Original Article

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The direction of the changes of rates of the internal and external training load under the influence of high-altitude hypoxia on mountain bikers

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Abstract

The aim of the research carried out was to establish the direction, and scope of the changes in internal, and external load indicator values in cyclists, men, and women, in high-altitude hypoxia conditions. The participants of the study were mountain bike cyclists, members of Russian and Polish Nationals Teams (women n=11, men n=9). They have done the graded incremental exercise test at the altitude of 170 m (Lonato del Garda, Italy) and 2250 m (Livignio-Trepale Italy). In the course of effort VO_2, VE, VCO_2 was measured by means of K4b2 analyser (Cosmed Italy). Effort intensity was determined at ventilators thresholds VT1 (AT), and VT2. Internal and external load indicators undergo changes during physical effort in cyclists under the influence of high altitude hypoxia. In groups of men and women, the changes in indicator values reach VE: 9% and 12%, HR: 0,5% and 15, O_2HR: 7% and 15%, VO_2: 14% and 20% respectively, as well as a decrease in 5 and 4% of the generated power, respectively. A decrease in the generated power by 5%, higher ventilation, amounting to 10%, a higher VO_2max, amounting to 17% in hypoxic conditions, in comparison with the conditions similar to those at sea level, show that it is necessary to modify training loads.

Keywords: cycling, altitude training, aerobic capacity, hypoxia

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INTRODUCTION

Training in the conditions of natural, or artificial hypoxia is carried out in order to improve the aerobic capacity of the body [1-5]. A decrease in the partial pressure of oxygen in the respiratory air, depending on the decrease in atmospheric (air) pressure, due to an increase in altitude above sea level, causes a decrease in the partial pressure of oxygen in the arterial blood. This, in turn, stimulates the synthesis of erythropoietin in the kidneys [6-7]. Erythropoietin boosts erythropoiesis (the creation of new erythrocytes)in the bone marrow. This results in an increase in the number of erythrocytes, and amount of haemoglobin in the circulating blood, as well as of haemoglobin mass, and the human red cell concentrate, and thereby the possibility of the transport of oxygen by the blood (the oxygen capacity of the blood) [8-16]. A classic training session referred to by means of the abbreviations: LH-TH means: live high-train high [17-22]. Traditional training camps making use of the classic LH-TH method consist in carrying out training tasks, and living at moderate heights (1800-2500 m above sea level) for a period of 2-4 weeks twice or three times a year. A high mountain training camp can be divided into some basic stages [23-27]: the acclimatization (adaptation) phase, the basic phase of training, the regeneration phase, and the preparation to go down to sea level, the return to sea level.

The stay, and training in high mountain conditions (LH-TH) is burdened with a number of inconveniences, and with the possibility of the occurrence of unfavorable changes which are to be taken into account while planning the training, otherwise the functional capacities of the athlete may even worsen during effort at sea level. Thus, at the beginning of the 1990s there appeared an idea of training called live high-train low (LH-TL) [18, 28-29]. Training camps making use of the LH-TL method, consist in carrying out training tasks at the altitude of 500-600 m above sea level. The second method of hypoxic training is the LH- TLH (live high-train low, and high) one. It consists in living in hypoxic conditions, while in the training micro cycle, there are units divided into those carried out in hypoxic conditions, and training sessions carried out at the altitude of 500-600 m above sea level. The third method is the LL-TH (live low-train high) one, consisting in both living and training in hypoxic conditions without changing altitudes throughout the entire training camp [19]. Research regarding the LL-TH method has shown that the training carried out by means of this method increases making use of some factors involved in the usage of oxygen in the muscles, as well as of the positive regulation of the pH, and the transport of lactate [27, 30-31]. There is no unambiguous research regarding the scope of the influence of the particular training solutions carried out in high mountain conditions. A couple of factors may cause divergent research results, they include:

- iron concentration in the serum – due to a deficiency of iron, erythropoiesis will not take place;
- training loads – while training at high altitudes (LH-TH), the athletes are forced to reduce training loads. This, in consequence may lead to deconditioning, after returning to the altitude of sea level, manifesting itself in a decrease in VO_2 max, and functional capacity;
- the degree of hypoxia and time of exposure;
- the individual reaction of a given athlete to high mountain training;
- the professional adjustment of training loads to the competitor's functional capacity during the first 5-7 days of their stay at an altitude, is a crucial issue of training in high altitude hypoxia conditions.

High-altitude hypoxia is a training load intensity regulator in cycling [18]. It regulates external loads (power, speed), and internal loads (HR, lactate concentrations) Intensity zones regulated by means of metabolic thresholds (aerobic, and anaerobic), are also influenced by this external factor [32]. The aim of the research carried out was to establish the direction, and scope of the changes in internal, and external load indicator values in cyclists, men, and women, in high- altitude hypoxia conditions.

MATERIAL AND METHODS

Subjects

The participants of the study were mountain bike cyclists, members of Russian and Polish Nationals Teams (women n=11, 23.4±2.6 year, 55.3±2.5 kg, 165.7±4.2 cm, men n=9, 24.1±3.3 year, 72.6±3.6 kg, 177.4±5.1 cm).

Procedures

The participants of the study have done the graded incremental exercise test (GXTs [33] at the altitude of 170 m (Lonato del Garda, Italy) and 2250 m (Livignio-Trepale Italy). The GXTs test was executed on ergometer Cyclus2 (RBM, Germany). The I-st step was 1 $W \cdot kg^{-1}$ b.m. and increased every 3 minutes by 0,5 $W \cdot kg^{-1}$ b.m. In the course of effort VO_2, VE, VCO_2 was measured by means of K4b2 analyser Cosmed Italy). The heart rate monitor, Polar V650 (Polar Finland) measured HR during GXTs. Effort intensity was determined at ventilators thresholds VT1 (AT), and VT2 (AnT) [34-38]. VT1 is called the first ventilatory threshold. It is a marker of intensity that can be observed in a person's breathing at a point where lactate begins to accumulate in the blood. As the intensity of the exercise begins to increase, VT1 can be identified at the point where the breathing rate begins to increase. A person who is at VT1 can no longer talk comfortably, but can still string together a few words while exercising. Also observed by way of a person's breathing during exercise is VT2, or the second ventilatory threshold. It is a higher marker of intensity than VT1. At VT2, lactate has quickly accumulated in the blood and the person needs to breathe heavily. At this rapid rate of breathing, the exerciser can no longer speak. The exercise duration will necessarily decrease due to the intensity level. VT2 can also be called the anaerobic threshold or lactate threshold [39-40]. After ethics approval by the Krakow Medica Ethics Committee (123/KBL/OIL/2013) in accordance with the Helsinki Declaration, the experimental protocols were explained and consent was obtained from each participant [41].

Statistical analysis

Basic descriptive statistics were calculated, and all variables were examined for normal distribution using the Shapiro-Wilk test. Paired t-test was used for normally distributed data and the Wilcoxon test for non-normally distributed data with statistically significant p value <0.05. All calculations were performed with STATISTICA ver. 12. (StatSoft, USA)

RESULTS

Research results are presented in table 1, 2 and on figure 1. Table 1 presents a characteristics of internal and external load indicators at the VT1, VT2 thresholds, and Pmax, observed in a group of women during an effort in high altitude hypoxia, and normoxia conditions. The values at the VT1 threshold in women indicate similar mean HR, and O_2HR values during the two efforts. Higher values in hypoxic conditions are there in the case of VO_2, VE, and P, in relation to the values observed in normoxic conditions. At the VT2 threshold, all the internal load indicators indicate higher values in high altitude hypoxia, as compared to the conditions of normoxia. Only the value of the power indicating external load does not change much. During an effort of maximum intensity, during which there appeared a refusal to workout, higher values in hypoxic conditions were indicated by all internal load indicators. Only Pmax was significantly lower.

Table 2 presents the characteristics of internal, and external load indicators, at the VT1, VT2 thresholds, and Pmax, observed in a group of men, during effort in high altitude hypoxia, and normoxia conditions. The values at the VT1 threshold in men, indicate similar mean HR values during the two efforts. In high altitude hypoxia conditions higher values are there in the case of the following indicators: VO_2, VE, O_2-HR, and P in comparison to the values observed in normoxic conditions. On the VT2 threshold, all internal load indicators indicate higher values in high altitude hypoxia conditions in comparison with normoxic conditions. Only the value of the power, which is an external load indicator, does not change significantly. Indicator values at VT2 threshold in men indicate higher load indicator values during effort carried out in hypoxic conditions with the exception of the generated power (external load). During effort of maximum intensity, during which there was a refusal to workout, the values of VO_2max, O_2-HR, and HRmax, were higher in hypoxic conditions. No statistically significant difference was demonstrated in the mean value of the VE indicator, the maximum power was relevantly statistically lower, however.

Table 1. Characteristics of internal, and external training load indicators, at the VT1,VT2 thresholds, and Pmax, in women group, in high altitude hypoxia, and normoxia conditions. Data expressed as mean ± standard deviation and min-max.

Variables	Condition	VT1	VT2	max
VE [l/min]	Normoxia	59 ± 7.6 (50–70)	83 ± 10.6 (64–92)	111 ± 16 (95–132)
	Hypoxia	63 ± 6.7 (53–72)	90.5 ± 2.8 (85–93)	124** ± 9 (115–138)
VO2 [ml/kg/min]	Normoxia	40.8 ± 3.1 (35–44)	49 ± 2.5 (45–52)	55.5 ± 3.6 (52–60)
	Hypoxia	42.8 ± 4.7 (35–49)	55** ± 3.2 (50–60)	62.8** ± 4 (57–68)
HR [bp/min]	Normoxia	148 ± 10.3 (135–160)	168 ± 5.4 (160–175)	184 ± 3 (180–189)
	Hypoxia	146 ± 8.7 (140–160)	171 ± 7.2 (165–180)	187* ± 4 (182–192)
O2HR [ml/bp]	Normoxia	14.3 ± 1.9 (11.7–17.2)	15 ± 1.46 (12.6–16.6)	15.3 ± 1.1 (13.4–16.5)
	Hypoxia	14.6 ± 1.4 (12.8–17.2)	16.2* ± 1.42 (14.6–18.8)	16.8* ± 1.2 (16.1–19.4)
P [W]	Normoxia	142 ± 17 (115–160)	189 ± 18.8 (160–210)	241 ± 10.8 (235–260)
	Hypoxia	134 ± 19 (110–160)	183 ± 20.4 (160–210)	228 ± 21.6 (210–260)

Statistical significance: * $p<0.05$, ** $p<0.01$

Table 2. Characteristics of internal, and external training load indicators, at the VT1, VT2 thresholds, and Pmax, in men group, in high altitude hypoxia, and normoxia conditions. Data expressed as mean ± standard deviation and min-max.

Variables	Condition	VT1	VT2	max
VE [l/min]	Normoxia	70 ± 10.2 (56–80)	90.6 ± 12.3 (70–100)	157 ± 30.8 (113–202)
	Hypoxia	80* ± 9.8 (62–91)	105* ± 12 (85–120)	157 ± 23.7 (126–187)
VO2 [ml/kg/min]	Normoxia	38 ± 5.5 (31–46)	48.5 ± 5.8 (38–54)	56 ± 7.7 (41–61)
	Hypoxia	48** ± 2.9 (45–51)	58** ± 3 (56–61)	65** ± 6.5 (53–71)
HR [bp/min]	Normoxia	148 ± 8.2 (140–160)	168 ± 7.6 (160–178)	194 ± 7.2 (185–205)
	Hypoxia	148 ± 2.3 (144–150)	171 ± 5.2 (164–180)	191* ± 7 (184–204)
O2HR [ml/bp]	Normoxia	16.1 ± 2.7 (12.6–18.2)	18.5 ± 3 (14.5–21.3)	19.1 ± 4.1 (12.4–23.7)
	Hypoxia	20.3 ± 2.5 (17.5–22.9)	21.7** ± 3.2 (17.3–25.1)	21.9** ± 4.1 (15.7–27.3)
P [W]	Normoxia	178 ± 25.4 (135–205)	238 ± 29 (190–260)	349 ± 59.3 (300–450)
	Hypoxia	183 ± 16.3 (160–205)	236 ± 26.3 (190–255)	316 ± 59.1 (270–420)

Statistical significance: * $p<0.05$, ** $p<0.01$

Figure 1 shows differences (in percentages) between the values of the particular internal, and external load indicators observed in hypoxic, and normoxic conditions. In the percentage structure of the differences for the selected internal, and external load indicators, the value of 100% was the one observed in normoxic conditions. In the group of women, during VT1 workout intensity, the values of P and HR are characterized by values lower by 4% in hypoxic conditions. The direction of percentage differences between indicators is as follows: VO_2 – 5%, VE – 6%, O_2-HR – 2% , and is reverse. The higher values were registered in conditions of high altitude hypoxia. At VT2 intensity, all internal load indicators (VO_2 – 12%, VE – 9% , HR-2%, O_2-HR- 8%), were characterized by higher percentage values during effort in high altitude hypoxia conditions, whereas the power was lower by 4%. At maximum load in high altitude hypoxia conditions, the power was lower by 6%, while the direction of the percentage differences of the remaining internal load indicators was reverse. The differences amounted to VO_2max – 23%, VEmax – 12%, O_2-HRmax – 10%, and HRmax – 2% respectively. In the group of men, at VT1 effort intensity, the values of the percentage differences, for internal, and external load indicators, demonstrated higher values gained in hypoxic conditions (respectively by VO_2 – 26%, VE – 14%, O_2-HR – 13%, and P – 2%).

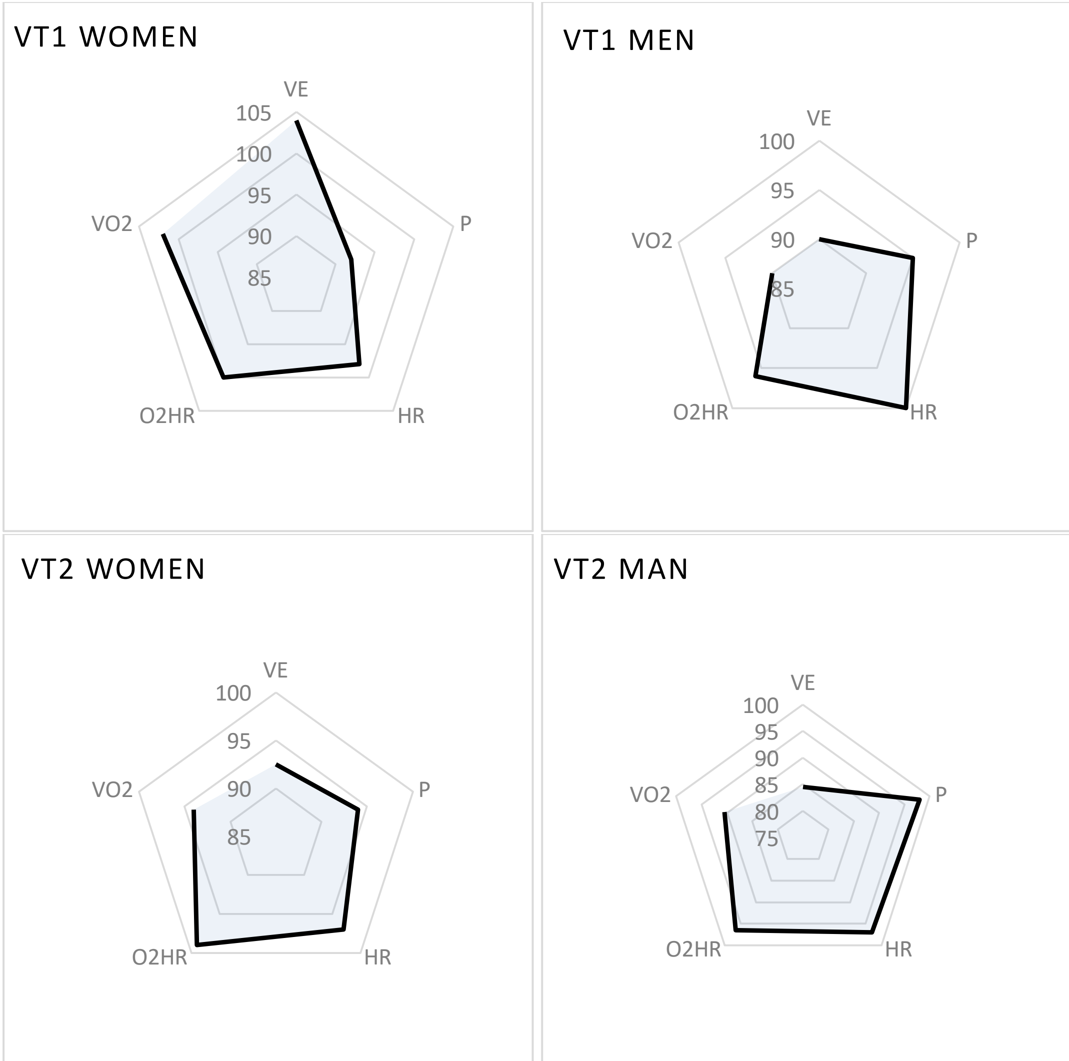

Figure 1. The structure of the differences between internal, and external load indicators in normoxia, and high-altitude hypoxia conditions, in cyclists, men, and women, at VT1, and VT2 thresholds.

At VT2 intensity, the nature, and range of the indicators registered in high altitude hypoxia, and normoxia conditions was similar for the determined VT1. All internal load indicators (VO_2 –- 19%, VE – 16%, O_2-HR – 17%, HR – 2%), during effort in high altitude hypoxia conditions, were characterized by higher percentage values, whereas, the power was lower by 1%. At maximum load, the power, in hypoxic conditions, was lower by 9.5%, whereas, the percentage differences between other internal load indicators, with the exception of HR, were reverse when it came to direction, and amounted, respectively, to: VO_2max – 16%, VEmax – 7%, O_2-HRmax – 15% .

DISCUSSION

Our own research demonstrates the necessity of decreasing the value of the external load during a training carried out at an altitude during the first 5-7 days of stay. Although the competitors gain some physiological benefits from staying at high altitudes, the effectiveness of the training may be decreased, as a result of a change in locomotor system loads (decreases in power). By the same token, my own research confirms the necessity of using solutions alternative to the traditional LH-TH training, i.e. using the LH-TL (live high-train low) training. During research [5, 19] the competitors applying it, lived, and/or slept at an altitude of 2000–2700 m, and trained at an altitude below 1000 m. Assumedly, this training was supposed to stimulate erythropoiesis, and maintain effort intensity comparable to the one gained at sea level. The LH-TH, and LH-TL models were devised at the beginning of 1990s by Levine, Stray-Gundersen [18], and Stray-Gundersen et al. [2]. Basically the LH-TL model, is based on the assumption that the athletes can, at the same time, experience the benefits of the altitude and adaptation to oxygen deficiency (hypoxia) (i.e. an increase in the volume of the erythrocytes) and of training at sea level (i.e. maintaining training effectiveness, and the stream of oxygen from the sea level.) thus causing positive haematological, metabolic, and neuro-muscular adaptations [30, 27]. The athletes who apply the LH-TL system: the stay at an altitude of: 2000-3000 m above sea level, and training at the altitude of <1500 m can carry it out by applying various devices, and methodological solutions [42]. The range, determined in my own research, of a decrease in power in hypoxic conditions on VT1, and VT2 thresholds, shows that maintaining high power in hypoxic conditions during the first 5-7 days of the stay in such conditions, may lead to an excessive load of the locomotor system due to a different response of the body than in lowland conditions observed in the internal load indicator values. The demonstrated decreases in VE, and VO_2 values at the VT1 threshold level by 5-6 %, and at VT2 level by 9-12% proves a much higher response of the internal training load of the athlete's body in hypoxic conditions, in comparison with external load. This happens because the decrease in power at the VT1, and VT2 thresholds amounts to 4%, and 2% respectively in high altitude hypoxia conditions. The experiment carried out by Levine's team [18], during which after an effort at the altitude of up to 1300 m above sea level, the athletes were transported to the altitude of 1800–2500 m above sea level, where they were to spend the rest of their free time, exposed the athletes to a lot of stress caused by constant moving, and changes in altitude, which led to their being tired by the very act of travelling. In addition, there were numerous costs related to transport, and training logistics, caused by weather conditions. This research has shown, that logistics-related solutions in LH-TL training, as well as the costs of travelling daily, can have a negative influence on the overall preparation of the competitor. At the same time, the effects of the training were pointed out to be satisfactory. Levine et al. [2] stated that the level of erythropoietin (EPO) was twice as high, and the concentration of haemoglobin (Hb) rose significantly in athletes after 27 days of their stay at 2500 m, and training at the altitude of 1250 m. Stray-Gundersen et al. [22] have shown that the 27 day stay at an altitude of 2500 m, the high intensity training at 1250 m has influenced the increase in EPO by 92% during the first 20 hours after exposing to hypoxia. Later, a progressive decrease in EPO was observed till the 19th day, when it reached the initial, sea level, value. After 27 days of LH-TL, the HB, the haematocrit (HTC), and the oxygen saturation (SaO_2 O_2), were increased.

The data confirm an observation from my own research proving it necessary to limit effort intensity during the first days of the stay in hypoxic conditions, even when the training is carried out in conditions of lowered altitude compared to the conditions of the stay. [43] In a research by Saunders et al [11] which aimed to investigate into the influence of the LH-TL phase on haematological parameters. A parallel increase in VO_2max as well as in Hb mass has been confirmed [44-46]. Hahn and Gore [47] stated that there was strong evidence confirming a decrease in the production of lactic acid, or an increase in its removal from the muscles during the adaptation to high altitudes. At the same time, limited evidence related to the increase in buffer muscle capacity, and the information on the potential improvement in the mechanical efficiency of cycling seem to be unconfirmed [48-49]. It is important that, intermittent exercise with hypoxia could stabilize the secretion of selected proangiogenic factors, reduce inflammation, potentially leading to improve cardiovascular function [50]. The authors claim that, contrary to popular opinion, the adaptation to a natural, or simulated high altitude does not stimulate red blood cell production to a sufficient extent which would lead to an increase in RBC capacity, and Hb mass. Hypoxia causes an increase in EPO levels in the serum, but the subsequent stage in the erythropoiesis cascade has not been clearly proven. These results confirm the idea, adopted during the training of the cyclists under research, that lowering the loads during the high altitude hypoxia adaptation period, does not influence the decrease of the haematological effect.

CONCLUSIONS

1. Internal, and external load indicators undergo changes during physical effort in cyclists under the influence of high altitude hypoxia. In groups of men, and women, the changes in indicator values

reach VE – 9% and 12%, HR – 0,5% and 15, O_2HR – 7% and 15%, VO_2 – 14% and 20% respectively, as well as a decrease in 5 and 4% of the generated power, respectively.

2. The range of changes in physiological indicator values differs from one individual to another. Its direction, however, is coincident for the whole group. There is a stable tendency of the decrease of the generated power in high altitude hypoxia conditions, in comparison to normoxic conditions, and an increase in VO_2, HR, O_2-HR, VE indicator values in hypoxic conditions in comparison with the conditions similar to those at sea level. The above-mentioned changes occur at a level of effort intensity corresponding to VT1, VT2, and at maximum level.
3. A decrease in the generated power by 5%, higher ventilation, amounting to 10%, a higher VO_2max, amounting to 17% in hypoxic conditions, in comparison with the conditions similar to those at sea level, show that it is necessary to modify training loads. Such significant differences in external, and internal load indicator values, require the correction of the value of the training load, both in terms of its intensity, and capacity, when carried out in high altitude hypoxia conditions.
4. In training units in which the basic emphasis is on the training of speed, the training of power, the training of endurance, compensation training, the changes in bodily functions in high altitude hypoxia conditions are to be taken into consideration. The lack of correction in a situation when the differences in training loads amount to 20% changes the nature of the effort load applied. Lengthening the workout of too high an intensity will cause, in the event of a lack of correction, an excessive emphasis on anaerobic lactic efforts in the overall training capacity.

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