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THE INFLUENCE OF INTERMITTENT HYPOXIC TRAINING ON THE BODY OF AN ENDURANCE ATHLETE

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Abstract. *In our research we monitored the influence of intermittent hypoxic training on the body of an athlete. We evaluated oxygen saturation of the blood during hypoxia, which ranged from 90% down to 75%, at the end of a three-week course. These results were also confirmed by the oxygen content in the inhaled air, which at the end of the period dropped down even below 9%, and that corresponded to a simulated altitude of about 7000 m. Spiroergometry revealed an increase in VO_2max, from 4105 $ml.min^{-1}$ to 4364 $ml.min^{-1}$, $VO_2max.kg^{-1}$ from 65,4 $ml.min^{-1}.kg^{-1}$ to 69,9 $ml.min^{-1}.kg^{-1}$ and submaximum performance W170 from 3, 34 W to 3, 40 W. Maximum performance in the 3-km walk improved by 13.7 seconds, the submaximum performance in the 10-km walk improved by 1:42 minutes. The load in the 10-km walk performed at the level of the anaerobic threshold showed an improvement of 1:29 minutes. We did not find any significant changes in the haematological components; the values of haemoglobin and haematocrit remained almost unchanged. A mild increase was recorded in the medium erythrocyte volume, which increased from 96.8 fl to 98.2 fl, and in the iron-binding capacity, which increased from 52 $\mu mol.l^{-1}$ to 58 $\mu mol.l^{-1}$. As far as blood is concerned, we found an increase in the number of reticulocytes from 5.1000^{-1} to 7.1000^{-1}, which amounts to 40%.*

Key words: *intermittent hypoxic training (IHT), maximum oxygen consumption, blood components, saturation, maximum performance*

INTRODUCTION

Hypoxic training attracted the attention of sports experts in the second half of the 20th century, primarily due to the fact that the Mexican metropolis won the right to host the Olympic Games in 1968. It is a well-known fact that endurance and strength-endurance training in a hypobaric hypoxic environment, while retaining the speed achieved at nor-

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mal heights, will increase load by 5 – 10% (Korčok - Pupiš, 2006), and this necessitates the reduction of load intensity. However, the appropriate application of load should result in positive changes in the body. Špringlová (1999) points out the benefits of altitude stay and training, which bring about the improvement in oxidative energy metabolism. This enhances performance and aerobic capacity, which has been confirmed by several researchers, e.g. Levin et al. (1997), Meeuwes et al. (2001), Pupiš- Korčok (2007).

Some authors, e.g. Komadel (1994), Gurský (1994), Levin et al. (1997), Pupiš- Korčok (2007), have pointed to an increase in the blood components which participate in oxygen transport in the body. In contrast to their findings, there are the opinions of Štulrajter et al. (2001) and Kobela (2007), who have stated that a high altitude stay brings about not only an increase in the number of erythrocytes, but also their rejuvenation, which enhances blood quality.

Recently, researchers have been trying to create the effects of hypoxic training using various methods. On the basis of experience, scientists in Finland in 1993 and in Sweden in 1994 constructed premises where normobaric hypoxia was simulated. Oxygen concentration on these premises was artificially reduced, but without the side effects caused by pressure changes. The Norwegians constructed a house in which they were able to simulate hypobaric hypoxia corresponding to the altitude of 2500 meters (Komadel, 1997). The working principle of these halls, houses, rooms and even tents lies in the fact that the level of nitrogen in these spaces was artificially increased, so that the concentration of oxygen was maintained at the level of 15, 3%, and its partial pressure at 116 mmHg (Komadel, 1997). The use of hypoxia is similar to the "live high – train low" model. A similar technique which uses the method of intermittent hypoxic training was started by Russian pilots (Hamlin and Hellemans, 2003). This method is based on exposure of the body to extreme hypoxia, corresponding to the altitude of 6 500 m or even higher. This method utilizes a device called the hypoxicator.

METHODS

Characteristics of the subject:

A 28-year-old man, body height 175 cm, body weight 62.6 kg ±0.2 kg, AT 178±1 bpm, sports specialization – race walking. During his career he participated in a number of training stays at various degrees of hypoxia (low, medium, high 5 times). He participated in several training stays in a hypoxic environment at altitudes of 1900 to 3600 m above sea level for periods from 3 to 8 weeks (Toluca– in Mexico, Sorata, La Paz and Cochabamba – in Bolivia, and Oberntauern in Austria). This tested sportsman is a multiple champion of the Slovak Republic in race walking (10 km event - juniors, 20 and 50 km events - men), a bronze medalist in the junior European Championships, he took part in European Championships, the under 23 European Championships, World and European Cups, the World Universiade and he was also a substitute for the Olympic Games.

Our research was conducted at the Matej Bel University and the Army Sports Centre Dukla in Banská Bystrica during July and August 2007. For the implementation of hypoxic training we used an AltiPower hypoxicator, which can produce air with about a 9% oxygen content. This is comparable to an altitude of 6500 meters (Fig. 1).

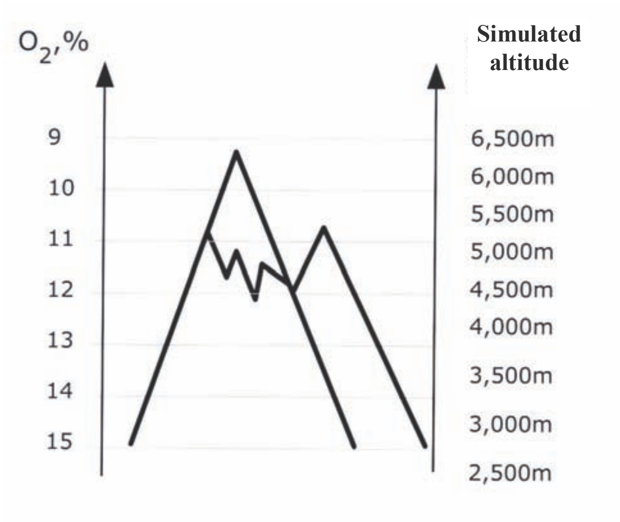


Fig. 1. Dependence of O_2 concentration in the air on altitude

The principle of hypoxia lies in the fact that an athlete is exposed to hypoxia during the off-training period. The tested athlete had 21 days of intermittent hypoxic training with three days without hypoxia. On the days of the intermittent hypoxic training he was exposed to hypoxia for a period of 90 minutes (10 times 6 minutes of hypoxia + 3 minutes of normoxia).

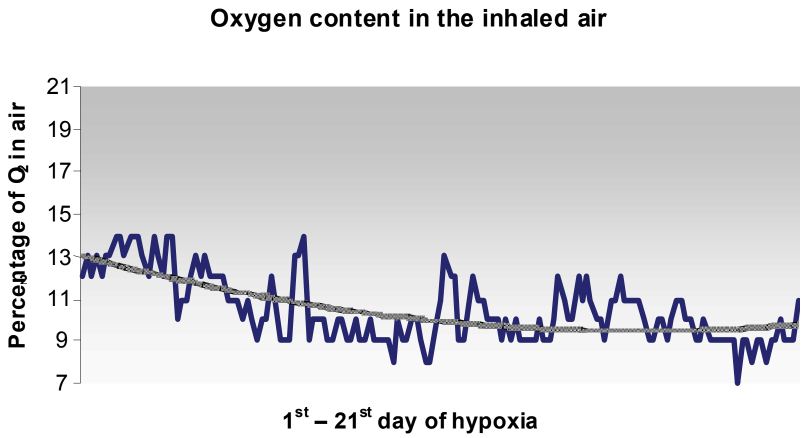


Fig. 2. O_2 content in the air inhaled during the IHT

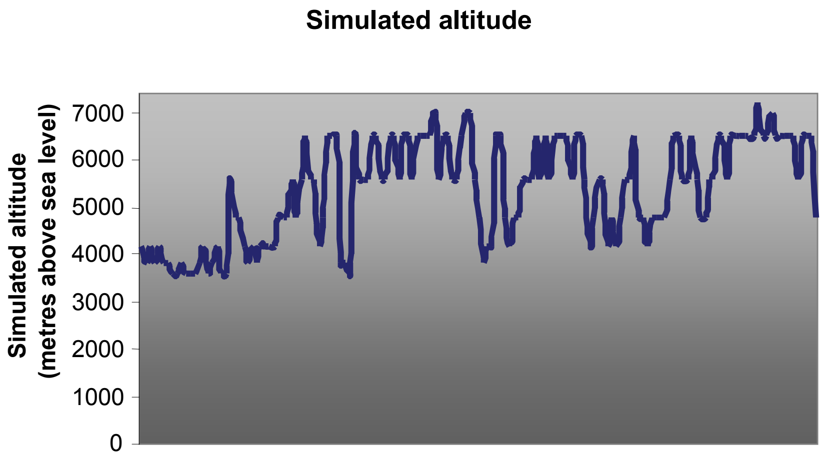


Fig. 3. Simulated altitude during the IHT

During IHT, the athlete was exposed to hypoxia of a 14 – 8 % (Fig. 2 and Fig. 3) O_2 content in the air (which corresponds to the altitude of 3500 – 7000 meters), while the oxygen saturation in the blood (SpO_2) was below 90%, down to 70% (Fig. 4). Our evaluation was based on three tests:

1. Spiroergometry – an initial test 2 days before the beginning of the IHT, followed by a post-test 10 days after the completion of the IHT. We used a running belt with the initial speed of 8 km an hour; this speed was increased by 1 km/hour every 2 minutes, up to the 6^{th} minute; starting from the 7^{th} minute the speed was increased every minute up to 16 km per hour. Then we did not increase the speed, but only the incline of the belt, because in terms of biomechanics, it is improbable that an athlete could run faster.
2. A test of sports performance (3-km race walking) – an initial test on the day of the start of the IHT, followed by a post-test on the second day after the completion of the IHT. The test was conducted on a tartan track at 9:00 o'clock a. m., by which we ensured approximately the same weather conditions.
3. Blood tests – an initial test 3 days before starting the IHT, followed by a post-test 9 days after the completion of the IHT. We monitored changes in the red cell count, the level of reticulocytes, the iron binding capacity and the level of iron. The measurements were conducted at the Department of Clinical Biochemistry using the apparatus ADVIA 60.

RESULTS AND DISCUSSION

On the first days of the IHT, we recorded an 90 – 85 % oxygen saturation in the blood of the tested athlete, at SpO_2 12 – 14 %. As the trend line in Figure 2 (or Figure 4) shows, hypoxia was gradually increased to the level which corresponds to the altitude of about 7000 meters (the concentration of O_2 in the air was about 7-8% and the SpO_2 was below 75%).

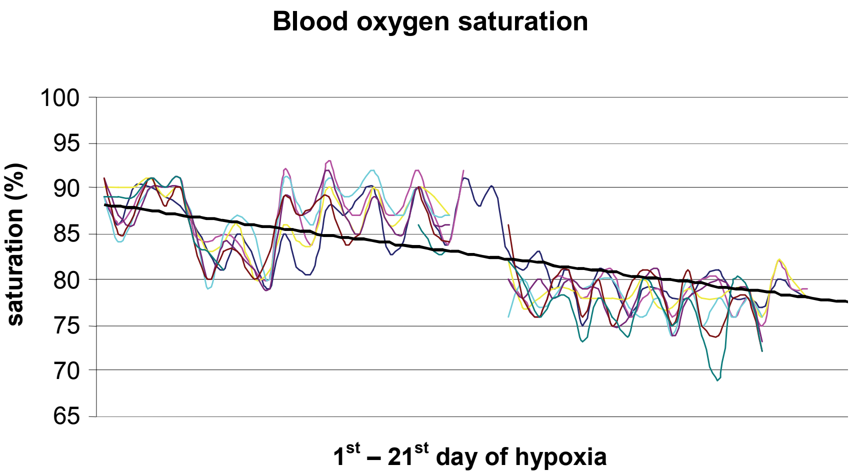


Fig. 4. Oxygen saturation of blood during the IHT

The athlete tolerated the hypoxia relatively well, without any marked negative manifestations, which often accompany hypobaric hypoxia. The only negative subjective feeling that he had was a feeling of weariness during the IHT, which contradicts the findings of Hamlin and Hellemans (2004), who did not record negative feelings in the tested sportsmen receiving IHT. After the completion of the IHT, these feelings had a wave-like character (two days of feeling good, one day of feeling bad). It was a paradox that our sportsman was able, in spite of the negative feelings, to bear a high level of load very well. During the training, he experienced better feelings and a lower heart rate; for example, he was able to bear submaximum loads during the 10-km walk at a 96% level of anaerobic threshold (AT) with the same heart rate which was 1.42 minutes faster during the IHT than before it (46.00 minutes before the IHT, 44.18 minutes during the IHT). A similar situation occurred during the 10-km load at the level of the anaerobic threshold (53.37 minutes before the IHT, 52.08 minutes during the IHT). During the 4 kilometers of alternating load (200 m at the level of 105% AT + 200 m at 95% AT), his performance improved by 21 seconds during the IHT (17.17 minutes before the IHT, 16.56 minutes during the IHT). On the whole, we can say that the sportsman was able to receive a higher load at the same heart beat rate in comparison to training in a normoxic regime.

The spiroergometric examinations that we conducted showed an increase in both the aerobic capacity and aerobic performance. During the examinations the tested sportsman recorded a maximum heart rate of 190, with 191 bpm while his heart rate at AT was 178, with 179 bpm. In accordance with Katayama et al. (2003) and Hamlin and Hellemans (2004), we recorded an indispensable increase in VO_2max, and $VO_2max.kg^{-1}$.

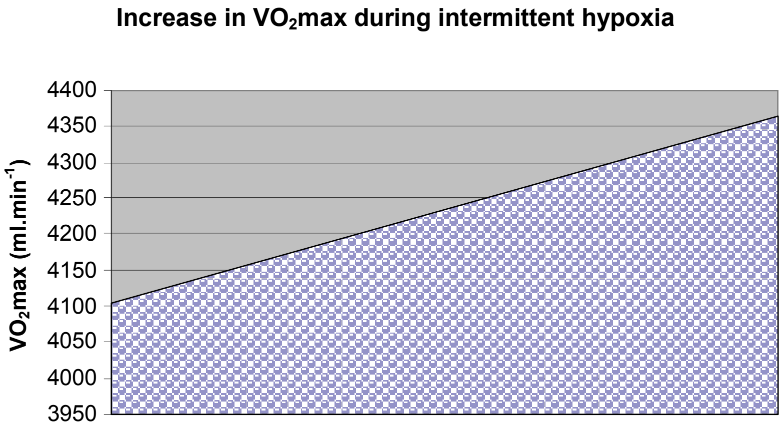


Fig. 5. Changes in VO_2max caused by the IHT

As we can see in Fig. 5 and 6, VO_2max increased from 4105 ml.min^{-1} to 4364 ml.min^{-1}. The morning body weight during the research fluctuated within the range of ± 0.4 kg, which naturally resulted in the increase in VO_2max.kg^{-1}, from 65.4 ml.min^{-1}.kg^{-1} to 69.9 ml.min^{-1}. kg^{-1}. Before the IHT, the consumption of O_2 two minutes after the completion of the load was 1379 ml.min^{-1} (i.e. 22, 0 ml.min^{-1}.kg^{-1}), and after the IHT it was 1227 ml.min^{-1} (i.e. 19.7 ml.min^{-1}.kg^{-1}), which suggests faster recovery after a maximum load.

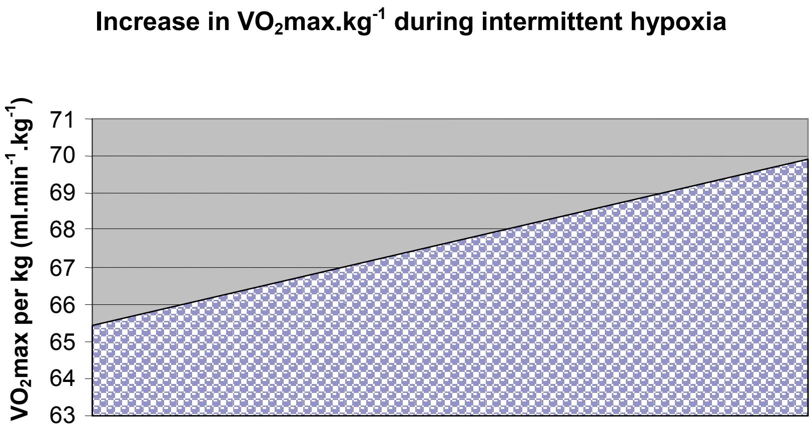
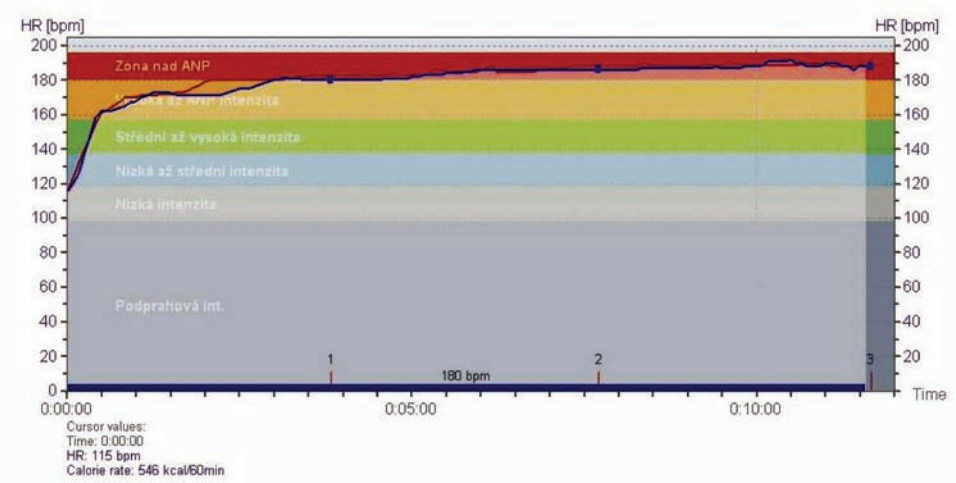


Fig. 6. Changes in VO_2max.kg^{-1} caused by the IHT

This was also proven by the fact that before the IHT, two minutes after the completion of the load, his respiration quotient was 1.34, and after the IHT it was 1.27. After the IHT, following the same testing methodology, the tested athlete performed with loads for 30 more seconds, which means that his maximum working capacity, Wmax.kg^{-1}, increased from 4.71 W to 4.76 W. A similar increase was recorded in submaximum performance, W170. The highest attained speed in both cases was 16 km.hod^{-1}; however, the incline of the belt in the second case was 4, 5%, while in the first case it was 4%. The total increase in anaerobic performance ranged between 2 - 7%.

In terms of sport, the most important parameter is maximum sports performance. The tested sportsman underwent performance testing in the form of the 3 km walk (Figure 7). After the IHT, his performance was by 13.7 sec better than before the IHT, whereas in the same climatic conditions, his average heart rate during the test was lower by 2 bpm. We chose a 3 km test, as it is a well-known fact that the rate of maximum oxygen consumption in race walkers decreases with the increase in race distance (Korčok and Pupiš, 2006), and so this test gave us adequate information about maximum aerobic performance, which also became evident during the laboratory tests. Our findings contradict the findings of Katayama et al. (2000), who did not record significant changes in their research; however, this could be due to the fact that they tested ultra-performance athletes at the national level, whose aerobic capacity is typically substantially lower. In our research, we tested an athlete whose performance in the test would rank him among the top ten athletes in the world, which is in terms of performance more similar to the top athletes tested by Hamlin and Hellemans (2003), who reported results similar to ours.



No	Exercise	Date	Cursor HR	Heart rate	Duration	Note
1. —	Profil1	18.7.2007	115	182 / 191	0:11:53.6	20°C sunny day
2. —	Profil1	10.8.2007	115	180 / 192	0:11:39.9	21°C sunny day

Fig. 7. The comparison of sports performance in the 3 km walk test and the comparison of load curves during the test.

We did not record any significant changes in the haematological parameters. Blood components, which are expressed as the ratio of blood plasma or as its relative concentration (haemoglobin, haematocrit, erythrocytes and haemoglobin in erythrocytes), remained (as we can see in Figure 8) almost unchanged. This contradicts the conclusions of Rodriguez et al. (2000), Katayama et al. (2003) and Hamlin and Hellemans (2004); however, these results are similar to those of Štulrajter, et al. (2001) and Kobela (2007), who consider the increase in reticulocytes as a more reliable indicator which would signal hematopoiesis, that is, the rejuvenation and improvement of the quality of blood.

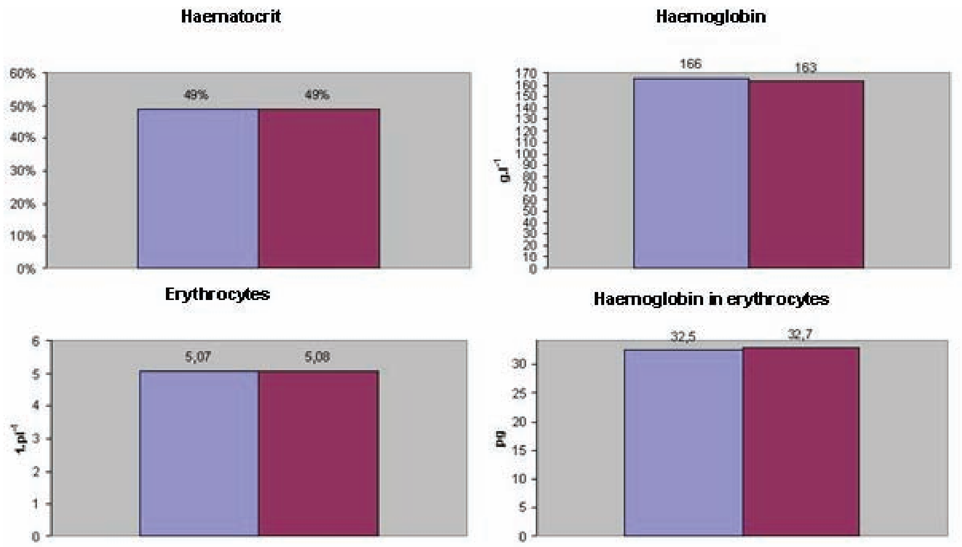


Fig. 8. The values of blood components dependent on the hydration of the body before and after the IHT

In endurance athletes, endurance load brings about haemodilution as a result of the increase in the volume of the blood plasma (hypervolemia) (Neumann et al., 2005), which causes a decrease in the relative values of the components of blood (haematocrit, haemoglobin, etc.). In this parameter, as can be seen in Fig. 9, we recorded an increase from 5.1000^{-1} to 7.1000^{-1}, which is a 40% increase. A significant improvement was recorded in the iron-binding capacity, which increased from 52 $\mu mol.l^{-1}$ to 58 $\mu mol.l^{-1}$, and in medium erythrocyte volume, where we recorded an increase from 96.8 fl to 98.2 fl.

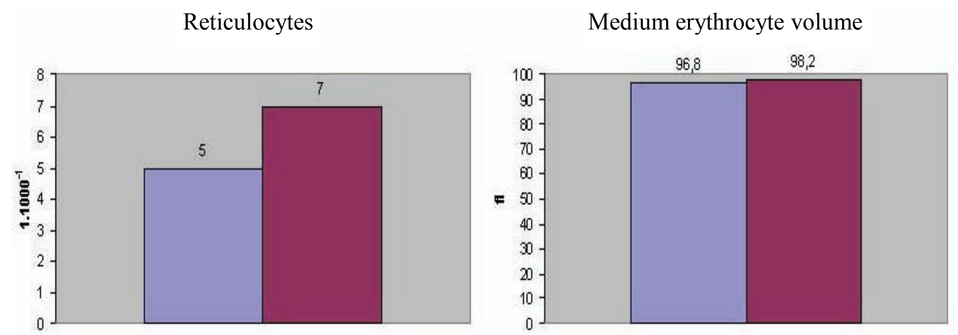


Fig. 9. Values of the blood components directly influenced by hypoxia before and after the IHT

Conclusion

Our findings are similar to those of Meeuwes et al. (2001), who in their research tested a group of elite triathletes; however, they did so in a natural hypobaric hypoxia.

They recorded a 7% increase in VO_2max, 7.4% increase in maximum performance and 5% increase in submaximum performance (per 1 kg of weight). Similar results for natural hypobaric hypoxia were recorded by some other authors, e.g. Levin and Stray and Gundersen (1997), Pupiš and Korčok (2007). Many authors, e.g. Komadel (1994), Gurský (1994), Levin et al. (1997), Pupiš and Korčok (2007) etc., who reported an increase in blood components as a result of hypoxia, which was not confirmed in our research in spite of the fact that Rodriguez et al. (2000), Katayama et al. (2003) and Hamlin and Hellemans (2004) recorded such an increase even during the IHT, that is, during the hypobaric hypoxia. On the other hand, our results are similar to the findings of Štulrajter et al. (2001) and Kobela (2007), who consider the increase in haemoglobin and haematocrit negligible, but they stress the importance of the repletion and rejuvenation of blood cells (reticulocytes, which was confirmed in our research, where we recorded a 40% increase in reticulocytes, as can be seen in Fig. 9). However, the most important was the maximum performance in the 3-km walk where we recorded an improvement of 13.7 seconds after the IHT. On the basis of our findings, we recommend inhaling air with a 7 - 14 % concentration of oxygen during IHT, which corresponds to an oxygen blood saturation of 75-85% during IHT. We found it appropriate to expose the sportsman to 90 minutes of hypoxy, following the pattern 6 minutes of hypoxy + 3 minutes of normoxy (10 times).

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UTICAJ NEKONTINUIRANOG HIPOKSIČNOG TRENINGA NA ORGANIZAM DUGOPRUGAŠA

Martin Pupiš, Ivan Čillík

U ovom radu pratimo uticaj nekontinuiranog hipoksičnog treninga na organizam sportiste. Ispitivali smo zasićenje krvi kiseonikom za vreme hipoksije, koje se kretalo od 90% do 75% na kraju tronedeljnog perioda. Posledica toga je i koncentracija O_2 u udisanom vazduhu, koja je na kraju iznosila 9%, što je posledica simulacije nadmorske visine od oko 7.000 m. Pri spiroergometriji smo zabelezili porast VO_2max od 4.105 $ml.min^{-1}$ na 4.364 $ml.min^{-1}$ i $VO_2max.kg^{-1}$ i to od 65,4 $ml.min^{-1}.kg^{-1}$ na 69,9 $ml.min^{-1}.kg^{-1}$, porast submaksimalnog rezultata W170 od 3,34 W na 3,40 W. Maksimalni rezultat na 3 km se poboljšao za 13,7 s, submaksimalni rezultat na 10 km se poboljšao za 1:42 min, a pri naporima na nivou aerobnog praga došlo je do poboljšanja rezultata na stazi od 10km za 1:29 min. Analize krvnih elemenata ne pokazuju značajne promene, pri čemu su vrednosti hemoglobina i hematokrita ostale nepromenjene. Promene smo primetili kod srednjeg obima eritrocita, koji se povećao od 96,8 fl na 98,2 fl, kao i kod vezivnog kapaciteta gvožđa od 52 $\mu mol.l^{-1}$ na 58 $\mu mol.l^{-1}$. Primećujemo i porast broja retikulocita od 5.1000^{-1} na 7.1000^{-1}, što je povećanje za 40%.

Ključne reči: *nekontinuirani hipoksični trening, maksimalna potrošnja kiseonika, krvi.*