ФІЗИЧНА КУЛЬТУРА І СПОРТ

THE KEY FACTORS OF ATHLETES' FUNCTIONAL FITNESS

КЛЮЧОВІ ФАКТОРИ ФУНКЦІОНАЛЬНОЇ ФІЗИЧНОЇ ПІДГОТОВКИ СПОРТСМЕНІВ

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Abstracts

Purpose is to study the most generalized properties (factors) of functional systems that make up functional fitness structure and to analyze the possibilities of diagnosing the functional fitness of skilled athletes (cyclists and rowers) based on complex research of the body oxygen transport system. **Material and methods.** The results of 264 complex physiological individual examinations conducted over a number of years using a holistic methodological approach (and specially adapted methods) were analyzed. One of the main tasks of our study was the development of methods for quantitative assessment of functional fitness factors, as well as some other theoretical and factual grounds for making a diagnostic model of functional fitness. A complex methodology for functional fitness level determination was used. It included registration of the main gas exchange parameters, external respiration, blood, and cardiovascular system at different loads. **Results.** The main factors of athletes' functional fitness are power, mobility, stability, economy, and functional potential realization. The power of systems determines the limit of functional manifestations in sports activity conditions. The mobility of systems determines the development speed of functional and metabolic responses at changes in work pace and intensity. The stability of systems determines the ability to keep high levels of energy and functional reactions. The economy of systems determines the functional and metabolic "cost" of the levels of work, gas transport and oxygen consumption, general economy of energy conversion. The degree of realization of the body system functional potential depends on the individual peculiarities of the neurovegetative status. **Conclusions.** The development of methods for analysis and assessment of the properties of function regulation that underlie the work capacity provision in cyclic sports events, as well as some other parameters that reflect the body functional potential, is of great importance for functional fitness diagnostics. Determination of the properties of the main functional systems regulation not only helps to explain the mechanisms of formation and manifestation of functional fitness structure factors and to obtain additional information about them but also can serve as a very efficient independent criterion for the body functional potential analysis.

Key words: athletes, external respiration, energy supply, oxygen transport system, circulation.

Мета – дослідити найбільш узагальнені властивості (чинники) функціональних систем, які становлять структуру функціональної підготовленості, проаналізувати можливості діагностики функціональної підготовленості кваліфікованих спортсменів (велосипедистів і веслувальників) на прикладі комплексного вивчення кисневотранспортної системи організму. **Матеріал та методи.** Проаналізовані результати 264 комплексних фізіологічних індивідуальних обстежень, проведених впродовж низки років з використанням єдиного методичного підходу (і спеціально пристосованих методик). Одним з основних завдань нашого дослідження була розробка методів кількісного оцінювання чинників функціональної підготовленості, а також деяких інших теоретичних і фактичних підстав для побудови діагностичної моделі функціональної підготовленості. Застосовували комплексну методику визначення рівня функціональної підготовленості. Методика включала реєстрацію основних параметрів газообміну, зовнішнього дихання, крові, серцево-судинної системи за різних навантажень. **Результати.** Основні чинники функціональної підготовленості спортсменів – потужність, рухливість, стійкість, економічність, реалізація функціонального потенціалу. Потужність систем визначає межу функціональних проявів в умовах спортивної діяльності. Рухливість систем визначає швидкість розгортання функціональних і метаболічних реакцій у разі змін темпу та інтенсивності роботи. Стійкість систем визначає здатність утримувати високі рівні енергетичних і функціональних реакцій. Економічність систем визначає функціональну і метаболічну «ціну» рівнів роботи, газотранспорту і споживання кисню, загальну економічність перетворення енергії. Міра реалізації функціонального потенціалу систем організму залежить від індивідуальних особливостей нервово-вегетативного статусу. **Висновки.** Велике значення в діагностиці функціональної підготовленості має розробка методів аналізу й оцінювання властивостей регуляції функцій, які лежать в основі забезпечення працездатності в циклічних видах спорту, а також деяких інших параметрів, які відбивають функціональний потенціал організму. Визначення властивостей регуляції основних функціональних систем не лише допомагає пояснити механізми формування і прояву чинників структури функціональної підготовленості і отримати додаткову інформацію про них, але і може служити дуже ефективним самостійним критерієм аналізу функціонального потенціалу організму.

Ключові слова: спортсмени, зовнішнє дихання, енергозабезпечення, кисневотранспортна система, кровообіг.

Introduction. Functional state is an integral characteristic of those human functions and qualities that directly or indirectly determine the efficiency of performing a particular activity [3; 13; 35]. Training status in sports reflects one of the highest degrees (stages) of adaptation to muscular activity and covers a wide range of issues [22; 49; 61]. The central issue (which reflects the part of sports work capacity provision conditioned by the capabilities of key functional systems) for cyclic sports events is functional fitness [19; 24; 44]. The oxygen transport and respiratory systems of the body are the most important for athletes of cyclic sports events. Quantitative and qualitative manifestations of the activity of these systems are some of the most significant objects of control and criteria of functional fitness diagnostics in the dynamics of the training process [5; 15; 32; 52].

The basis for developing an integral approach to functional fitness diagnostics is the definition of its structure in sport. The objectivity of diagnostic methods, in this case, is directly dependent on our vision of the most essential properties and factors of systems that underlie the specialized structure of athlete functional fitness [2; 25; 56]. One must have clear ideas about what exactly should be tested and according to what system.

An important prerequisite for the physiological analysis of functional fitness is the developments of sports pedagogy, which allows for assessing the level and some aspects of athletes' special fitness [24; 34; 47]. This enables to judge their functional fitness [26; 42; 53].

To date, the concept of functional fitness has more often appeared in sports-pedagogical research and the practice of sport than in physiological analysis. There is a large number of publications on studies with a complex approach to assessing the functional state of skilled athletes' bodies and differentiation of functional fitness various aspects [23, 33; 57 et al.]. Functional fitness is a number of multicomponent in its structure qualities [8; 48; 54 et al.]. The analysis of functional fitness is associated with the need to take into account the holistic "vegetative portrait" of the athlete, with a multicomponent cause of work capacity limitation in the absence of one limited weak link [14; 21; 59 et al.] or its presence [10; 18; 40 et al.]. A number of energy criteria – power, capacity, and efficiency – have been proposed to characterize metabolic states [1; 38; 58 et al.].

Most of the works is connected with generalizations and structural analysis within one functional system. Especially many important studies in this direction concern the activity of the cardiovascular system [4; 17; 50 et al.]. The most complete developments relate to the analysis of changes in the "oxygen regime" of athletes' bodies [7; 20; 41 et al.].

The currently available research results allow sufficient differentiation of the components of sports functional fitness and determination of its association with the complex of key physiological factors [9; 36; 51]. At the same time, the practice of functional fitness diagnostics and the majority of works (which address this question) are aimed at estimating the possibilities of maximization of systems, which reflect the limits of their functioning (estimation of their power) [6; 11; 46; 55]. The same is peculiar for the creation of diagnostic complexes and determination of functional and energy criteria of sports training management.

Methodical literature and recommendations of recent years, as well as the practice of managing the improvement of functional fitness, usually address the issues of assessing and developing the level of maximum aerobic and anaerobic power of the body. In this case, such important energy indicators as maximum oxygen consumption, maximum "oxygen debt", as well as a number of other functional parameters are determined [16; 43; 60].

Such developments in sports physiology and functional control in sports meet practical needs. Nowadays, it is an important factor in assessing the functional fitness level and managing the training process (especially at the initial stages of sports preparation or during the selection of athletes).

The functional fitness diagnostics with account for only the mentioned criteria is not always satisfactory. One should take into account other indicators that characterize the functional fitness of athletes (economy, development speed of reactions, "accuracy" of regulation, etc.). However, in most cases, the range of factors that form the functional fitness basis is significantly narrowed. The significance of many factors for the formation of functional fitness in general and achievement of high sports results (as well as the methodology of diagnostics and targeted impact on them), has not been properly substantiated.

Despite all the attempts to integrate, generalize, simplify, and search for one or two specialized "simple" indicators of functional fitness, it has not yet been possible to develop any kind of an integrated approach [12; 37; 45]. This is due to the absence of a fundamental theoretical basis (there is no system of generalization of a large number of methods and data), which would allow us to approach a reasonable simplification, limitation of the number of indicators and methods (important for the practice of physiological control in sports).

Purpose is to study the most generalized properties (factors) of functional systems that make up functional fitness structure and to analyze the possibilities of diagnosing the functional fitness of skilled athletes (cyclists and rowers) based on complex research of the body oxygen transport system.

Material and methods. *Participants.* The results of 264 complex physiological individual examinations conducted over a number of years (2004–2016) using a holistic methodological approach (and specially adapted methods) were analyzed [27; 28]. One of the main tasks of our study was also the development of methods for quantitative assessment of functional fitness factors, as well as some other theoretical and factual grounds for making a diagnostic model of functional fitness.

Methods. The testing program, methods, and equipment are given in our article [29; 30; 31].

Statistical analysis. The research results were subjected to mathematical processing. The following statistical parameters of the sample were calculated: arithmetic mean (X); standard deviation (S); coefficient of variation (V%); ΔX – the confidence interval corresponded to 95%. The Student's t-test was used to compare two normal distributions. The critical level of significance for testing statistical hypotheses was $p<0.05$. Correlation analysis of the results was performed using Pearson's linear correlation coefficient. The integrated statistical and graphical packages MS Excel-7 and Statistica-10 were used for experimental material processing.

Machine mathematical methods of analysis were used, in particular, elements of correlation and factor analysis. The limits of variation of functional fitness factors, the range of typical values, and the frequency and degree of their deviation during annual and long-term training periods were determined.

The study was conducted in compliance with the ethical principles of the European Convention and the Helsinki Declaration (ethics principles regarding human experimentation). It was confirmed by the Bioethics Commission of the University. Examined provided written approvals for analysis and subsequent disclosure.

Results and discussion. Long-term specialized sports training causes profound changes in the whole body of an athlete. Specialization of athletes is reflected in morphofunctional changes, the features of energy processes, as well as neurohumoral regulation in general. It is the specialization of development and adaptation of functional systems that are the key for a given type of muscular work and the specificity of their regulation properties that form the basis of functional training effect in sport.

Our special analysis of the reactions of external respiration, cardiovascular system, gas exchange, blood gas transport, metabolic changes, and shifts in the internal milieu during the application of different methodical techniques of testing the general and special work capacity of skilled cyclists and rowers shows that the basis of their functional fitness is the five most common properties – the main factors (Fig. 1): *power, mobility, stability, economy, and realization of functional potential.*

1. *The power of functional systems* determines their upper limit. It is closely related to maximal aerobic performance and the ability to anaerobic energy formation. The internal structure analysis of this factor of functional fitness (the role of individual functional systems, "bottlenecks" of the gas exchange system, transport or diffusion of gases, their utilization, as well as the balance of aerobic and anaerobic performance) significantly deepens the information about the body functional adaptations. As the analysis shows, despite the importance of this factor for functional fitness, it is necessary to take into account that its specific weight is only about 50% of the total structure of functional fitness. Therefore, in characterizing the functional fitness of highly skilled athletes as a whole, one may not be confined to only this factor (Table 1).

A detailed study of the "power" of systems provides the best results in diagnosing functional fitness at the stages of sportsmanship development. This is especially noticeable in sports specializations in which the competitive distances are covered at more than 1–2 minutes, although it is clearly enough manifested (as it will be shown below) at a competitive load duration of about 1 minute (track cyclists specialized in time trials).

The "power" of systems determines only the limit of functional manifestations in conditions of sports activity and does not guarantee a high level of functional fitness in general.

Particular difficulties in functional fitness assessment while using only the factor of systems power and anaerobic-aerobic relations arise during the period of the most focused specialized training, that is, in the competitive period above all. During this period, the indicated indices lose their informative value for the general assessment of functional fitness to a large extent. Similar results have been obtained by other researchers. This can be interpreted in terms of the theory of compensatory-adaptive reactions and is probably associated with the onset of the phase of "stabilization of organ shifts".

What criteria can be used to reliably assess this factor? What is the system of its signs in functional and metabolic manifestations? Of all the abundance of criteria described in the literature to characterize this aspect of functional fitness, those indices that are presented in Table 1 characterize the power of the systems most comprehensively. Most of them are quite widely known.

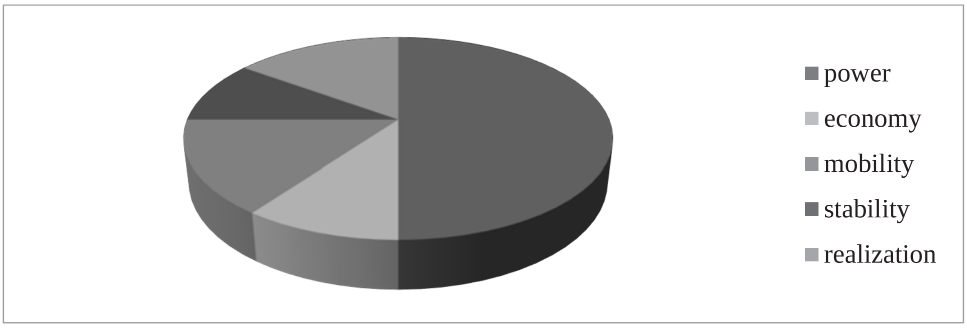

Fig. 1. Key factors in the general functional efficiency of the energy system

Table 1

Indices of functional systems' power

№	Indices
Integral and energy indices	
1	Maximum oxygen consumption, $ml.kg^{-1}$
2	The value of the ultimate power of 10 s load, $kg.min^{-1}$
3	Oxygen debt at 60 s load, $ml.kg^{-1}$
4	Total "excessive" CO_2 release at 60 s load of maximum intensity, $ml.kg^{-1}$
5	Maximum gas exchange ratio at the critical level of load performed until failure
Direct circulatory indices	
6	Maximum cardiac index, $L.m^2$
7	Maximal systolic index, $ml.m^2$
Indirect circulatory indices	
8	Maximal systolic pressure, mm.Hg
9	Difference between HRmax during exercise and resting HRmin of metabolic rate, %
10	Product of HRmax. by maximal systolic pressure
11	Ratio of heart volume to O_2 of maximal pulse at Wkr
Ventilatory indices	
12	Maximum pulmonary ventilation during exercise, $L.kg^{-1}$
13	Maximum respiratory volume, $ml.kg^{-1}$
14	Ratio of maximal ventilatory capacity to resting pulmonary ventilation of basal metabolic rate
General conductance indices	
15	Lung diffusion capacity for O_2, $ml.mm.Hg.min^{-1}$
16	Maximum O_2 transport by arterial blood, $ml.kg^{-1}$
17	Maximum body conductance for O_2
18	Maximum body conductance for CO_2

Only the method of determining the body conductance (Du) for O_2 and CO_2 requires some explanation.

Conductance for O_2 (DuO_2) and CO_2 ($DuCO_2$) is calculated as follows:

$$DuO_2 = P_iO_2 - P_EO_2/P_iO_2 - P_AO_2;$$

$$DuCO_2 = P_iCO_2 - P_ECO_2/P_iCO_2 - P_ACO_2;$$

where P_i – gas tension in inhaled air; P_E – gas tension in exhaled air; P_A – gas tension in arterial blood.

In the practice of testing athletes, one may use a smaller group of test loads and indices depending on the athlete's specialization and the examination goals. An indispensable condition is the consistent application of selected indices from each group in dynamic observations.

2. *The mobility of systems* determines the development speed of functional and metabolic reactions during the work pace and intensity changes, which always take place in the conditions of sports competitions. Studies show that the faster functional systems, metabolic reactions, and buffer mechanisms "respond" at the beginning of the load, when its intensity or other parameters of work (frequency and strength) change, the less oxygen deficit is formed, the less "regulatory difficulties" of functional systems are accumulated in the body as a whole, and the greater their overall efficiency. This factor has a high specific weight in the general structure of functional fitness and is one of the most specialized, i.e. associated with sports specialization.

To describe and quantitatively express the above factor of functional fitness, two groups of indices (Table 2) were identified, characterizing the speed, ability to quickly mobilize various functional and metabolic reactions of the body systems under conditions of transient modes available at different load power, which is evaluated by its ratio to the critical load power (Wcr).

Table 2

Indices of functional systems' mobility

№	Indices
Rate of functional reactions	
1	Time constant t50 HR during the transition from 0.5Wcr to Wcr, s
2	t_{50} HR during the transition from rest to 0.5Wcr
3	t_{50} HR of pulmonary ventilation during the transition from 0.5Wcr to Wcr
4	Rapid component of pulmonary ventilation at the onset of exercise (10 s) at Wcr
5	Activation degree of metabolic acidosis respiratory compensation: ΔV_E0.5Wcr and end Wcr/P_ACO_2 at the same points
6	Time of HR half-recovery after 0.5Wcr, s
The development speed of metabolic reactions	
7	t50 of oxygen consumption at Wcr, s
8	Oxygen "deficiency" at the onset of exercise 0.5Wcr, $ml.kg^{-1}$
9	t_{50} of excessive CO2 release at 1.5Wcr
10	Rate of La release into the blood in terms of peak delay time (or decrease) after the end of 1.5Wcr load, min
11	Rate of La "utilization" within 8 min after the end of the 1.5Wcr load, $mmol.min^{-1}$
12	Rate of La "utilization" within 8 min after the transition from 1.5Wcr load to 0.5Wcr load, $mmol.min^{-1}$
13	Rate of activation of La "utilization" of light exercise as the ratio of p.12 and p.11

To assess this factor during sports activity, the indicated criteria of heart rate and other parameters, which are available for registration under these conditions, can be correlated with different speeds of athlete movement.

3. *System stability* determines the ability to maintain high levels of energy and functional reactions, primarily oxygen consumption and the oxygen transport system as a whole. This ability is the result of important, acquired in the process of specialized training, functional properties of the body regulatory mechanisms and homeostatic systems, which to a large extent determine the training status dynamics of highly skilled cyclists in the annual cycle. The specific weight of this factor constitutes about one-third of the total structure of functional fitness of cyclists and rowers.

The ability to maintain high O_2 consumption values during the competitive period of skilled athletes' training proved to be a more informative criterion for assessing the athlete's state than the maximum O_2 consumption values.

That is why we recently observed more common testing of "endurance time" at critical or other load power, determining aerobic and anaerobic "capacity", "metabolic productivity", comparing movement speed with functional and epidemic shifts, and a number of other criteria designed to increase the informative value of means of physiological assessment of athletes' functional fitness.

The literature indicates the importance of functional stability mechanisms for athletes.

The crucial applied task of functional fitness in examining this factor is determining its criteria, specific indices, and generalized quantification.

To assess this factor of functional fitness, we have developed a set of indices (Table 3). It includes four groups of indices (three main and one additional): functional stability; metabolic stability (assessment of oxidation substrates utilization); maximum shifts of internal milieu parameters; indices reflecting the degree of decrease in the course of loading of the regulatory ability of the oxygen transport system to rapid mobilization in response to standardized adequate nervous and humoral stimuli ("fatigue" of regulatory mechanisms). The last of the four (additional) groups of indices is given in the table

Table 3

Indices of functional systems' stability

№№ п/п	Indices
Functional stability	
1	Time of maintaining Wcr, min.
2	Time of maintaining 85%VO_2max, min.
3	HR of the beginning of systolic volume or pulse pressure decrease
4	HR difference at the end of the first and last minutes at Wcr divided by the time of work, min.
5	HR difference of 30^{th} and 5^{th} min at 0.7Wcr
6	VE difference of the first and last min at Wcr divided by time of work, min.
7	O_2-pulse difference of the first and last minutes at Wcr divided by time of work, min.
8	Degree of heterochronism of decrease in ventilation efficiency and blood flow at Wcr as a ratio of p.6 and p.7
9	"Endurance time" of respiratory muscles in the mode of voluntary ventilation 60% of maximum pulmonary ventilation with maintenance of P_ACO_2, min.
10	"Anaerobic stability" of respiratory muscles: maximum ventilation volume in 40 s (with P_ACO_2 maintenance), %
Assessment of oxidation substrate oxidation	
11	Rate of blood glucose content decrease by the end of prolonged (40–120 min.) laboratory or competitive load, %
12	Rate of La content decrease from 10th min. to the end of prolonged (40–120 min.) load 0.6–0.7Wcr, $mmol.min.^{-1}$
13	Rate of decrease in respiratory quotient from the 10th min to the end of prolonged (40–120 min) load 0.6–0.7Wcr, %
14	Degree of blood free fatty acids content increase from the 10th minute to the end of prolonged (40–120 min.) load 0.6–0.7Wcr, %
Maximum shifts of internal milieu parameters	
15	Marginal values of mixed venous blood CO_2 tension at the end of or after 1.5Wcr load until failure or competitive load, mmHg
16	Marginal values of base deficit at the end of or after 1.5Wcr load until failure or competitive load, mmHg
17	Marginal pH values at the end of or after a 1.5Wcr load until failure or competitive load
18	Extremely low P_ACO_2 values at the end of or after a 1.5Wcr load until failure or competitive load
19	Body temperature at the end of or after a 1.5Wcr load until failure or competitive load

without detailing the method of the data quantitative expression, as this issue requires separate consideration.

The variety of physiological mechanisms providing stable maintenance of high work intensity is not limited to the range of indices presented in Table 4. However, in relation to the specializations of cyclic sports events we are considering, such an approach provides an objective assessment of this factor when using a more limited number of parameters from those given in this table. This is explained by the fact that many of them are mutually conditioned and therefore interchangeable within certain limits. Their choice is determined by specific conditions and testing objectives. An indispensable condition is the need to take into account heterogeneous indices from the groups we have identified.

4. *The economy of systems* determines both the functional and metabolic "cost" of given levels of work, gas transport and oxygen consumption, and the overall economy of energy conversion. This factor is closely associated with the structure of cyclists' working movements and pedaling technique. Significant individual differences in its specific weight are noted. This factor is especially significant for cyclists who specialize in team racing. This index can change significantly during annual training cycle.

Additional indices that reflect the economy of functional systems are presented in Table 5.

Indices of *metaboli*c (energy) and *functional* efficiency are given in Table 5. In the conditions of sports activity, economy testing can be performed by replacing in a number of the indices specified in a table the values of load power and O_2 consumption (if there is no possibility to measure them in natural conditions) by the athletes' movement speed.

While analyzing the functional economy of work, it is necessary to dwell separately on the diagnostic significance of assessing the relationship between the structure of cyclic movements and functional adaptations. This issue has been understudied, however, it is already clear that the strength, frequency of cyclic working movements, and intracyclic force distributions are expedient (economical) not only from the standpoint of the athletes' movement biomechanics but from the point of view of the occurrence of the most effective and economical conditions of energy supply of muscle work, activity of the body physiological and biochemical systems as well.

Table 4

Additional indices of functional systems' stability

№№	Indices
Indices reflecting the degree of decrease in the ability to rapidly mobilize systems ("fatigue of regulatory mechanisms", changes in the balance of nervous and humoral influences) under conditions of prolonged (40–120 min.) load (or training) in the range of about 0.6–0.7Wcr in response to standard short-term (10–30 s) stimuli	
1	Humoral stimulus – hypercapnia with hypoxia (6–7% CO_2 and 12–14% O_2 in nitrogen) as the degree of decrease (in %) in the intensity of ventilation responses and HR by the end of work compared to the 10th and 30th minutes of work
2	Sharp (1.5–2.0 times) rectangular increase in the load intensity as the degree of decrease (in %) in the intensity of HR response, ventilation, O_2 consumption, change in "O_2 deficit" by the end of the load compared to the 10th and 30th minutes of work
3	Degree of change in the rate of "excessive" CO_2 release, increase in lactate content during short-term (30 s) enhancement of load intensity (1.5Wcr) under the same conditions of prolonged exercise or training session as a characteristic of stability of the anaerobic component of energy formation

Theoretically and in some practical conditions they can enter into alternative relationships. The essence of one of the aspects of economization in the process of sports training, in this case, consists in the formation of such frequency, strength, and other characteristics of cyclic movements of a given sports specialization, in which the optimal relationships of these biomechanical and functional factors are formed and such structural components of the movement are selected, which favor the necessary level of muscle blood supply, blood outflow, the functioning of the "muscle pump", and oxygen transport system as a whole, that is, the provision of metabolism, supply, and excretion.

The only exceptions are probably short sprint loads, final efforts in competitive conditions of other sports specialization types, and other similar conditions of loads.

Table 5

Economy indices of functional systems

№	Indices
	Metabolic indices of economy
1	Anaerobic metabolic threshold oxygen consumption, $ml.min.kg^{-1}$
2	Work critical power, $kGm.min.kg^{-1}$
3	Oxygen cost of pulmonary ventilation marginal working levels, $ml.L^{-1}$
4	Mechanical efficiency of work of 0.5Wcr power
5	Gas exchange ratio of the beginning of reaching VO_2max at Wcr (lactate, pH)
6	Indices that are determined by the law of dependence of power (speed) of special work and acidemic shifts (lactate, pH). For laboratory testing: simplified version as the ratio of Δ1.5Wcr and 0.5Wkr to ΔLa (pH) at the same points, i.e. ratio 1/ΔLa; (1/ΔpH).
	Functional indices of economy
7	"Watt-pulse": ratio of load power to HR, $watts\text{-}beats^{-1}$
8	"Pulse cost" of a unit of work: ratio of the total amount of work performed to the sum of heartbeats above resting level during that time, $kGm.beats^{-1}$
9	HR of beginning VO_2max at Wcr, $beats.min^{-1}$
10	HR AnT, %
11	Ratio of ΔVO_2 to ΔHR calculated from three or more points of different VO_2 levels, $ml.beats.kg^{-1}$
12	"Pulmonary ventilation optimum": the highest level of ventilation at the highest O_2 utilization from the air, $L.min.kg^{-1}$
13	"Critical respiratory rate": the highest value after which a sharp increase in respiratory rate and a decrease in respiratory volume are noted, $breath.min^{-1}$
14	Ventilatory equivalent of 0.5Wcr and onset of reaching VO_2max at Wcr: V_{EBTPS}/VO_2
15	Hemodynamic equivalent: ratio of cardiac output to VO_2, $l.min^{-1}$
16	O_2/VO_2

Efficient movement technique has both biomechanical and functional components. The combination of these components provides the highest energy productivity, speed of movement at a specific duration of competitive load. This is confirmed by the experimentally established presence (depending on the sports event and qualification of the athlete) of individual optimal frequency and strength components of the load. For cyclists, the optimal frequency of pedaling (in terms of economy and overall working capacity when controlling for energy and functional parameters) is about 100 (95–110) $rev.min.^{-1}$. For rowers of the same skill level (for whom this work is non-specific as for healthy untrained individuals), the optimal pedaling frequency is within the range of only 50–65 $rev.min.^{-1}$. It is at these frequencies that high economy and maximum individual aerobic and overall working capacity can be achieved. This indicates a close relationship between the economy and the power of the body systems.

Studying the distribution of strength characteristics during the work cycle and finding its optimal variants from the standpoint of functional adaptive responses claim special attention.

In view of the study of the issue of realizing the reserves of functional and metabolic economy of work, a need to investigate the possibility of directional modulation in the process of training of frequency parameters of movements, internal strength structure of the cycle, that is, the ratio of frequency and strength parameters arises. The necessity of such modulation is conditioned by the fact that optimal relationships are not always formed in practical conditions. This aspect of training process management is especially important in the dynamics of age development at the stage of sports mastery formation. In addition, it has a direct relation to the selection of sports equipment (power transmission, pedal cranks – in cycling, oar sizes – in rowing, etc.). Literature data and our data on this issue indicate, on the one hand, a close connection between functional economy and strength parameters of movements, and on the other hand, the difference in the mechanisms of work capacity limitation even with small differences in the strength component of cyclic work.

In this regard, a need is brought about to classify cyclic loads to normalize the training orientation according to the value of the strength component (e.g., in % of the maximum strength in the movement cycle). A number of criteria developed on this basis can be additionally used to evaluate not only the factor of *economy*, but also *power* and *stability*.

It has to be considered that in sports there are always strictly conditioned parameters of the structure of sports movements, which in many cases prevent maximum manifestation of the body aerobic capabilities. The same applies to other aspects of sports work capacity. In such cases, the athlete is only somewhat approaching the maximum potential of the respiratory system in the conditions of competitive activity. In this respect, we can talk about a different realization level of the potential of the systems.

In a number of cases, an athlete, possessing high functional indices (for instance, a high maximum O_2 consumption), fails to realize them to a full extent in conditions of competitive activity.

5. *The ability (degree) to realize the functional potential* of the body systems is an important independent factor of functional fitness, which changes during the annual cycle and long-term training periods. It depends not only on training and sports specialization, but is also connected with individual peculiarities of neurovegetative status.

We consider the "realization" factor in three aspects: 1) according to the degree of function mobilization, estimating their ratio with the maximum possibilities of functions and "reserve" possibilities of their manifestation in the most favorable conditions; 2) according to the greatest tolerable shifts of the internal milieu in model conditions; 3) according to the ratio of real functional and energy indices with model (proper) for athletes of this specialization.

The list of indices that can be used for quantitative expression of this factor is given in Table 6.

The core issue in the development of the methodology of functional fitness structure diagnostics is the determination of the range of informative tests and parameters that can objectively reflect each of the five factors (as well as evaluation criteria and their "specific" weight). An important practical issue is the number of used indices and tests.

The objective assessment of functional fitness (as well as functional state in general) requires the usage of a set of qualitatively heterogeneous indices. This enables to significantly reduce the risk of error in functional fitness assessment (this is due to the presence in the body of variable opportunities to achieve high special work capacity and vivid individual characteristics).

In this regard, in the process of developing a method for analyzing the functional fitness structure, we used a large number of indices. The application of numerous comprehensive criteria for evaluating individual factors enables the assessment of possible "bottlenecks", the reasons for the factors' "lagging", and its internal structure in parallel. The latter is especially important in sports events, which are characterized by the share of the anaerobic component of the work energy supply. Therefore, the internal structure of factors (especially power and stability) is highly specialized.

Table 6

Indices that characterize the realization of potentialities

№	Indices
Degree of function mobilization	
1	Ratio of heart volume to systolic volume Wcr, %
2	Ratio of maximum pulmonary ventilation to a maximum working pulmonary ventilation, %
3	Working respiratory volume, %
4	Presence of hypercirculatory (hyperventilation) or hypocirculatory (hypoventilation) type of response to load Wcr
5	O_2 consumption on the competitive distance, %
Shifts in the internal milieu	
6	The internal milieu shifts at supermaximal loads in relation to the limit shifts in the maximum value of lactate content, %
7	The internal milieu shifts at supermaximal loads in relation to the limit shifts in the minimum pH value, %
8	The internal milieu shifts at supermaximal loads in relation to the limit shifts on the minimum value of arterial blood CO_2 tension, %
9	The internal milieu shifts during prolonged loads in terms of the minimum value of glucose content
10	The internal milieu shifts during prolonged loads by the maximum value of body temperature
Correlation with the proper values, %	
11	Maximum oxygen consumption
13	Heart volume, %
14	Maximum pulmonary ventilation
15	Arteriovenous O_2 difference
16	Oxygen pulse
17	Oxygen utilization in the lungs
18	O_2 "deficit" of VO_2 time constant at the onset of exercise within Wcr as a reflection of the rate of the aerobic process development
19	Half recovery time of HR, arterial pressure after load within 0.7Wcr
20	Total oxygen debt
21	Mechanical efficiency of work

The usage of five groups of heterogeneous indices (one from each factor) according to HR measurements in the analysis of functional fitness will result in obtaining a more reliable estimate of functional fitness than the application of all the criteria of a single factor indicated in the tables.

Such an increase in the heterogeneity of indices provides significant improvement in the reliability of estimates and expansion of the qualitative analysis of functional fitness (even without introducing new research methods, but only using the available data of physiological examinations, telemetric, and biochemical control of training).

The transition from the system of individual indices to the integral evaluation criteria (as well as the determination of significance, specific weight of indices in the evaluation of the factor as a whole, their harmonization with other factors) proved to be one of the most time-consuming tasks. The possibility of practical quantitative evaluation of each factor, the balance of the internal structure of functional fitness factors is provided by the evaluation scales of indices we have compiled, taking into account the criteria of reliability of the results obtained. In numerical programmed evaluation scales (which are expressed in points of standard evaluation scales) the points are multiplied by weighting coefficients and summarized.

Rowers and cyclists of different specializations are characterized not only by specific features of functional adaptations, but some general regularities of ratios of certain factors development, their "contribution" to the overall level of functional fitness. For instance, Fig. 2 shows the most general ratios of factors of functional fitness structure of road cyclists and track cyclists (time trial).

For skilled cyclists specializing in the time trial, along with a large role of the power of the systems of work energy supply (which is distinguished by an emphasis on anaerobic power), high mobility of the systems is peculiar unlike road cyclists specializing in team racing.

It should be noted that the application of this method of functional fitness analysis reveals individual features of athletes of approximately equal skill levels within the same specialization, which is quite noticeable in the analysis of a set of indices characterizing the power of systems and the internal structure of this factor. Individual differences are even more clearly manifested when analyzing the structure of functional fitness in general.

Fig. 3 shows individual differences in the structure of functional fitness of three highly skilled cyclists. There may be cases of significant differences in the specific weight of even such a fundamental factor for road cyclists as power. The analysis of functional systems mobility of track cyclists' functional fitness indicates the presence of significant individual deviations with a general natural tendency to its specific weight increase.

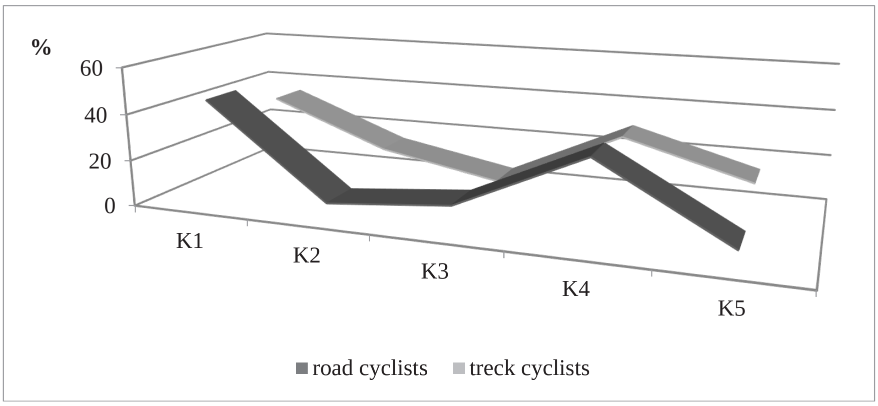

Fig. 2. Ratio of functional fitness key factors in cyclists of different specializations

Footnotes: K1 – power; K2 – degree of realization of potentialities; K3 – economy; K4 – mobility; K5 – functional stability

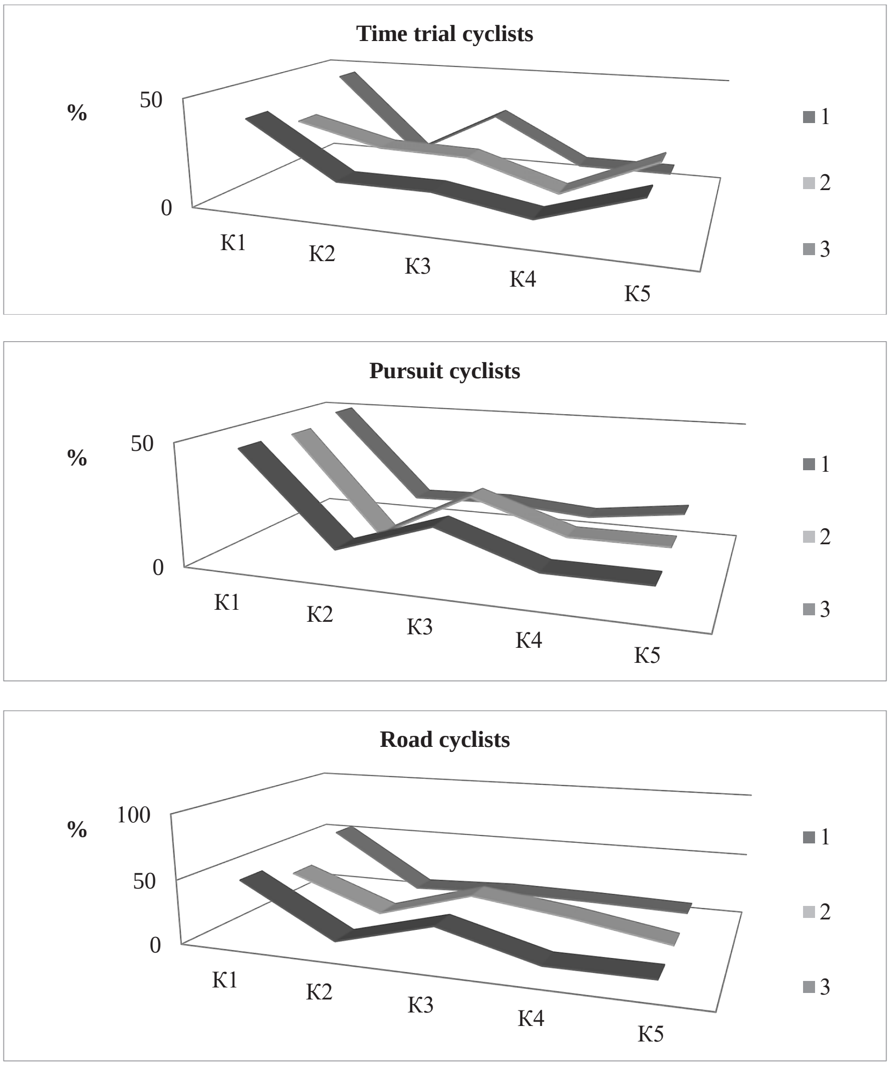

Fig. 3. Individual differences in the specific weight of factors of functional fitness structure of highly skilled cyclists

Footnotes: 1–2–3 – different athletes; K1 – power; K2 – degree of realization of potentialities; K3 – economy; K4 – mobility; K5 – functional stability

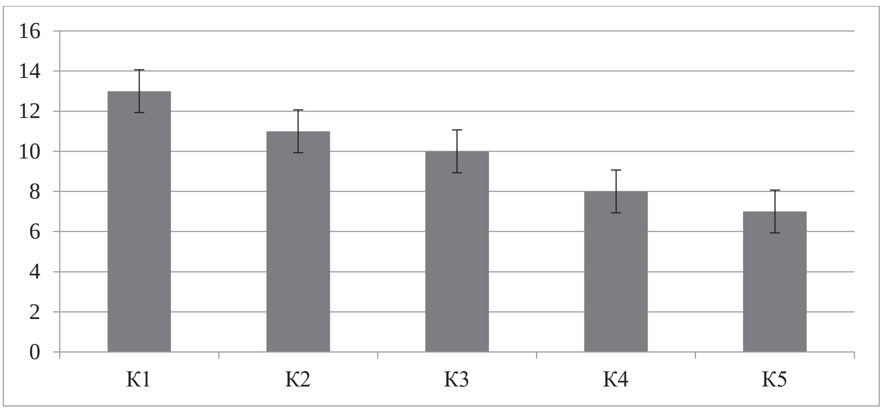

Fig. 4. Degree of changes (variability, %) in the factors of functional fitness structure during the annual preparation cycle of road cyclists (n=18)

Footnotes: K1 – stability; K2 – economy; K3 – realization of potentialities; K4 – mobility; K5 – power

In highly skilled athletes during the annual training cycle, the factors of stability and the power are the most and the least variable, respectively (Fig. 4).

In one and the same athlete, changes in functional fitness structure, reflecting not only the long-term dynamics of the training process content of the athlete, but alterations in his reserve capabilities as well, occur over several years of training. For instance, a tendency to decrease of the specific weight of the mobility and realization factor at a fairly stable level of power and economy is peculiar for a road cyclist, who has been subjected to high training loads over several years.

The maintenance of high special work capacity along with inevitable changes in some of its aspects is provided by increasing the specific weight of the stability factor. The internal factor dynamics of changes is also important, and requires a separate consideration.

Of special interest is the analysis of functional fitness structure in the dynamics of age development, which is combined with practicing sport (rowing, cycling). Fig. 5 presents the average data of changes in each of the five factors of functional fitness in young athletes and untrained individuals in the age period 12 to 20 years. It is not clear yet to what extent the presented dynamics of the functional fitness factors is optimal for the full realization of the body potential capabilities during the period of the highest sports achievements. Such analysis may allow to increase the degree of physiological determinancy of long-term planning of training loads. The rates of development of factors and the presence of the most sensitive periods for their directed change are different.

Most of the *power* criteria of systems are focused on specific values of parameters (per kg, m^2 of body surface). The specific weight of the power factor decreases after 15 years along with a significant increase in the specific weight of the *stability* factor. The specific weight of the *mobility* factor also decreases.

We have analyzed individual cases when an athlete, having achieved good sports results at the age of 17–18, fails to improve them anymore. The analysis of functional fitness structure has shown that in this case the upper limit of the power of the systems of this athlete is reached. The mobility retains the usual age dynamics, and turns out to be at a lower level in these athletes. Factors of stability and realization are at a high level, but do not increase significantly further on. The analysis of functional fitness structure allows us to come closer to the understanding of mechanisms of such changes from the point of view of estimating the reserve capabilities of the growing body as a whole and to determination of ways of targeted influence on their realization.

The outlined functional fitness factors are interrelated. Functional changes, which are peculiar for top-qualification athletes in periods of extremely high sports work capacity, are largely due to the perfection of regulatory processes. The commonality of regulatory mechanisms underlies that of functional fitness factors. Each of the factors influences the other to a greater or lesser extent. Thus, stability is most clearly connected with economy and power, whereas realization depends on stability. Alternative ratios of some factors are possible in the dynamics of training status development.

Factors of functional fitness structure are related to those or other categories (important for sports training) in a different extent. These are phases (states), physical load power, periods of training, and sports preparation as a whole, etc. The factor of *mobility* of systems is of the greatest importance for the effective course of the phase of physical load working in, whereas in the final part – the factors of *stability* and *realization*. If for short-term work the manifestation of the *power* factor of systems and their *mobility* is of decisive importance, then for subcritical power of competitive loads – *economy* and *stability*.

Analysis of the role of these or those factors in the improvement of functional fitness in different periods of training (taking into account the ultimate training effect) demonstrates that the *power* of systems is improved in the preparatory period of training, whereas *mobility* and *realization* are increased in the transition and general preparatory, and mainly the competitive period, respectively.

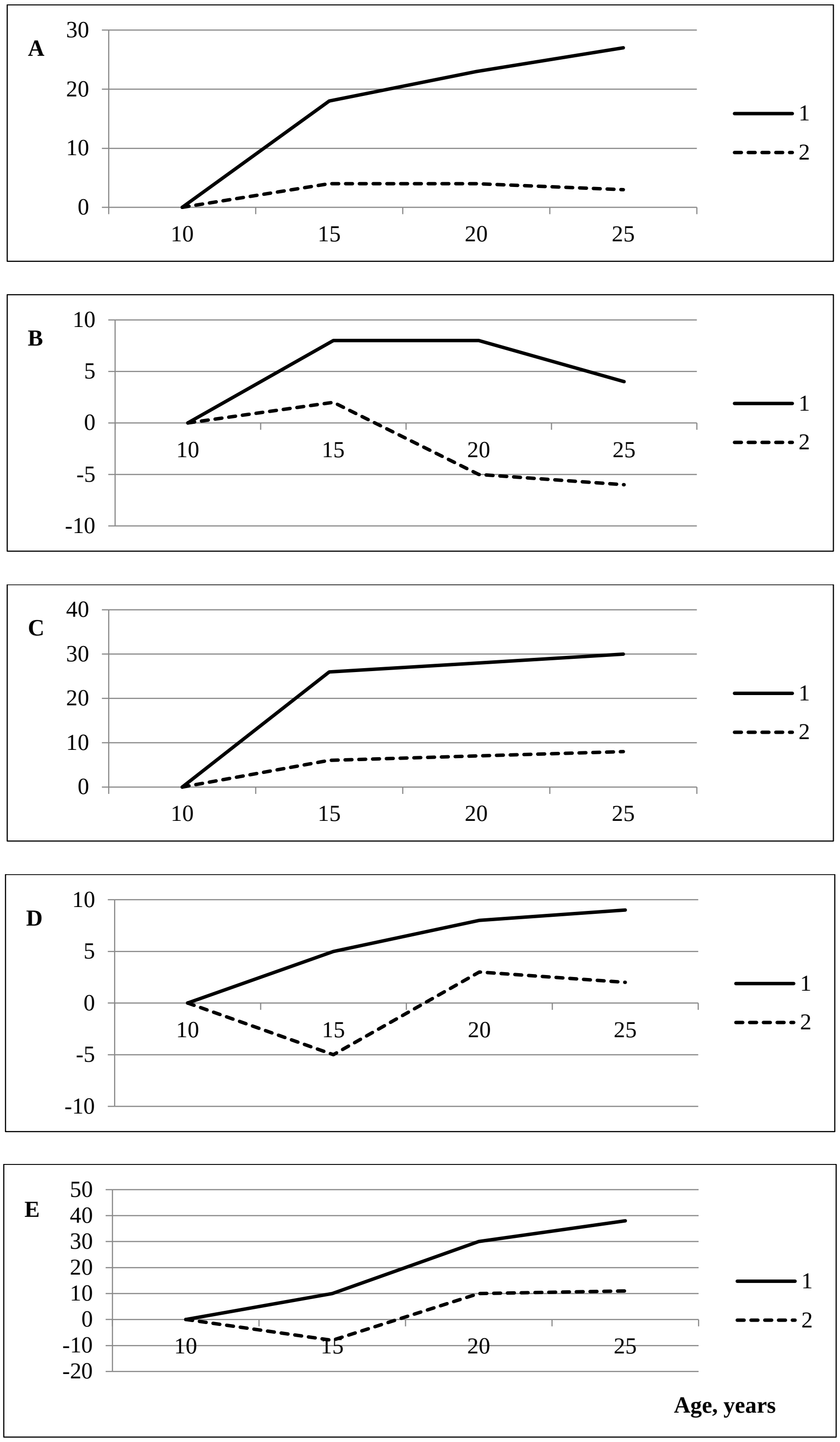

Fig. 5. Change in factors determining functional fitness in the process of age development, which is combined (1) and not combined (2) with sports activities (in % of values at 12 years of age, n=64)
Footnotes: A – power; B – mobility; C – stability; D – economy; E – realization

At the stages of long-term preparation, the greatest increase of power and mobility occurs at the stage of preliminary preparation and initial specialization, whereas the highest improvement of economy and stability is observed at subsequent stages. The analysis of functional fitness structure is also important in terms of expediency of certain aspects of control in the process of training. It allows us to identify functional fitness factors (which are associated with genotypic or phenotypic features). All these issues need to be detailed and clarified in the process of further research.

The study of functional fitness structure indicates significant specificity of physiological adaptations in highly skilled athletes. The high selectivity of adaptive responses at the stage of high sports mastery is as typical as the presence of known general nonspecific adaptation features.

The period of the highest sports work capacity is characterized by high stability of the internal structure of each factor and functional fitness structure as a whole. This is ensured at the expense of the stable maintenance of the law of integration of functions and regulatory properties and indicates the optimality of the control mode.

There are several commonly overlooked but equally important factors of functional fitness that should be monitored and managed as traditionally analyzed ones. There is a fundamental possibility of a targeted impact on the factors of functional fitness structure by specialized means. Application in the training of variable and repeated exercises in a certain mode improves not only aerobic and anaerobic performance and power of systems as a whole, but also increases mobility of systems, although reducing their economy. Prolonged loads of relatively low intensity ("volume training") improve the *economy*, whereas with increasing intensity the *power* is enhanced. At the same time, however, they reduce the *mobility* of systems.

In the process of training session management, a need to balance between the beneficial effect of this or that orientation of training loads and their undesirable influence arises. One of the next stages of research in this direction should be the specification of training means in relation to the factors of functional fitness structure and the development on this basis of a system of targeted functional fitness improvement. No less important is the study of the ratio of factors for the greatest individual efficiency of sports work capacity, i.e. their optimization levels, the possible leading role of improving the factors in ensuring the growth of functional fitness and sports results at an elite level.

The analysis of functional fitness structure provides more in-depth consideration of some aspects of the theoretical analysis of functional fitness. Further study of functional fitness factors, clear identification of indices of their evaluation, and integrative quantitative expression will allow to consider the most general concepts important for the evaluation of functional fitness (reliability, reserve capabilities, etc.). Such a program can be implemented in a diagnostic model of functional fitness. We assume that reliable functional fitness and stability of competition form takes place only at a certain individual ratio and dynamics of functional fitness factors.

Conclusions

Analysis of the functional fitness of athletes who specialize in cyclic sports events is far from exhausting all necessary aspects of the study of the body functional states in the process of adaptation to high training loads, but is only an important part of it. In practice (apart from evaluating functional fitness structure) other diagnostic tasks may arise, which are related to determining the potential (reserve) capabilities of an athlete, load tolerance, approaching the peak of functional fitness, evaluating the overall intensity of training, predicting the dynamics of the functional state, etc.).

Of great importance in the diagnosis of functional fitness, belongs to the development of methods for analyzing and evaluating the properties of regulation of functions that underlie the provision of work capacity in cyclic sports events, as well as some other parameters that reflect the body functional potential.

Determination of the regulation properties of the major functional systems not only helps to explain the mechanisms of formation and manifestation of the factors of functional fitness structure and to obtain additional information about them, but also can serve as a very efficient independent criterion for analyzing the body functional potential. Further development of the suggested methodology of functional fitness assessment will allow to generalize the existing great variety of data, to plan the application of methods of functional fitness testing, and to channel them into the direction of targeted control for managing key properties (factors) of athletes' functional fitness.

Conflict of interest

The authors declare that there is no conflict of interests.

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