The purpose of the present study was to examine the influence of systematical training on the ventilatory response to hypoxia. A rebreathing technique - progressive isocapnic hypoxia - was used to measure hypoxic chemoreflex reactivity. The ventilatory response was measured in a group of 22 world class adult kayakers (22.6 ±1.9 yr), 16 young kayakers (17.8 ±1.1 yr), and 38 control subjects (21.9 ±1.9 yr). The ventilatory response to hypoxia - analyzed as the relationship (slope) MV/SaO$_2$ (minute ventilation/oxygen arterial blood saturation) - in the adult kayakers was significantly lower (-1.03 ±0.28 L/min/%, P<0.01) compared with those in the control group (-1.81 ±0.54 L/min/%) and the young kayakers (-1.54 ±0.6 L/min/%; the difference between the latter two was insignificant). The following values of P$_{0.1}$/SaO$_2$ (mouth occlusion pressure/oxygen arterial blood saturation) relationship were found for the investigated groups: adult kayakers (-0.20 ±0.1 cmH$_2$O/%, P<0.05), young kayakers (-0.47 ±0.1 cmH$_2$O/%, N.S.), control group (-0.48 ±0.18 cm H$_2$O%). Correlation between the hypoxic ventilatory response and VO$_2$max was significant in both groups of kayakers. These findings indicate that tolerance for hypoxia was elevated in the group of athletes compared with the control group. Hypoxic tolerance correlates with the duration of training.

**Key words:** hypoxia, kayakers, training, ventilatory response

**INTRODUCTION**

Respiratory effects of hypoxia are modified by the severity and duration of hypoxic exposure. Ventilation shows a biphasic pattern of changes: after an
initial increase, a decrease is observed during the first 30 min of hypoxic exposure (1). A more complex ventilatory response to hypoxia is generated in response to long-term (lasting several days) hypoxic exposure. Such exposure results in ventilatory acclimatization to hypoxia. In humans, the process of acclimatization to high altitude takes from 4 to more than 30 days depending on the altitude (2).

In humans, the ventilatory response to hypoxia originates in peripheral carotid chemoreceptors that respond to hypoxia and stimulate respiration within a few seconds (3). The notion that carotid chemoreceptors are primarily destined for the ventilatory response to short-term hypoxia is supported by studies in animals and in humans (4, 5). Carotid chemoreceptors also provide a tonic drive for ventilation in normoxia (6). They also show adaptation prolonged hypoxia in some pathological conditions (7). The important modulators of the ventilatory response to hypoxia include PCO$_2$, state of consciousness, CNS hypoxia, and neurochemical modulation of peripheral chemoreceptor functions. The hypoxic ventilatory response also is influenced by the sex of a patient, hormones, and the level of metabolic activity (1, 6).

Some studies suggest that exercise may influence the activity of carotid chemoreceptors. The exercise hyperpnea may be mediated by these receptors as a result of their increased gain. Such a hypothesis is supported by experiments showing increased in carotid bodies firing rate during passive hind limb exercise in anesthetized cats (8). Exercise hyperkalemia is another possible mechanism (9). There also is evidence suggesting that exercise hyperpnea is mediated by carotid chemoreceptors activated by changes in the arterial pressure of CO$_2$, O$_2$, and in H$^+$ concentration (10).

Repeated exercise-related activation of carotid chemoreceptors may activate a mechanism of their adaptation. In the present study we addressed this issue by investigating the ventilatory response to hypoxia in a group of athletes.

**MATERIAL AND METHODS**

The study was approved by a local Ethics Committee and informed consent was obtained from all study participants. Sixty seven healthy young male athletes were divided into 5 groups depending on the sport discipline, age, training intensity, and the duration of sport activity. A control group consisted of 38 age-matched men. Physical characteristics of the subjects investigated are presented in Table 1.

The ventilatory response to progressive isocapnic hypoxia was investigated by a rebreathing method (11). A computerized experimental setup for ventilatory studies during changes in inspiratory gas mixtures consisting of a closed circuit with a built-in CO$_2$ scrubber (soda lime) to maintain automatically a constant end-tidal PCO$_2$ and with an electromagnetic valve closing every 5 breaths at 100 ms from the beginning of inspiratory effort to measure mouth occlusion pressure ($P_{O.1}$) was used in the study (MES, Cracow, Poland). The rebreathing test took 16 min. Oxygen arterial blood saturation (SaO$_2$) was monitored by a finger pulse oximeter (Trident, Poland).

Hypoxic ventilatory drive was determined by minute ventilation (MV) and by the ratio of tidal volume/duration of inspiration (VT/TI). Slopes of the regression curves MV/SaO$_2$ (L/min/%) , VT/TI/SaO$_2$ (L/s/%), occlusion pressure $P_{O.1}$/SaO$_2$ (cmH$_2$O/%) , MV/P0.1 (L/min/cmH$_2$O) were
analyzed in all groups. To estimate the relationship between the ventilatory response to isocapnic hypoxia and aerobic fitness in the group of athletes, the slope of the regression curve MV/SaO$_2$-VO$_2$ max (L/min/%/ml/kg/min) was calculated. The maximum oxygen uptake (VO$_2$ max) is regarded as the best single measurement of cardiorespiratory endurance and aerobic fitness (12). All data were expressed as means ±SD. Student’s t-test was applied for the statistical analysis.

RESULTS

The ventilatory response to progressive isocapnic hypoxia presented as the mean values of the slopes, intercepts, and values of MV at 80% of SaO$_2$ are presented in \textit{Table 2}. There was a significant decrease in the MV/SaO$_2$ slope (P<0.01) in the groups of athletes (\textit{Fig. 1A}) compared with the control group. The values of intercept and MV-80% differed significantly between the athletes and the controls (\textit{Fig. 1B}). There were no significant differences either in the MV/SaO$_2$ slope or MV-80% between the group of junior kayakers and the control group (\textit{Fig. 1A} and \textit{B}).

The linear relationship between the inspiratory drive VT/TI and SaO$_2$ is presented in (\textit{Fig. 2}). A significant decrease (P<0.01) in VT/TI values in response to progressive desaturation was found in the groups of world class kayakers,

\begin{table}
\centering
\begin{tabular}{|l|l|l|l|l|l|l|l|l|l|}
\hline
Group & n & Age (yr) & Body weight (kg) & Height (cm) & BMI (kg/m$^2$) & Sport activity duration (yr) \\
\hline
Kayakers & 9 & 22.6 ±1.9 & 87.0 ±9.1 & 185.9 ±7.4 & 24.9 ±1.1 & 10 \\
World class A Kayakers & 13 & 19.5 ±0.8 & 76.3 ±8.7 & 180.6 ±7.3 & 23.3 ±1.6 & 7 \\
Junior kayakers & 16 & 17.8 ±0.4 & 77.1 ±4.1 & 179.1 ±6.0 & 24.0 ±1.0 & 5 \\
World class B Slalom kayakers & 16 & 17.8 ±1.1 & 67.3 ±6.3 & 174.5 ±5.4 & 22.1 ±1.7 & 5 \\
Rowers & 13 & 19.5 ±0.9 & 78.1 ±10.1 & 185.5 ±4.7 & 22.7 ±2.3 & 7 \\
Control group & 38 & 21.9 ±1.9 & 74.3 ±6.7 & 177.9 ±7.9 & 23.5 ±1.5 & - \\
\hline
\end{tabular}
\caption{Physical characteristics of the subjects.}
\end{table}

\begin{table}
\centering
\begin{tabular}{|l|l|l|l|l|}
\hline
Group & n & Slope (L/min/%) & Intercept (%) & MV-80 (L/min) \\
\hline
Kayakers & n=9 & -1.03 ±0.3** & 114.8 ±5.1** & 34.92±7.5** \\
World class A Kayakers & n=13 & -1.11 ±0.4** & 117.5 ±6.8** & 40.11 ±10.1** \\
Junior kayakers & n=16 & -1.53 ±0.6 & 112.5 ±6.6* & 46.34 ±14.1 \\
World class B Slalom kayakers & n=16 & -1.11 ±0.4** & 115.1 ±7.8** & 36.11 ±8.4** \\
Rowers & n=13 & -1.29 ±0.3** & 111.8 ±5.6* & 39.89 ±6.9** \\
Control group & n=38 & -1.81 ±0.5 & 108.1 ±3.4 & 49.73 ±11.4 \\
\hline
\end{tabular}
\caption{Mean values ± SD of ventilatory responses to progressive isocapnic hypoxia MV/SaO$_2$ in the groups of active sport training men, compared with the control group; *P<0.05, **P<0.01.}
\end{table}
slalom kayakers, and junior kayakers compared with the control group. There was no difference in the response to hypoxia between the rower group and the control group. Furthermore, the ventilatory response to hypoxia expressed as the slope of the MV/SaO$_2$ relationship correlated with the values of VO$_2$$_{max}$. There was a positive linear relationship between MV/SaO$_2$ and VO$_2$$_{max}$ in the group of young kayakers (P<0.001, Fig. 3). By contrast, a significant inverse relationship between MV/SaO$_2$ and VO$_2$$_{max}$ was found in the groups of world class kayakers (class A and class B) and slalom kayakers (P<0.001) (Fig. 3).

**DISCUSSION**

Arterial chemoreceptors are responsible for the ventilatory response to progressive isocapnic hypoxia. The rebreathing test - progressive hypoxia - allows estimating a role of carotid chemoreceptors in the regulation of the ventilatory drive. Several studies indicate a relationship between the hypoxic ventilatory response and a level of physical activity (13). However, the presence of this relationship has not been unequivocally supported by experimental results (14).

In the present study, the hypoxic ventilatory response was decreased, as assessed from the lower values of the MV/SaO$_2$ slope, in the groups of athletes compared with control non-training subjects. Ventilatory adaptation to hypoxia...
can provide an explanation for diminished hypoxic responses in athletes. At the beginning of exercise, the oxygen transport system (respiration and circulation) does not supply muscles with oxygen immediately. It takes several minutes for the required steady level of oxygen supply to be reached and for the aerobic mechanisms to be activated. Transition from rest to exercise generates an oxygen deficit in the body. During exercise hyperpnea, regulation of the airway diameter and of the tension developed by respiratory muscles minimizes breathing effort and the oxygen cost of breathing. Intensive exercise may induce arterial hypoxemia in some instances (15).

The level of exercise hyperpnea depends on chemical and mechanical conditions in the working muscles. Carotid chemoreceptor contribution to the hyperventilation of heavy exercise may have to do with increased plasma levels of $[\text{H}^+]$ (15), $K^+$ (9), and catecholamines (16); each being capable of stimulating chemoreceptor activity and reactivity. Several studies indicate that a number of
physiological systems, among others, cardiorespiratory or metabolic, can undergo specific training adaptations (17). Therefore, an adaptation process in carotid chemoreceptors to exercise may result in their limited reactivity to hypoxia. Different relationships between the hypoxic ventilatory response and maximal oxygen uptake in young and older kayakers (linear proportional relationship in the young kayakers and inversely proportional relationship in the world class and slalom kayakers) support the hypothesis that physical training decreases carotid chemoreceptors reactivity.

Takano at al (18) showed that the exercise hyperventilation is greater in subjects with greater activities of the central and peripheral chemoreceptors. Thus, smaller activity of peripheral chemoreceptors seems at play in the diminished ventilatory response during exercise, and even in lower oxygen costs of breathing.

In the present study, differences in the hypoxic ventilatory responses among the investigated groups of athletes were observed. Kayaking is a sport putting a great demand on the body, depending on the type of contest and distance. A greater exercise tolerance and higher anaerobic threshold were found in elite kayakers (19). Lutosławska at al (20) showed seasonal variations in anaerobic arm performance and blood metabolites levels. It is known that low-intensity high-volume training may be a reason for better anaerobic performance. Such training is a dominant component of the world class kayakers training program. Training of "elite kayakers" consists of aerobic, anaerobic, and strength components, which all improve the athlete's anaerobic performance (20). The sport called whitewater canoeing consists of two disciplines, wildwater and slalom. Wildwater (in our study junior kayakers belonged to this group) and slalom are two entirely different disciplines as far as the process of training goes.

Fig. 3. Relationship between the hypoxic ventilatory response (MV/SaO₂ slope) and the maximal oxygen uptake (VO₂ max) in athletes. (△ - slalom kayakers, ■ - kayakers junior, ◆ - world class A and B kayakers). Note the linear directly proportional relationship in the group of young kayakers (P<0.001) and inverse relationship in the other groups (P<0.001).
The wildwater is a typical endurance discipline. In the slalom, the velocity of muscle contractility and various types of strength elements prevail. Physical load in slalom is more unpredictable than that in wildwater (21).

We conclude that the years of training and repeated hypoxic stress may influence hypoxic reactivity of carotid chemoreceptors, elevating the overall tolerance to hypoxia.

REFERENCES


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