

Training at Moderate Altitude and Under Normobaric Hypoxia Conditions as a Reliable Endurance Development Way

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ABSTRACT

This article is dedicated to an important problem of contemporary sports – the use of natural and artificial hypoxia in the training process. Briefly outlines the problem origin, the existing training strategies, adaptive reconstructions in the athlete's body, the application of hypoxic training (HT). The prospects of HT relying on various sports and the need for correction (revision) of the existing principles for building the training process are discussed.

KEYWORDS: Altitude training; Hypoxia; Performance of athletes

INTRODUCTION

Study of the biological mechanisms that sense and respond to oxygen levels (normoxia, hypoxia, ischemia) in mammals has promoted a better understanding of the multiple changes in the norm and pathology of physiological processes in humans. Numerous works have opened new opportunities for the elaboration of the treatment methods for such diseases as anemia, cardiovascular and pulmonary diseases, hypertension, stroke, etc. This area of research is recognized as one of the most promising in the treatment development for many illnesses associated with oxygen deficiency in the human body [1].

The empirical coaching approach to the sports training process has revealed significant advantages of training in natural and

artificial hypoxia conditions. Since Mexico City, located in high altitude (2250 m above sea level), was announced (1963) as the venue for the XIX Olympic Games, a focused study of the natural hypoxia effects on a person's physical performance began. Athletes of many sports started to conduct regular multi-week training sessions at moderate and high altitude not only with the purpose of preliminary adaptation to the conditions of natural hypoxia, but also to improve sports results in subsequent competitions at sea level. Gradually, principles of the preparation process were formed, in which hypoxia is used as an additional tool for adaptation to muscle work, especially in cyclic endurance sports. Combinations of using different elevation above sea level with training loads were also substantiated, and technological methods for the impact of

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moderate altitude on the athlete's body were developed in order to improve the results in competitions. Special "hypoxicators" were designed to create an air environment with a low oxygen content, for breathing, both at rest and during muscle work. Even though many years have passed since the well-known generalizing symposium on the problem of altitude training [2], the number of publications around the world on the problem under consideration continues to grow and is difficult to account. Therefore, we cite only a modest part of this flow of scientific periodicals.

We sought to make a brief description of the adaptive adjustments that occur in the athlete's body as a result of exposure to normobaric hypoxia at rest and during muscular work, which are the basis for improving the athlete's sports (professional) level.

Training Strategies

Different versions of training strategies are used at moderate altitude. The first one is classified as "living high-training high" (LHTH). In this version of the training strategy, athletes live and train in midland at the same altitude above sea level (from ~1,500 to ~3,000 m). The second strategy is "living high-training low" (LHTL). Under the LHTL conditions, athletes live in moderate altitude at ~2500, but train lower, approximately ~1000-1200 m above sea level. This strategy was proposed by B Levine & J Stray-Gundersen [3]. The third is "living low-training high" (LLTH). In this case, the altitude of the temporary residence and the altitude of the training site are combined in the reverse order. GP Millet et al. [4], analyzing these training strategies, offer additional forms of combining different altitudes and hypoxia levels with the distribution and alternation of training loads. Thus, the trainer can use the cited studies as teaching aids.

In contemporary sports, a constant increase in results in cyclic sports is unthinkable without the use of altitude training and normobaric hypoxia. Further study of the effects of these factors on the athlete's body as an important component of endurance development is an extremely relevant topic for physiological research. Also, in RL Wilber's review [5] the use of devices such as hypoxicators, as well as rooms where an atmosphere with a lower oxygen concentration in the inhaled air created for the athlete during the rest period are discussed. Currently, the use of these devices in sports training around the world has acquired an extraordinary scope because, creating an air flow for breathing with an oxygen concentration from 19.8% to 9.8%, which corresponds to an altitude from 500 m to 6000 m above sea level, they can be used individually. Thus, hypoxic training (HT) was added to the established training strategies, which is used both as a necessary component in conventional training programs for athletes at sea level, and in combination with physical activity at various altitudes.

Adaptive reconstructions in the athlete's body using moderate altitude and HT are described in several reviews [4-8]. Adjustments in the athlete's body occur along the entire path of transport and utilization of oxygen from the alveoli of the lungs to the muscles, heart, central nervous system, and other organs and tissues. Further, we will address only some of the questions that relate to adaptive changes in the body during oxygen transfer. We limit ourselves to the discussions of adaptive reconstructions in the system of oxygen transport and utilization in working muscles in athletes.

Changes in the Oxygen Transport Function of the Blood

It is known that during the implementation of multi-week training programs in the middle altitude, quantitative changes in the blood composition are observed. Due to an increase in

the concentration of erythropoietin, the number of red blood cells, reticulocytes, and hemoglobin (Hb) mass is increasing. The hematocrit, soluble transferrin receptor increases, and the saturation of arterial Hb with oxygen (SpO_2) and others gradually increase [9-11]. If the regular repetition of high intensity and duration exercises in hypoxia conditions is combined with breathing air with low oxygen content at rest, this gives an additional effect to an increase in the quantitative blood indices [4]. The study of the adaptive response of erythropoiesis as a training result under hypoxic conditions remains the subject of study. For detailed familiarization with the problem, you can refer to the reviews [12,13]. And yet, to single out the quantitative changes in the blood composition as signs of adaptation to the altitude only partially reflects the reconstructions in the athlete's body to hypoxic environment conditions [14,15]. Non-hematological mechanisms of adaptation to altitude and hypoxia also play a significant role. At the same time, exercise effectiveness [16-19] that based on the improvement of microcirculation and mitochondrial efficiency [4] is improved.

One of the adaptation mechanisms is the expansion of blood vessels and micro vessels during severe hypoxia. In this regard, let us pay attention to the dual role of an erythrocyte in providing oxygen to tissues, which has been studied in the past more than two decades [20,21-24]. It is known that red blood cells of vertebrate's service tissues in two ways. First, erythrocytes provide the opportunity for adequate O_2 transport between the respiratory surface of the lungs and tissues through a high concentration of Hb in them, corresponding allosteric relations between the ligand-binding sites of Hb, and a regulated intracellular chemical environment, which allows one to sharply tune the relationship of Hb to O_2 . Secondly, red blood cells can sense the O_2 request by tissues due to the degree of deoxygenation when moving through micro vessels secreting vasodilating formations which expand the blood flow in hypoxic tissues. This last function is important in triggering O_2 tissue delivery in connection with a local O_2 demand [24]. The second function of red blood cells may be the main one because the delivery of O_2 to tissues at a great distance depends on the systemic blood flow. The picture is created that erythrocytes are not only a transport that carries a large amount of O_2 into the tissues, but they also control the effectors of local blood flow. This allows contributing to hypoxic vasodilation, in a mechanism guaranteed to quickly trigger local O_2 delivery in muscles by O_2 demands [25, 24]. The oxygen advancement through the membranes of erythrocytes, the walls of small and the smallest arteries and capillaries into tissue cells of active organs occurs along the O_2 concentration gradient, forming an oxygen tensions field [26]. Inside muscle fibers (MF), diffusion of O_2 to mitochondria is also provided by the difference in the partial tension of O_2 .

After the end of an intense and prolonged exercise during the period of acute recovery of the body, there is an intensification in the reconstructions of many mechanisms involving hemoproteins. So, due to an increase in hepcidin concentration in blood serum during the period of acute recovery after exercise with an intensity of 60-90% of $\dot{V}O_{2max}$, the ferroportin transport channel is destroyed (disrupted), the ability of macrophages to process "damaged" iron decreases, and its availability decreases.

The hepcidin fraction circulation increases during early recovery after exercise (~3 hours). It remains unknown how acute muscular exercise can alter hepcidin expression [27]. Hypoxia is one of the hepcidin synthesis regulators. It weakens its expression and increases the expression of ferroportin [27-28]. During this

period reliable availability of iron is especially required to maintain Hb mass that can be a serious problem in athletes [16,31,32] which must be considered in the training process. Recommended iron therapy should be based on a preliminary analysis of ferritin and transferrin levels in blood serum. In the example of long-distance runners it was shown that at a low concentration of ferritin (<35 mg/L) and transferrin saturation <20% the iron therapy (duration of iron therapy is 6 weeks) is more effective than in runners with suboptimal (<65 mg/L) ferritin concentration. Herewith, the intravenous use of iron-containing medicines ensures iron availability more efficiently (ferritin grows faster), and significantly increases the duration of work to exhaustion at $\dot{V}O_2\text{max}$ compared to the oral use of appropriate agents [33]. It's necessary to add that over the course of a day iron is best absorbed in the morning, immediately after training despite an increase of hepcidin level in blood [34].

Intracellular Mechanisms of O_2 Transport and Utilization

It is important to consider that adaptive changes involving hemoproteins occur along the entire path of O_2 transport and utilization in the organism. In addition to O_2 diffusion, when hypoxia increases, myoglobin (Mb) is connected, which facilitates the diffusion of O_2 to mitochondria. The portion ratio of the O_2 diffusion and Mb-facilitating O_2 diffusion mechanism in the total oxygen flow to mitochondria in the sarcoplasm varies in accordance with the change of hypoxia level and muscle work power as it approaches $\dot{V}O_2\text{max}$ [35,36,15]. After the termination of an intense and prolonged muscular work, there is an increase of mitochondria production in MF. Their total oxidizing surface increases, especially when exposed to hypoxia [37-40].

It has been shown that at the final stage of O_2 delivery and utilization inside the MF with a very long respiratory delay, which is carried out by the elite level divers, there is equal control of Mb activity, but lower consumption of O_2 by mitochondria in divers in comparison with the selected control group [41]. This denotes into a decreased level of muscular performance in divers. At the same time, as $\dot{V}O_2\text{max}$ is reached, when all the mechanisms that ensure the maximum transport of O_2 to mitochondria are mobilized, a more detailed study of the behavior of the Mb-facilitating diffusion of O_2 mechanism remains a problem [41]. At that, adaptive reconstructions of mitochondria are quite understandable, and the development of the necessary research methods is encouraging [42].

Thus, the rise of capillary network density, mobilization of erythropoiesis, an increase in the overall oxidative surface of mitochondria, and a possible strengthening of the Mb-facilitating diffusion of O_2 mechanism (which remains to be shown in the experiment) increase the delivery and utilization of O_2 in MF as the load approaches $\dot{V}O_2\text{max}$. Long-term adaptive changes are additionally supported by hypoxic conditions of muscle work. There is a sufficient amount of specialized knowledge to improve the training process.

Training with the Use of Hypoxia

The implementation of long-term training programs in moderate altitude and the long-term use (multiple during the year-round training cycle, as well as long-term application) of normobaric HT intentionally creates an athlete advantages over regular training in normoxic conditions.

In connection with this statement, we present data from studies using normobaric hypoxia in the training process for

several micro-cycles. Using the example of long-distance runners it was demonstrated that the additional inclusion of training on a treadmill with an intensity of the ventilation threshold 2 level duration of 24-40 minutes, and breathing during exercise with mixture containing 14.5% oxygen (~3000 m above sea level) within a regular workout program, enhances the metabolic stimulus to the muscles. So, despite a slight increase of $\dot{V}O_2\text{max}$ in the subjects, a significant rise in the duration of the run at $\dot{V}O_2\text{max}$ to exhaustion was revealed, by almost 42%. The authors showed that for this contingent of athletes, the performed training series had a targeted effect on the aerobic energy supply of muscles [43-45].

In addition to these works, there are several publications substantiating the use of HT in sports games [46,47], swimming [48-50]. GP Millet and O Girard [6] cite a number of works that explain the methods of HT in such sports as cycling, country ski racing, football, rugby [51-55]. Details can be found in meta-analyzes [11,30].

Possibilities of HT Employment in Other Sports Not Listed Above

It is known that fatigue during cyclic work approaching $\dot{V}O_2\text{max}$ has both a central and peripheral component. At the same time, supraspinal commands (motor control) support the preservation of muscle work power at the limit of intensity and duration of physical load. There are details in Amann & Calbet [56].

Since the increased motor activity of a person during sports for a long period of his life is clearly manifested in morpho-functional reconstructions of his brain [57], it can be confidently stated that HT can significantly improve performance (adaptability) not peripheral (muscle) energy production mechanisms only and the central apparatus of motor control that are specific in each of sport. It is necessary to emphasize that degree mobilization of the central mechanisms for voluntary movement control different sports are different significantly too.

For example, a 1,500-m runner or a pursuit-racer on a cycle track, working on $\dot{V}O_2\text{max}$ for ~4 minutes, solves the relatively simple task of his movement control. Supraspinal commands primarily provide the highest possible muscle performance. At the same time interval, the figure skater performs a large number of complicated coordinated actions with the maximum speed-power motor qualities mobilization. Against the background of central and local fatigue increasing induced by maximal muscular work, the figure skaters' CNS is utmost mobilizing the vestibular stability and accuracy of movements [53,54].

The HT technique allows through hypoxicator to affect different levels of motor control and their energy supply. Thus, in conditions of hard hypoxia at rest when the inhalation O_2 fraction ($F_I O_2$) is ~0.1, the athlete undergoes a restructuring of the blood flow in CNS and heart. Under conditions of moderate hypoxia ($F_I O_2$ ~0.14-0.15) during muscle work, the reorganization of the blood flow in CNS and heart is added by the reorganization of the blood flow and other adaptive reconstructions in the muscles [55,56].

Exercises to balance maintaining under hard hypoxia for several minutes are more significantly mobilize the central and spinal postural control mechanisms, i.e., with repeated use significantly improve sensorimotor coordination, and cyclic exercises with individually selected severe and moderate hypoxia more effectively trigger off the muscle adaptation. Thus, the use of HT by figure skaters will enlarge the level of their aerobic performance and vestibular stability (VS) without increasing the total time spent

on general physical training. It is important to emphasize that the figure skater who has a higher level of aerobic performance is much faster recovery despite the fact that he performs high-speed power muscular work in training. The growth of aerobic performance allows him to mastermind more volume of speed-power work in the total training program [57].

Even though figure skating selects children with high by nature VS, in the monograph by AN Mishin & VA Shapiro [58] gives experimentally justified diagnostics of VS and methods of individual selection of rotation loads to improving this basic motor quality in elite level of figure skaters. Mild and moderate hypoxia conditions (selected individually $F_{I}O_2 \sim 0.17-0.15$) during rotation can significantly enhance the effectiveness of the vestibular resistance training device.

The CNS blood circulation strengthening under hard hypoxia conditions and relative muscle rest at aiming in shooting should contribute to additional mobilization of the sensorimotor cortex and all subcortical structures of the corresponding fields in the visual and motor (fingers) analyzers. Combinations of various training means (for example, the use of electronic aim simulators at standing on the platform for equilibrium maintenance) are improved the aiming under hypoxia conditions not only in biathlons, but also in shooters from any type of weapon. These ways allow significantly increase the training volume with an emphasis on aiming, because mobilization of cortical and subcortical centers, which provide targeted action, is important for improving and consolidating a stable motor skill "for accuracy".

The experience of HT in beach soccer teams [59] shows that the use of HT can significantly increase the level of aerobic performance in traditional footballers. The specificity of beach soccer is running by sand, which strengthens the static component in muscle contraction. The combination of HT with game actions on loose soil, compared with running on a lawn or firm (elastic) artificial lawn, significantly enhances local muscle endurance. The combination of the targeted effects of hypoxia on CNS and leg muscles in special exercises significantly enhances aerobic endurance. The combination can maintain a high level of aerobic endurance individually throughout the game season with strict monitoring of the athlete's functional state.

In conclusion, it's necessary to emphasize that aerobic performance in any sport can significantly enhance by the use of HT. The athlete has an advantage in his main type of activity due to faster recovery between intense and prolonged training and competition. The conditions are created for the implementation of higher quality special preparing in a particular sport. It remains up to the coach to apply HT in the training program of his sport, learn to combine the usual training loads with hypoxia exposure. Based on our own experience of working with coaches of various sports specializations, it is important to add, that there is no increase in the total volume of training work. However, it will take great efforts to thoroughly revise the "well-beaten" training plans that have been practiced for years and familiar (conventional) views on the training process.

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