Journal of Physical Education and Sport ® (JPES), Vol. 22 (issue 3), Art 92, pp. 732 - 740, March 2022
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Peculiarities of cyclists' respiratory adaptation to strenuous muscular activity in different training periods

ALEXANDR KOLUMBET[1], NATALIA MAXIMOVICH[2], MIKHAIL KOROP[3], VIACHESLAV GAMOV[4], OLEKSANDR BAKANYCHEV[5]
[1]Kyiv National University of Technologies and Design, Kyiv, UKRAINE
[2]National University “Odessa Academy of Law”, Odessa, UKRAINE
[3,4]Kyiv National University of Trade and Economics, Kyiv, UKRAINE
[5]National Pedagogical Dragomanov University, Kyiv, UKRAINE

Published online: March 31, 2022
(Accepted for publication March 15, 2022)
DOI:10.7752/jpes.2022.03092

Abstract
Purpose: This research aimed to reveal the peculiarities of cyclists’ respiratory adaptation to strenuous muscular activity in different periods of their preparation**. Material & Methods:** Highly skilled cyclists specialized in road cycling (masters of sports, international masters of sports, merited masters of sports) - 44 persons; aged 19-25 years were studied. Indices that objectively reflected the training status of cyclists were determined. Functional fitness for important competitions was investigated. Studies were conducted three times a year in different periods of the annual cycle of preparation for major competitions. The research was carried out both under conditions of the basal metabolism, and in the dynamics of strenuous muscular activity. **Results:** Pulmonary ventilation (V_E) at reaching maximum oxygen consumption (VO_{2max}) constituted 132.0+4.64 $l.min.^{-1}$, whereas maximum tidal volume (VO_{2max}) - 2.9+0.06 l. Oxygen cost of heart contraction (VO_2/HR) ranged from 22.0 to 32.5 $ml.beats^{-1}$. Further increase of cyclists’ training status during the competitive period was associated with an improvement in the economization and efficiency of the respiratory system under the conditions of the basal metabolism and standard loads. This is manifested in a decrease of respiratory frequency (f) and heart rate (HR), pulmonary and alveolar ventilation, a tendency to increase V_T, a decrease of CO_2 per kg of body weight, and increased oxygen utilization. Changes of O_2 and CO_2 tension peculiar for relative lung hypoventilation are noted. This is a reflection of a more favorable respiratory system adaptation to muscular activity in the competitive period compared with the transition and preparatory ones. During strenuous work in the competitive period, the maximum values of V_E and VO_2 per kg of body weight did not undergo statistically significant changes at a more pronounced tendency to decrease f and HR. At the same time, a significant improvement in the relation between V_T and vital capacity (VC) and more rational use of VC were observed. In the most trained cyclists, V_T during work constituted about 50% of VC. **Conclusions:** Estimation criteria for training status and functional fitness of cyclists for major competitions: high efficiency and economy of respiration; high efficiency and economy of blood circulation; capacity of oxygen utilization mechanisms for maximally long-term tension; high stability of mechanisms of maintenance of close to maximal levels of pulmonary gas exchange; high stability of respiratory system functioning.
Keywords: cyclists, oxygen transport system, respiratory system, preparation periods.

Introduction

A functional state is an integral characteristic of those human functions and qualities that directly or indirectly determine the efficiency of performing a particular activity (Kolumbet et al., 2018). Training status in sports reflects one of the highest degrees (stages) of adaptation to muscular activity and covers a wide range of issues. One of them a functional fitness is a core issue for cyclic sports events. Functional fitness reflects the part of athletic work capacity provision that is conditioned by the capacities of key functional systems (Pryimakov, 2020). For cyclic sports events, this is the body oxygen transport system (oxygen supply system, respiratory system). Quantitative and qualitative manifestations of the activity of these systems are one of the most important objects of control and criteria of functional fitness diagnostics in the dynamics of the training process (Coffey & Hawley, 2017). The results of current studies allow sufficient differentiating the components of sports functional fitness and determining its relationship with a set of key physiological factors. The practice of diagnosing functional fitness and most of the works dealing with this issue are aimed at assessment of the ability to maximize the systems that reflect the limits of their functioning, i.e. their power. This is characteristic for creating diagnostic complexes and defining functional and energy criteria of sports training management (Branco et al., 2017). Methodical literature and recent recommendations, the practice of managing functional fitness improvement, address the issues of assessment and development of the level of body maximum aerobic and anaerobic power (Dada et al., 2018). At the same time, such important energy indices as maximum oxygen

Corresponding Author: ALEXANDR KOLUMBET, E-mail: coloumbet@gmail.com

consumption, maximum “oxygen debt” as well as a number of other functional parameters are determined (Macinnis & Gibala, 2017). Nowadays, this is an important factor to assess the level of functional fitness and manage the training process, especially at the initial stages of sports preparation or while selecting the athletes. As for the further stages of sports improvement, the diagnostics of functional fitness with account for only the mentioned criteria is not always satisfactory (Nagy et al., 2020; Tambasco et al., 2017).

The problem of adaptation to strenuous muscular activity is one of the most important issues of the theory and methodology of sports training and applied physiology. The study of ensuring a high level of athlete functional activity is always relevant (Grove et al., 2017; McKenzie, 2012).

A high level of functioning of the oxygen supply systems is the basis for record result achievement in cyclic sports events. The respiratory system occupies one of the leading places (Chen et al., 2016; Durmic et al., 2015). Due account for the regularities of the respiratory system adaptation to the maximum muscular activity is an indispensable condition for proper organization of the sports training process. Objective assessment of athletes' functional fitness for important competitions is also impossible without studying the respiratory system (Barbieri et al., 2019; Suszter et al., 2017).

Limited oxygen delivery (and special work capacity) may be caused by low efficiency and high oxygen cost of respiration (Pereira et al., 2010). In addition, the dynamics of respiratory indices reflects training status of athletes (Mercier et al., 1994).

Despite numerous studies of this issue, the peculiarities of adaptive changes in the respiratory system of highly qualified cyclists to muscular activity in different periods of their training have not been fully investigated.

The objective of the work was to study the peculiarities of cyclist respiratory system adaptation to strenuous muscular activity in different periods of their preparation.

Materials & Methods

Participants. Highly skilled cyclists specialized in road cycling (24 masters of sports, 12 international masters of sports, 8 merited master of sports) - 44 persons; age: 19-25 years; height: 172-181 cm, weight: 66-80 kg.

Organization of study. The data of the long-term study are summarized in the work. We determined indices, which objectively reflected the training status of cyclists specialized in road cycling. Besides, the functional fitness for major competitions was examined.

Studies were conducted both under the conditions of the basal metabolism and in the dynamics of strenuous muscular activity three times a year in different periods of the annual cycle of preparation for major competitions.

A cycle ergometer test with stepwise power increments was used as a testing load. The work was performed to exhaustion (or inability to maintain the specified loading parameters). The work power was increased every 5 minutes and constituted 660, 1330, 1990, 2320, and 2650 $kGm.min^{-1}$. The chosen load model allowed direct obtaining the values of maximal oxygen consumption, analyzing the dynamics of adaptive changes of different respiratory indices to work intensity changes, studying respiration adaptation to standard conditions of relatively steady state at different levels of oxygen consumption, objective determining the body work capacity.

More than 50 indices of gas exchange, respiration, efficiency, and economy of body oxygen regimes were synchronously determined under the conditions of basal metabolism, in the dynamics of muscular activity, and 30 minutes of the recovery period and subsequently calculated on the computer (per each minute) by the method developed in the Problem Scientific and Research Laboratory of High Training Loads (Kolumbet et al., 2019; Monogarov et al., 1979). In addition, the oxygen cost of breathing was determined at different levels of O_2 consumption in the dynamics of the load (Lounana et al., 2007).

Statistical analysis. During experimental data processing, we determined the average values of indices and their errors (M±m), the degree of difference of averages and the significance of differences (t, p).

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 & Discussion

The character of respiration adaptation to strenuous muscular activity depends on the period of sports training and is conditioned by the specificity of applied loads at different stages of the annual training cycle and individual peculiarities of athletes.

A relatively low level of respiratory system functional state in the examined athletes during the transition period of training at the largest intragroup differences of the studied parameters (Table 1) was established.

Relatively low mean values of respiratory indices of cyclists during the transition period were established. Pulmonary ventilation (V_E) at reaching maximum oxygen consumption (VO_{2max}) constituted 132.0+4.64 $l.min^{-1}$ with individual variations ranging from 106 to 162 $l.min^{-1}$ The maximum tidal volume (VO_{2max}), which was reached several minutes earlier, constituted 2.9+0.06 l., with a range of variations from 2.30 to 3.46 l. VO_{2max} was within 58.0 and 79.7 ml.min.kg of body weight. The oxygen cost of cardiac contraction (VO_2/HR) ranged from 22.0 to 32.5 ml.beats^{-1}. Such high intragroup differences of the studied parameters are probably due to the different training statuses of the examined athletes in the transition period of training. Dynamics of tidal volume (V_T) in the course of work during the transition period is characterized by its decrease by 15-20% by the end of the load (Table 2).

Table 1. Some indices of the oxygen supply system of cyclists at the moment of reaching the maximum oxygen consumption during the transition and preparatory periods

Indices	Transitional period of training M±m	Preparatory period of training M±m
V_E, l.min^{-1}	135.1±10.1	158.2±9.9
f, breats.min^{-1}	48.2±8.3	54.2±9.4
V_T, l	28.4±0.6	32.1±0.5
VO_2max, ml.kg.min^{-1}	70.2±5.2	78.2±4.9
$\%O_2$, %	5.2±0.6	4.8±0.7
HR, beats.min^{-1}	207.2±8.8	199.1±9.5
VO_2/HR, ml.beats^{-1}	27.1±2.4	31.2±2.5

Legend: V_E – respiratory minute volume; f –respiratory frequency; V_T –tidal volume; VO_2max –maximum oxygen consumption; $\%O_2$ – a percentage of oxygen consumption; HR – heart rate; VO_2/HR – oxygen pulse effect

This indicates the availability of significant functional reserve in this link of the respiratory system. In the transition period, low respiratory efficiency during strenuous muscular activity followed by relatively low utilization of oxygen from alveolar air in the nearest recovery period after it were noted.

Table 2. Dynamics of cyclists' respiration indices during transition period

Periods	t, min	q_AO_2/VO_2, l	V_A/V_E, %	V_E/VO_2, %	VO_2/f, ml.breats^{-1}
Strenuous muscular activity, M±m	0	3.61±0.04	72.1±8.3	24.1±2.9	45.2±9.3
	1	3.44±0.05	75.2±8.1	23.0±2.3	60.1±9.2
	2	3.33±0.04	77.1±8.1	22.3±3.4	70.2±8.2
	3	3.26±0.06	78.3±8.3	21.8±3.5	82.2±7.7
	5	3.21±0.06	79.2±7.9	21.4±2.3	91.3±9.3
	7	3.25±0.05	80.1±8.8	21.6±4.1	98.1±9.3
	9	3.31±0.03	80.2±8.7	22.2±2.2	120.1±11.3
	11	3.35±0.08	79.5±8.5	22.5±2.0	130.3±11.2
	13	3.44±0.02	79.3±8.3	23.2±3.1	124.1±12.1
	15	3.54±0.04	78.8±7.7	24.0±3.1	118.1±11.1
	17	3.71±0.10	77.7±9.1	25.5±2.9	113.3±10.9
	19	3.88±0.08	75.2±8.2	27.8±2.8	107.4±11.1
	22	-	-	-	-
	23	-	-	-	-
Recovery period, M±m	0	3.92±0.08	75.2±6.5	27.5±4.6	100.1±11.2
	1	4.11±0.10	69.1±6.6	29.1±4.2	90.6±9.9
	3	4.22±0.11	64.4±7.1	32.6±3.9	60.5±7.1
	5	4.31±0.09	66.4±7.3	33.4±3.1	55.5±4.4
	7	4.11±0.09	69.3±6.2	30.7±4.3	50.2±5.8
	10	4.00±0.10	71.1±7.7	29.4±4.3	52.2±6.3
	13	3.95±0.08	72.2±7.9	28.6±3.5	53.2±4.9
	15	3.85±0.08	72.4±8.2	27.5±3.3	56.1±5.2

Legend: q_AO_2/VO_2 – ratio of the velocity of oxygen inflow in alveoli to oxygen uptake; V_A/V_E - ratio of alveolar ventilation to pulmonary ventilation; V_E/VO_2 – ventilatory equivalent; VO_2/f – oxygen effect of respiratory cycle

This is indicated by significantly higher values of relations between the volumetric velocity of O_2 inflow into the lungs and alveoli and VO_2, ventilation equivalent (V_E/VO_2) lower oxygen effect of the respiratory cycle, and a lower portion of alveolar ventilation in V_E during the transition period as compared to the competitive one (Table 3). The level of "non-metabolic excess" of carbon dioxide, as well as the dynamics of gas exchange indices, indicate a large specific weight of aerobic mechanisms of work energy supply and some decrease in the body anaerobic performance or the ability to fully mobilize this mechanism, increase special work capacity during the transition period in the examined cyclists.

Table 3. Dynamics of cyclists' respiratory indices during the competitive period

Periods	t, min	q_AO_2/VO_2, l	V_A/V_E, %	V_E/VO_2, %	VO_2/f, ml.breats^{-1}
Strenuous muscular activity, M±m	0	3.51±0.11	74.2±7.7	23.1±4.5	45.4±9.3
	1	3.21±0.08	76.2±8.4	21.5±3.2	70.2±9.2
	2	3.12±0.08	80.4±8.9	20.8±4.6	90.2±8.2
	3	3.02±0.09	81.2±8.8	20.4±3.3	100.1±11.0
	5	3.05±0.11	82.3±9.9	20.2±2.2	100.3±10.9
	7	3.09±0.10	86.2±10.3	20.1±3.9	130.1±10.9
	9	3.12±0.09	87.3±11.0	20.2±3.8	138.3±11.3
	11	3.15±0.09	86.3±9.9	20.3±3.8	144.1±11.1
	13	3.21±0.09	87.1±5.6	20.5±3.4	154.2±12.0
	15	3.26±0.09	87.2±9.4	20.7±4.1	158.2±12.1
	17	3.35±0.11	87.3±6.8	21.1±4.7	156.1±9.3
	19	3.51±0.10	85.9±11.3	21.6±3.3	150.2±15.0
	22	3.66±0.10	83.1±9.3	22.6±3.2	130.3±13.3
	23	3.78±0.09	82.5±10.5	23.5±3.6	130.2±10.2
Recovery period, M±m	0	3.78±0.09	82.5±10.5	23.5±3.6	130.1±9.9
	1	3.81±0.10	73.5±10.9	25.9±3.1	110.1±9.9
	3	3.91±0.07	68.1±8.4	28.8±3.9	70.2±7.9
	5	3.93±0.12	72.1±7.7	27.7±3.8	55.1±8.2
	7	3.90±0.05	75.2±9.1	25.4±4.1	53.2±7.6
	10	3.81±0.09	76.1±8.6	24.5±3.9	52.2±5.6
	13	3.72±0.09	76.3±8.5	23.9±4.3	52.4±4.9
	15	3.63±0.10	76.2±7.9	23.4±5.0	53.1±5.8

Legend: q_AO_2/VO_2 – ratio of the velocity of oxygen inflow in alveoli to oxygen uptake; V_A/V_E - ratio of alveolar ventilation to pulmonary ventilation; V_E/VO_2 – ventilatory equivalent; VO_2/f – oxygen effect of respiratory cycle

Comparison of the results of cyclists' examination in the preparatory period with the data of the transition period demonstrated an increase in the body aerobic performance and the power of the respiratory system.

Significant improvement of the respiratory system functional state in the preparatory period was observed in almost all parameters, the only exception being the degree of oxygen utilization from alveolar air, which even slightly decreased compared with the transition period (Table 4).

Table 4. Indices of cyclists' respiratory system under conditions of basal metabolism for the competitive period of training

Indices	M±m
f, breath.min^{-1}	8.6±0.9
V_T, ml	800.2±15.8
V_E, l.min^{-1}	6.88±0.06
V_A, l.min^{-1}	5.25±0.09
VO_2, ml.min^{-1}	317.3±9.8
VO_2, ml.kg.min^{-1}	4.38±0.04
V_{CO2}, ml.min^{-1}	266.3±10.1
RQ, %	0.84±0.006
HR, beats.min^{-1}	47.4±1.03

Legend: f – respiratory frequency; V_T – tidal volume; V_E – respiratory minute volume; V_A – alveolar ventilation; VO_2 – oxygen consumption; V_{CO2} - carbon dioxide excretion; RQ –respiratory coefficient; HR – pulse

The noted changes may be due to different character of applied training loads at separate stages of athletes' training and indicate that increase of volume and intensity of training loads in the preparatory period is provided, first of all, owing to increase of power of the body oxygen supply systems. Improvement of efficiency and formation of optimal relationships in the functioning of the respiratory system during this period of training lags behind the increase of its power, which, probably, reflects some disagreement between the processes of respiration and pulmonary circulation.

Low respiratory efficiency in the preparatory period of training was also observed by other researchers (Araujo et al., 2004; Byrne et al., 2002).

The increase of the maximum values of V_E, VO_2, and some other parameters in the preparatory period (Table 1) is observed at a much smaller range of individual fluctuations. This indicates the elimination of significant differences in the training status of some highly skilled cyclists and the increase in the functional capacities of the respiratory system during the preparatory period of training compared with the transition one.

Further improvement of cyclists' training status during the competitive period is associated with improved economization and increased efficiency of respiratory system functioning under conditions of basal metabolism and standard loads. This is manifested in decreased respiratory frequency (f) and heart rate (HR), pulmonary and alveolar ventilation, tendency to increase V_T, decreased CO_2 per kg of body weight, elevated oxygen utilization. Changes in O_2 and CO_2 tensions peculiar for relative pulmonary hypoventilation (Table 4) are noted. This is a reflection of a more favorable adaptation of the respiratory system to muscular activity in the competitive period compared with the transition and preparatory ones.

The long-term observations resulted in establishing optimal ratios of a number of the most important indices of the respiratory system, which characterize the high level of the functional state of cyclists specialized in road cycling (Table 5).

Table 5. Indices of cyclists' respiratory system efficiency under conditions of basal metabolism for the competitive period

Indices	M±m
$\%O_2$, %	5.12±0.05
V_A/V_R, %	76.3±3.9
V_E/VO_2, c.u.	21.7±0.7
V_E/VCO_2, c.u.	25.9±0.9
VO_2/f, ml.breaths^{-1}	37.0±1.1
pAO_2, mmHg	101.8±3.6
VO_2/HR, ml.beats^{-1}	6.8±0.2

Legend: $\%O_2$ – percentage of oxygen consumption; V_A/V_R – ratio of alveolar and pulmonary ventilation; V_E/VO_2 - ventilatory equivalent for oxygen; V_E/VCO_2 - ventilatory equivalent for carbon dioxide; VO_2/f – oxygen effect of respiratory cycle; pAO_2 – oxygen partial pressure in alveolar air; VO_2/HR – pulse oxygen effect

The maximum values of V_E AND VO_2 PER KG OF BODY WEIGHT OF EXAMINED CYCLISTS DURING STRENUOUS WORK IN THE COMPETITIVE PERIOD DID NOT UNDERGO STATISTICALLY SIGNIFICANT CHANGES WITH A MORE PRONOUNCED TENDENCY TO DECREASE F AND HR. AT THE SAME TIME, A SIGNIFICANT IMPROVEMENT IN THE RATIO OF V_T AND VITAL CAPACITY (VC), MORE RATIONAL USE OF VC WERE OBSERVED. IN THE MOST TRAINED CYCLISTS, V_T DURING WORK CONSTITUTED ABOUT 50% OF VC.

An increase in respiratory volume enhances the diffusion surface of the lungs. This leads to a relative decrease in physiological dead space and a greater increase in alveolar ventilation (Table 6).

Table 6. Indices of cyclists' respiratory system efficiency under physical loads at the moment of reaching maximum oxygen consumption

Indices		Training periods		p
		Preparatory	**Competitive**	
V_A, l.min^{-1}	M	119.0	130.0	
	S	4.922	7.910	<0.001
	m	1.074	1.523	
V_A/V_E, %	M	78.2	83.2	
	S	3.107	2.656	<0.001
	m	0.676	0.5111	
V_E/VO_2, c.u.	M	25.0	22.1	
	S	1.554	2.415	<0.05
	m	0.339	0.465	
VO2/f, ml	M	116.0	131.0	
	S	13.73	16.90	>0.05
	m	2.996	3.252	
VO_2/HR, ml	M	30.4	32.8	
	S	2.69	2.23	>0.05
	m	0.579	0.496	

Legend: V_A – alveolar ventilation; V_A/V_E - ratio of alveolar and pulmonary ventilation; V_E/VO_2 - ventilatory equivalent for oxygen; VO_2/f - oxygen effect of respiratory cycle; VO_2/HR - pulse oxygen effect

This determined a significantly higher V_A/V_E ratio during the competitive period. This contributed to an increase in the velocity of oxygen delivery to the alveoli and an improvement in the ratio between the velocity of oxygen delivery and consumption. This was one of the main reasons for the higher oxygen utilization and respiratory efficiency on the whole.

Increased oxygen utilization from alveolar air during the competitive period while maintaining high breathing intensity is a significant reserve to improve the special work capacity of cyclists (Kolumbet et al., 2019). The possibility of increased oxygen utilization during work accompanied by VO_2 within 80% and more of VO_{2max} shows a close correlation with training status and functional fitness of the examined athletes.

The competitive period of training is characterized by a significant increase in the duration of maintaining high efficiency and economy of respiration during strenuous muscular activity. The time of maintaining high respiratory efficiency in the competitive period reached 75-80% of the total duration of work. During the preparatory period, respiratory efficiency was within the range of 60-65%. A decrease of respiratory efficiency by the end of the load occurs later and is less expressed.

In the preparatory period, the disturbance of the linear relationship between VO_2 and V_E occurred at VO_2 equal to 3.4±0.6 $l.min^{-1}$, whereas in the competitive period - at VO_2 equal to 4.5±0.08 $l.min^{-1}$ (Fig. 1). As long as ventilation did not exceed 120 $l.min^{-1}$, no significant differences in the oxygen cost of respiration of cyclists were observed during the preparatory and competitive periods. As ventilation increased, the oxygen cost of respiration was significantly lower during the competitive period. Longer maintenance of the efficiency of the O_2 intake process contributed to the maintenance of a high level of a gas exchange over a long period. One of the mechanisms ensuring long-term maintenance of close to maximal VO_2 levels is the high stability of the parameters of gas exchange, respiratory system, and its efficiency in the process of strenuous muscular activity (Akalan et al., 2008; Guimaraes et al., 2008).

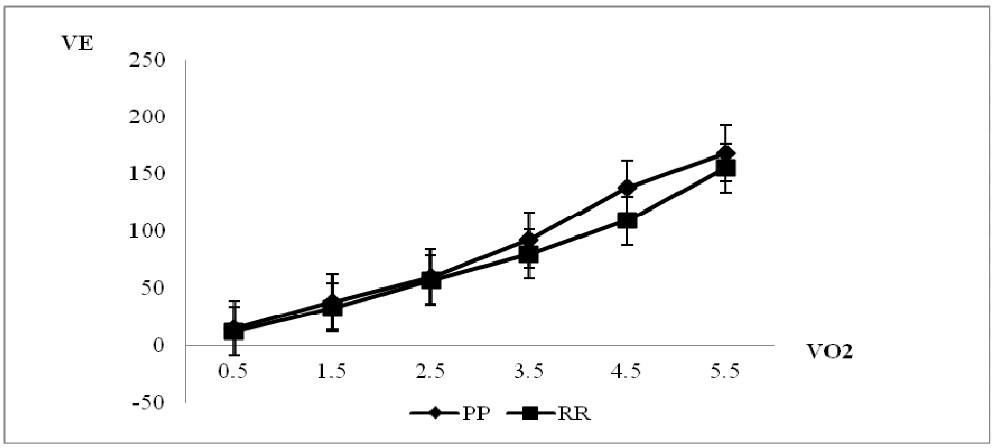

Fig. 1. Relationships between changes of pulmonary ventilation (V_E) and oxygen consumption rate (VO_2) in cyclists during strenuous muscular activity in the preparatory (PP) and competitive (RR) periods

One of the factors of cyclists' special work capacity improvement during the competitive period of training and the result of training influence on the respiratory system functional state during the annual cycle was the increase of respiration efficiency and economy in the process of strenuous muscular activity while maintaining high power and maximum mobilization of pulmonary gas exchange mechanisms.

Among the most important mechanisms determining respiratory efficiency is the uniformity of air distribution in different parts of the lungs. It leads to improved relations between ventilation and perfusion in the lungs. This indicates improved coordination between respiratory and pulmonary circulation processes as training status increases in the annual training cycle. Improved respiration efficiency in the process of training is explained not only by the described above increase of oxygen utilization in lungs, but the changes occurring in all links of the body oxygen supply system, as well, and increased utilization of oxygen from arterial blood, in particular, as was shown by W.A. Sparrow et al. (1998), W.L. Beaver et al. (2022), A. Bolotin et al. L. (2016), V.D. Monogarov et al. (1979) and other authors. The improved oxygen effect of cardiac contraction along with the increase of training status indicates an enhancement in the circulatory economy. The oxygen effect of cardiac contraction is an expression of integration of systolic volume, arteriovenous difference, minute volume, and heart volume (Nunes et al., 2017; Ranisavljev et al., 2014). The improvement of the oxygen effect during the annual training cycle indicates the increased role of systolic volume and arteriovenous difference in the adaptation of the athletes' body to strenuous muscular activity (Bolotin et al., 2016; Medeiros, 2009).

Along with cyclists' training status improvement during the annual training cycle, greater functional mobility of respiration and faster recovery of the studied parameters are observed after physical loads (Tables 2-3). At the same time, respiration modes at each stage of the load are faster established and more steadily maintained than in the preparatory and transition periods of the annual training cycle.

More adequate adaptation (as well as better respiration efficiency during strenuous muscular activity) represents a reflection of more perfect neurohumoral respiration regulation as a result of improved intra- and intersystem coordination of vegetative processes in the competitive training period (Monteiro et al., 2009).

Long-term observations for the dynamics of the studied parameters in athletes have established the dependence of respiratory adaptation peculiarities to strenuous work, its economy, and individual levels of O_2 utilization on the volume of the pulmonary reservoir, VC, specific weight of muscle mass, and other morphological data. The athletes with relatively low specific weight are characterized by the predominant increase of maximal indices of minute volume, respiratory frequency, rate of O_2 consumption per kg of weight and m^2 of the body surface. With the increase of training status during the annual cycle of training, respiratory adaptation in such athletes is aimed at a more complete and rapid mobilization of the function. Insufficient development of the mentioned morphological data (as it was noted in some athletes) was compensated by an increase in mobility of regulatory processes at the expense of faster respiration response to the change of the body oxygen demand, general higher intensity, tension and maximum possible increase of respiratory system power at low oxygen utilization and respiration efficiency. The use of the body reserve capacities by relatively heavy athletes with high VC indices during the competitive period of training is primarily focused on increasing oxygen utilization, efficiency, and economy of respiration at relatively low frequency characteristics and maximum values of the respiratory system.

One of the examples of individual peculiarities of respiration adaptation to strenuous muscular activity is shown in Table 7.

Table 7. Some respiratory system indices during cycle ergometry in cyclists K-v and M-v at the competitive training period

Indices		K-в	M-в
VC, l		6.5	4.8
VO_2max, ml.min.kg^{-1}		78.6	82.0
V_E, l.min^{-1}		132	143
f, breats.min^{-1}		40	68
V_T	maximal	3.7	2.4
	at VO_2max	3.3	2.1
%O_2	maximal	6.1	5.4
	at VO_2max	4.8	4.0
VO_2/f при VO_2max, ml.breats^{-1}		142.5	75.6
HR, beats.min^{-1}		181	206
VO_2/HR, ml.beats^{-1}		31.5	24.9

Legend: VC – vital capacity; VO_2max – maximal oxygen consumption; V_E – pulmonary minute volume; f – respiration frequency; V_T – tidal volume; %O_2 - % of oxygen consumption; VO_2/f – oxtgen effect of respiratory cycle at VO_2max; HR - pulse; VO_2/HR – pulse oxtgen effect

Individual peculiarities of respiration adaptation to strenuous muscular activity are indicative of a variety of ways for coordination of functions and indices of one and the same function in the process of adaptation to strenuous muscular activity (Nunes et al., 2016). Change of individual indices of vegetative systems during physical loads due to the development of training status can go in different directions (both in the direction of economization and in the direction of their faster and more complete mobilization). Finding out the specific ratios of the indicated processes at different stages of the annual cycle of training is one of the important tasks of medical and pedagogical control.

Conclusion

With the improvement of training status during the annual training cycle the character of respiration adaptation to strenuous muscular activity changes. This is manifested in the improvement of pulmonary gas exchange regulation, an increase of efficiency, and the improvement of general adaptive capacities of the respiratory system. Ways of achieving maximal efficiency of gas exchange and respiratory system depend on individual peculiarities of athletes. Improved during the annual cycle of preparation training status provides the most optimal ratios of indices of pulmonary gas exchange, power and efficiency of respiratory system functioning, as well as oxygen supply, utilization, and conditions of the diffusive capacity of lungs for respiratory gases for an individual state of an athlete. The above should be taken into account when assessing the functional state of the athlete's body in different periods of training.

Criteria of estimating training status and functional fitness of cyclists for major competitions: high respiration efficiency and economy; high efficiency and economy of blood circulation; capacity of oxygen utilization mechanisms to maximum and prolonged tension; high stability of mechanisms of maintaining close to maximal levels of pulmonary gas exchange; high stability of respiratory system functioning.

Conflict of interest

The authors declare that there is no conflict of interests.

References

Akalan, C., Robergs, R. A., & Kravitz, L. (2008). Prediction of $VO_{2máx}$ from an individualized submaximal cycle ergometer protocol. *Journal of Exercise Physiology Online*, 11(2), 11-17.

Araujo, C.G.S., Carvalho, T., Castro, C.L.B., Costa, R.V., Moraes, R.S., & Oliveira Filho, J.A. (2004). Supervision of cardiovascular rehabilitation equipment and techniques. *Arquivos Brasileiros de Cardiologia*, 83(5), 31-39.

Barbieri, J.F., Figueiredo, G., Castano, L.A., Guimaraes, P., Ferreira, R.R., Ahmadi, S., & De Moraes, A.C. (2019). A comparison of cardiorespiratory responses between CrossFit practitioners and recreationally trained individual. *Journal of Physical Education & Sport*, 19(3), 1606-1611.

Beaver, W.L., Wasserman, K., & Whipp, B.J. (2022). A new method for detecting anaerobic threshold by gas exchange/ Journal of Applied Physiology, 133, 448-458.

Bolotin, A., & Bakayev, V. (2016). Efficacy of using isometric exercises to prevent basketball injuries. *Journal of Physical Education & Sport*, 16(4), 1177-1185.

Bolotin, A., & Bakayev, V. (2016). Factors that determine high efficiency in developing speed and strength abilities of female hurdlers. *Journal of Physical Education & Sport,* 16(3), 910-913.

Branco, B.H.M., Carvalho, I.Z., Oliveira, H.G., Fanhani, A.P., Santos, M.C.M., Oliveira, L.P., Boni, S.M., & Nardo, N. (2020). Effects of 2 Types of Resistance Training Models on Obese Adolescents' Body Composition, Cardiometabolic Risk, and Physical Fitness. *Journal of Strength and Conditioning Research*, 34(9), 2672–2682.

Byrne, N.M., & Hills, A.P. (2002). Relationships between HR and VO_2 in the obese. *Medicine & Science in Sports & Exercise*, 34(9), 1419-1427. http://dx.doi.org/10.1249/01.MSS.0000027629.94800.17.

Chen, C.K., Ismail, N.S., & Al-Safi, A.A. (2016). Effects of brisk walking and resistance training on cardiorespiratory fitness, body composition, and lipid profiles among overweight and obese individuals. *Journal of Physical Education & Sport*, 16(3), 957-963.

Coffey, V.G., & Hawley, J.A. (2017). Concurrent exercise training: do opposites distract? *The Journal of Physiology*, 595(9), 2883–2896.

Dada, R.P., Branco, B.H.M., Terra, C.M. de O., Lazarin, S.P.B., Hintze, L.J., & Nardo Junior, N. (2018). Nutritional status and cardiometabolic risk in women: relationship with usual and non-usual components of body composition. *Journal of Physical Education*, 29, e2935.

Durmic, T., Lazovic, B., Djelic, M., Lazic, J.S., Zikic, D., Zugic, V., et al. (2015). Sport-specific influences on respiratory patterns in elite athletes. *Journal of Bras. Pneumol*., 41(6), 516-522.

Grove, T.P., Jones, J.L., & Connolly, S.B. (2017). Cardiorespiratory fitness, oxygen pulse and heart rate response following the MyAction programme, *British Journal of Cardiology*, 24(1), 25-29. http://doi.org/10.5837/bjc.2017.006.

Guimarães, G.V., Silva, M.S.V., D'Avila, V.M., Ferreira, S.M.A., Silva, C.P., & Bocchi, E. A. (2008). Peak VO_2 and VE/VCO_2 slope in the beta-blocker era in heart failure: a Brazilian experience. *Arquivos Brasileiros de Cardiologia*, 91(1), 42-48. http://doi.org/10.1590/S0066-782X2008001300007.

Kolumbet, A.N., Natroshvili, S.G., & Chernovsky, S.M. (2018). Energy supply during cyclist muscular activity *Journal of Physical Education and Sport*, 18(1), 12, 98-102. https://doi.org/10.7752/jpes.2018.01012.

Kolumbet, A.N., Dudorova, L.Y., Dovgych, A.A., Ivaschenko, E.A., Melnik, A.A., Nichiporenko, I.V., & Suprunenko, M.V. (2019). Improvement of cyclist pedaling technique by studying their individual differences. *Journal of Physical Education & Sport, 19*(3), 229, 1577-1584. https://doi.org/10.7752/jpes.2019.03229.

Kolumbet, A.N., Dudorova, L.Y., Dovgych, A.A., Ivaschenko, E.A., Melnik, A.A., Nichiporenko, I.V., & Suprunenko, M.V. (2019). The correction of cyclists pedalling techniques by means of teaching guidelines. Journal of Physical Education and Sport, 19 (2), 151, 1048-1052. https://doi.org/10.7752/jpes.2019.02151.

Lounana, J., Campion, F., Noakes, T.D., & Medelli, J. (2007). Relationship between $\%HR_{max}$, $\%HR_{reserve}$e, $\%VO_{2max}$, and $\%VO_2$ reserve in elite cyclists. *Medicine & Science in Sports & Exercise*, 39(2), 350-357 http://doi.org/10.1249/01.mss.0000246996.63976.5f.

Macinnis, M.J., & Gibala, M.J. (2017). Physiological adaptations to interval training and the role of exercise intensity. *Journal of Physiology*, 595(9), 2915-2930.

McKenzie, D.C. (2012). Respiratory physiology: adaptations to high-level exercise. *British Journal of Sports Medicine,* 46(6):381-384.

Medeiros, A.C. (2009). Prediction VO_{2max} during cycle ergometry based on submaximal ventilatory indicators. *Journal of Strength & Conditioning Research*, 23(6), 745-751. http://doi.org/10.1519/JSC.0b013e3181b45c49.

Mercier, J., Le Gallais, D., Durand, M., Gouda, C., Micallef, J.P., & Préfaut, C. (1994). Energy expenditure and cardiorespiratory responses at the transition between walking and running. *European Journal of Applied Physiology & Occupational Physiology*, 69(6), 525-529.

Monogarov, V.D., & Bratkovsky, V.K. (1979). Coordination motions of sportsmen in the period of the compensated fatigue during muscular work of cyclic character. Kiev.

Monteiro, W.D., & Araújo, C.G. (2009). Cardiorespiratory and perceptual responses to walking and running at the same speed. *Arquivos Brasileiros de Cardiologia*, 93(4), 418-425. [in Russian]

Nagy, D., Horváth, Z., Melczer, C., Derkács, E., Ács, P., & Oláh, A. (2020). Comparison of cardiopulmonary changes during cycle and treadmill tests. *Health Problems of Civilization*. https://doi.org/10.5114/hpc.2020.98087.

Nunes, R., Castro, J., Silva, L., Silva, J., Godoy, E., Lima, V., Venturini, G., Oliveira, F., & Vale, R. (2017). Estimation of specific VO_{2max} for elderly in cycle ergometer. *Journal of Human Sport & Exercise*, 12(4), 1199-1207. http://doi.org/10.14198/jhse.2017.124.06.

Nunes, R.A.M., Castro, J.B.P., Machado, A.F., Silva, J.B., Godoy, E.S., Menezes, L.S., Bocalini, D.S. & Vale, R.G.S. (2016). Estimation of VO_{2max} for elderly women. *Journal of Exercise Physiology Online*, 19(6), 180-190.

Pereira, D.A.G., Vieira, D.S.R., Samora, G.A.R., Lopes, F.L., Alencar, M.C.N., Lage, S.M., Parreira, V.F., Velloso, M., Moreira, M.C.V., & Britto, R.R. (2010). Reproducibility of the determination of anaerobic threshold in patients with heart failure. *Arquivos Brasileiros de Cardiologia*, 94(6), 771-778. http://doi.org/10.1590/S0066-782X2010005000044.

Pryimakov, O. (2020). Interaction mechanisms of muscular and cardiovascular systems of elite cyclists in different physiological states during a muscular activity. *Journal of Physical Education and Sport*, 20(2), 729-735.

Ranisavljev, I., Ilic, V., Soldatovic, I., & Stefanovic, D. (2014). The relationship between allometry and preferred transition speed in human locomotion. *Human Movement Science*, (34), 196-204.

Sparrow, W.A., & Newell, K.M. (1998). Metabolic energy expenditure and the regulation of movement economy. *Psychonomic Bulletin Reviev*, 5(2), 173-196.

Suszter, L., Szakály, Zs., Ihász, F., & Mák, E. (2017). Short- and medium-term effects of DXN cordyceps sinensis and beta-alanine supplementation on the cardiorespiratory system of elite rowing athletes. *Magyar Sporttudományi Szemle*, 18(70), 77. [in Hungarian]

Tambasco, L. de P., Silva, H.S. da, Pinheiro, K.M.K., & Gutierrez, B.A.O. (2017). A satisfação no trabalho da equipe multiprofissional que atua na Atenção Primária à Saúde. Saúde Em Debate, 41(spe2), 140–151.