load of 3 W/kg can be used as informative indicators of aerobic capacity. These physiological variables, as our studies have shown, have high factorial validity. The coefficient "b" of the Muller equation and the time of maintaining a load of 3 W/kg can be used as informative indicators of aerobic capacity. These physiological variables, as our studies have shown, have high factorial validity.

The presence of two relatively independent factors associated with the power of the aerobic source of energy supply for muscular activity in adolescents is apparently due to the fact that absolute indicators of the body's aerobic performance increase significantly due to a sharp increase in total body weight during the pubertal growth spurt and poorly reflect real changes in the oxygen transport and utilization system (fig. 2). In contrast, relative indicators characterize the true change in aerobic capacity during puberty. Therefore, it is advisable to use VO_2max and WP values related to body mass as informative parameters of aerobic power. These results are in full agreement with the data of other studies, which have shown that during puberty there is an increase in the absolute values of VO_2max, associated mainly with an increase in skeletal muscle mass, while the relative values of this indicator change little [2, 6].

Anaerobic performance is represented by two factors. They accounted for more than 21% of the total sample variance. The anaerobic alactate performance factor included indicators reflecting the maximum power and efficiency of performing extremely intensive anaerobic loads, as well as the level of development of speed-strength, strength and speed motor abilities. The PDAI after sprint running and the general motor fitness assessment were highly informative in relation to this factor.

The anaerobic glycolytic performance factor included indicators related to the corresponding energy supply source and the level of strength endurance development. The most informative variables were the duration of maintaining a load of 5 W/kg and the power of work with the maximum implementation time of 40 s.

It was established that the values of physiological indicators associated with the identified factors of physical performance depended on the stage of puberty. It is known that changes in physical performance and muscle energy during puberty are controlled by sex hormones that affect the formation of energy supply mechanisms and the metabolic capabilities of skeletal muscles. During this period, testosterone supplements the anabolic effects of growth hormone in men [6]. It plays a key role in regulating physical performance and motor fitness at various stages of puberty: it affects body composition, bone tissue development, aerobic and anaerobic capacity, muscle strength, circulatory system function, muscle enzyme activity, use of energy substrates, and erythropoiesis [3, 6, 8, 18]. It is important to note that during puberty, circulating testosterone concentrations in men increase, with a dose-response relationship observed between circulating testosterone, muscle mass and strength, and circulating hemoglobin [8].

The results of the study, showing that with an increase in the stages of puberty, the indices of aerobic power and capacity change in different directions and are consistent with the data of other studies. It was established that in the prepubertal period and at the beginning of puberty, the physical performance of children increases mainly on the basis of the intensive development of the aerobic mechanism of energy supply. At the initial stages of puberty, a higher percentage of type I fibers is observed in skeletal muscles, which ensure the implementation of physical activity primarily through aerobic resynthesis of ATP [14, 19, 20]. The power of the aerobic system at this time increases significantly, in particular due to the enhanced development of the capillary network, an increase in the number of mitochondria in skeletal muscles in relation to the area of myofibrils, and the activity of oxidative enzymes [2, 21]. A further increase in performance during puberty occurs mainly due to the intensive development of anaerobic energy supply mechanisms, against the background of weakly expressed dynamics of relative aerobic power [2, 22, 23].

Our data on high aerobic capacity in male adolescents with stage III of puberty are confirmed in the scientific literature. It has been shown that at this stage, there is an increase in the functional capabilities of the oxygen transport and utilization system, associated with the processes of growth and development of the body. During this period, the heart and lungs grow intensively, the systolic volume, volumetric blood flow velocity, and vital capacity of the lungs increase. All this creates favorable conditions for improving the supply of oxygen to tissues and the development of energy supply mechanisms for muscle activity [24]. Stage III of puberty is characterized by the first phase of muscular pubertal differentiation, which contributes to the manifestation of obvious "traits of aerobic metabolism" in most muscle fibers: the size and number of mitochondria increase, and the activity of oxidative enzymes increases [2, 24]. The composition of skeletal muscles is transformed towards an increase in the proportion of type I fibers, a temporary increase in the power of the aerobic threshold and a corresponding expansion of the aerobic energy supply zone occur [2]. It is assumed that this is largely due to changes in endocrine functions, the capabilities of the oxygen transport system and the organization of tissue energy. For example, data on the relationship between the concentration of circulating testosterone and the timing and manifestations of puberty in male adolescents are well known. Characteristic clinical signs of masculinization, such as muscle growth, increased body length, body hair, voice changes, and increased hemoglobin levels; appear only when the concentration of circulating testosterone in mid-puberty reaches the level of adult men [8]. As a result, there is a significant increase in the amount of hemoglobin, which provides the biological effect of increasing the blood oxygen capacity, enhancing oxygen transport to tissues and increasing aerobic energy expenditure [6, 8], while there is a linear relationship between changes in the hemoglobin level and aerobic performance. Perhaps, testosterone under these conditions promotes an increase in energy expenditure due to increased mitochondrial biogenesis in skeletal muscles [25], and also regulates the aerobic capacity of skeletal muscles by increasing the expression of myoglobin [26]. A significant increase in aerobic capacity at stage III of puberty may be due to changes in the level of cortisol [6] and thyroid activity, causing activation of oxidative metabolism of muscles [7, 14, 27].

The development of anaerobic alactic and anaerobic glycolytic mechanisms during the pubertal period occurs both synchronously and heterochronically, which determines the structure of energy processes and the specificity of the motor abilities formation associated with them. The most pronounced growth of anaerobic capabilities is noted in the final stages of puberty, when the definitive structure of energy supply for muscle activity is formed [11, 22, 23]. The development of anaerobic sources occurs to a large extent in conjunction with changes in basal concentrations of sex hormones and depends on the stage of puberty [6, 8, 11].

According to available data, during the transition from the initial to the final stage of puberty, under the influence of male sex hormones in skeletal muscles, an increase in the activity of key enzymes of anaerobic glycolysis and an increase in the thickness of IIB subtype (fast glycolytic) fibers is noted [2, 3, 8]. Based on the use of the Wingate test, a significant increase in anaerobic power in boys during puberty was revealed [18], while an average degree of correlation was found between peak and average anaerobic power on the one hand and testosterone levels on the other [28]. It has also been shown that the motor fitness of male adolescents improves during puberty [13]. Differences between the stages of puberty are manifested primarily in relation to strength and speed-strength abilities [4]. With an increase in the degree of sexual maturity, not only do motor abilities improve, but body length and weight also increase sharply [4]. Significant differences in anthropometric indicators make it possible to predict the stage of puberty with high accuracy based on changes in physical development [29]. In general, in adolescents with stage IV of puberty, the boundaries of the zones of maximum and submaximal relative power are noticeably expanded.

The differences we identified in the physical condition of adolescents of the same passport age largely reflect the classic variants of individual morphofunctional development – normal, slow (individual retardation) and accelerated (individual acceleration) [15, 30]. In the last two cases, development can be harmonious and inharmonious. With inharmonious individual acceleration, for example, a temporary decrease in the functional capabilities of the oxygen transport system and a decrease in the effectiveness of its reactions to standard and maximum physical loads can be observed [15].

As noted above, the rate of puberty has a noticeable effect on the structure of physical performance and muscle energy. There is evidence that individuals with a slow rate of puberty have a higher efficiency of the aerobic source of energy supply for muscle activity [6, 20, 30], while with an accelerated rate of maturation, there is an increased efficiency of the anaerobic glycolytic source of ATP resynthesis [6, 22]. In adolescents with a slow rate of puberty, a higher percentage of oxidative muscle fibers (type I) is observed in the skeletal muscles, characterized by the predominance of the aerobic source of energy supply for muscles [1, 19, 20], an increased density of mitochondria and a higher activity of oxidative enzymes [1, 11, 20]. A reflection of this can be seen in the trend described in our study of a temporary decrease in the relative value of VO_2max in 13–14-year-old adolescents with stage III and especially stage IV of puberty in relation to stage II. In general, it is assumed that in individuals with high rates of puberty, the activity of anaerobic glycolysis enzymes is higher than in individuals with low rates of maturation, while the activity of aerobic enzymes, on the contrary, is higher in adolescents with low rates of puberty compared to subjects with advanced maturation [11].

The obtained results show that students of the same calendar age with different levels of sexual maturity may have a pronounced specificity in the development of muscle energy and physical performance, which must be taken into account in the process of school physical education, health and sports training. Teenage boys aged 13-14 years, who are in the initial stages of puberty, are distinguished by high functional readiness to perform physical work of an aerobic nature and favorable conditions for the effective development of general endurance, while those in the final stages of puberty – to perform work of an anaerobic alactate and anaerobic glycolytic nature, as well as the development of strength, speed-strength and speed abilities. All this indicates that separate standards for assessing physical performance and motor fitness should be developed for adolescents of the same passport age with high and slow rates of biological development. Based on the data obtained, it is necessary to identify groups of adolescents with the initial and final stages of puberty in the process of physical training. This will allow for a differentiated "training" effect on the development of aerobic and anaerobic components of physical performance and related motor abilities, taking into account changes in the adaptive capabilities of the body during puberty. The results of the study should be taken into account when selecting valid and reliable indicators of physical performance in different zones of relative power, creating systems for its comprehensive assessment within wide limits of available loads, standardizing training effects and developing effective programs for physical exercise during puberty.

CONCLUSION

The study identified five relatively independent factors characterizing the physical performance of 13-14 year old male adolescents within a wide range of available loads: aerobic capacity; absolute aerobic power; anaerobic alactic performance; anaerobic glycolytic performance; relative aerobic power. These factors are considered as key links in the dominant functional system that ensures adaptation to intense muscular activity and correlate well with V.S. Farfel's relative power zones.

Good indicators of diagnostics of factors of aerobic and anaerobic performance in adolescents at different stages of puberty were revealed. Analysis of physical performance in adolescents aged 13–14 years showed that during puberty, changes in indicators combined into different factors occur nonlinearly and non-simultaneously. The obtained results indicate that subjects of the age group studied, at stages II, III and IV of puberty, differ significantly in the level of key bioenergetic criteria for assessing physical performance. It has been established that with the increase in the stage of puberty, progressive changes occur in most indicators of anaerobic alactic and anaerobic glycolytic performance, while the indicators of aerobic power and capacity change in different directions, in some cases showing a tendency to a temporary decrease. The motor abilities associated with the factors studied change in a similar manner.

The obtained data on the factor structure and level of physical performance of 13-14 year old students should be taken into account when developing measures to standardize physical activity of aerobic, anaerobic glycolytic and anaerobic alactate nature in the process of systematic physical exercise classes, for operational, current and stage-by-stage monitoring of the functional state of adolescents at different stages of puberty. The results of the study can serve as a basis for the effective use of physical activity of various metabolic orientations in order to improve the functional capabilities of the students' body during the critical period of ontogenesis associated with the process of puberty.

In conclusion, it should be noted that in the pubertal period, the basis for complex control of load parameters in the process of physical improvement of adolescents with different stages of puberty should be based on taking into account the structure and level of physical performance, as well as the morphofunctional maturity of the leading physiological body systems that ensure the implementation of intense muscular activity.

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Conflicts of interest

No potential conflict of interest relevant to this article reported.

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