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[1]Radziejowski P., [2]Radziejowska M.

EVALUATION OF THE EFFECTIVENESS OF NATURAL AND ARTIFICIAL HYPOXIC INFLUENCES USING MATHEMATICAL MODELS OF THE FUNCTIONAL RESPIRATORY SYSTEM AND BODY OXYGEN REGIMEN

[1]Higher School of Education and Therapy prof. Kazimiera Milanowska (Poznań, Poland)
[2]Czestochowa University of Technology (Częstochowa, Poland)

Анотація: *Адаптація до гіпобаричної гіпоксичної гіпоксії в умовах гірського клімату традиційно використовується в системі підготовки спортсменів високої кваліфікації. Також у сучасному спорті знайшли своє застосування різні модифікації гірського клімату. Метою роботи було порівняння ефективності адаптації до гіпоксичної гіпоксії під час тренувального заняття в горах та на рівні моря під час інтервального гіпоксичного тренування (ІГТ). Ефективною заміною тренувань в умовах гірського клімату може стати метод ІГТ, який використовується поза плановими спортивними тренуваннями в стані спокою, коли на організм спортсмена діє лише один вид гіпоксії – гіпоксична гіпоксія. Різниця в характері ефектів гіпоксичної гіпоксії та гіпоксії в ІГТ дозволяє досягти тих самих результатів, що і під час тренувальних занять у горах, без втручання в запланований тренувальний процес, значних дорожніх витрат і необхідності досягти рівня акліматизації, необхідного для відповідного тренування навчання.*

Ключові слова: *функціональна дихальна система, кисневий режим організму, гіпоксична гіпоксія, інтервальне гіпоксичне тренування, гірські умови.*

Abstract. *The adaptation to hypobaric hypoxic hypoxia in mountain climate conditions is traditionally used in the system of training of high-qualified athletes. Also, in modern sport various modifications of mountain climate found their application, e. g. normobaric interval hypoxic training (IHT). The purpose of the work was to compare the efficiency of adaptation to hypoxic hypoxia during training session in the mountains and on the sea level in the course of IHT. The IHT method which is used outside planned sport training in the dormant state, when the athlete body is affected by only one type of hypoxia – hypoxic hypoxia, could serve as an effective substitution for training in mountain climate conditions. The difference in the nature of effects of hypoxic hypoxia and hypoxia in IHT allows the achievement of the same results as during training sessions in the mountains without interference in the planned training process, substantial travelling expenditures and necessity to reach the level of acclimatization required for appropriate training.*

Key words: *functional respiratory system, body oxygen regimen, hypoxic hypoxia, interval hypoxic training, mountain condition.*

Introduction.

The problem of optimization of human functional system activities in order to maintain and improve health and work capacity remains one of important and burning issues of today's biology and medicine [1, 2]. Nowadays more and more attention is paid by physiologists and medics to the description of mechanisms of adaptation to various types of hypoxia and the increase of functional capabilities of external respiration, blood circulation, transportation of oxygen by blood to the tissues and its further utilization in the cells mitochondria in the process of this adaptation [3, 4, 5, 6].

The training process in mountain conditions has become widespread practice in the sport of highest achievements [2, 7] but there are differences still to be analyzed in the mechanisms of adaptation of a human to hypoxic hypoxia in the process of hypobaric hypoxia in the mountains and under normobaric interval hypoxic training (IHT), which is quite widespread practice in sport now [8-13].

The aim of the study.

To compare the efficiency of adaptation to hypoxic hypoxia while conducting training sessions in the mountains with that taking place on the sea level in course of interval hypoxic training.

Object and research methods.

We used the system approach to the estimation of the parameters of the body basic physiological systems which deliver oxygen from the air to the working muscles. This approach combines instrumental studies with mathematical modeling of the body oxygen modes (BOM), aerobic productivity and work capacity.

For fulfilling our tasks we carried out the research in normoxic conditions in the mountains and under the reduced partial oxygen pressure in the air inhaled (p_iO_2). We used the following physiological and biochemical methods of the functional system of respiration, aerobic productivity and working capacity: spirometry, gas analysis of the air exhaled and of the alveolar air, measurement of cardiac rhythm (CR), determination of minute volume of blood, the acid-base balance of blood, the hemoglobin content in blood, lactate content, the urine content at rest and in the muscle activity.

The maximal Oxygen consumption (MOC) was measured by means of an ergometric test with the exercise load increasing by stages. The methods of study of general and special working capacity of athletes during a year cycle of training included: questionnaires, the analysis of competition activities, pedagogical testing, the method of automatised analysis of respiratory system function, aerobic capacities of the body and working capacity; mathematical statistics.

6 groups of students underwent testing among which there were 3 groups of athletes specialized in cycling. The 1-st group included 14 women aged 22,4±1,8 weighing 57,7±1,4 kg, with the height 168,5±2,1 cm. The

2-d group included 12 women aged 24,7±1,3 with the weight 59,4±1,1 kg, height 165,0±2,3 cm; The 3-d group was formed from 16 female athletes aged 20,3±2,8, the weight 57,7±1,4 kg, the height 163,3±1,2 cm.

All athletes were of a very high sport qualification – Honoured Master of Sport, Master of Sport of International Class.

The athletes of the 1-st group were examined before, during and after a month-lasting adaptation to hypobaric hypoxic hypoxia in the conditions of middle-height mountains. The examined of the 1-st group took the course of normobaric interval hypoxic training (IHT). The examined of the 3-d group took the course as a placebo group i.e. during the course they inhaled the air with the normoxic content of Oxygen.

The IHT course for the athletes consisted of 24 sessions conducted round-the-clock except for Sundays after breakfast before day training. Each IHT session consisted of five 5-minute series of inhalations of 11% Oxygen hypoxic mixture (from the 1st to 8th session), 10,5% Oxygen mixture (9-18 sessions), 10% Oxygen mixture (19-24 session) alternating by 5-minute normoxic intervals.

For detecting the reaction of athletes to the inhalation of hypoxic mixture a hypoxic test was carried out. Under normal Oxygen content (20,9%) in the inhaled air, before inhaling hypoxic gas mixtures (HGM) and also on the 3-d and 8th minute of breathing HGM there were the following objects of measurement such as a Respiratory Rate, the Minute Volume of Breathing by means of Volumeter «Atem volumeter 45084» (Germany), the gas content of the inhaled, exhaled, alveolar air – by means of "Spirolit" (Germany).

The saturation of blood by Oxygen and cardiac rate were measured throughout the test by means of pulse oxymeter «Oxyshattle» (USA). The hypoxic mixture was supplied by the device "HYPOXICATOR" which converts the air from 20,9% of Oxygen into a gas mixture with 8 – 20% of Oxygen in Nitrogen.

Before and after the test the blood samples (from the finger) were taken and the content of hemoglobin and lactate was detected.

The female athletes of the 1-st group were tested at the sea level i.e. in the conditions of normoxia, in the 1-st days of acclimatization after going to mountains (2100-2200 metres high, the town of Terskol, Kabardino-Balkaria, Russian Federation), at the end of the 3-week training session in the mountains and on the 1-st days after returning from the height 2100 m above the sea level.

Before and after the IHT course, besides the tests described above, another sort of tests was arranged which allowed us to speak about the dynamics in aerobic productivity and working capacity as a result of the course. All tests took place with normal content of 0_2 before the IHT course and after it.

The testing of general physical working capacity for all groups of the examined was carried out by means of a bicycle ergometer (KE-2000, Finland) whereas for special working capacity natural conditions of sporting activities were used such as the measurement of speed of covering 20 km race distance at some checking points of the road.

According to the data of athletes' diaries the analysis of parameters of training and competition load was made in combination with the minutes of competitions, the results of laboratory testing by means of bicycle ergometer, the testing of working capacity under natural training conditions.

The validity of difference of sampling average was determined according to the Student's test (t). The mathematical treatment of statistical material was carried out on the personal computer IBM PS with the use of statistical packages STADIA, STATGRAPHICS, STATISTICA.

Research results and their discussion.

The results of research indicated that moving to middle height mountains causes compensated hypoxia which shows itself not only in the strengthening of the respiratory system function but also leads to the redistribution of its reserves.

It is important to point out that the state of the functional respiratory system at rest at the different levels in the mountains depends on the degree of reduction of pO_2 fluctuations of parameters from their analogues under conditions of the plain were the more higher the lower was the partial pressure of oxygen in the air inhaled.

Being at the height of 2100 m above the sea level during the first day causes probable decrease in the working capacity and aerobic productivity which causes the decrease in the volume and intensity of training load.

Due to the adaptation to hypoxia in the mountains the state of FRS of high-quality cyclers in comparison with the results of examination conducted during the first days improved but the laboratory research of physical working capacity done at the beginning and at the end of practice training indicated that the 3-week stay of athletes in middle-height mountains under conditions of reduced partial Oxygen pressure in the inhaled air does not lead to the significant growth of power of maximal bicycle ergometer load and the level of Maximal Oxygen Consumption.

It was possible to observe the increase in FRS capacities, work capacity and aerobic productivity after a month-lasting adaptation to the two types of hypoxia considering the results of examination after returning of the athletes to normoxic conditions.

These results showed that the training session in the mountains led to the growth of FRS activity, positively reflected on aerobic productivity and working capacity which went up after returning of the examined to normoxic conditions.

All above mentioned gives reasons to conclude that 3-week training session spent in the conditions of middle-height mountains during which the athlete's body is imposed to both physical exercise hypoxia and hypoxic hypoxia essentially improves the parameters of FRS and parameters of BOR.

The power of critical bicycle ergometer exercise load increased by 15-17%, while a maximal Oxygen consumption, which is an integral parameter of aerobic capacities of the body, increased during one training session in the mountains by 7,12%±1,20%.

Emphasizing the availability of positive alterations in the state of FRS, BOR, aerobic productivity, working capacity of athletes after 3-week stay at the height of 2100 m above the sea, we would like to point out to the complexities of arranging training sessions in the mountains:

not always there are conditions for sporting training of full value; due to the process of acclimatization there is a necessity of more durable stay in the mountains than in the case of usual training sessions; great expenditures on the rent, transport costs etc.; and most importantly, the insufficient scientific foundation of training process arrangement in the mountain conditions for the achievement of a necessary level of acclimatization and the resulting effect of training in the mountains which causes functional capabilities and sporting results in normoxic conditions.

All above mentioned were the reasons for searching for new methods and instruments for complementing and substituting the training process in the mountains.

The growth of FRS efficiency notably increases aerobic productivity and working capacity of athletes.

The method based on the use of normobaric IHT during training of athletes when hypoxic hypoxia and exercise hypoxia have an asynchronous effect because the IHT is carried out in the state of rest before the planned training, not being an obstacle to the training, thus having some obvious advantages over the sporting training in mountain conditions while the bodies of the athletes are affected by the hypoxia of two kinds simultaneously i.e. hypoxic hypoxia and exercise hypoxia.

By contrast, different effects made by hypoxic hypoxia and exercise hypoxia when the physiological mechanisms compensating these two types do not overlap but complement one another, enable the athletes to train in accordance with their plan, not reducing the amount and the intensity of exercise which results in more favorable conditions for FSR improvement, the growth of aerobic productivity, the development of a general, and most importantly, special working capacity i.e. those qualities that determine high sport achievements.

The comparison of the results from a cycle ergometer test conducted before and after the IHT course, indicated that the power of maximal amount of exercise for 3 weeks of a separate effect of the two types of hypoxia increased by 16,67%±2,41%, and the level of maximal oxygen uptake grew by 8,54%±1,50 %.

As it was indicated by a comparative analysis of efficiency of natural hypoxic effect (in the mountains) and artificial hypoxic training (IHT) the increase on the level of maximal oxygen uptake after the session in the mountains was somewhat lower than after 3-week course of IHT on the plain.

There were no other differences in the dynamics of FSR state, aerobic productivity and general physical working capacity after the session in the mountains and the one resulting from IHT.

The percentage growth of the level of special working capacity of female athletes under conditions of natural competition activities after mesocycle in the mountains was not any different from that at the beginning. After the course of IHT the level of special working capacity of female cyclers increased more significantly than after training sessions in the mountains.

WE determined special working capacity under natural conditions of sporting activities of female cyclers (individual 20 km race). The average speed to cover a checking distance after training sessions with IHT grew significantly (from з 35,89±0,45 до 37,65 km per hour ± 0,55 km per hour) which is much more than after training sessions in the mountains and after the mesocycle on the plain.

Method of IHT proved to be highly efficient in the process of athletes training. Over its course hypoxic hypoxia and exercise hypoxia have an asynchronous effect on the bodies of athletes as the IHT is done at the rest state, before the planned training and not impeding the process. Thus this method has obvious benefits in comparison with hypoxic training in the mountains where the bodies of athletes are exposed to the hypoxia of two types such as hypoxia hypoxia and exercise hypoxia and therefore the cumulative and destructive effect of both types could arise.

Our observations proved the results of the research which was carried out on mathematical models [5] and which single out the priority features of exercise hypoxia compensation both under the conditions of the plain and with the reduced partial Oxygen pressure in the inhaled air. This is a high Oxygen demand which requires the high level of Oxygen consumption; high gradients of partial Oxygen pressure and its consumption in tissue; which are typical features of hypoxia zone in the muscle tissue; intensified Oxygen transmission between blood and tissue; the reduction of the average level of tissue Oxygen tension and availability of potential anoxic zones in the most unfavourable parts in terms of O2 delivery (Lethal corners), the development of significant Oxygen debt.

In the conditions of cumulative effect of hypoxic hypoxia and exercise hypoxia a crucial role is played by the diffusive limitations of Oxygen delivery to muscles mitochondria which is the key factor limiting the transportation of Oxygen in a muscle tissue and also the development of venous hypoxemia as a result of intensive utilization of Oxygen from blood.

High efficiency of IHT in the improving of the state of all FRS units of athletes is caused by alternating the hypoxic effects by normoxic intervals between them during which the level of plastic processes remains high whereas oxygen tension in arterial blood and tissues reaches normoxic parameters.

The asynchronous combination of IHT and traditional planned training process within the same period of time increases the efficiency of hypoxia positive effect. The cumulative effect from hypoxic hypoxia and exercise hypoxia essentially improves the state of FRS, increases aerobic productivity and working capacity of athletes.

The crucial point in the use of IHT for high achievement sports is the individual selection of hypoxic mixture which does not lead to negative consequences but instead causes the processes which are typical for subcompensated hypoxia. When the level of pO_2 falls sharply the tissue hypoxia becomes generalized which makes adaptation to hypoxia impossible.

Conclusions.

The method of IHT in sport training is based on the asynchronous effect on the athlete's body made by hypoxic hypoxia and exercise hypoxia since the IHT is conducted at the rest state before the planned sport training and does not prevent it. This method has advantages over the method of hypoxic training in the mountains when the bodies of athletes are exposed to constant and simultaneous effect from both hypoxic hypoxia and exercise hypoxia.

It is known that the compensation mechanisms of exercise hypoxia and hypoxic hypoxia are different in many aspects. The cumulative effect created as a result of these two types of hypoxia as it is often the case after moving to mountains shows itself in the decrease in efficiency of the function of compensatory mechanisms striving for Oxygen, the number of parts with tissue hypoxia grows, the state of FRS worsens sharply, the working capacity and aerobic productivity falls which signals about the need of the reduction of the amount and intensity of training.

It is important to note that the intensity of training in the mountains rarely goes beyond the level of the plain even by the end of training sessions in the middle-height mountains. The lack of appropriate conditions for training creates additional difficulties for the development of general and special working capacity, technical and tactical skills of athletes. By contrast, the asynchronous and different effects of hypoxic hypoxia and exercise hypoxia when these two physiological mechanisms do not overlap but, instead, complement each other allows the athletes to train by the plan not reducing the amount and intensity of training and this results in more favourable conditions for FRS improvement, aerobic productivity growth, the development of a general and special working capacity which determines the possibility of achieving higher results in sports.

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