Features of manifestation the energy potential of qualified athletes and sensitivity of cardiorespiratory system to hypercapnia

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Abstract. *Objective.* To identify the types of cardiorespiratory system (CRS) responses to hypercapnic shifts in respiratory homeostasis of qualified athletes who specialized in competitive distances of different duration, and to determine their association with the character of the energy and functional potential realization under physical loads. *Methods.* To analyze the CRS responses to physical loads, a set of tests was used to determine the aerobic and anaerobic capabilities of the athlete's body. To evaluate the CRS responses to hypercapnia, progressive hypercapnic stimulation by the method of "recurrent respiration was used. Characteristics of the athletes' functional fitness were determined as well. *Results.* With an increase in the duration of the main competitive distance and the level of overall work capacity of athletes, the sensitivity of CRS to CO_2-H^+ stimulus was decreased. A positive relationship was established between the sensitivity characteristics of CRS to CO_2-H^+ stimulus with the level of CRS responses and the rate of their development under conditions of average aerobic load and the negative relationship – under conditions of load of maximal aerobic power.
Keywords: athletes, cardiorespiratory system, physical loads.

Особливості прояву енергетичного потенціалу кваліфікованих спортсменів і чутливість кардіореспіраторної системи до гіперкапнії
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Резюме. *Мета.* Виділити типи реакції кардіореспіраторної системи (КРС) на гіперкапнічні зрушення дихального гомеостазису кваліфікованих спортсменів, які спеціалізувалися на змагальних дистанціях різної тривалості, а також визначити їх взаємозв'язок з характером реалізації енергетичного і функціонального потенціалу в умовах фізичних навантажень. *Методи.* Для аналізу реакцій КРС на фізичні навантаження було використано комплекс тестів, який дав можливість визначити аеробні й анаеробні можливості організму спортсменів. Для оцінки реакції КРС на гіперкапнію використовували прогресуючу гіперкапнічну стимуляцію методом «зворотного дихання». Визначали характеристики функціональної підготовленості спортсменів. *Результати.* Зі збільшенням тривалості основної змагальної дистанції і рівня загальної працездатності спортсменів відзначалося зниження чутливості КРС до CO_2-H^+-стимула. Встановлено позитивний взаємозв'язок між характеристиками чутливості КРС до CO_2-H^+-стимула з рівнем реакцій КРС і швидкістю їх розвитку в умовах навантаження середньої аеробної потужності і негативний взаємозв'язок – в умовах навантаження максимальної аеробної потужності.
Ключові слова: спортсмени, кардіореспіраторна система, фізичні навантаження.

Особенности проявления энергетического потенциала квалифицированных спортсменов и чувствительность кардиореспираторной системы к гиперкапнии
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Резюме. *Цель.* Выделить типы реакции кардиореспираторной системы (КРС) на гиперкапнические сдвиги дыхательного гомеостазиса квалифицированных спортсменов, которые специализировались на соревновательных дистанциях разной продолжительности, а также определить их взаимосвязь с характером реализации энергетического и функционального потенциала в условиях физических нагрузок. *Методы.* Для анализа реакций КРС на физические нагрузки использовался комплекс тестов, позволяющих определить аэробные и анаэробные возможности организма спортсменов. Для оценки реакции КРС на гиперкапнию использовали прогрессирующую гиперкапническую стимуляцию методом «возвратного дыхания. Определяли характеристики функциональной подготовленности спортсменов. *Результаты.* С увеличением продолжительности основной соревновательной дистанции и уровня общей работоспособности спортсменов отмечалось снижение чувствительности КРС к CO_2-H^+-стимулу. Установлена положительная взаимосвязь между характеристиками чувствительности КРС к CO_2-H^+-стимулу с уровнем реакций КРС и скоростью их развития в условиях нагрузки средней аэробной мощности и отрицательная взаимосвязь – в условиях нагрузки максимальной аэробной мощности.
Ключевые слова: спортсмены, кардиореспираторная система, физические нагрузки.

Introduction.

Human's ability to resist for extreme factors appreciably depends from individual features of an organism physiological reactivity, speed of involving and efficiency urgent adaptation mechanisms. Mechanisms of adaptation at various environment influences and physical loadings have as the common and individual features. A probable basis of arising individual differences in adaptation underlies hereditary features of reactivity on humoral stimulus and character of metabolisms which are under the genetic control and are interconnected to development, structure and actions of skeletal muscles [1, 7, 9]. The specific metabolic capacities usually are related to aerobic potential realization during loads of different power and specific of athletes' aerobic-anaerobic energy potential utilization for sports event [2, 3, 5, 10, 12]. During human's adaptation to intense physical loadings the special urgency is got with specific features realization of power organism opportunities which are presumably connected to specific features of cardiorespiratory responsiveness [4, 6, 8, 10, 11]. The **aim** was put to allocate features of cardiorespiratory responses on hypercapnic shifts respiratory homeostasis at the elite sportsmen, which are long specialized in running different distances of various duration, and also to reveal interrelation of these features with character of power realization and functional potential in conditions physical loadings.

Methods. Research spent in the competitive period with participation of 54 highly elite athletes – male in the age of 19–24 years who have been training for 5–8 years in 100 m running (n = 19), 800 m running (n = 15) and 5000 m running (n = 16).

For evaluating physiological reactivity of CRS we have used a progressively increasing «purely» hypercapnic stimulation in the rest and have determinate characteristic of functional fitness of athlete. For the analysis of reaction CRS on physical loadings was used the complex of the testing loadings, allowing to estimate aerobic and anaerobic opportunities of a sportsman's organism: 15 sec the loads of maximal power is characterizing of anaerobic alactate potential (W15max); 60 sec loads of submaximal power is characterizing of anaerobic glycolytic potential (W60max); loads of graded exersise stress test is characterizing of aerobic potential of energy supply (W_{KL} – power at $\dot{V}O_2$max).

During testing, «breath-by-breath» gas exchange data («Oxycon Pro», Jager), acid-base balance of blood («Dr Lange LP 400») and heart rate (Polar Electro Inc.) to maximum and standard physical loads were continuously obtained. Treadmill LE-200 CE («Jager», Germany) and «Monark 824 E» cycle ergometer («Monark», Sweden) was used during this study.

Estimation of results was based on motor manifestations of work capacity, on shifts in physiological and biochemical indices. The method of parallel forms when three-four or more indices characterizing one aspect in functional fitness of athlete was used for promotion reliability of studies. Index complex was determined which significantly reflected the level of functional fitness in the body of athletes.

1. Load power relative body mass (W, $Watt \cdot kg^{-1}$).

2. The value of maximum oxygen uptake ($\dot{V}O_2$max, $ml \cdot min^{-1}$, $ml \cdot kg^{-1} \cdot min^{-1}$) was registered during performance of loads of graded exersise stress test and load of «critical» power until refusal.

3. Oxygen pulse ($\dot{V}O_2 \cdot HR^{-1}$, $ml \cdot beats^{-1}$) was determined as ratio $\dot{V}O_2$ to HR at that moment.

4. Functional stability factor according to HR (HR drift) at standard work (HR FSF, %):

$$HR\ FSF = ((a - b) \cdot c^{-1}) \times 100\ \%,$$

where, a – HR averaged from 10^{th} to 12^{th} min of loads, min^{-1}; b – HR averaged from 2^{nd} to 4^{th} min of loads, min^{-1}; c – HR averaged from 2^{st} to 12^{th} min of loads, min^{-1}.

5. Functional stability factor according to ventilatory equivalent for O_2 uptake at «standard» work (EQO_2 FSF, %) – similar to HR FSF of «standard» work but for EQO_2.

6. Half-period responses to HR, time constant (T_{50} HR, sec).

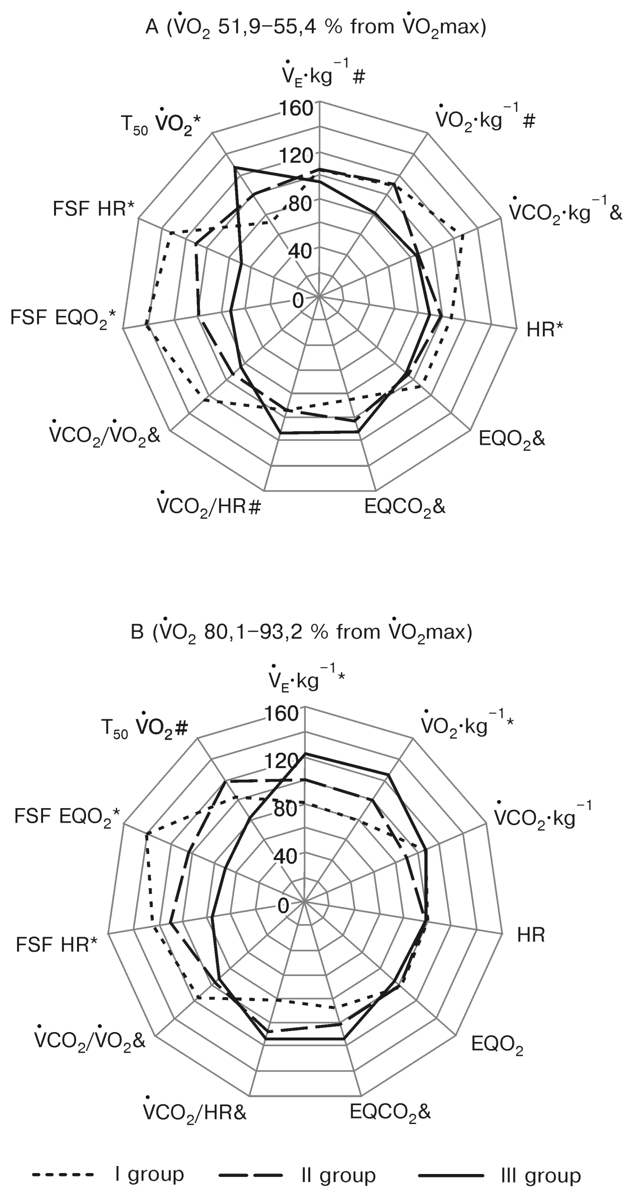
Statistics 5.0 PL in Excel 2007 packet was used.

Results and Discussion. The investigation of the features in physical reactivity of CRS to the shifts occurring in respiratory homeostasis of skilled athletes with various directions of long-term adaptation process and its mutual conditionality with characteristics in CRS responses, manifestations of physical work capacity and mobilization features in aerobic and anaerobic mechanisms of energy-supply under conditions of physical loads having different energy-supply character are presented in the article. So, with increasing the duration of the major competitive distance and the level of general work capacity, decreased sensitivity of CRS to CO_2-H^+-stimulus was observed (tabl. 1).

We have established a close correlation between indices of distance speed in the running and parameters of sensitivity to hypercapnic and

TABLE 1. **Level of work capacity (W) and cardiorespiratory responses to hypercapnia, to exercise test's of anaerobic and aerobic character energy supply of long, middle and long distance athletes (Mean and SD)**

Indices	Group of athletes			p (t–test) < 0,05
	100 m (1)	800 m (2)	5000 m (3)	
$\Delta\dot{V}_E/\Delta P_ACO_2$, l · min^{-1} · mm Hg	26,50 ± 2,08	21,06 ± 1,86	16,78 ± 2,12	1–2, 3; 2–3
$\Delta HR/\Delta P_ACO_2$, beats · min^{-1} · mm Hg	1,29 ± 0,13	0,96 ± 0,09	0,64 ± 0,14	1–2, 3; 2–3
W15max, Watts · kg^{-1}	10,48 ± 0,19	9,49 ± 0,09	9,08 ± 0,20	1–2, 3; 2–3
W60max, Watts · kg^{-1}	6,48 ± 0,09	6,82 ± 0,07	6,71 ± 0,19	2–1
W_{KL}, Watts · kg^{-1}	3,18 ± 0,17	3,27 ± 0,15	4,82 ± 0,22	3–1,2
HLa immedialy after, mmol · l^{-1}	11,79 ± 0,75	8,96 ± 0,86	7,64 ± 0,96	1–3
$\dot{V}_E$max (peak), l · min^{-1} · kg^{-1}	1,575 ± 0,124	1,873 ± 0,119	2,223 ± 0,078	1–2, 3; 2–3
$\dot{V}O_2$max, ml · min^{-1} · kg^{-1}	42,97 ± 3,36	50,11 ± 3,20	61,08 ± 2,38	1–2, 3; 2–3
$\dot{V}CO_2$max, ml · min^{-1} · kg^{-1}	56,94 ± 3,71	52,03 ± 3,06	55,09 ± 2,41	
HRmax, beats · min^{-1}	191,0 ± 4,55	186,50 ± 4,51	184,29 ± 5,65	
$\dot{V}O_2$max · HRmax^{-1}, ml · beats^{-1}	15,84 ± 0,65	20,26 ± 1,25	21,97 ± 0,80	1–2, 3
$\dot{V}CO_2 \cdot \dot{V}O_2^{-1}$ at $\dot{V}O_2$max	1,17 ± 0,14	1,07 ± 0,12	0,98 ± 0,09	
$\dot{V}CO_2 \cdot \dot{V}O_2^{-1}$ at recovery	1,45 ± 0,12	1,22 ± 0,11	1,18 ± 0,08	1–2, 3; 2–3



hypoxic stimulation in the training process. The greater is the sensitivity to hypercapnic stimulus, the greater is the speed of the athlete running a short distance ($r = 0,58$, $p < 0,05$). When an athlete is most affective running a sprinter distance, the factor that become to be most important in the structure of functional fitness is anaerobic capacity and mobility. The lower is the physiological reactivity of the respiratory system on the hypercapnic stimulus, the greater is speed on long distances ($r = -0,61$, $p < 0,05$). In addition, when the testing distances have been increased, we have observed a decrease in sensitivity to hypercapnic stimulus, plus an increase in the coefficients of correlation of sensitivity to hypoxic. In the structure of functional fitness of the long-distance runners, the most significant are the aerobic capacity, stability and economy of the body.

The studies have demonstrated the differences of groups of sportsmen with the different type of sensitivity of CRS responces to hypercapnia on a level and structure of responses of CRS at implementation of the testing physical loads with the different level of distance O_2 consumption are represented on Fig.1. These features represent the changes which provide stability and economy of functional responses at high level of the power

Fig. 1. Differences of responses of the cardiorespiratory system (in % in relation to middle data for all sportsmen – 100%) in of loads of moderate (A) and maximal (B) aerobic power of long (I group), middle (II group) and long (III group) distance athletes.

Note: * – are reliable distinctions between all groups ($p < 0,05$); # – are reliable distinctions of the III group in relation I and II groups ($p < 0,05$); & – are reliable distinctions of the III group in relation to the I group ($p < 0,05$).

TABLE 2. **Speed of development of responses of the cardiorespiratory system at of loads of moderate aerobic power ($\dot{V}O_2$ 51,86–55,39 % from $\dot{V}O_2$max) and loads of maximal aerobic power ($\dot{V}O_2$ 80,1–93,2 % from $\dot{V}O_2$max) of long, middle and long distance athletes (Means and SD)**

Indices	Group of athletes			p (t-тест) < 0,05
	100 m (1)	800 m (2)	5000 m (3)	
Work loads with $\dot{V}O_2$ 51,86–55,39 % from $\dot{V}O_2$max				
Half-period responses to HR, T_{50} HR_{ST}, sec	20,73 ± 4,21	21,96 ± 4,34	35,56 ± 5,17	3–1,2
Half-period responses to $\dot{V}O_2$, $T_{50}\dot{V}O_{2ST}$, sec	23,52 ± 3,04	35,84 ± 3,08	49,17 ± 8,14	1–2, 3; 2–3
Work loads with $\dot{V}O_2$ 80,1–93,2 % from $\dot{V}O_2$max				
Half-period responses to HR, T_{50} HR_{KL}, sec	156,44 ± 12,32	134,7 ± 14,57	69,56 ± 13,56	3–1,2
Half-period responses to $\dot{V}O_2$, $T_{50}\dot{V}O_{2KL}$, sec	178,23 ± 15,72	144,05 ± 10,31	123,46 ± 17,06	1–2, 3; 2–3

physical loads. At sportsmen with the low sensitivity of CRS on CO_2-H^+-stimulus (5000 м, III group) in the conditions to loads of moderate aerobic power (Fig. 1. A) was higher the responses CRS and noted in relation to the level of lung ventilation ($\dot{V}_E$), of oxygen uptake ($\dot{V}O_2$) and heart rate (HR) that was 82–94 % from middle data for all sportsmen ($p < 0,05$). In the conditions of physical to loads of maximal aerobic power (Fig. 1. B) high level of work capacity was provided for certain more high-rate of utilization O_2 ($\dot{V}O_2$ 122,16 ± 2,18 %) and level of lung ventilation ($\dot{V}_E$ 117,77 ± 2,09 %).

Thus, at implementation of loads of different aerobic power at sportsmen with the low sensitivity of CRS on CO_2-H^+-stimulus the level of to efficiency of lung ventilation O_2 (EQO_2 91,02–97,13 %), economy ($O_2 \cdot HR^{-1}$ 121,34–124,96 %) and stability (functional stability factor according to HR (HR FSF) 70,22–76,14 %, EQO_2 FSF 69,94–72,85 %) of functioning of CRS was noted higher, that combined with more low level of respiratory compensation of metabolic asid, about that more low level of carbon dioxide production ($\dot{V}CO_2$ 82,19–83,76 %) and respiratory exchange ratio ($\dot{V}CO_2 \cdot VO_2^{-1}$ 82,02–93,79 %).

Results of our researches testify, that at sportsmen with a different level of sensitivity CRS on CO_2-H^+-stimulus and features of long-term adaptation speed of expansion functional responses different and depends on intensity of testing physical loads (tabl. 2). So, in conditions of uniform aerobic loading of average capacity with remote consumption of O_2 ($\dot{V}O_2$) 51,86–55,39 % from $\dot{V}O_2$max high speed expansion of functional responses which was estimated on a half-period reaction of increase in consumption O_2 ($T_{50}\dot{V}O_2$) and frequency of heart rates (T_{50} HR), was marked at sportsmen with a high level of physiological reactivity ($T_{50}\dot{V}O_{2ST}$ 23,52 ± 3,04 sec, T_{50} HR_{ST} 20,73 ± 4,21 sec), and the least speed is characteristic for sportsmen with the low of sensitivity CRS on CO_2-H^+-stimulus (T_{50} $\dot{V}O_{2ST}$ 49,17 ± 8,14 sec, T_{50} HR_{ST} 35,56 ± 5,17 sec). With increase in power of physical loads (loads of the maximal aerobic power with $\dot{V}O_2$ 85,92–93,33 % from $\dot{V}O_2$max) on the contrary, higher mobility of functional reactions was marked at sportsmen with the low of sensitivity CRS on CO_2-H^+-stimulus ($T_{50}\dot{V}O_{2KL}$ 123,46 ± 17,06 sec), than at sportsmen with a high level of sensitivity cardio respiratory system ($T_{50}\dot{V}O_{2KL}$ 178,23 ± 15,72 sec). Thus at sportsmen with a high level physiological reactivity performance of testing load in different character always is accompanied by a high level of activity anaerobic glycolytic processes in energy-supply of loading, and also the reduced level of profitability and stability of functioning CRS.

Thus, in the conditions of loads of moderate aerobic power high level sensitiveness of CRS on CO_2-H^+-stimulus, as it took place at sportsmen-runners on distance 100 м, depend on fast responses of CRS on the changes of acid base balance of blood. In the conditions of loads of maximal aerobic power low sensitiveness of CRS to hypoxic and hypercapnia at runners mobilizations promoted on 5000 м, to not oppressing of speed of development of functional responses. Positive interrelation was revealed between characteristics of CRS sensitivity to CO_2-H^+-stimulus with the level of CRS responses and the rate of their development under conditions of average-power aerobic loads and negative interrelation – under conditions of maximum-power aerobic loads. Opposite interrelation was observed between the level of CRS sensitivity to CO_2-H^+-stimulus and the level of functioning economy and stability as well as positive interrelation with the level of activity in anaerobic glycolytic processes during physical-load energy-supply.

Conclusion.

The orientation of connections between characteristics of physiological reactivity CRS on hypercapnic shifts respiratory homeostasis and physical capacity for work allows to assume presence of the general appropriateness, consisting that increase of a level of sensitivity and general reactivity CRS on CO_2-H^+-stimulus are mutually conditioned by prevalence in training process of training loads mainly anaerobic character, and decrease in sensitivity by prevailing use trainings ways directed on development of aerobic opportunities of an organism and increase level sportsmen endurance. It specifies that changes of physiological factors which determine a level of sensitivity responses cardiorespiratory systems on shifts respiratory homeostasis, on the one hand, display long accumulation the same training influences on character of metabolism, and with another – are closely connected.

In conditions load of average aerobic power the high level of sensitivity CRS on CO_2-H^+-stimulus as it took place at sportsmen – runners on a distance 100 м, caused fast reaction CRS to change of acid-base equilibrium condition of blood, and in conditions of long load maximal aerobic capacity sensitivity of reactions CRS system to hypercapnic at sportsmen – long-distance runners (5000 m) is reduced promoted mobilization, instead of oppression speed of expansion functional reactions.

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