Ramos-Campo, D.J.; Martínez, F.; Esteban, P.; Rubio-Arias, J.A. y Jiménez, J.F. (2016). Entrenamiento en hipoxia intermitente y rendimiento ciclista en triatletas / Intermittent Hypoxic Training and Cycling Performance in Triathletes. Revista Internacional de Medicina y Ciencias de la Actividad Física y el Deporte vol. 16 (61) pp. 139-156. Http://cdeporte.rediris.es/revista/revista61/artefectos677.htm
DOI: http://dx.doi.org/10.15366/rimcafd2016.61.011

ORIGINAL

INTERMITTENT HYPOXIC TRAINING AND CYCLING PERFORMANCE IN TRIATHLETES

ENTRENAMIENTO EN HIPOXIA INTERMITENTE Y RENDIMIENTO CICLISTA EN TRIATLETAS

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Código UNESCO / UNESCO code: 5899 Otras Especialidades Pedagógicas: Educación Físico-Deportiva / Other Educational Specialties: Sport and Physical Education.
Clasificación del Consejo de Europa / Council of Europe classification: 17: otras (entrenamiento deportivo) / other (sport training)

Recibido 18 de diciembre 2012 **Received** December 18, 2012
Aceptado 27 de enero de 2014 **Accepted** January 27, 2014

ABSTRACT

Athletes include altitude training as a complement to their conventional training to improve performance. The aim of the study was to analyze the effects on anaerobic threshold (AT) produced by an IHT program in triathletes.

18 male trained triathletes were divided into intermittent hypoxic training group (GIHT: n=9; age: 26±6.73 years, height 173.33±5.94 cm, weight: 66.38±5.91 kg) and control group (GC: n=9; age: 29.27±6.84 years, height 174.89±4.59 cm, weight: 71.59±6.81 kg). The IHT program consisted of two 60-min sessions per week at intensities over the AT and atmospheric conditions between 14.5 and 15% FiO2. Before and after the program, cycling performance in a lactate thresholds test was determined. The treatment caused an improvement in the power output and perceived exertion in AT and enhanced cardiac performance in the aerobic threshold and AT.

KEYWORDS: Intermittent Hypoxia Training, Simulated Altitude, Anaerobic Threshold, Triathlon.

RESUMEN

Los deportistas incorporan como complemento a su entrenamiento convencional, programas de entrenamiento en altitud para incrementar el rendimiento. El objetivo del estudio fue analizar los efectos sobre el umbral anaeróbico (Uan) producidos por un programa de entrenamiento en hipoxia intermitente (IHT) en triatletas.

Participaron 18 triatletas divididos en un grupo de entrenamiento en hipoxia (GIHT: n=9; Edad: 26±6.73 años; Talla 173.33±5.94 cm; Peso:66.38±5.91 kg) y un grupo control (GC: n=9; Edad:29.27±6.84 años; Talla 174.89±4.59 cm; Peso: 71.59±6.81 Kg). Se aplicó un programa de IHT, complementario al entrenamiento habitual de 7 semanas al 15-14.5% de FiO_2, 2 sesiones semanales de 60 minutos en cicloergómetro a la intensidad del Uan. Se llevó a cabo un test de umbrales lácticos previo y otro posterior al programa. El tratamiento propuesto produce un incremento en la potencia y el esfuerzo percibido en el Uan y disminuye la frecuencia cardiaca en el umbral aeróbico (Uae) y el Uan.

PALABRAS CLAVE: Entrenamiento en Hipoxia Intermitente, altitud simulada, Umbral anaeróbico, Triatlón

INTRODUCTION

Exposure to hypoxic conditions is a technique used by athletes to improve their exercise performance at sea levels. These recent methods improve endurance performance. Traditionally, there are different hypoxic training methods, such as living high-training high (LHTH), living low-training high (LLTH) and living high-training low (LHTL).

In addition, interest in intermittent hypoxic training has been increasing in the last years. There are two principal intermittent hypoxic training methods: intermittent hypoxic exposition (IHE), in which athletes are in a room with hypoxic ambient air or with a lower oxygen concentration than in normal conditions; and intermittent hypoxic training (IHT), which can be conducted in normobaric or hypobaric ambient air and in which the athlete carries out continuous or interval training in hypoxic air ambient (Millet, Roels, Schmitt, Woorons, & Richalet, 2010).

Despite the sustancial differences between hypoxic methods, all of them have the same aim, which is to induce adaptations in the athlete’s body in order to improve their performance at sea level (Millet, Faiss, Pialoux, Mounier.y Brugniaux, 2012; Balsalobre-Fernández, Tejero-González, del Campo-Vecino & Alonso-Curiel, 2013).

Theoretically, the realization of a training program together with hypoxic stimulus generates stress on the athlete’s body producing adaptations that increase the athlete's performance. This increase is due to different biochemical and structural changes in the musculoskeletal system that improve the oxidative process. (Zoll et al., 2006; Geiser, Vogt & Billeter, 2001). The most common theory explaining the increases in performance produced by hypoxic training program, are related to increases in the oxygen carrying capacity of blood as a result of increases in the erythropoietin hormone (EPO), hemoglobin (Hb) and erythrocytes (Stray-Gundersen, Chapman & Levine, 2001; Levine & Stray-Gundersen,1997; Levine & Stray-Gundersen, 2005; Meeuwsen, Hendriksen & Holewijn, 2001; Hamlin, Marshall, Hellemans & Ainslie, 2010) also an improvement in anaerobic performance (Hamlin et al, 2010; Bonetti, Hopkins & Kilding, 2006; Hendriksen & Meeuwsen, 2003) due to an increase in the muscle buffer capacity (Gore et al., 2001) and an increase in the enzyme activity (Puype, Van Proeyen, Raymarkers, Delcicque, & Hespel, 2013; Katayama et al., 2004).

Some studies have shown intermittent hypoxic programs as effective methods of increasing aerobic performance at sea levels (Zoll et al., 2006; Hamlin et al., 2010; Meeuwsen et al., 2001; Czuba et al., 2011; Terrados, Melichna, Sylven & Jansson, 1998), however, others studies have found no changes in performance (Morton & Cable, 2005; Truijens, Toussaint, Dow, & Levine, 2003; Roels, Bentley, Coste, Mercier, & Millet, 2007). Specifically, in triathletes, Vallier, Chateaou, & Guezennec (1996) showed that IHT increased physical performance (34%) without modifying maximal oxygen uptake (VO_2max) or blood variables after 3 weeks at 4000 m of simulated altitude program. In contrast, Meeuwsen et al. (2001) observed an increase in hematocrit, hemoglobin, VO_2max parametres and an increase in the average power output in a Wingate test conducted after an IHT with 10 sessions of 2 hours at 2500m. Two years later, Hendriksen & Meeuwsen (2003) using the same protocol found

a maintenance of the VO_2max and peak power in a 20-km cycloergometer test and an increase in the average power and peak power in a Wingate test. Furthermore, Roels et al. (2005) have showed an increase in the average power in a 10-min cycloergometer test, with also increases in the VO_2max and maintenance of cycling economy after 14 sessions at 10-14% of FiO_2.
The effect of IHT in sport performance is influenced by the training protocol, the type of hypoxic stimuli (normobaric or hypobaric), the duration and intensity of the training program, the number of sessions per week and the simulated altitude (Millet, Woorons & Roels, 2009). The effects of IHT also depend on the training level, as athletes with lower training levels have showed greater improvements in performance compared with high trained athletes (MacDougall et al., 1998).

Despite these differences, the research results suggest that the use of short duration hypoxic stimuli attached to training at intensities close to the anaerobic threshold could induce an improvement in the ability to carry oxygen in blood due to physiological adaptations in the athlete´s body as a results of intermittent hypoxia programs. Therefore, the aim of the present study was to analyze changes in cycling aerobic performance after a 7-week IHT program with 2 session per week, 60 min per session at 14-15% of FiO_2 in trained triathletes.

MATERIAL AND METHODS

Experimental Design: A pre-post randomized controlled training intervention design was employed to analyze the effect of an IHT program on aerobic performance in trained triathletes. Participants were randomly divided into two groups: the first group performed normal normoxic training during a 7-week period, while the second group performed an IHT program along with normoxic training during a 7-week period. The protocol was reviewed and approved by the Physical Activity and Sport Science Department and by the local ethics committee.

Subjects: 18 male elite trained triathletes were divided randomly in two groups: an intermittent hypoxia training group (IHTG) in which each athlete performed his usual normoxic training plus an IHT program, and a control group (CG) in which each athlete performed his usual normoxic training. The study was designed in compliance with the recommendations for clinical research of the Helsinki Declaration of the World Medical Association. The characteristics of the participants are shown in Table 1.

Table 1. Characteristics of the participants

Group		Age	Height (cm)	Weight (Kg)	Free Fat Mass (Kg)	Fat content(%)	VO_2max (ml/Kg/min)
IHTG	Mean	26,00	173,33	66,38	55,33	13,25	59,53
	SD	6,73	5,94	5,91	5,25	2,02	5,04
CG	Mean	29,67	174,89	71,59	59,07	13,47	58,93
	SD	6,84	4,59	6,81	4,14	2,68	4,53

VO_2 max= Maximal Oxygen Uptake

Procedure: Lactate threshold tests were carried out before and after the 7-week training period. Subjects performed a stair incremental cycling test: a 5-min warm-up at 50 watts, followed by increases of 50 watts per minute until exhaustion, according to previous literature (Carig et al., 2000) (Figure 1). Cycling cadence during test was maintained between 90-105 rpm.

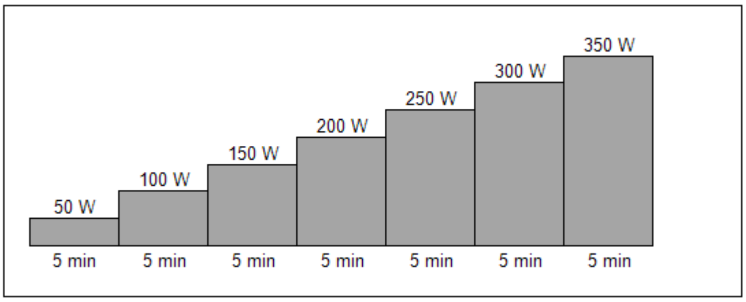

Figure 1. Lactate threshold test procedure in cycloergometer

During the last 15 seconds of each work-load, heart rate (HR), rating of perceived exertion (RPE) were measured and capillary blood sample of the index finger at the right hand was taken in order to analyze the lactate blood concentration. The test was terminated when the athlete could not either maintain the cadence within the delimited range or finish the stage of 5 min due to the fatigue or asked to finish the test (Carig et al., 2000). Anaerobic thresholds were estimated according to Kindermann, Simon & Keul (1979).

Intermittent hypoxia program: One day after completion of the pre-tests, participants began the 7-week training period. The IHTG performed an IHT protocol twice a week during the 7-week period combining continuous and interval training methods in which the percentage of oxygen in the inspired air gradually decreased while the session length remained stable (60 min) (Millet et al., 2010). The frequency of the hypoxia program was 2 days per week (Tuesday and Thursday). Oxygen saturation, monitored by a pulseoximeter placed on the index finger of the athlete’s left hand, was used as a control factor of the hypoxia program load and was adjusted to the ratio of 78-85. These parameters decreased progressively as the training program progressed. The characteristics of the IHT program are shown in Table 2. During the 7-week period, both training groups (IHTG and CG) performed the same training sessions in normoxia. The intensity of the hypoxia training sessions was established for each individual based on a hypoxia test carried out before starting the training program, according to a published protocol (Campbel et al., 2001), determining the heart rate and the power output in each of the simulated altitudes during the study.

Variables: The variables measured through the lactate thresholds test were the power output (W), the heart rate (bpm), the rating of perceived exertion and the power divided by the weight (W / kg) at 2.5, 4 and 8 mmol / l of blood lactate concentrations.

Instruments: The lactate thresholds test was performed on a Monark 839E cycloergometer (Monark Exercise, Vansbro. Sweden). A Dr.Lange LP-20 lactate analyzer (Bruno Lange, Germany) was used to determine the lactate concentration and Suunto T3C heart rate monitor was used to record the heart rate. The rating of perceived exertion was measured by using the Borg scale whose values fluctuate from 6 to 20 points. The hypoxic training sessions were simulated by using a GO_2altitude Hypoxicator (Biomedtech Australia, Melbourne, Australia) with a 120-l Douglas bag and a suitable mask. The training sessions were registered in watts and controlled by a Monark 839E (Monark Exerc., Vansbo, Sweden) cycloergometer and a Suunto T3C heart rate monitor.

Table 2. Intermittent hypoxia training program characteristics

Week		Sessión 1	Sessión 2	
0	Pre-test			
1	Duration	60	60	15 $\%FiO_2$
	Intensity	60%	65%	
	Training method	Continous	Continous	
2	Duration	60	60	
	Intensity	70%		
	Training method	Continuo	Interval	
3	Duration	60	60	
	Intensity	70%		
	Training method	Continous	Interval	
4	Duration	60	60	
	Intensity	70%	60%	
	Training method	Continous	Continous	
5	Duration	60	60	14,5% FiO_2
	Intensity	60%	65%	
	Training method	Continous	Continous	
6	Duration	60	60	
	Intensity		65%	
	Training method	Interval	Continous	
7	Duration	60	60	
	Intensity	65%	60%	
	Training method	Continous	Continous	
8	Post- test			

Intensity: % anaerobic threshold at this altitude
Continous method: Session with extensive continous method.
Interval: 10 min of warm up (60%) + 8x(2.5 min (80%) + 2.5 min (60%))+ 10' min of cool down(50%)

Duration (min). % FIO_2 and training method

Training program: The study was conducted during the first macrocycle of the triathletes training season which had a duration of 32 weeks. The periodization model was paralle-complex model which uses regular loads (Matveiev, 1985). The IHT program was located in the pre-competition and competition mesocycles. The pre-competition mesocycle consisted in 4 microcycles (3 with high load and 1 of recovery) whose aims were to develop the anaerobic threshold, the pace of competition and the aerobic strength. The competition mesocycle consisted in other 4 microcycles (3 to prepare the first competition and 1 from the competition). The main aim of the month was develop the pace of competition and the secondary aims were to maintain the anaerobic and aerobic threshold levels of the athletes. The intensity of the normoxia cycling training sessions was established according to the lactate thresholds test results. The intensity was monitored by heart rate and power. Similarly, each subject ran and swam individually using training zones defined according to an initial test and established in the literature (Navarro, 1998). After each session, the subjects completed a diary detailing the training conducted to determine if the load periodizated and the load performed were similar.

The training load of swimming, cycling and running sessions performed by the triathletes was quantified each week using the Training Impulse method (TRIMP) (Banister, 1991) (Table 2). This method takes into account the duration and the intensity of exercise, expressing quantitatively the load level. This method has been used to quantify training load in different long endurance sports research (Padilla, Mujika, Orbañanos & Angulo, 2000; Padilla et al, 2001; Ramos et al, 2011).

Statistical analysis: The SPSS statistical package (version 20.0; SPSS, Inc., Chicago, IL.) was used to analyze the data. First, data analysis by descriptives, mean, standard deviation, maximum and minimun of all variables were realized. Normality and homoscedasticity were checked using a Shapiro-Wilks test. Finally, a two-factor (group x sample) ANOVA repeated measures with Bonferroni post hoc test was used to analyse the results. In no parametrics variables U de Mann Whitney test and Wicoxon test were used to compare intra and intergroups differences. The level of significance was set at $p<0.05$ for all statistical analyses.

RESULTS

The lactate threshold test values before and after the program IHT, according to the group, showed differences statistically significant between the two evaluation times in GIHT in the heart rate at 2.5 mmol/l (Fc2.5, P=0.033) , in the absolute and the relative power output at 4 mmol/l of lactate (P4, P=0.012 ; Prelat4, P=0.012) and in the rating of perceived exertion at 4 mmol/l of lactate (RPE4, p =0023). There were no significant differences in any of the variables in CG during the 7-week training period (Table 3). On the other hand, heart rate values at 4 mmol/l and 8 mmol/l of lactate and power output at 2.5 mmol/l remained the same in GIHT. The power at 8 mmol/l increased by 25.64%, but this was not significant. The weight relative power at 2.5, 4 and 8 mmol/l of lactate increased between 9 to 25 %, but the differences were no significant. In addition, the rating of perceived exertion at 2.5,4 and 8 mmol/l of lactate did not change significantly.

By contrast, there were no significant differences in CG in the parameters measured. Rating of perceived exertion and power output at all the different lactate concentrations remained the same. Nonetheless the heart rate decreased between 1-4% at all the different intensities.
Finally, the basal values of the absolute power output were higher in CG compared with the IHTG but the relative power values were the opposite. After completing the 7-week training program an increase in the power output at 4 and 8 mmol/l of lactate were found in the IHTG which produced that the power

output was higher in the IGHT than in the CG. Equally, the relative power output increased at all the lactate concentrations in IGHT witch also showed higher values than the CG.

Table 3. Power output, heart rate and rating of perceived exertion values in lactate thresholds test

		$P_{2,5}$ (W)	$Fc_{2,5}$ (bpm)	$RPE_{2,5}$	P_4 (W)	Fc_4 (bpm)	RPE_4	P_8 (W)	Fc_8 (bpm)	RPE_8	$Prelat_{2,5}$ (W/kg)	$Prelat_4$ (W/kg)	$Prelat_8$ (W/kg)
IHTG (n=9)	Pre	116,74	131,01	10,77	189,49	153,4	14,93	234,17	170,45	17,97	1,72	2,84	3,52
		±48,99	±12,03	±1,37	±29,87	±12,5	±0,78	±37,25	±14,46	±1,03	±0,75	±0,36	±0,54
	Post	114,14	115,27	10,61	205,67	148,66	15,89	294,22	174,66	18,35	1,89	3,12	4,43
		±41,64	±14,67	±2,37	±28,11	±12,7	±1,07	±48,64	±10,12	±1,47	±0,68	±0,28	±1,37
	D	-2,23	-12,01	-1,49	8,54	-3,09	6,43	25,64	2,47	2,11	9,87	9,86	25,85
	(*p*)	(0,893)	(0,033*)	(0,802)	(0,012*)	(0,136)	(0,023*)	(0,172)	(0,71)	(0,648)	(0,347)	(0,012*)	(0,154)
CG (n=9)	Pre	131,31	126,49	11,85	209,06	151,76	15,57	258,13	168,21	17,62	1,7	2.69	3,34
		±37,02	±14,07	±1,21	±22,62	±11,41	±1,4	±39,33	±15,61	±1,87	±0,65	±0,99	±1,33
	Post	135,64	124,09	12,29	200,5	146,5	15,16	253,03	165,47	17,04	1,69	2.51	3,17
		±32,75	±9,22	±1,51	±28,3	±8,41	±1,55	±46,98	±14,29	±2,33	±0,61	±1,03	±1,4
	D	3,30	-1,90	3,71	-4,09	-3,47	-2,63	-1,98	-1,63	-3,29	-0,59	-6.69	5,09
	(*p*)	(0,894)	(0,576)	(0,58)	(0,103)	(0,286)	(0,102)	(0,415)	(0,484)	(0,612)	(0,458)	(0,094)	(0,381)

Mean ± standard deviation

IHTG: Intermitten Hypoxia Group; CG: Control Group; Pre: Pre IHT evaluation; Post: Post IHT evaluation; $P_{X=}$ Power output at x mMol; $Fc_{X=}$ Heart rate at x mMol; $RPE_{X=}$ rating of perceived exertion at x mMol; Prelat= weight relative power at 2.5,4 y 8 mMol; w= watt; bpm= beat per minute. w/kg= watt per kilogram

There were no significant differences in power output, heart rate or RPE between the study groups in any of the measured times. Both groups started the study with similar values, and these values were maintained in post-treatment evaluation.

There were no significant differences in the TRIMP values during the 7-week training period between the IHTG and the CG (Table 4). The p values ranged from 0.746 to 0.896 during the treatment.

Table 4. Average trimps values during the 7 weeks training program by group

Mesocycle	Precompetition			Competition			
Week	1	2	3	4	5	6	7
IHTG (n=9)	1248,79	1258,87	971,85	961,39	1046,41	991,47	821,31
	±81,66	±82,32	±69,05	±59,52	±69,94	±57,15	±53,24
CG (n=9)	1244,44	1254,49	964,02	959,78	1037,00	985,77	815,00
	±53,48	±53,91	±41,11	±37,07	±48,86	±44,66	±39,44
D(trimps)	4,34	4,38	7,82	1,61	9,40	5,71	6,31
P	(0,896)	(0,896)	(0,775)	(0,946)	(0,746)	(0,817)	(0,779)

Mean ± standard deviation; TRIMPS= training impact. IHTG: Intermittent Hipoxia Group; CG: Control Group

DISCUSSION

In this research have been measured the power output, heart rate and rating perceived exertion at the anaerobic threshold, determined at a constant concentration of 4mmol/l of lactate in triathletes. At 2.5 mmol/l and 8 mmol/l were placed the lipolitic or aerobic threshold and the aerobic capacity respectively. The most important finding of this study is that a 7-week IHT program, consisted in two weekly sessions of 60 minutes each at 15-14.5 % FiO_2 in triathletes, caused a significant higher increase by 8.54% in the power output and in the rating of perceived exertion at the anaerobic threshold (RPE_{4Pre}=14.93 ± 0.78; RPE_{4Post}=15.89 ± 1.07) than the same training procedure performed under normoxia conditions.

The increase in the power output at anaerobic threshold was higher when the power was divided by the weight (9.86%). These variables were steady in CG. In addition, there was a significant decrease in the heart rate at 2.5 mmol/l of lactate in the IHTG that was not found in the CG ($Fc_{2.5}$:-12.01% in IHTG; -1.9% in CG). Intermittent hypoxic training could increase aerobic capacity and endurance performance at sea level due to several adaptive changes in the athletes's body. However, recent research findings on IHT as an effective method for enhancing performance at sea level are unclear (Czuba et al., 2013).

Previous studies (Dufour et al, 2006; Czuba et al., 2011) that checked the effects produced in the anaerobic threshold by IHT programs found a clear improvement in performance related to this variable which is in accordance with the results of our study. Dufour et al. (2006) observed an improvement of 4% in the anaerobic threshold in high trained endurance athletes after performing 12 sessions of 1 hour at 14.5 % of FIO_2. These results are in accordance with those obtained by Czuba et al. (2011) where elite cyclists increased their anaerobic threshold after exercising 60 min at 15.2 % of FiO2, three times a week for three weeks. This increase can be justified due to an improvement in order to produce and stand lactate during exercise (Hendriksen & Meeuwsen, 2003; Mizuno, Juel & Bro- Rasmussen, 1990; Saltin, Terrados & Kim, 1995). This adaptation is performed by an increase in ventilation which decreases PCO_2 resulting in an increase in pH levels. As a results is observed an increase in the renal secretion of bicarbonate in order to reduce H + ions and buffer the lactate acid concentration. This produces an increase by 5-18 % in muscle buffer capacity (Mizuno et al, 1990; Saltin et al, 1995).

However, this improvement in performance is not so clear in exposure intermittent hypoxia programs. Many studies have shown only either a maintenance of the anaerobic threshold or a non-significant shitf of the lactate curve to the right, which suggests a possible adaptation to the training and to the hypoxic program were observed. Bonetti et al. (2006) observed a maintenance of the power anaerobic threshold after ten rowers performed fitteeen sessions of an hour at 76-90 % of SpO_2. Similarly, Hinckson, Hopkins, Downey and Smith (2006) did not observe an improvement in the anaerobic thresholds of rowers after the completion of a program consisting of 14 sessions with a duration of 90 minutes between 80-92 % SpO_2. In other previous studies (Calbet et al, 2003; Consolazio, Nelson, Matoush & Hansen, 1996; Wolfel, Groves & Brooks, 1991; Tadibi, Dehnert, Menold & Bartsch, 2007) that used intermittent hypoxia exposure as a stimulus, observed that the anaerobic threshold was unchanged or even it decreased after a simulated altitude program (Katayama, Matsuo , Ishida , Mori & Miyamura, 2003; Lundby, Dela & Nielsen , 2005).

The results of our research are in accordance to those obtained by Bonetti et al. (2009), who found an increase by 6.5% in the anaerobic threshold power output in 18 triathletes and cyclists after 15 sessions of 60 minutes at 76-90 % of SpO2 and the results found by Friedmann et al (2005) who showed an increase by 3 % in the anaerobic threshold speed of sixteen swimmers after the completion of a IHE program consisting of 4 hours a day at 15% of FiO_2. These results are in accordance with those showed by Rodriguez, Ventura and Casas (2000) who found a significant increase in the power output at the anaerobic threshold intensity in cyclists after three weeks of intermittent hypoxia exposure at 5500 m for 3 hours 3 times per week.

Moreover, recent studies (Girard et al, 2013; Millet, Faiss, Brocherie & Girard, 2013) suggest that intermittent hypoxia programs could also produce performance benefits in intermittent sports, confirming the results by Wood, Dowson and Hopkins (2006) who found an increase by 3.7% in the anaerobic threshold speed in team sports after 15 session between 70-100% of SpO_2. Morton & Cable (2005) showed a maintenance of the anaerobic threshold in team sports players after 4 weeks of IHT, 3 times per week, 30 minutes per session.

Mainly, disagreements in previous studies are justified by the diversity of protocols applied in the programs. Thus, the duration either of the program or of the session could change the athlete’s adaptations. The shortest session needed to stimulate the adaptive threshold and produce an acute reaction was 90 min in the IHE programs (Rodriguez et al., 2000) and 60 min in the IHT (Millet et al., 2010). Weekly frequency, the simulated altitude or type of hypoxia (hypobaric or normobaric) must also be taken into account because they are features that affect the variability of the results and should be clarified to ensure a correct application of these methods (Millet al., 2010). Furthermore, the session intensity is a key factor, which should be close to the anaerobic threshold, and the duration of the stimulus which should be approximately last 20-45 min (Millet et al., 2009).

The different responses from the athletes to IHT are likely more related to genetic factors (Gomez-Gallego et al., 2009), and in some cases, the effects are similar to those obtained by the administration of exogenous erythropoietin (Sanchis-Gomar et al., 2009) generating a debate about its legality (Hinghofer-Szalkay, 2010).

The increase in the anaerobic threshold after performing an intermittent hypoxia program is caused by a decrease in the submaximal heart rate and a shift of the lactate curve to the right (Casas, Casas & Pages, 2000). In the present research, were observed a significant decrease in the heart rate at 2.5 mmol/l of lactate concentration (Pre= 131.01 ± 12.03; Post= 115.27 ± 14.67 ppm) and a non-significant decrease in the heart rate at anaerobic threshold (Pre= 153.4 ± 12.5; Post= 148.66 ± 12.7 ppm) in the IHTG. These adaptations are due to a greater efficiency of the cardiovascular system that is associated with a better contractility of the left ventricle causing an increase in stroke volume, along with an increase in the myocardial contractility (Spina, 1999). This decrease in the heart rate at submaximal intensities showed in our study has been found by other studies. Svedenhag, Piehl - Aulin , Skog and Saltin (1997) showed a decrease in the heart rate of skiers at submaximal and maximal intensities at 1900 m of altitude . Wood et al. (2006) also observed an increase in heart rate at the anaerobic threshold after completing 15 sessions between 70-100% of SpO_2 in team sports players.

Heart rate at 8 mmol/l of lactate showed a non-significant increase (Pre= 170.45 ± 14.46; Post= 174.66 ± 10.12 ppm) due to an increase in sympathetic nervous system discharge by the concentration of circulating catecholamines and the increased venous return (Spina, 1999). These results are in accordance to those obtained by Rodriguez et al. (2007) in heart rate at maximum intensity after IHE program of 4 weeks of duration in swimmers and runners. Similarly, Hamlin and Hellemans (2007) observed an increase in the maximum heart rate during a treadmill running test after 3 weeks of exposure to intermittent hypoxia program.

Heart rate adapts individually, accentuating these differences by hypoxia effect. The dynamics of adaptation could be linked to the performance capabilities of the subjects and their responsiveness to altitude (responders or non-responders) (Funes et al., 2010). Heart rate must be determined individually in order to adjust the training load, (Friedmann et al., 2005), so that the same values of heart rate in normoxia and hypoxia, the relative intensity of effort is higher in altitude conditions (Friedmann, Bauer, Menold & Bartsch, 2004). Then the best way to adapt the training load is based on the calculation of the individual anaerobic threshold of the subject in each of the altitudes used in the program (Millet et al., 2010).

Finally, it can be said that the hypothesis that asserts that IHT programs increase the anaerobic threshold of triathletes study is confirmed in this research. The changes observed are usually small as the system is difficult to be altered and the changes require a certain period of time to occur and become constant. It is also important to highlight that the improvement in this system not only affects athletic performance but also improves recovery and assimilation of high training loads, health, life quality and prevents diseases associated with altitude in athletes who use these specific training programs. (Millet el al., 2010). Finally, as a practical approach, intermittent hypoxia programs in elite athletes could be used during the competitive period, with two

IHT sessions per week at a simulated altitude between 2500-3000 m in order to develop the anaerobic threshold. These training sessions can also be complemented with three hours of IHE four or five times per week (Millet et al., 2010).

CONCLUSION

The implementation of an IHT program during 7 week, 60 min per session, 2 times per week at 14.5-15% FiO_2 together with normoxic training increased sea level endurance performance of the trained triathletes who participated in this study more that only normoxic training . The completation of the treatment produced an increase in the lactate threshold, causing an enhance in the power output and the rating of perceived exertion at the anaerobic threshold and also increased the efficiency of heart function at the aerobic threshold. Disagreements in previous studies about the effectiveness of training programs in intermittent hypoxia on aerobic performance are justified by the application of diverse protocols that make the response to hypoxic stimulus different.

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