ФІЗИЧНА КУЛЬТУРА І СПОРТ

SPECIALIZED FUNCTIONAL PROPERTIES OF MUSCULAR ACTIVITY ENERGY SUPPLY SYSTEM OF HIGHLY SKILLED CYCLISTS OF DIFFERENT SPECIALIZATION

СПЕЦІАЛІЗОВАНІ ФУНКЦІОНАЛЬНІ ВЛАСТИВОСТІ СИСТЕМИ ЕНЕРГОЗАБЕЗПЕЧЕННЯ М'ЯЗОВОЇ ДІЯЛЬНОСТІ ВИСОКОКВАЛІФІКОВАНИХ ВЕЛОСИПЕДИСТІВ РІЗНОЇ СПЕЦІАЛІЗАЦІЇ

Kolumbet A. N.[1], Paryshkura Yu. V.[2]
[1, 2]State University of Trade and Economics, Kyiv, Ukraine
[1]ORCID:0000-0001-8775-4232
[2]ORCID:0000-0002-8777-1726

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Abstracts

Purpose is to analyze the functional features of the body energy supply system, which are specific to high levels of special work capacity in cycling. Material and methods. In total 44 highly skilled cyclists were examined: 16 athletes specializing in road team racing, 12 athletes specializing in 4000 m pursuit, 9 athletes specializing in 1000 m time trial, and 7 athletes specializing in sprint. The studies were conducted in 2017–2019. A complex methodology for determining the level of functional fitness was used. It included the registration of the main parameters of gas exchange, external respiration, blood, and cardiovascular system at different loads. Results. The highest values of MOC (70.2±0.63 ml.min.kg^{-1}), VC (6985±5.219 ml), maximum minute volume of blood circulation (36.6±0.37 l.min.$^{-1}$), systolic volume (201.5±5.17 ml), the amount of oxygen transported by arterial blood (91.7±4.06 ml.min.kg^{-1} of body weight), lung diffusion capacity at MOC (102.5±2.96 ml.min.$^{-1}$, mmHg), and some other indices were registered in road racers. Cyclists specialized in sprint and time trials were distinguished by the highest values of CO_2 excretion rate at supercritical working efficiency, "alactate" and "lactate" power, high ratio of ventilation and circulation to gas exchange. In addition, they had the highest buffer capacity (51±0.7 meq.l^{-1}), sensitivity to CO_2 (34.4±3.92 ml.min.$^{-1}$ mmHg.kg^{-1}), and the rate of rapid CO_2 storage (98 ml.min.$^{-1}$, mmHg). The values of MOC in sprinters (54.8±1.21 ml.min.kg^{-1}) were significantly lower than in cyclists specialized in time trials (62.6±0.86 ml.min.kg^{-1}) and pursuit (67.3±1.05 ml.min.kg^{-1}). Conclusions. Specialization in different types of cycling races significantly affects both the work capacity in tests and the dynamics of the maximum manifestations of the indices of gas exchange, external respiration, blood circulation, blood gas transport, and changes in the body internal milieu. The economy of functional responses during the work of critical power is higher in road racers and cyclists specialized in pursuit. The highest level of aerobic power development is observed in road racers, whereas the lowest value of this index is characteristic of sprinters. The highest value of anaerobic power is noted in athletes specialized in time trials, whereas the ability to explosive energy expenditure is peculiar for sprinters.

***Key words*:** cyclists, external respiration, energy supply, oxygen transport system, blood circulation.

Мета – аналіз функціональних рис системи енергозабезпечення роботи організму, які характерні для високих рівнів спеціальної працездатності у велоспорті. **Матеріал та методи.** Досліджено 44 велосипедисти високої кваліфікації: 16 спортсменів, які спеціалізуються в шосейних командних гонках, 12 спортсменів, які спеціалізуються в гонках переслідування на 4000 м на треку, 9 спортсменів, які спеціалізуються у гіті на 1000 м на треку, і 7 спортсменів, які спеціалізуються у спринті на треку. Дослідження проводилися в період 2017–2019 років. Застосовували комплексну методику визначення рівня функціональної підготовленості. Методика включала реєстрацію основних параметрів газообміну, зовнішнього дихання, крові, серцево-судинної системи під час різних навантажень. **Результати.** У велосипедистів (шосе) зареєстровані найбільші величини МСК (70.2±0.63 мл.хв.кг$^{-1}$), ЖЄЛ (6985±5.219 мл), максимального хвилинного об'єму кровообігу (36.6±0.37 л.хв.$^{-1}$), систолічного об'єму (201.5±5.17 мл), кількості кисню, що транспортується артеріальною кров'ю (91.7±4.06 мл.хв.кг$^{-1}$ ваги тіла), дифузійної здатності легенів при МСК (102.5±2.96 мл.хв.$^{-1}$, мм.рт.ст.) і деяких інших показників. Велосипедисти (спринт та гіт) виділялися найвищими величинами швидкості виведення CO_2 у разі надкритичної потужності роботи, «алактатної» і «лактатної» потужності, високим відношенням вентиляції та циркуляції до газообміну. У них же відзначена найбільша місткість буферних підстав (51±0.7 мекв.л$^{-1}$), чутливість до CO_2 (34.4±3.92 мл.хв.$^{-1}$ мм.рт.ст.кг$^{-1}$), швидкість швидкого запасання CO_2 (98 мл.хв.$^{-1}$, мм.рт.ст.). Величини МСК у велосипедистів (спринт) – 54.8±1.21 мл.хв.кг$^{-1}$ були достовірно нижчі, ніж у велосипедистів (гіт) – 62.6±0.86 мл.хв.кг$^{-1}$ і велосипедистів (переслідування) – 67.3±1.05 мл.хв.кг$^{-1}$. **Висновки.** Спеціалізація в різних видах велосипедних гонок істотно впливає і на працездатність у тестах, і на динаміку максимальних проявів показників газообміну, зовнішнього дихання, кровообігу, транспорту газів кров'ю, зрушень внутрішнього середовища організму. Економічність функціональних реакцій під час роботи критичної потужності вище у велосипедистів (шосе) і велосипедистів (переслідування). Найбільш високий рівень розвитку аеробної потужності спостерігається у велосипедистів (шосе), а найнижча величина цього показника характерна для велосипедистів (спринт). Найбільша величина анаеробної потужності відзначається у спортсменів, що спеціалізуються в гіті, а здатність до вибухового витрачання енергії – у спринті.

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

Introduction. The training of elite athletes represents an extremely complex multifactorial process that relies on the methodology of physical education, the practice of the training process, and modern achievements of medico-biological science [5; 71].

The functional fitness of an athlete is an integral index, which is determined by a set of body different properties [10; 20]. First of all, it is the ability of the cardiorespiratory system to provide the working organs and tissues with oxygen and energy substrates. Its efficiency depends on the performance of cardiovascular and respiratory systems, volume, and composition of circulating blood [26; 65; 74].

The analysis of scientific studies in the field of elite sports indicates that the morphofunctional and metabolic shifts in the body, which determine the economy of the work of systems and organs, the speed of deployment of the cardiorespiratory system functional reactions and metabolism to the performed physical load are the basis of athletes' functional fitness [22; 31; 45; 47].

To determine the functional fitness level and assess body adaptation to physical loads in the process of sports training, national and foreign experts in the field of sports physiology recommend determining the state of the cardiorespiratory system [49; 57; 77]. In addition, it is necessary to study the responses of the blood oxygen transport function at rest and after physical loads of different orientations in order to investigate the acute, delayed, and cumulative training effects [6; 16]. Such studies allow to determine the dynamics of functional changes that develop in the process of sports training and may indicate an increase in the functional capabilities of the body or fatigue [11; 61].

Analysis of athletes' functional fitness in the dynamics enables to assess the body adaptation to physical loads and identify factors that limit the work capacity of the athlete. It ultimately permits to optimize the training process and increase the effectiveness of competitive activity [58; 63; 75].

The functional state of external respiration in sports has always been given great importance as a factor that reflects the ability of the body to long-term, extensive muscular activity [6; 19].

In the conditions of sports activity, extremely high requirements are imposed on the external respiratory apparatus, the realization of which ensures the effective functioning of the entire cardiorespiratory system. Pulmonary ventilation is the most important indicator of the external respiratory system functional state [21; 27; 59].

Researchers [60; 64] note the need to emphasize the attention of specialists not only to the issues related to the assessment of long-term adaptation of the athlete's body to the training loads but also to the problems of recovery and strengthening of the respiratory system of athletes.

It is believed that the maximum development of the respiratory system functional capacities is peculiar to athletes of cyclic sports events, during training sessions of which endurance is preferentially developed [7; 30]. Consideration of respiratory parameters during training enables to increase its efficiency significantly. The study of the external respiration peculiarities in athletes allows not only to assess their functional state, but also contributes to the optimization of training [29; 36].

Some researchers [37; 42; 56] propose to use the coefficient of complex oxygen supply to assess the functional capacities of the athletes' bodies. This index allows the assessment of compensatory and adaptation responses of the body when performing the load of increasing power. A number of other researchers [68; 76] have developed a methodology for determining the current state of cardiovascular and respiratory systems in athletes. It allows for the evaluation of functional capacities during online mode training.

It was found that both the work capacity indices (according to the PWC_{170} test) and the functional parameters of the respiratory system (number of respiratory cycles per minute, inspiration and expiration breath-hold, and maximum oxygen consumption) increased as the athletes grew older [14; 24; 34].

The state of the cardiorespiratory system is of great importance in the body adaptation to physical loads [9; 13]. Indices of external respiration illustrate the body adaptation to specific loads [8; 17; 38]. Correlations between vital capacity of lungs and duration of inhalation, respiratory rate with inhalation and exhalation duration have been established, which illustrate the increase of functional reserves. According to morphological features, athletes do not differ from the standards, whereas according to physiometric and functional indices of the external respiratory system they significantly exceed their peers [4; 12; 35]. This characterizes the range of functional reserves, and the obtained correlations reflect the orientation of the adaptation process in specific conditions of sports event [2; 18; 33].

The competitive activity analysis of boxers from the standpoint of sports physiology confirmed the possibility of using respiratory technologies to increase the aerobic capacity of athletes [40; 48; 54].

Athletes of different specializations are distinguished by high work capacity primarily in the types of muscular activity that they are accustomed to. This is due to the corresponding morphofunctional and physiological adaptation mechanisms [54; 62]. Such differences are formed during a certain period of cumulation of a certain range of the same-type effects on the body according to the key mechanism.

Sports pedagogy has developed practically substantiated forms of combinations of exercises and training sessions, repeated or alternating in a certain sequence of muscle loads, maximally contributing to the selective improvement of some aspect of human physical work capacity [4; 41; 51]. There are also other aspects of specialized body adaptations associated with differences in the total mass and structure of muscle groups involved in work, the posture, and the environment in which it is performed [4; 53].

As for the highly specialized adaptation mechanisms providing special work capacity of highly skilled athletes, these issues have been studied only piecewise.

Objective is to analyze the functional features of the body energy supply system, which are specific to high levels of special work capacity in cycling.

Materials and methods. *Participants*. In total 44 highly skilled cyclists were examined: 16 athletes specializing in road team racing, 12 athletes specializing in 4000 m pursuit, 9 athletes specializing in 1000 m time trial, and 7 athletes specializing in sprint. The studies were conducted in 2017–2019.

Metods. The testing program performance took a total of two hours. In terms of the total amount of work, intensity of energy expenditure, and subjective feeling of load heaviness, the testing can be equated to a training session.

Testing program:

1. Warm-up (5 min.) without load on the cycle ergometer wheel and (5 min.) with a load of 2.0 kg, pedaling frequency 100 rpm^{-1}.
2. Test No. 1 (Wn): a block of specialized functional 15-second tests with a wheel load of 1-2-3-4-5-6 kg.
3. Rest (10 min.): pedaling without load.
4. Test No. 2 (Wmax): athletes performed the maximum volume of work in 60 seconds with a load of 5.0–5.6 kg.
5. Rest (10 min.): pedaling without load.
6. Test No. 3 (Wst): stepwise ergometric load, starts at 1200 kgm.min^{-1} power and increases every 2 min by 150 kgm.min.$^{-1}$. This load was continued until the athlete was unable to maintain the target pedaling frequency within 5% (100 rpm^{-1}).
7. Rest (10 min.): pedaling without load.
8. Test No. 4 (Ws): standard work (15 min.) with a constant work power of 3 watts per kilogram of body mass.
9. Rest (10 min.): pedaling without load.
10. Test No. 5 (Wcr): critical power work "to failure". Critical power was defined as the lowest power of work at which the maximum oxygen consumption (MOC) is reached.

Athletes were examined (Fig. 1) using a stationary gas analyzer *"Oxycon Pro"*, a cycle ergometric device by *"Monark"* (Sweden), and a telemetric heart rate analyzer T31 *"Polar"* (Finland).

Fig. 1. Testing in the laboratory

We determined the interrelated parameters of gas exchange, external respiration – frequency, depth, respiratory minute volume, alveolar ventilation, O_2 and CO_2 content in exhaled and alveolar air, main pulmonary volumes; indices of diffuse conductivity – respiratory and circulatory components; blood circulation – minute blood volume according to Defar in modification of V.S. Mishchenko [32; 72]. Systolic volume, pulse, arterial tension, proportion of venous blood admixture; blood respiratory function – blood oxygen capacity, hemoglobin content, O_2 and CO_2 tension in blood, O_2 tension in arterialized blood according to Astrup, arterial blood oxygen saturation by oxyhemometry method using a special calibration method; body temperature of the athlete; indices of arterialized blood acid-base balance, and the content of lactic acid and glucose in it.

The study of the oxygen transport system of the athletes' bodies during physical load involved the analysis of oxygen and carbon dioxide parameters in parallel with the analysis of the activity of the main functional systems that determine them. Quantitative and qualitative assessment of the correlations between the indices of work capacity and O_2 consumption – CO_2 release, other oxygen and carbon dioxide parameters and functional indices were investigated.

Blood lactic acid concentration was determined using a *"Biosen S.-Line lab+"* analyzer (according to Barker-Summerson in Strom's modification) at the 3rd and 5th minutes of the recovery period.

The following generalized physiological properties determining the dynamics of functional fitness were identified for analysis: systems power (functional and energetic), stability (functional and metabolic), mobility of systems reflecting the speed of deployment of functional and metabolic reactions, as well as economy (functional and energetic) and the degree of the body functional potential realization in specific conditions of extreme intensity work [3; 15; 28].

To increase the reliability of the tests, the method of parallel forms was used, in which several indices that characterize one of the aspects of an athlete's functional fitness are applied [43; 44].

The data obtained in the competitive period of training were used.

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.

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. Specialization in different types of cycling races significantly affects both the work capacity in tests and the dynamics of maximum (peak) manifestations of indices of gas exchange, external respiration, blood circulation, blood gas transport, and shifts in the body internal milieu.

The highest values of MOC (70.2±0.63 ml.min.kg^{-1}), VC (6985±5.219 ml), the maximum minute volume of blood circulation (36.6±0.37 l.min.$^{-1}$), systolic volume (201.5±5.17 ml), the amount of oxygen transported by arterial blood (91.7±4.06 ml.min.kg^{-1} of body weight), lung diffusion capacity at MOC (102.5±2.96 ml.min.$^{-1}$, mmHg), and some other indices were registered in road racers. Cyclists specialized in sprint and time trials were distinguished by the highest values of CO_2 excretion rate at supercritical working efficiency, "alactate" and "lactate" power, high ratio of ventilation and circulation to gas exchange. In addition, they had the highest buffer capacity (51±0.7 meq.l^{-1}), sensitivity to CO_2 (34.4±3.92 ml.min.$^{-1}$ mmHg.kg^{-1}), and the rate of rapid CO_2 storage (98 ml.min.$^{-1}$, mmHg). The values of MOC in sprinters (54.8±1.21 ml.min.kg^{-1}) were significantly lower than in cyclists specialized in time trials (62.6±0.86 ml.min.kg^{-1}) and pursuit (67.3±1.05 ml.min.kg^{-1}).

Differences in the efficiency of gas exchange processes (one of the physiological mechanisms of their stability) are manifested in the final part of critical power work (Wcr) "to failure". In this case, the economy of functional reactions is higher in road racers and pursuit riders. The duration of such work in road racers is significantly higher than in cyclists of other specializations (Table 1). These differences are even more pronounced when calculating the total amount of work performed per kilogram of body mass.

Differences in carbon dioxide excretion are most clearly manifested under conditions of respiratory compensation for metabolic acidosis, «excess» CO_2 excretion. This period ("anaerobic transition threshold") begins relatively later in road racers and earliest in sprinters. The same applies to an increase in lactate concentration above 4 mmol.l^{-1}. The highest and the lowest manifestations of hyperventilation to the same degree of acidemia were observed in sprinters and road racers, respectively.

The range of the blood acid-base state changes in cyclists of different specializations during strenuous muscular activity reflects specialized features of involvement of buffer and functional compensatory mechanisms under conditions of acidemic shifts (Fig. 2).

Dynamics of blood pH (Fig. 2) and lactate (Fig. 3) in cyclists of different specializations have common and specific features. More intensive work causes more pronounced acidosis. Differences in the degree of developing acidemia also depend on specialization [76]. The greatest range of changes in P_ACO_2, pH, and the power of the body buffer systems is observed in track cyclists (time trial, pursuit).

The general direction of adaptation development in highly skilled cyclists of different specializations can be characterized by the key physiological properties of the body systems. Thus, the "power" of the body functional systems

Table 1

Indices of oxygen transport system and energy supply of critical power work (Wcr) in cyclists of different specialization (M±m)

Indices	road racing	track		
		pursuit	time trial	sprint
Wcr, $w.kg^{-1}$	5.11±0.55	4.71±0.09	4.33±0.13	–
tWcr, min.	10.2±0.96	7.16±0.56	6.25±0.56	–
tHRWcr, min.	3.6±0.07	4.5±0.33	5.2±0.15	–
$La_{max}Wcr$, $mmol.l^{-1}$	7.48±0.16	8.76±0.38	7.6±0.53	–
$pH_{min}Wcr$,	7.31±0.01	7.29±0.01	7.32±0.02	–
EVHRWcr, %	96.5±0.48	96.0±0.31	97.3±0.42	–
AnT, $w.kg^{-1}$	4.22±0.04	3.92±0.08	3.28±0.11	–
P_ACO_2, mmHg	27.8±0.37	26.1±1.52	25.5±0.86	22.5±0.82

Footnotes: Wcr – critical power work; P_ACO_2 – partial pressure of carbon dioxide in arterial blood; tWcr – time to maintain critical power work; tHRWcr – time to restore heart rate to 120 bpm^{-1} at critical work power; $La_{max}Wcr$ – blood lactate level at critical work power; $pH_{min}Wcr$ – blood acidity at critical work power; AnT – threshold of anaerobic metabolism; EVHRWcr – efficiency of respiration system by pulse at critical work power

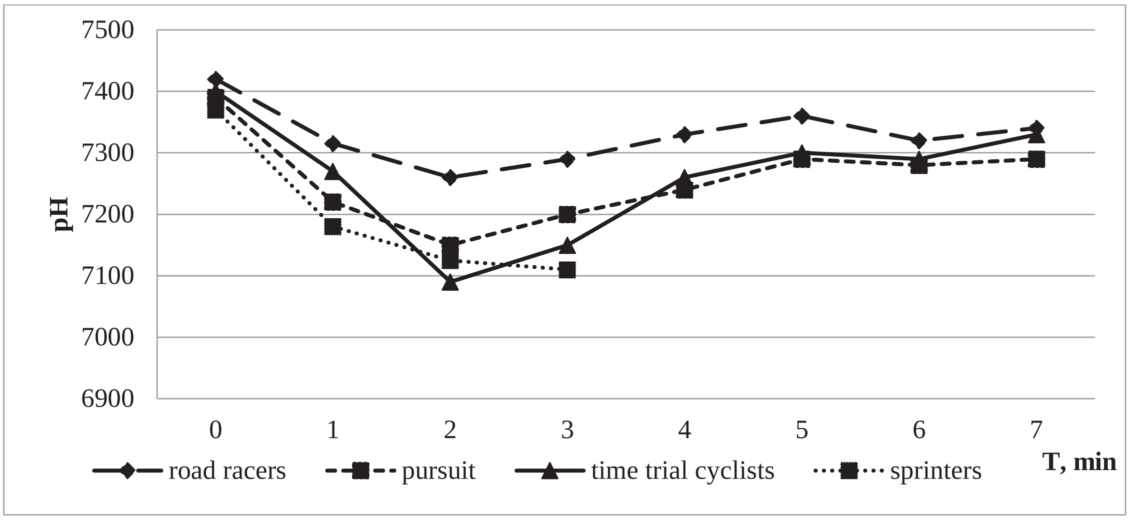

Fig. 2. Dynamics of pH in the arterial blood of high-class cyclists of different specializations during a performance of a complex testing program (1-2-3-4-5-6-7 points of blood sampling). Baseline – rest. 1 – 4th min after 15-s acceleration (6 kg); 2 – 4th min after 1-min work; 3 – 8th min after 1-min work; 4 – immediately after incrementally increasing work power; 6 – immediately after maintaining critical work power; 7 – 4th min after maintaining critical work power

reflects the ability of the oxygen transport system and energy processes to achieve short-term highest (peak) values of the intensity of functioning. The highest level of aerobic power development is observed in road racers, whereas the lowest value is characteristic of sprinters (Table 2). The highest value of "anaerobic power" is noted in athletes specialized in time trials, whereas the ability to explosive energy expenditure is peculiar to sprinters.

As a result of the research, a certain correlation between "lactate power" and body weight was found (Fig. 4).

When analyzing such indices as duration of work at critical power, HR functional stability coefficient, the process of O_2 utilization in alveoli at standard or critical power of work according to ventilation equivalent for O_2 and some others, the highest functional stability of cyclists specialized in road racing is determined.

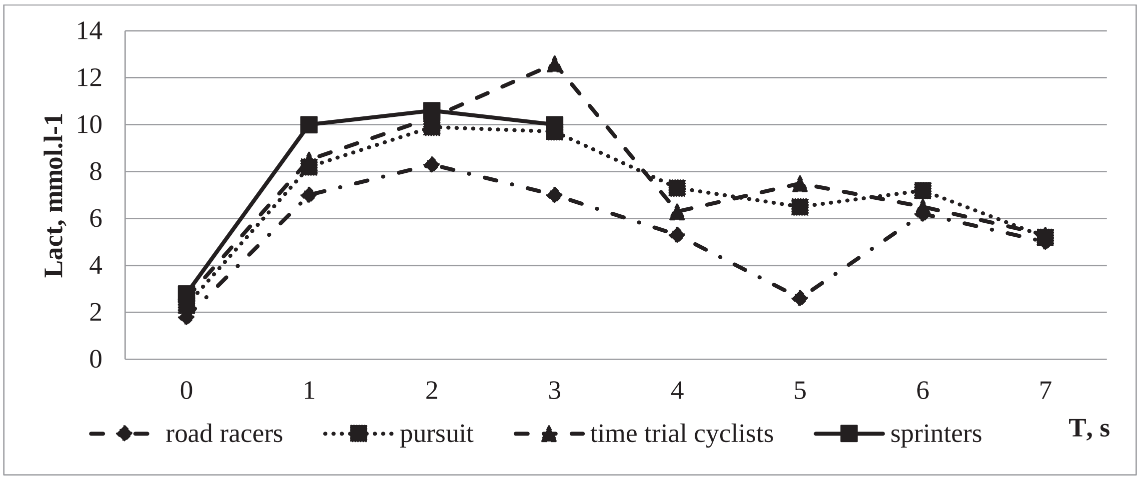

Fig. 3. Dynamics of lactic acid concentration (Lact) in the arterial blood of high-class cyclists of different specializations while performing a complex testing program (1-2-3-4-5-6-7 points of blood sampling). Baseline – rest. 1 – 4th min after 15-s acceleration (6 kg); 2 – 4th min after 1-min work; 3 – 8th min after 1-min work; 4 – immediately after incrementally increasing work power; 6 – immediately after maintaining critical work power; 7 – 4th min after maintaining critical work power

Table 2

Indices of oxygen transport system and energy supply of stepwise power work (Wst) in cyclists of different specialization (M±m)

indices	road racing	Track		
		pursuit	Time trial	sprint
VO_2/HRWst, ml.beats^{-1}	62.0±1.27	42.0±2.31	56.0±2.79	–
AnT, w.kg^{-1}	4.22±0.04	3.92±0.08	3.28±0.11	–
P_ACO_2, mmHg	27.8±0.37	26.1±1.52	25.5±0.86	22.5±0.82

Footnotes: P_ACO_2 – partial pressure of carbon dioxide in the arterial blood; VO_2/HRWst – the ratio of oxygen consumption and pulse during stepwise work; AnT – threshold of anaerobic metabolism

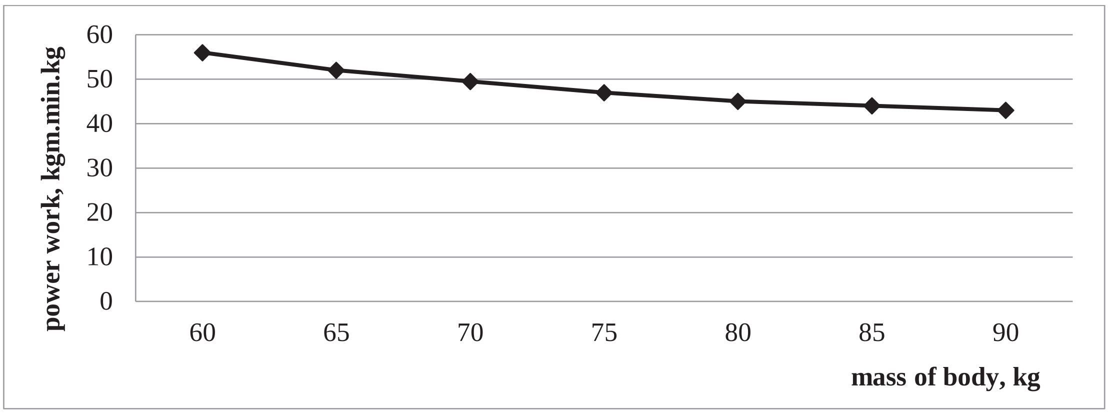

Fig. 4. Relationship between lactate load power and body weight in skilled cyclists

Differences in HR stability and O_2 utilization, systolic volume, and blood O_2 utilization during prolonged standard work indicate possible physiological mechanisms for these differences.

It should be noted that cyclists of different specializations differ both in general and specialized stability. For instance, road racers are distinguished by a high capacity of carbohydrate stores, characteristic of prolonged strenuous work, along with lactate utilization. They are characterized by a stable, although decreased level of sensitivity and "functional reactivity" to standard levels of stimuli adequate for the system of external respiration and hemodynamics. In addition, they are characterized by the stability of cardiac rhythm regulation and a number of other features of regulating oxygen transport system functions [23].

Cyclists specialized in pursuit are distinguished by a highly specialized ability to maintain a high level of aerobic processes (along with a high level of anaerobic metabolism).

The speed of deployment of functional and metabolic reactions in the initial period of work also has significant differences depending on the specialization of athletes (Table 3, Fig. 5–6).

The dynamics of O_2 consumption and pedaling speed during the one-minute maximal load indicate the highest functional mobility of time trial cyclists during the initial period of work (Fig. 5–6).

Sprinters have the lowest speed of deployment of reactions. This is explained by the fact that during short-term work of maximum power, respiratory functional reactions are usually developed intensively only after work [25]. The

Table 3

Indices of oxygen transport system and energy supply of standard power work (Ws) in cyclists of different specialization (M±m)

indices	road racing	Track		
		pursuit	time trial	sprintFootnotes
CFSHRWs, %	5.03±0.34	5.9±0.44	5.3±0.43	–
$CFSV_EWs$, %	8.1±0.38	8.9±0.26	9.3±0.28	–
WHRWst, $w.beats^{-1}$	1.57±0.04	1.23±0.01	0.16±0.02	–
$VO_2/HRWs$, $ml.beats^{-1}$	62.0±1.27	42.0±2.31	56.0±2.79	–
M_EWs, %	32.2±0.65	30.6±1.18	29.3±0.83	–
V_EWs	24.4±0.34	26.5±0.85	27.5±0.77	–
Wst_{50}, s	15.6±0.74	14.1±0.51	12.1±0.38	–
P_ACO_2, mmHg	27.8±0.37	26.1±1.52	25.5±0.86	22.5±0.82

Footnotes: P_ACO_2 – partial pressure of carbon dioxide in the arterial blood; tWcr – time to maintain critical power work; CFSHRWs – coefficient of pulse functional stability during work of standard power; $CFSV_EWs$ – coefficient of functional stability by V_E during work of standard power; WHRWs – load to pulse ratio during work of standard power; Wst_{50} – time constant of the start of work of standard power; M_EWs – mechanical efficiency of work of standard power; V_EWs – ventilation equivalent according to oxygen of work of standard power

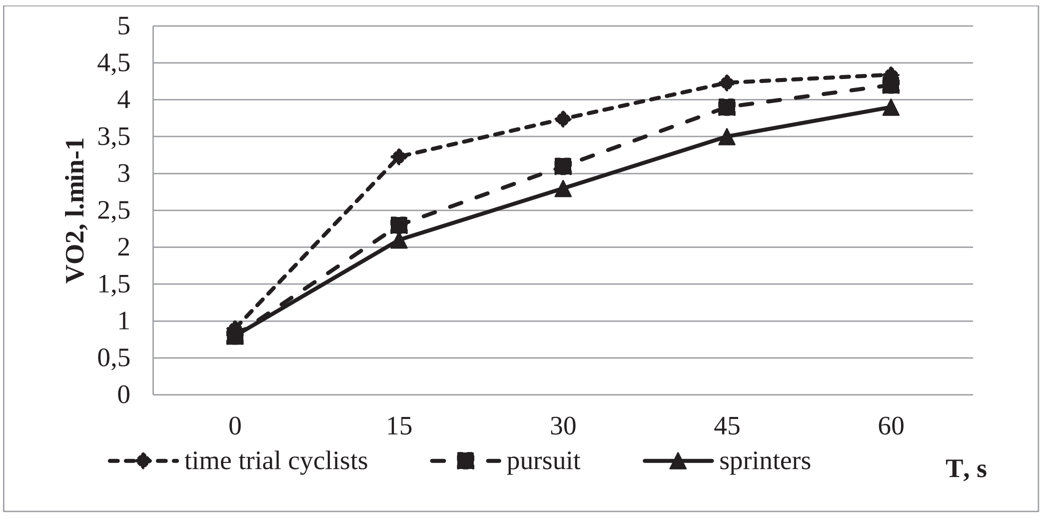

Fig. 5. Oxygen consumption dynamics during maximum one-minute load in highly skilled cyclists (track) of different specialization

road racers lag behind time trial cyclists in the development of this capacity. Differences in the rate of deployment of ventilation reactions, HR, and gas exchange are most pronounced at a load specialized for time trial cyclists (1 min.). It is of interest to note that, as a rule, only the time trial cyclists tend to reach maximum levels of functions and O_2 consumption by the end of this work (45th–60th seconds). The other aspect of functional mobility – the rate of HR recovery, pulmonary ventilation, cardiac output, and lactate utilization rate – was found to be higher in road racers and pursuit riders.

One of the important aspects of training status formation is the economization of functions and work [46]. The properties of the economy were assessed by a set of functional indices – mechanical efficiency of work, the relationship between changes in O_2 consumption and HR, some hemodynamic and biochemical parameters. The greatest economy in this analysis was revealed in athletes who specialize in road racing, whereas the least – in time trial cyclists. Significant development of the economy is not characteristic of athletes who specialize in time trials. However, there are grounds to assume the presence of specific manifestations of economy in this type of specialization as well. They are found during work of maximum power (Wmax) and are associated with the ratio of its frequency-force parameters and vegetative support of working muscles. That is, at such a high strength component of work due to the high rate of development of aerobic reactions, the energy economy already after 30–35 s turns out to be the highest just in time trial cyclists (Table 4). There are other factors of specialized economy that require further study [52].

Determining the degree of the respiratory system potential realization is one of the most difficult tasks in assessing the athletes' functional fitness [50]. A number of criteria that take into account the degree of using morphofunctional prerequisites available in the athlete to maximize the key parameters of work energy supply and his ability to achieve the maximum levels of aerobic performance in conditions of special loads were used. The data obtained indicate the highest level of this factor development in time trial cyclists. Road racers and pursuit riders are somewhat behind them.

Therefore, specialized to a different extent features of physiological adaptation of the gas transport system of highly skilled cyclists are revealed. During the formation of the highest level of training status, not only does the specialization of changes in metabolism, energy supply, and mode of muscular work take place,

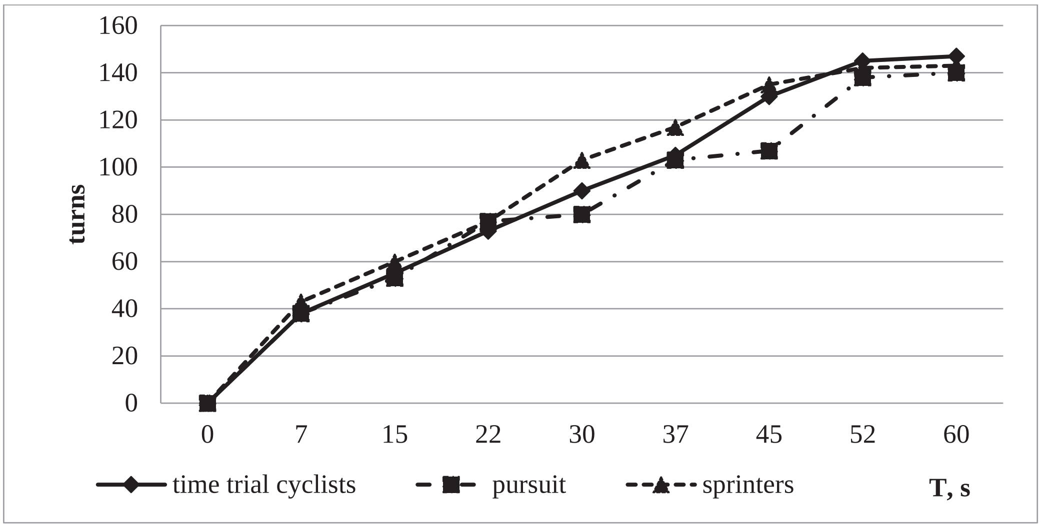

Fig. 6. Dynamics of the number of the cycle ergometer wheel revolutions at maximum one-minute load in highly skilled cyclists (track) of different specialization

but the specificity of the whole complex of key functional features of the body system. In the conditions of training of different orientations, the adaptation of functional systems providing gas transport in the body is also specific [55].

Cumulation of training effect for specialized development of speed-strength qualities of sprinters has a clearly pronounced specialized character. In such a case, there is no significant increase in the delivery of oxidation substrates and respiratory gas transport. At the same time, a significant increase in HR is observed, which occurs already in the first seconds after the beginning of work. It has a reflexive character, without close conditioning by the energy of work, represents a "preventive" reaction, and is aimed at increasing the reliability of metabolic support of motor activity as a whole [70].

Circulatory response has clearly expressed specialized features in all types of training and is a universal adaptive response, including in sprinters. However, the degree of circulatory shift during speed-strength training in sprinters is below the threshold necessary to achieve the training effect of influence on this system. The trainability of the specialized circulatory response during different types of training in cycling is related not only to the degree of shift, but its speed as well [73]. The latter either increases or decreases under the impact of training, often exceeding the degree of shift.

When cyclists specialize in types of sports work of about one minute and about 4–5 minutes duration (i.e., in time trial and pursuit races), the metabolic role of the circulatory response and the glycolytic energy supply system is dramatically increased in limiting work capacity. Specialized training influences are largely associated with them, although they extend further.

In terms of the formation of specialized functional properties, the stability of functions, their "reserve" capacity or functional reserve of organs, buffer systems of the body are becoming increasingly important [66]. Specialized

Table 4

Indices of oxygen transport system and energy supply of maximum power work (Wmax) in cyclists of different specialization (M±m)

Indices	road racing	Track		
		pursuit	time trial	sprint
VO_2max, ml.min.kg^{-1}	70.2±0.63	67.3±1.05	62.6±0.86	54.8±1.21
HRmax/HRmin , %	420±8.57	400±9.05	360±16.7	330±23.1
O_2 -HRmax, ml/beats	29.4±0.41	27.9±0.43	25.2±0.62	24.0±0.86
SPmax •HRmax/100	389±7.58	401±11.1	396±14.3	301±8.36
aLaWmax, w.kg^{-1}	0.20±0.003	0.20±0.006	0.21±0.004	0.22±0.005
LaWmax, w.kg^{-1}	7.86±0.19	8.09±0.17	8.41±0.20	8.20±0.16
EPOCWmax, ml.kg^{-1}	110±3.6	116±10.2	127±10.1	150±8.75
LaWmax, mmol.l^{-1}	9.50±0.27	11.8±0.22	11.8±0.5	12.0±0.84
pHminWmax,	7.19±0.01	7.12±0.02	7.09±0.02	7.07±0.02
V_EWmax, meqv.l^{-1}	-16.7±0.31	-20.5±0.51	-21.0±0.57	-23.1±0.46
VO_2Wmax, number	1.97±0.08	2.50±0.18	2.85±0.11	–
Wmaxt$_{50}$, s	9.5±0.19	–	–	–
EVHRWmax, %	90.2±0.37	90.6±0.34	94.6±0.64	–
EVO_2Wmax, %	73.5±0.74	77.4±0.61	83.1±0.58	–
AnT, w.kg^{-1}	4.22±0.04	3.92±0.08	3.28±0.11	–
P_ACO_2, mmHg	27.8±0.37	26.1±1.52	25.5±0.86	22.5±0.82

Footnotes: VO_2max – maximal oxygen consumption; HRmax/HRmin – ratio of maximum and minimum pulses; O_2-HRmax – ratio of oxygen consumption to pulse; SPmax •HRmax/100 – ratio of systolic pressure to pulse; aLaWmax – alactate power of maximum power work; LaWmax — lactate power of maximum power work; EPOCWmax – oxygen debt during work of maximum power (excess post-exercise oxygen consumption); pHminWmax – blood acidity during work of maximum power; V_EWmax – ventilatory oxygen equivalent during work of maximum power; P_ACO_2 – partial pressure of carbon dioxide in arterial blood; VO_2Wmax – rate of oxygen consumption increase during work of maximum power; Wmaxt$_{50}$ – time constant of start of maximum power work; AnT – anaerobic metabolic threshold; EVHRWmax – respiratory system efficiency by pulse during work of maximum power; EVO_2Wmax – respiratory system efficiency by oxygen consumption during work of maximum power "vascular conductivity", the ability of circulatory removal of "metabolic slags", being the most pronounced of all types of work is also observed. The highest levels of training status at such work are invariably associated with the optimization of the balance of the above energy and functional processes at high intensity of each of them [67].

Specialization in sustained, relatively uniform work for two or more hours, which is typical for road racing, is characterized by absolutely the highest level of development of the capacity of oxygen supply systems and "metabolic productivity". An important factor of training status formation in this case is an increase in the stability of the respiratory system regulatory processes, the ability of functions to adequately respond to stimuli and "perturbations" that arise during special long-term work [69].

The findings allow us to outline those highly specialized features of functional fitness, which should be primarily taken into account when diagnosing its structure in cyclists of this or that specialization.

Conclusion.

1. Specialization in different types of cycling races significantly affects both work capacity in tests and the dynamics of maximum manifestations of indices of gas exchange, external respiration, blood circulation, blood gas transport, shifts in the internal environment of the body.

2. The economy of functional reactions during work of critical power is higher in road racers and pursuit riders. The duration of such work in road racers is significantly higher than in cyclists of other specializations.

3. The anaerobic transition threshold starts relatively later in road racers and earliest in sprinters. The manifestation of hyperventilation for the same degree of acidemia is lowest in road cyclists and highest in sprinters.

4. The highest level of aerobic power development is observed in road racers, whereas the lowest – in sprinters. The highest value of "anaerobic power" is noticed in time trial cyclists, whereas the ability to explosive energy expenditure – in sprinters.

5. Road racers are distinguished by a high capacity of carbohydrate stores, characteristic of prolonged strenuous work, along with the utilization of lactate during work. They are characterized by a stable, although reduced level of sensitivity and "functional reactivity" to standard levels of stimuli adequate for the system of external respiration and hemodynamics, as well as stability of cardiac rhythm regulation and a number of other features of regulation of oxygen transport system functions.

6. Pursuit riders are distinguished by their highly specialized ability to maintain high levels of aerobic processes (along with high levels of anaerobic metabolism).

7. The speed of deployment of functional and metabolic responses in the initial period of work also has significant differences depending on the specialization of athletes. The highest economy is observed in road racers, whereas the lowest – in time trial cyclists. Significant development of the economy is not characteristic of athletes who specialize in time trials.

Conflict of interest. The authors declare that there is no conflict of interests.

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