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Training-related modulations of the respiratory hypoxic and hypercapnic response sensitivity in young elite endurance athletes

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abstract

Background The present study was performed to clarify of training-related modulations of the cardiopulmonary system (CPS) response sensitivity to a hypoxic and hypercapnia stimulus in young endurance athletes. The practical objective was to estimate a possible association between the reduction in sensitivity to respiratory homeostasis shifts and young athletes' early sports specialization.

Material/Methods Twenty-eight young male athletes aged 12.4–17.5 years with experience of strenuous endurance training in kayaking served as the subjects. The impact of strenuous endurance training was estimated in three parts of studies with athletes divided into age groups.

Results Studies have demonstrated that endurance training in kayaking results in a distinct decrease in the CPS response sensitivity to hypoxia in young athletes. The responses to hypoxia in elite 16-year-old athletes do not significantly differ vs. elite adult athletes. Respiratory responses to hypercapnia also decreased (although to a lesser extent). Hypercapnic sensitivity in 16.3 yrs. do not significantly differ vs. elite adult athletes. When the responses were normalized to body mass, body surface and vital capacity, such differences were reliable. Chemo sensitivity CPS of young elite kayakers in 16.3 yrs. was significantly lower than in 14.9 yrs. The most expressed changes of respiratory responsiveness were noted in the response output during standard levels of hypercapnia and hypoxia. The greatest differences between young and adult elite athletes were revealed in hypercapnic ventilatory response.

Conclusions It is possible to believe that monitoring sensitivity and kinetic features of CPS responses in long-lasting high intensity of endurance training may be a prerequisite of best stimulation of its morphological and functional improvement. It can be assumed that the decrease in the CPS response sensitivity to the combined hypoxic and hypercapnic stimuli at long-lasting heavy kayaking training may deviate from the optimal one. In young kayakers it may be linked with trainability decline. But special studies need to confirm this assumption.

Key words elite young athletes, endurance training, respiratory response sensitivity, hypoxic and hypercapnia stimulus

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INTRODUCTION

Taking into account a long period during which an athlete's body remains in the state of oxygen deficiency and acidosis, it is quite natural for it to adapt to the shifts of PCO_2, pH and PO_2 to a certain extent under long-term physical training. The choice of young athlete kayakers for the study was determined by the presence during work of the difficulties in free breathing which are associated with the difficulty in strokes matching breathing when working with hands under a heavy load of arm exercise and a high frequency of strokes (about 120 per min). It is known that during dynamic whole-body exercise many healthy highly trained men are unable to maintain arterial blood gases homeostasis [1, 2]. Hypoxemia develops at all exercise intensities with varying patterns and is more common in aerobically trained young subjects; however, some untrained persons also develop hypoxemia [3]. In case of a rational training process, adaptation is closely related to increased O_2 utilization (a more favorable ratio of alveolar ventilation and pulmonary blood perfusion) and more efficient compensation of acidosis, i.e. enhanced economization of cardiopulmonary functions and reserve capacities of the respiratory homeostasis system [4, 5]. This is confirmed by decreased ventilatory sensitivity and a lower circulatory response to a hypoxic stimulus in high performance endurance athletes at rest as compared to untrained persons [6, 7, 8, 9]. Available evidence indicates that chemoreceptors are a significant mechanism that explains breathing matching the metabolic rate [10, 11, 12, 13].

It is known that the plasticity of the sensory response of the carotid body is critical for ventilatory adaptations at rest as well as during exercise [14, 15, 16]. A significant increase in pulmonary ventilation (V_E) in highly trained athletes has only been observed after PaO_2 decrease below 50–60 mm Hg [6, 7]. This increment of response per unit of PaO_2 (SaO_2) decrease in athletes as compared to untrained persons was 3–5 times and 0.6–2.5 times lower for V_E and central circulation, respectively [17]. The above may be indicative of an association between the reduced sensitivity to hypoxia and the development of special endurance work capacity. Higher P_ACO_2 at rest and a lower response during CO_2 rebreathing have been noted in the trainees holding breath and in highly experienced elite endurance athletes [7, 18, 19]. Divers possess a lower ventilatory response to CO_2, which was not affected by exercise or the tested oxygen pressures suggesting an adaptation of central CO_2 sensitivity [20]. It has also been demonstrated that the fatigue, which is common during high training loads in sport, may lead to a transient decrease in CPS sensitivity of responses and its fast kinetics [17]. Repeated training loads in fatigue are characterized by a relatively hypokinetic response of CPS. Long-lasting training loads may similarly result in accumulation of these events [21]. Maturation of chemoreceptors may be an explanation of the differences in hypoxic response at various stages of development. Sensitivity to CO_2 sensors also undergoes maturation [22]. In connection with this, there is a reason to believe that intermittent acidosis and hypoxemia from long time of endurance training may influence the hypercapnic and hypoxic drive of the respiratory control system in young kayaker athletes. The degree of reduction may have consequences for the training effect of heavy training loads and its sustainability in the age development. Entire realization of the individual "development potential" of body CPS underlies optimization of age development and training of young athletes [23, 24]. In this regard the homeostatic factors of system regulation formation and changes in sensitivity of responses to hypoxic and acidosis, in particular, should be taken into consideration.

It is known that there are critical periods in a young person's life, when the effects of training can be maximized [25]. This has led to the development of athletic models which identify appropriate training aims at each age stage [26]. In boys the highest increase in physical fitness along with possible transient disproportions of body functional aerobic and anaerobic capacities are observed at about 14 years of age [27]. There are data indicating that during the period of body growth and development heavy training loads may produce several negative effects [26, 28, 29]. This may refer to the fact that young elite endurance athletes are subjected to heavy loads close to those used by adult athletes. Numerous cases of significant reduction in an increase in special work capacity and sports results in many young athletes in the process of long-term training have been reported [24, 25]. Previous research showed that nonfunctional overreaching or overtraining occurred in approximately 30 per cent of young athletic population [25]. Risk associated with early specialization in high endurance sports includes burnout and overuse injuries [5]. This may result in loss of motivation in young talented athletes to further athletic training. The fact that young athletes who were the best at a young age (15–18 years) usually failed to achieve high performance at a mature age has been accentuated more than once [7, 23].

We have supposed that a decrease in CPS response sensitivity of young kayakers to respiratory homeostasis shifts during chronic adaptation to heavy endurance loads may go beyond the optimum values. This may be reflected in a decrease in the trainability potential. The aim was to study training-related modulations of the CPS response sensitivity to a hypoxic and hypercapnia stimulus in young endurance athletes (kayakers).

METHODS

PARTICIPANTS AND SETTING

Twenty-eight young male athletes aged 12.4–17.5 yrs with experience of strenuous endurance sport training in kayaking served as the subjects. The impact of heavy endurance kayaking training was estimated in three parts of the study with athletes distributed into the age groups. In the first part of the study, which assessed the differences in the respiratory response to a hypoxic mixture in athletes of different ages, analysis was carried out by comparing three groups of young athletes: 12.4 (12.0–13.1), 14.9 (14.1–16.0) and 16.3 (16.1–16.5) yrs. In the second part of the study, the differences in characteristics of response sensitivity to a hypoxic and hypercapnic stimulus (in a rebreathing test) in the age groups of high performance athletes 14.9 ±0.26, 16.8 ±0.24 and adults (21.6 ±0.8 yrs.) were analyzed. In the third part of the study, the differences in response sensitivity were analyzed in young athletes who commenced endurance training at different ages (earlier or later) and with 3.2–4.3 years of training experience. For this purpose, groups of 13.1–14-year-olds (started training at the age of 9–10 yrs), 16.3–17.2-year-olds (started training at 12.5–14.5 yrs), and 18.9–21.4-year-olds (started training at 16.3–17.5 yrs) were studied. In this part of the study, in order to assess the impact of 3.2–4.3 yrs of kayaking training in comparison with untrained persons of a similar age, groups of 13-14-year-olds (n = 10), 16–17-year-olds (n = 8) and 19–21-year-olds (n = 7) were studied. To assess the degree of change in the sensitivity of responses to hypoxia and hypercapnia in athletes of different ages under the influence of training in kayaking, the criterion for inclusion in the groups was high individual sport performance, taking into account that a kayaker could be assigned to elite athletes of a given age. One of the criteria for inclusion in a group was a level of aerobic power. Maximal O2 intake (VO2max) of young athletes was typical of elite athletes in all age groups and constituted 55.3 (1.1), 63.2 (1.0) and 67.8 (1.2) ml·kg-1·min-1 at the age of 13.1–14.2 yrs, 16.3–17.2 yrs and 18.9–21.4 yrs, respectively. To assess the impact of a similar duration of sports training, but which began at different ages, groups of kayakers were formed on the basis of the availability of preliminary duration (experience) of sports training of 3.2–4.3 years and a high sports qualification among a given age of athletes. Groups of healthy untrained individuals were selected taking into account age and body height and mass similarity with groups of athletes of a given age. The untrained persons were schoolchildren whose motor activity was mainly determined by the obligatory curriculum of Physical Education. The persons aged 19–21 yrs were students who did not participate in sports programs. Body height, mass and BMI of the athletes and untrained persons were within local age norms. Consent of athletes and parents of young athletes and of the local ethics commission was obtained as well. Studies were conducted in the setting of stationary training camp during the final part of the main training season (August–September). The results of the existing medical control showed that during the phase of studies young athletes had no signs and symptoms of overload or overreach nor of the autonomic nervous system disorders. To assess the latter one, an orthostatic test, a measurement of the sinus arrhythmia of the heartbeats and blood pressure and EKG monitoring in the morning after awakening were used.

TRAINING CONTENT

Already at the age of 12–14 years young athletes were training 2.0–2.5 hours, 5–8 times per week according to sports school programs. At the age of 14–16, the intensity of training significantly increased reaching that peculiar for training of the national team reserve. It should be noted that some of young athletes were the best in their age category. Aerobic endurance and aerobic-anaerobic endurance types of training were used. A sound basis of aerobic endurance of a child by using intermittent workload was fundamental for all young athletes up to 14–15 years. We suggest that they performed a type of training that was tailored to their physiology and that the type and the intensity of training were most effective for developing their endurance. Taking into account the higher anaerobic threshold in young athletes (about 80–85% of VO_2max) as compared to that of adult athletes, the intensity of training loads was focused on that level. If we assume that a 12–14-yr-old child's maximum heart rate is about 205 bpm, then the optimum training heart rate for continuous cardiovascular training will be 170–175 bpm which is considerably higher than the rate normally recommended for the average adult [30].

PROCEDURES AND MEASUREMENTS

Three procedures for determining indices that characterize the sensitivity of pulmonary ventilation (V_E) and the heart rate (HR) responses to a hypoxic and hypercapnic stimulus were used. The sensitivity of response to hypoxia was measured during inhalation of a standard hypoxic mixture as well as during rebreathing. The subjects refrained from intensive exercise during the previous 24 hours (rest day) and did not perform exercises 48 hours before strenuous training workloads. Subjects were instructed to take a carbohydrate rich diet the days before the tests.

HYPOXIC AND HYPERCAPNIC VENTILATORY RESPONSIVENESS

A short-term (5 min) hypoxic mixture (PiO_2 = 84 mm Hg in nitrogen) breathing was performed in a reclining position 20-30 minutes after awakening (at minimal activity). Indoor temperature was 20–22°C, whereas the atmospheric pressure – 740–746 mm Hg. Subjects were breathing through a standard sack mouthpiece with previously prepared gas mixture. Data were averaged during 5 min of breathing. P_AO_2, P_ACO_2 were estimated according to end-tidal PO_2 and PCO_2. 6 minutes before hypoxic mixture breathing, the initial values characterizing the basal level of respiration characteristics were measured. VO_2 at rest was measured by means of the Douglas bag method.

Twenty-seven male young athletes were examined by isocapnic progressive hypoxia and CO_2 rebreathing tests also at morning standard rest 30-40 min after waking up, in the reclining position. Ventilatory and heart rate responses to isocapnic hypoxia were evaluated in a hypoxic rebreathing test [31] as the slope of the hyperbola between $P_{ET}O_2$ and minute ventilation (parameter A) [32], and as the slope of regression between oxygen desaturation (SaO_2) and HR.

HR increment per 1% of SaO_2 decrease (DHR/DSaO_2) was calculated proceeding from the linear dependence of S_aO_2 and HR. Hypoxic ventilatory responsiveness was derived from the isocapnic one, with $P_{ET}CO_2$ maintained at the spontaneous eucapnic level at about 36–38 mm Hg (by diverting the gas flow through a CO_2 absorber). Hypoxic ventilatory responsiveness was normalized to body mass and surface. Hypercapnic ventilatory responsiveness (the slope of the linear region of the V_E – $P_{ET}CO_2$ relationship) was derived from a hyperoxic CO_2 rebreathing test (initial gas composition 7% CO_2 in O_2) [33]. Pulmonary ventilation and end-tidal CO_2 were determined during rebreathing by means of the Jaeger Oxycon Alfa device. The ventilatory response to hyperoxic hypercapnia was analyzed by a linear regression and was determined by the slope of the DV_E/DP_ACO_2 line (S value) and intercept of the $P_{ET}CO_2$ axis (B) by the method of least squares. The S value was normalized to the body mass and vital capacity (VC). The response output at standard levels of $P_{ET}CO_2$ 50 mm Hg (V_{E50}) and 84% blood oxygen saturation (V_{E84}, HR84) were also calculated. Characteristics of respiration were measured (breath by breath using 5 s stationary averages throughout the test protocol) by Jaeger Oxycon Alfa, Germany; Oxymeter ChoicemMed MD 300W, Polar Accurex Plus, Waltham, MA, USA.

STATISTICAL ANALYSES

Between-group baseline characteristics, anthropometric data (mass, height, and the body mass index, vital capacity, aerobic power and respiratory response characteristics) were compared with a cross-sectional ANOVA method. Prior to all analyses, normality of the data was assessed by the one-sample Kolmogorov–Smirnov test. In addition, the homogeneity of variances was assessed with Levene's test. Differences in the value of hypoxic and hypercapnic response sensitivity between young athletes of various ages and adult elite athletes and in the value of the percent decreasing between young athletes who commenced endurance training at different age vs. untrained (of similar ages) were examined by Student's t test. Values were presented by means ± standard deviations, and statistical significance was set at $p<0.05$. Statistical analyses were performed using a statistical software package SYSTAT.

RESULTS

Results obtained during hypoxic mixture breathing (84 mm Hg O_2) demonstrated a significant decrease with age in the respiratory response to hypoxia in young athletes (Table 1). The responses to hypoxia in elite 16-yr-old athletes were close to those of elite adult athletes.

Table 1. Response of lung ventilation and HR (changes relative to the initial level) to short-term (5 min) hypoxic mixture (PiO_2 = 84 mm Hg) breathing in young athletes of different ages. Years in strenuous athletic training in groups 1, 2, 3 amounted to 2.2-3.1, 4.5-5.1, 6.1-6.5 and 7.9-10.2, respectively (mean 5 min values are presented)

Characteristics	12.4 (12.0–13.1) yrs (Group 1), n = 12	14.9 (14.1–16.0) yrs (Group 2), n = 10	16.3 (16.1–16.5) yrs (Group 3, elite), n = 6	21.6 (19.5–23.1) yrs (Group 4), n = 8	P < 0.05
ΔVE, ml · kg-1· min-1	47 (4.3)	40(3.2)	27.7(1.7)	27.3(1.9)	1,2-3,4
ΔRF, in min-1	0.05	-1.0	-0.9	0.9	ns
ΔHR, bpm	22.1(2.0)	18.0(1.7)	9.8(0.5)	8.1(0.6)	1,2-3,4
ΔPAO2, mm Hg	-53.2(3.1)	-52.7(2.4)	-51.6(2.1)	50.7(3.1)	ns
ΔPACO2, mm Hg	-2.7	-2.4	2.0	3.3	ns

Pulmonary ventilation and HR responses tended to decrease with age in young athletes. A significantly lower response was noted in 16-yr-old elite athletes. At the same time, significant differences in the degree of changes of the respiratory rate, P_AO_2 and P_ACO_2 were not observed.

Evaluation of training-related modulations of the CPS response sensitivity to a hypoxic and hypercapnic stimulus was made in the rebreathing test according to several indices. They represented various characteristics of response sensitivity and output (Table 2).

Table 2. Characteristics of response sensitivity to hypoxic and hypercapnic stimulus (in the rebreathing test) in young high performance athletes of different ages and in adult elite athletes. Mean (SD)

Characteristics	Age, yrs			Significant at P < 0.05
	14.9 ±0.26 (n = 10)	16.8 ±0.24 (n = 9)	21.6 ±0.8 (n = 8)	
	1	2	3	
DVE/DPACO2, l·min-1·mm Hg-1	1.51(0.08)	1.21(0,02)	1.10(0,09)	1-2;1-3
DVE/DPACO2 ml·kg-1·min-1 per 1 mm Hg	0.238(0.02)	0.170(0.01)	0.138(0.01)	1-2;1-3;2-3
(DVE/DPACO2)/VC, l·min-1·mm Hg-1 per 1 l	0.320±0.02	0.240±0.08	0.183±0.02	1-2;1-3;2-3
VE50, l·min-1	38.3±1.0	30.2±1.6	18.2±1.2	1-2;1-3;2-3
SP-DP at PACO2 50 mm Hg	53.2±2.0	50.9±3.4	43±2.3	1-3
DVE/DSaO2, l·min-1 per 1 %	0.89±0.09	0.62±0.11	0.39±0.08	1-2;1-3;2-3
VE84, l·min-1	23.1±1.0	19.7±1.2	12.8±1.1	1-3;2-3
DHR/DSaO2, bpm per 1 %	1.58±0.08	1.37±0.13	1.25±0.09	1-2;1-3
HR84, bpm	98.1±1.5	92.6±2.7	76.2±2.1	1-3;2-3

Significantly lower sensitivity of responses was noted in athletes aged 16.9 ±0.24 yrs as compared to those aged 14.9 ±0.26 yrs in a great number of indices. Differences between young and adult elite athletes aged 21.6 ±0.8 yrs were observed as well. The latter had lower sensitivity of ventilatory and circulatory responses to both the hypoxia and the hypercapnic stimulus in all cases. The above referred to the absolute response value and normalized to 1 kg of body mass or during the ventilatory response referred to vital capacity. The most expressed differences in the cardiopulmonary system reactivity were noted in the response output at standard levels of stimuli (V_{E50}, V_{E84}, HR_{84}).

Analysis of the response sensitivity to a hypoxic stimulus in the rebreathing test (according to ventilatory and circulatory responses under isocapnic conditions) was performed in three groups of young athletes with the purpose of quantitative assessment of the impact of years in training and the age of becoming engaged in a long-term training process. Each group started strenuous athletic training at a different age (Tables 3 and 4).

Table 3. The values of changes in the young athletes (vs. untrained persons of a similar age) in the sensitivity of lung ventilation response to a hypoxic stimulus (A, dependence of V_E–P_AO_2 per m^2 of body surface) and HR response (DHR/DSaO_2) as well as the ventilatory sensitivity to hypercapnia. The young athletes began endurance training at different ages and their years in training amounted to 3.2–4.3. Mean (SD)

Age groups (age of beginning training)	Characteristics			
	A (VE–PAO2)/ m2	DHR/DSaO2, bpm per 1%	DVE/DPACO2, ml·kg-1·min-1 per 1 mm Hg	VE50, l·min-1
13.1–14.2 (n = 11) (began training at 9.1–10.1 yrs)	- 59.9(4.1)*	-0.78(0.11)*	-0.048 (0.005)	-9.46(1.1)
16.3–17.2 (n = 9) (began training at 12.5–14.5 yrs)	-50.0(3.7)	-0.68(0.11)	-0.049 (0.002)*	-9.42(1.3)*
18.9–21.4 (n = 8) (began training at 16.3–17.5 yrs)	-45.1(3.4)*	-0.53(0.09)*	-0.024 (0.004)*	-4.75(0.51)*

* significant at $p < 0.05$

The significant differences in the degree of decrease in the sensitivity of the ventilatory response to hypoxia (per m^2 of the body surface), as well as the heart rate responses, were significantly different between young athletes aged 13.1–14.2 yrs (began training at 9.1–10.1 yrs) and 18.9–21.4-yr-old athletes (began training at 16.3–17.5 yrs) (Table 3). In the characteristics of the response sensitivity to hypercapnia, such differences were between 16.3-17.2-yr-old athletes (began training at 12.5–14.5 yrs) and 18.9–21.4-yr-olds. The percentage differences in the sensitivity of responses to hypoxia and hypercapnia (rebreathing tests) of the young athletes vs. untrained persons of a similar age are shown in Table 4.

Table 4. Decrease (in %) in the hypoxic and hypercapnic response characteristics in young athletes vs untrained persons of similar age. Young athletes began endurance training in different ages. In all age groups training experience amounted to 3.2-4.3 years

Age groups	Characteristics				Significant at $p < 0.05$
	A (VE–PAO2)/ m2	DHR/DSaO2, bpm per 1 %	DVE/DPACO2, ml·kg-1·min-1 per 1 mm Hg	VE50, l·min-1	
	1	2	3	4	
13.1–14.2 (n = 11); began training at 9.1–10.1 yrs	-49.2(7.8)	-61.7(7.5)	-20.1(2.2)	-24.7(3.1)	1–3; 2–3
16.3–17.2 (n = 9); began training at 12.5–14.5 yrs	-48.1(5.9)	-63.7(6.1)	-28.9(3.4)	-31.2(3.9)	1–3; 2–3
18.9–21.4 (n = 8); began training at 16.3–17.5 yrs	-46.2(5.1)	-69.0(7.6)	-17.8(2.7)	-26.1(3.0)	1-2; 1-3;2-3

There were no significant differences in the percentage decrease in the hypoxic and hypercapnic main characteristics of response sensitivity related to the surface area or kg of body mass between young athletes who commenced endurance training at different ages and whose years in training (in all age groups) constituted about 3–4 yrs vs. untrained persons (of similar ages). At the same time, attention is drawn to the varying degrees of decrease in the sensitivity of reactions to hypoxia and hypercapnia, on the one hand, and hypoxic sensitivity of ventilation and heart rate response, on the other hand. The decrease in the sensitivity of the heart rate response was more pronounced.

In this way, the highest reduction of sensitivity to a hypoxic stimulus occurred when strenuous endurance training began at the age about of 9-10. Years in training of the analyzed groups constituted about 3-4. The lowest sensitivity decrease, both according to absolute values of the sensitivity of lung ventilation response and values of the circulatory responses according to HR, in particular, took place when strenuous training began at the age of 16–17 yrs. A decrease of the ventilatory response sensitivity to hypercapnia was 2-2.5 times less than that to hypoxia. According to the response to hypercapnia in percentage, the only tendency to a smaller decrease in comparison to untrained persons was observed at later engagement in strenuous training (16.3–17.5 yrs). The tendency to a higher reduction (in %) of the response sensitivity to CO_2 was observed when strenuous training began at the age of 12.5–14.5 yrs.

Differences in hypoxic sensitivity of responses between young athletes and untrained persons of the same age are presented in Fig.1 and Fig.2. These data are shown for ventilatory response (“A” parameter – dependence of VE–P_AO_2 per m^2 body surface) and the HR response (according to $\Delta HR/\Delta SaO_2$). Changes in young athletes aged 13.8, 16.7 and 19.6 yrs that started strenuous athletic training at different ages are also presented.

As Table 3 and Fig.1 and Fig.2 show, significantly lower levels of hypoxic CPS responsiveness were noted in young athletes of all age groups as compared to untrained persons of the similar age. In untrained young persons, sensitivity of the ventilatory response to hypoxia (A) decreased by 19.9 (2.2) and 13.1 (1.7) units from 13.1–14.2 yrs to 16.3–17.2 yrs and from 16.3–17.2 to 18.9–21.4 yrs, respectively. Sensitivity of the HR response ($DHR/DSaO_2$) within the indicated time intervals decreased by 0.17 (0.07) and 0.21 (0.09) bpm per -1% SaO_2.

These data indicate that the decrease in the response sensitivity to a hypoxic stimulus due to age development is significantly smaller than that induced by endurance training.

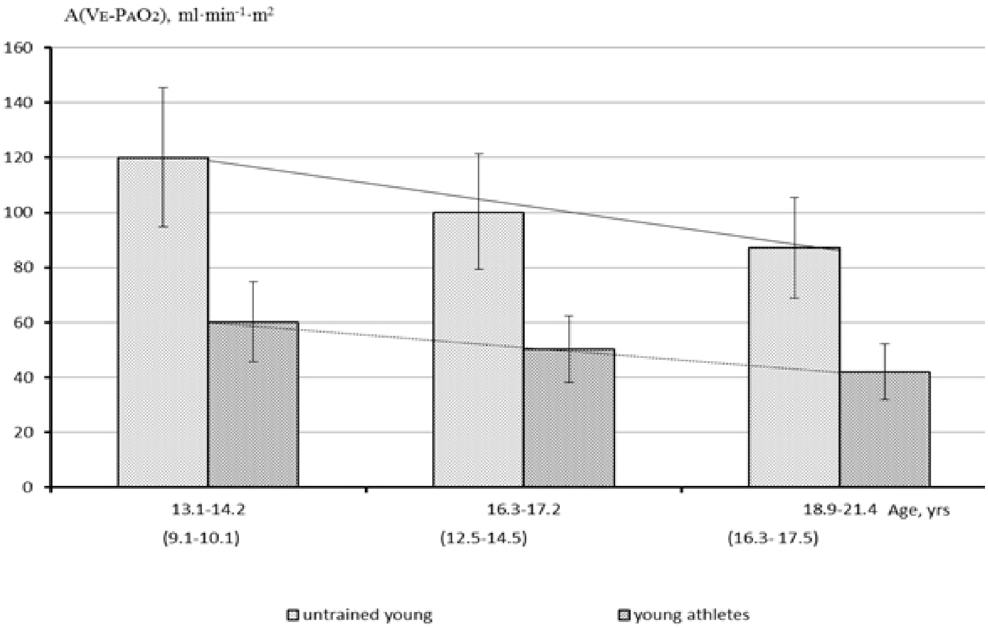

Fig. 1. Changes of the hypoxic ventilatory response (parameter ‘A’ – characteristic of hyperbola for V_E–$P_{ET}O_2$) in young elite athletes aged 13.8 (13.1–14.2) yrs, 16.7 (16.3–17.2) yrs and 19.6 (18.9–21.4) yrs who begin strenuous training at different ages (shown in parentheses)

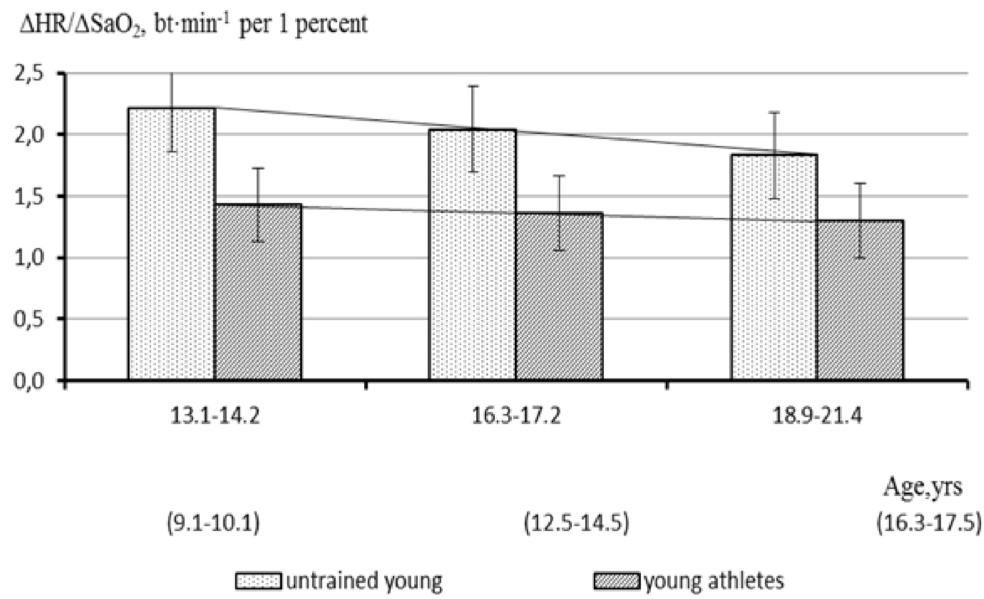

Fig. 2. Changes of the hypoxic circulatory response ($\Delta HR/\Delta SaO_2$) in young elite athletes aged 13.8 (13.1–14.2) yrs, 16.7 (16.3–17.2) yrs and 19.6 (18.9–21.4) yrs who began strenuous exercise training at different ages (shown in parentheses).

The most expressed differences in the sensitivity of responses were manifested when strenuous endurance training began at an earlier age. The “older” young athletes were at the beginning of training, the lesser impact on the sensitivity to a hypoxic stimulus was produced by kayaking training. However, while calculating the decrease in the response sensitivity in percentage (in comparison to untrained persons), the degree of decrease within 3.2–4.3 years of training which started at different ages showed no significant differences (Table 4). Although the degree of response sensitivity decrease (vs. untrained children) did not differ in each age group, faster achievement of sensitivity characteristics peculiar for adult highly skilled athletes was observed. This analysis shows that the later the age at which athletes started strenuous training, the lesser was the decrease in the analyzed characteristics of response sensitivity. The most significant differences were observed while calculating differences in CPS responses sensitivity to hypoxia between young and adult kayakers. In the case of similar training experience (about 3–4 yrs), the differences in hypoxic sensitivity (A parameter) between athletes aged 13–14 and 16–17 yrs and adult athletes constituted 43.2 (7.1)% and 19.4 (3.6)%, respectively ($p < 0.05$), whereas differences in $DHR/DSaO_2$ constituted 10.0 (1.9)% and 4.6 (1.2)% ($p < 0.05$).

DISCUSSION

We have proceeded from the fact that heavy endurance load is accompanied by respiratory homeostasis shifts and tension of its controlling systems. These are a cause of adaptation changes including those in chemo sensitivity. Such influences of heavy physical exertion can be more clearly expressed in kayakers due to the difficulty in breathing movements when working with hands. Significant differences in the majority of characteristics of the CPS response sensitivity to hypoxic and hypercapnic stimuli have been noted between young athletes of different ages and adult kayakers.

Studies have demonstrated that kayaking training results in a distinct decrease in the CPS response sensitivity to hypoxia and hypercapnia in young athletes. In older young athletes, the sensitivity of the CPS responses was lower than in the younger ones. In elite young athletes already at the age of about 16 years it did not differ from that of adult high performance athletes. When intensive training started at a very young age (about 9–11 yrs), the decrease in the sensitivity of the responses was more pronounced, even with the same number of years in training (training experience). When calculating the changes per kg of body mass or body surface as a percentage of relatively untrained individuals of similar age, no significant differences were noted. Although the percentage degree of response sensitivity decrease (vs. untrained children) did not differ in each age group, faster achievement of sensitivity characteristics peculiar for adult, highly skilled athletes was observed. At the same time, there was a greater decrease in the response to hypoxia than to hypercapnia and to hypoxic sensitivity of the heart rate than to ventilation response.

The above has been illustrated by the response to hypoxic gas mixture inhalation as well as by hypoxic tests of rebreathing. Hypercapnic sensitivity also decreased (although to a lesser extent) and was lower in young elite athletes. This decrease may be explained by both the impact of the stage of age development changes and increased years in athletic training. The most expressed changes of respiratory responsiveness have been noted in response output during standard levels of hypercapnia and hypoxia (V_{E50}, V_{E84}, and HR_{84}). The most distinct decrease in HR response sensitivity normalized to kg of body mass and body surface V_E has been observed in young athletes at the ages of 9–11 and 15–16 yrs. Hypercapnic sensitivity of the ventilatory response in young elite athletes normalized to 1 kg of body mass constituted 0.170 (0.01), whereas in adult elite athletes – 0.138 (0.02) $ml \cdot kg^{-1} \cdot min^{-1}$ per 1 mm Hg. Thus, the difference amounted to 18.8 (2.2)%. Sensitivity of the HR response to hypoxic stimulation (DHR/$DSaO_2$) constituted 1.37 ±0.13 and 1.25 ±0.09 bpm per 1% in elite young and adult athletes, respectively, reaching the difference of 8.8 (1.1)%. The distinct decrease in the hypercapnic ventilatory response in young and adult elite athletes may be related to higher volume of anaerobic glycolytic loads in adult and post pubertal elite athletes [24]. V_E gain in young athletes during P_ACO_2 increase per 1 mm Hg (during the period from 9–10 to 16 years of age) significantly decreased from 42 to 30 $ml \cdot kg^{-1} \cdot mmHg^{-1}$. According to available data, this value constituted 20–25 $ml \cdot kg^{-1}$ per 1 mm Hg in 20-26-year-old males [7]. Analysis of age differences in V_E at P_ACO_2=50 mm Hg (V_{E50}) also indicated the decrease in reactivity to CO_2 with age. For instance, at the age of 10, V_{E50} constituted 0.50 (0.06) $l \cdot kg^{-1} min^{-1}$, whereas at the age of 15-16 years – only 0.32 (0.03) $l \cdot kg^{-1} min^{-1}$. Comparison of V_{E50} and maximal V_E during physical load (V_{Emax}) convincingly demonstrated the reduction of the net weight of CO_2–respiration stimuli with age. V_{E50} in children aged 10 yrs constituted 44.3 (4.9)% of V_{Emax}, whereas at the age of 15–16 yrs it was equal only to 28 (2.3)%. The presented data demonstrate that heavy endurance kayaking training tends to accelerate age reduction of the respiratory response sensitivity to CO_2 in young athletes.

A decrease in response to hypoxia and resistance to hypoxia in athletes has been reported long ago. Data on the differences in sensitivity to hypercapnia in athletes are quite controversial [6, 34, 35]. The ratio of training content and changes of response sensitivity as well as peculiarities of these effects of training in young athletes have not been determined sufficiently. Data of other studies on the increase in the duration of voluntary breath holding under the influence of endurance training (in young runners, swimmers and rowers of the given age) provide indirect confirmation of enhancement in the stability and reduction of sensitivity to hypercapnic and hypoxic stimulation. Quantitative measurements, however, are inadequate.

It is known that a decrease in sensitivity to hypoxia and hypercapnia may reflect the economization of CPS responses at load and at rest [4]. Improvement in ventilatory and HR responses economization at rest in the studied groups of athletes approximately corresponded to a decrease in chemo sensitivity responses. These characteristics may be consistent as they were obtained under similar basal conditions – within 30–40 minutes after waking up. It is noteworthy that in some elite young athletes the same degree of CPS economization was observed as in adult athletes. For instance, basal HR and VO_2 in young athletes in the group aged 16.7 yrs were 53.6 ±1.32 bpm and 3.70 ±0.09 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, whereas in elite adult athletes – 46.4 ±1.2 bpm and 3.31 ±0.1 $ml \cdot kg^{-1} \cdot min^{-1}$. The degree of these changes is almost the same, which may indirectly argue for the monitoring of economization of rest of young athletes for the assessment of long-term influence of training [5, 7]. More economic activity is one of the well-known criteria of perfect control mechanisms of CPS in trained persons [4, 5]. In this regard, we can assume that a decrease in chemo sensitivity is also a reflection of the improvement of control processes. During analysis of response sensitivity changes in the process of training one should bear in mind that the total amount of afferent impulsions necessary for efficient system functioning is reduced [36]. This indicates one of the important criteria of adaptation in system control CPS as a result of responsiveness optimization. It is suggested that control of ventilation simultaneously involves at least two variables, one being proportional to the pulmonary CO_2 output and the other being proportional to blood acidity [12]. Trainability of the cardiovascular system and limit of cardiac output may be related to sensitivity of the CPS response to CO_2-H^+ complex. It is also known that hypercapnic and hypoxic stimuli may enhance each other's effect within certain limits [11, 32]. Therefore, this is the evidence of the meaning of decreasing chemo sensitivity CPS response in order to understand the essence of young athletes' adaptation.

The study has demonstrated that the age of starting heavy training is of importance for the evaluation of a decrease in response sensitivity to hypoxia and hypercapnia. Changes in response sensitivity under the impact of about 3–4 yrs of training commenced at different age (9–10, 12–14 and 16–17) have been compared. Although the degree of response sensitivity decrease (vs. untrained children) did not differ in each age group, faster achievement of sensitivity characteristics peculiar for adult, highly skilled athletes was observed. It is safe to suppose that a more positive course of long-term adaptation of young athletes occurs when the level of decreased response sensitivity does not exceed certain optimum limits. To estimate this optimality, the degree of approaching the levels of response sensitivity peculiar for adult elite athletes may be used. That is, in order to assess the degree of long-term training effect, one should take into account the speed achieving the levels typical of adult athletes. The degree (speed) of approaching these levels has proved to be higher when training started at an earlier age (9–10 yrs). This is also confirmed by data illustrating a more expressed general influence of endurance training during certain periods of age development, namely at the age of 9–11 and 15–16 years [25, 27, 29]. Specifics of young athlete training load regulation holds some risks of deviations from the optimum adaptation. The consensus from the research is that children can improve their aerobic fitness but not to the same degree as adults, when following a similar training program, suggesting that higher intensity training will be more appropriate for children [25]. This is related to higher AT in children (about 85% of max HR in comparison in adults – about 75%). Some scientists have hypothesized that the reason for this diminished training effect in children is a 'hormonal trigger' which limits CPS responses and trainability until puberty. CPS responsiveness is closely related to this. It seems reasonable that until growth hormone levels, such as testosterone, rise, increasing the size of the heart and strength of respiratory muscle through endurance training may be limited [23, 28]. Research has proved that for adults and elite young athletes who have been training consistently for a long period and whose fitness levels are already high, the basic level of endurance training will not bring about any further improvements. This is why elite endurance athletes build up to train 10 to 14 times a week and use high-intensity interval training at maximal heart rates alongside the moderate-intensity continuous training [27, 28]. A related idea that children may need to train quite hard to improve their VO_2 max is a factor which may explain children's reduced trainability observed in the research. It has been demonstrated in our study that the highest decrease in ventilatory hypercapnic sensitivity (normalized to body mass and surface area, otherwise vital capacity) occurred from 15 to 17 yrs. In long-term training this is a period of tremendous increase in loads of anaerobic glycolytic type.

One may suppose that it creates additional prerequisites for excessively high intensity of training of young athletes and higher speed of CPS responsiveness decrease as compared to adult athletes.

Estimation of the significance of decreased response sensitivity to training effects requires account for the role of chemoreception during a physical load. It is reasonable to presume that sensitivity of responses to hypoxia and hypercapnia at rest reflects the role of indicated response stimuli during physical loads. For instance, a hypoxic stimulus of response tends to decrease in trained persons at standard levels of load [1, 9], which is one of the reasons for higher hypoxemia at heavy exercises in endurance athletes [3, 7]. It has also been demonstrated that the slope of the line of $V_E – P_ACO_2$ dependence during moderate intensity physical loads remains stable. As far as CPS responsiveness optimization represents the important mechanism of the long-term adaptation, the decrease in response sensitivity already at a young age may be one of the causes of trainability potential decline in young athletes. The obtained results, however, do not permit asserting the above univocally. They demonstrate that in the case of commencing endurance training at the age of 9–11 yrs a higher decrease in response sensitivity to hypoxia and hypercapnia is observed within about 3–4 years as compared to the case when endurance training started at the age of 13–14 yrs or even later. Insofar as the high and long lasting lactate acidosis may be one of the reasons of decreased sensitivity of responses to hypercapnia in young athletes, resistance (stability) to it as well as that of response sensitivity should be made allowance for. It is an important factor of acidosis respiratory compensation. It is known that the carotid chemoreceptors contribute to the tightness of arterial pH and PCO_2 regulation and the magnitude of the transient arterial hypoxemia in the non-steady-state phase of exercise [11, 12]. According to some data, the decrease in sensitivity to hypercapnia may occur during fatigue under conditions of repeated performance of anaerobic glycolytic loads at the end of training sessions [17, 21]. Beside the known metabolic factors, it may be related to high tension of regulatory processes as well. One may assume that in young athletes these phenomena of regulatory (control system) fatigue should be more expressed than in adult athletes. We have proceeded from the fact that controlling fatigue characteristics are changes of CPS responsiveness (sensitivity, stability and kinetics of responses) and best possible character of responses. If the characteristics of CPS chemo sensitivity of highly trained endurance athletes may be in a young age too, then the speed of decreasing CPS chemo sensitivity of young athletes is higher.

In this analysis, specifics of kayaking training should be taken into account. It is linked with certain biomechanical restrictions of complete realization of respiratory response capacities (elements of breath holding) at upper body exercise. If all of the above-mentioned decreases in response sensitivity in young athletes are due to training, then the question arises about expediency of such deep changes of chemo sensitivity during incomplete age formation and controlling mechanisms of CPS. It was shown that the additive exercise drive to breathe was lower in trained subjects [9]. Higher plasticity of sensitive elements of CPS control in a young developing body represents a certain risk for stability of this stimulation. This adaptive change is thought to underlie ventilatory acclimatization to chronic hypoxia, and hypercapnia is caused by many plastic morphological and biochemical changes in both the carotid bodies and the central nervous system. An important factor of these plastic changes is the transcription hypoxia inducible factor 1 (HIF-1) that induces the transcription of many genes encoding substances indispensable for the body adaptation to sustained hypoxia and acidosis [8, 15]. A possible decrease in peripheral and central chemoreception as the stimuli of CPS responses may be related to long-lasting fatigue on CPS chemo sensitivity response and lead to body trainability decline. But special studies need to confirm the essence of response sensitivity changes under fatigue in situations of long-repeated impacts of endurance training in young athletes.

CONCLUSIONS

Significant differences in the majority of the characteristics of response sensitivity to hypoxic and hypercapnic stimuli have been noted between the young athletes of different ages and adult kayakers. The respiratory hypoxic and hypercapnic response sensitivity of young elite kayakers (about 16 yrs old) under the influence of training can be reduced to the same extent as in adult elite athletes. In the case of similar years in training (3–4 years) the tempo of decrease was highest at a younger age (11–14 yrs). It is possible to believe that monitoring sensitivity and kinetic features of CPS responses in long-lasting high intensity of endurance training may be a prerequisite of best stimulation of its morphological and functional improvement. It can be assumed that the decrease in the CPS response sensitivity to the combined hypoxic and hypercapnic stimuli at long-lasting heavy kayaking training may deviate from the optimal one. In young kayakers it may be linked with trainability decline. But special studies need to confirm this assumption.

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