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ORIGINAL ARTICLE

Anaerobic performance after endurance strength training in hypobaric environment



La performance anaérobie après l'entraînement en force d'endurance en milieu hypobarique

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KEYWORDS

Jumping
performance;
Hypobaric chamber;
Altitude training;
Intermittent hypoxia

Summary

Objective. — This study was aimed to assess anaerobic capacity after an endurance strength training (EST) protocol for 4 weeks.

Methods. — A group of volunteers ($n=5$) trained in a hypobaric chamber at a simulated altitude of 2500m (HYP), while the other ($n=7$), trained at sea level (NOR). Anaerobic power was tested before and after the training protocol through the widely used Bosco's vertical jump test procedures: squat jump (SJ), countermovement jump (CMJ) and sixty seconds repeated maximal countermovement vertical jump (60CMJ). The mean height for the whole 60CMJ test (cm), partial heights every 5 and 15 sec were measured and the fatigue index (60CMJ/CMJ) was calculated.

Results. — Hypoxic training significantly improved mean height for 60CMJ by 6.75% ($P=0.029$) in comparison to normoxic training. The fatigue index was also significantly lower ($P=0.031$) in the HYP group than in the NOR group. Partial heights at 45–60'' intervals increased by 32.9% in the post-training test for the HYP group ($P=0.004$), compared to a lower improvement of 21.9% for the NOR group ($P=0.022$).

Conclusions. — Our study shows a better anaerobic capacity after EST training at a moderate simulated altitude compared with that attained following the same training protocol at sea level.

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MOTS CLÉS

Performance ;
Saut verticale ;
Caisson hypobare ;
Entraînement en altitude ;
Hypoxie intermittente

Résumé

Objectif. — Cette étude avait pour objectif à évaluer la capacité anaérobie après un protocole d'entraînement d'endurance de puissance (EST) pendant 4 semaines.

Méthodes. — Un groupe de volontaires ($n=5$) a été entraîné dans un caisson hypobare à une altitude simulée de 2500 m (HYP), tandis que l'autre ($n=7$), l'a été au niveau de la mer (NOR). La puissance anaérobie a été testée avant et après le protocole d'entraînement au moyen de la procédure largement utilisée du test de détente verticale de Bosco : squat jump (SJ), saut de contremouvement (CMJ) et sauts verticaux maximaux répétés de contremouvement dans 60 secondes (60CMJ). La hauteur moyenne pour l'ensemble du test 60CMJ (cm), les hauteurs partielles chaque 5 et 15 secondes ont été mesurées et l'indice de fatigue (60CMJ/CMJ) a été calculé.

Résultats. — L'entraînement en hypoxie a considérablement amélioré la hauteur 6,75 % ($p=0,029$) pour 60CMJ par rapport à l'entraînement en normoxie. L'indice de fatigue était également significativement plus faible ($p=0,031$) dans le groupe HYP que dans le groupe NOR. Des hauteurs partielles à intervalles de 45–60'' ont augmenté de 32,9 % dans le test post-entraînement pour le groupe HYP ($p=0,004$), comparativement à une amélioration inférieure de 21,9 % pour le groupe NOR ($p=0,022$).

Conclusions. — Notre étude montre une meilleure capacité anaérobie après l'entraînement EST à une altitude simulée modérée par rapport à celui atteint en suivant le même protocole d'entraînement au niveau de la mer.

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1. Introduction

The use of hypoxic training to improve sports performance through enhancing aerobic and anaerobic metabolic pathways has received much attention in recent years due to the good results obtained by athletes who born and live in altitude [1]. However, performance is significantly compromised when high intensity sport is achieved in hypoxia [2]. Although several studies have described the positive effects of altitude exposure (chronic and intermittent) on aerobic [3,4] and anaerobic capacity [5–11] following different hypoxia protocols, other have failed to found these effects [12,13]. By this reason a scientific consensus on anaerobic training and performance following the use of hypoxia to improve sea level performance remain unclear. This can be due at least in part because of the large number of studies, which have employed different methodologies or measured different variables [14].

Most sports require very specific high workload training [15–18] when anaerobic metabolism is primarily involved. It has been hypothesized that it is possible to further stimulate the lactic anaerobic pathway at maximal and supra-maximal intensities by training under high altitude conditions, thus yielding enhanced athletic performance [19]. The importance of endurance strength training (EST) has been well established for several sports, such as soccer, basketball or volleyball which some actions depend primarily on speed of execution and the ability to accelerate, being these parameters dependent of maximum strength and maximum strength/power output [20]. Sprinting and other high intensity actions depend of explosive strength as the ability of the neuromuscular system to generate coordinated high-speed actions [21].

Some research has focused on the response to intense and maximal exercise at altitude with possible benefits for performance in specific sports. Stimulation of anaerobic

metabolism through strength training could have the following benefits:

- increased glycolytic metabolism after submaximal exercise [15,16,19], probably as a consequence of an enhanced contribution by anaerobic pathways during the post-exercise recovery phase [22];
- changes in cell metabolism regulation, enhancing tolerance to the accumulation of anaerobic pathway waste products, thus reducing fatigue and cell stress [15,23];
- enhanced muscular buffer capacity [5,19];
- switching phosphofructokinase gene expression to anaerobic pathway [24];
- and increased energy production via anaerobic pathways as a compensatory mechanism for the reduced energy supplied by aerobic pathways [25].

In consequence, a certain similarity between the stresses induced in the human body by altitude exposure and by a maximal intensity specific training can be deduced, since maximal intensity specific training in hypoxia could enhance anaerobic capacity by increasing the efficiency of the glycolytic energy production mechanisms [26]. The combination of these two stimuli (hypoxia and endurance strength training) could be beneficial to athletes by independently and simultaneously eliciting the same or some complementary adaptive responses.

Most of the previous studies have focused on specific work performed in hypoxia (running, cycling, rowing, etc.) measuring overall performance, including the technical component of execution. Nevertheless, to the best of our knowledge, no studies exist to date on strength training in hypoxia as a method for improving anaerobic capacity. It is common practice in sport to use strength training to enhance power, and different strength training methodologies have been employed to improve specific high intensity

Table 1 Anthropometric characteristics of the subjects.

Parameter	Normoxia		Hypoxia	
	Pre	Post	Pre	Post
Age (y)	24 ± 4.5		23.8 ± 3.8	
Height (cm)	174.4 ± 7.2		172.2 ± 10.3	
Weight (kg)	65 ± 5.7	64.8 ± 5.1	72.2 ± 8.2	71.3 ± 8.0
Basal heart rate (beats/min)	63.8 ± 14.1	59.2 ± 11.0	62.2 ± 11.0	57.1 ± 7.9

sports performance [27]. In this study we tested the hypothesis that specific strength training in hypoxia would increase efficiency of anaerobic metabolism and muscular performance. A major focus of this study was to test a different concept of training methodology, since we used strength training in hypoxia as a method for maximal challenge to muscle anaerobic metabolism. Through training in moderate hypoxia, the specific workload required can be raised during strength training, but generating greater physiological stimulation than the same training at sea level and thus eliciting a higher degree of morphofunctional and metabolic adaptations in skeletal muscle. To test this hypothesis, we designed a program of 12 training sessions aimed both to enhance the endurance and the explosive strength of the lower limbs. After the end of this protocol, we tested anaerobic capacity by performing the countermovement jump test during 60 seconds, thus comparing the two groups trained using the same protocol but under different environmental conditions: sea level and moderate simulated altitude.

2. Methods

2.1. Participants

A total of twelve healthy, physically active Sports Science students voluntarily agreed to participate in this study. All of them were recreational athletes with no more of four training sessions by week. The basic anthropometrics characteristics of the subjects are presented in Table 1. After attending an information session describing the objectives, advantages, risks and a detailed protocol of the study, each subject signed an individual informed consent form. All procedures were conducted in accordance with the Declaration of Helsinki as amended by the 59th WMA General Assembly, in Seoul, Korea, October 2008 and the IJSM's ethical standards [28]. This study obtained approval of the Comité de Bioética de la Universitat de Barcelona (Institutional Review Board IRB0003099, Resolution 30/06/2010). According to the results of the initial test, subjects were divided into two groups in order to establish a balanced fitness composition between the group training at sea level (NOR) composed by 6 men and 1 women (aged 24 ± 4.5 years) and that training at a simulated altitude of 2500 m (HYP) composed by 3 men and 2 women (mean age: 23.8 ± 4 years). The participants did not receive financial compensation or any other kind of reward.

2.2. Experimental design

The protocol consisted of a classical “before” versus “after” design in order to compare the possible differences between the two training conditions (Table 1). Baseline and final tests were based on the well-established Bosco battery of vertical jump tests, in which an athlete performs a series of continuous jumps for a specified duration of 60 seconds. This test evaluates anaerobic power, utilizing stretch-shortening cycle actions of the lower extremities to induce and evaluate fatigue from the contact time between jumps. This methodology facilitates detection of a possible increase in anaerobic capacity. In accordance with the aim of this study, anaerobic capacity was tested by an “all out” 60-second countermovement jump test (60CMJ). Different authors have confirmed that the 60CMJ test is an exercise with supra-maximal characteristics, during which 70–85% of the energy used is supplied by anaerobic pathways and consequently, any decrease in work capacity during the test will be directly related to depletion of the anaerobic substrates, accumulation of metabolite waste due both to insufficient removal and exacerbated production, and diminished alkaline reserves [29].

All the subjects lived at sea level throughout the study. As physical activity students, they were active subjects but anyone among them was a weight trainer or sprint runner. No one was a competitive athlete or was maintaining a non-study related training throughout the protocol with a potential alien impact on the post-study outcomes. Three training sessions were performed weekly for a month (4 weeks). Each session lasted for about two hours, was conducted at room temperature (ranging from 20–24 °C) and was exactly equal in workload and volume for both groups. The NOR group trained at near sea level (75 m a.s.l), whereas the HYP group trained inside a computer-controlled hypobaric chamber (CHEx-1; Moelco, Spain) at a barometric pressure of 747 hPa, equivalent to 2500 m of altitude. The HYP group was exposed to hypobaric hypoxia for a total time of about 26 hours. The time of “ascent” to altitude inside the hypobaric chamber (10 min) was used for warming-up, and the “descent” (15 min) for the recovery procedure, and an identical procedure was also established for the NOR group. All subjects were instructed on the level of effort required during training. None described intolerance to training under normoxic nor hypoxic conditions.

The training exercises chosen were half-squats with extra weight, half-squat weight lifting exercises with jumps and extra weight repeated vertical countermovement jumps

(CMJ). Speed of execution was controlled by means of an electronic metronome in order to facilitate a suitable and rhythmic pace among all subjects. The workload during training was individually assigned according to the explosive nature of the effort and the higher possible velocity of execution [30].

2.3. Data acquisition

A baseline test (T1) was performed 4 days before start the training protocol, whereas the final test (T2) was carried out 6 days after the end of the training program. All the subjects were given an appointment for the test on the same day, and at a similar time as regards the last meal eaten.

To evaluate anaerobic capacity, the well-established test developed by Bosco for measuring lactic anaerobic capacity was used [31]. Maximal explosive strength was measured by the squat jump (SJ) and countermovement jump (CMJ) tests, considering only the best of three attempts, while to assess anaerobic capacity a continuous series of 60 seconds maximal countermovement jumps (60CMJ) was used. This test consisted of continuous jumps involving stretch-shortening cycles. In this test protocol, performance in mechanical parameters depends on the structure of the innervation pattern and training status of the neuromuscular system in terms of contractile and elastic abilities [21]. Obviously, any decrease in power output during the test would be directly related to muscle fatigue. The results of the 60CMJ test were used to evaluate anaerobic capacity over 60 seconds in both groups. During the tests, data were registered by means of an Ergo Jump Bosco System contact mat, which was connected to a computer through a USB port. Data were acquired, stored and processed using Chronojump 0.8 software in order to calculate jump height using body mass and flight time. This equipment and set-up has been widely used in previous studies to assess anaerobic capacity.

Additionally, both tests (T1 and T2) were recorded by means of a Casio Exilim Pro-Ex-F1 (300 Hz) camera and 2D digitized by means of motion analysis software (Kwon3D) to evaluate flexed knee angles for every jump and subject. All jumps with a flexion angle 5% lower or higher than the previously established angle of 90° were not considered.

2.4. Statistical analysis

Data were statistically analyzed and graphically presented by means of Sigmaplot 12.3 software (Systat Software Inc., USA). Pre-training versus post-training differences were tested by means of a repeated measures two-way ANOVA. Comparison between the HYP and NOR groups was performed by a simple repeated measures two-way ANOVA test. The Student's *t*-test was performed for specific comparisons when appropriate. In some cases, data are presented as a percentage of the baseline test in order to avoid individual variability and provide greater clarity. Statistical significance was determined as $P < 0.05$. Data are presented as mean values $\pm$ standard deviation.

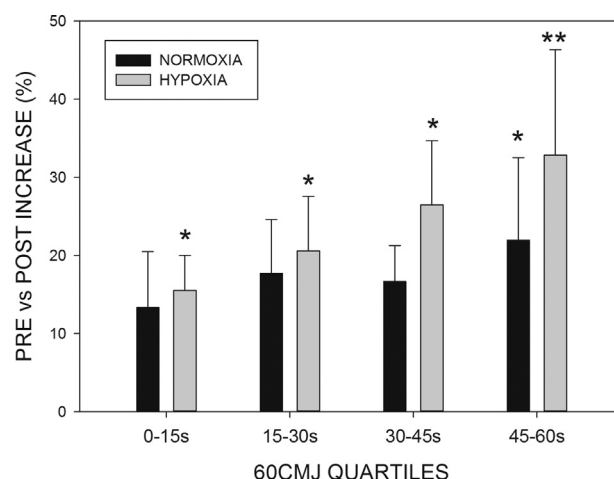


Figure 1 After training percent increases in jump height during CMJ60 quartiles (1: 0–15 seconds; 2: 15–30 seconds; 3: 30–45 seconds; 4: 45–60 seconds). *: denotes statistical significance pre- versus post-training. **: indicates statistical significance when comparing normoxia vs hypoxia groups.

3. Results

3.1. Squat jump and countermovement jump

The squat jump (SJ) and countermovement jump (CMJ) from resting are measures of explosive strength. The SJ is an explosive, active manifestation of strength from static position (90° leg flexion). The CMJ is also a reactive manifestation of explosive strength. In accordance with the Bosco's test, these parameters were measured at the beginning of the study. Measurements were taken from resting conditions in order to evaluate maximum explosive strength performance. As can be seen in Table 2, performance in both groups was similar for T1 and no statistically significant differences were found after the training between groups or pre- and post training. As expected, the results indicated that both groups showed a similar level of improvement. No differences in training stimuli were found for post-training results.

3.2. The 60CMJ test

The results are shown in Table 2. At baseline (T1), measures of maximal explosive strength (squat jump (SJ) and countermovement jump (CMJ) were taken from resting to assess performance and use this data to calculate the fatigue index (FI). The specific indicator of anaerobic capacity was calculated from the mean height. Results for T1 were similar between HYP and NOR groups as a consequence of the arbitrary group composition. Two way ANOVA for repeated measures yielded no statistically significant differences between groups for T1 ($P = 0.772$). However, as can be seen in Table 2 and Fig. 1, results for the 60CMJ test improved for both groups following the protocol training. After protocol training (T2), a considerable improvement in mean height was observed for the HYP group (22.6% versus 15.8% NOR). In Table 2 the differences in the improvement attained by both groups are clearly evident, as are also the

Table 2 Protocol training volume, exercise and model session.

	Total Repetitions	Exercise	Workload	Session model
Week 1	380	Half-squat	Moderate intensity (controlled execution)	[15r-4s/2'rec] (10')-2bk [20r-4s/2'rec] (10')-2bk [25r-4s/2'rec] (10')-1bk
Week 2	600	Half-squat	Maximal volume (low execution)	[25r-4s/90''] (8')-2bk
Week 3	420	Half-squat jumping (weighted jumps)	High intensity (high speed execution)	[10r-5s/45''] (6')-3bk
Week 4	225	Plyometrics (unweighted vertical jumps)	Maximal intensity	[5j-5s/3''] (6')-3bk

Codes for description of the study protocol training for HYP and NOR groups. r: repetitions; s: sets; rec: recovery time between sets; j: jumps; bk: blocks; ': minutes; '': seconds. First parenthesis in Session model column indicates a whole training block, whereas the second parenthesis indicates the time recovery between consecutive blocks.

marked effect of protocol training. Jumping performance in the 60CMJ test showed a statistically significant difference ($P=0.029$; post-hoc Student's *t*-test) in the mean height of the 60CMJ test between the HYP group and the NOR group.

In regards to a diagnostic analysis of the effort applied by the subjects (voluntary involvement of the subject throughout the test), this can be estimated from the decrease in muscular work along the whole test duration (Mean Height 0–15 seconds/CMJ) as originally described by Bosco. The aim of this calculation is to assess the subjects' level of involvement when performing the test. The maximum possible value will be 1 if the subject reaches a mean jump height during the first 15 seconds equal to their baseline CMJ test value. The 60CMJ and CMJ test values obtained for both groups indicate a similar high level of involvement when performing the test: NOR group yielded $0.79 (\pm 0.06)$ in T1 and $0.72 (\pm 0.05)$ in T2, and HYP group, $0.74 (\pm 0.09)$ in T1 and $0.75 (\pm 0.04)$ in T2 (see Table 2). No statistically significant differences were found pre- or post-training between the two groups.

3.3. Fatigue index

The original protocol by Bosco established the term Fatigue Index (FI). This concept analyzes the effect of fatigue throughout the test. The FI is calculated by dividing the height reached during the 60-second test by the maximum height in CMJ test at the beginning of the protocol. Fig. 1 and Table 2 show the differences found between groups and the significant differences obtained in T2. The HYP group improved after the training protocol, from $0.62 (\pm 0.11)$ in T1 to $0.66 (\pm 0.04)$ in T2, but the NOR group failed to show any statistically significant improvement in the fatigue index: $0.58 (\pm 0.05)$ in T1 and $0.56 (\pm 0.08)$ in T2. When comparing T1 and T2 between both groups, a significant difference was detected for T2 (0.56 for the NOR group versus 0.66 for the HYP group) ($P=0.031$; post-hoc Student's *t*-test), whereas no differences were detected in T1, thus confirming the homogeneity in the assignation of the subjects to the two experimental groups.

3.4. Height jumps at 5- and 15-second intervals during the 60CMJ test

The mean jump height at each 5- and 15-second interval was compared between T1 and T2 for both groups. The aim of this analysis was to evaluate the evolution of performance and anaerobic capacity as measured by progressive decrease in jump height (cm). The results obtained for mean height attained during the 60CMJ test for both groups show that the HYP group performed better in the final phase of the test (from 40 seconds until the end). This clear difference in performance can be observed in Table 3 and Fig. 2. "Before" versus "After" differences were marked in the last 15 seconds of the 60CMJ test, and significant differences in both groups between T1 and T2 (HYP $P=0.004$, NOR $P=0.022$) were detected. These results for the final intervals

Table 3 Bosco test's results. Changes in mean height jumps and fatigue index.

	HYP	NOR
Height of squat jump (SJ) (cm)		
Pre	28.62 (± 5.8)	30.95 (± 2.8)
Post	32.95 (± 3.7)	32.84 (± 4.1)
Pre vs. post	NS	NS
Height of countermovement jump (CMJ) (cm)		
Pre	31.9 (± 4.1)	32.48 (± 3.95)
Post	34.01 (± 2.3)	35.74 (± 4.7)
Pre vs. post	NS	NS
CMJ60 mean height jump (cm)		
Pre	18.42 (± 2.0)	18.46 (± 3.5)
Post	22.57 (± 2.3)	21.37 (± 4.1)
Pre vs. post	$P=0.029$	NS
CMJ60 fatigue index		
Pre	0.62 (± 0.11)	0.58 (± 0.05)
Post	0.66 (± 0.04)	0.56 (± 0.08)
Pre vs. post	$P=0.031$	NS

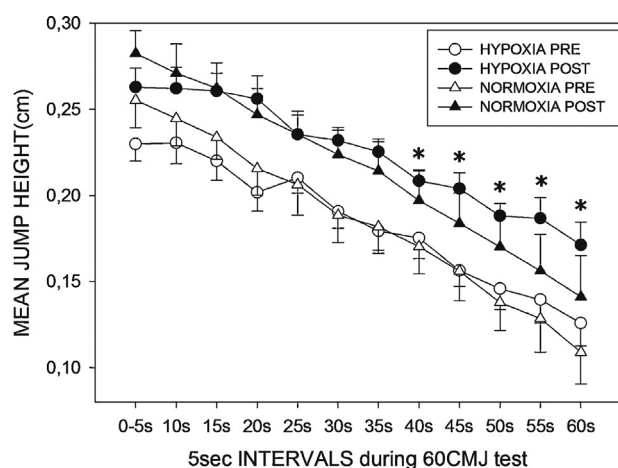


Figure 2 Fatigue evolution, reflected as mean jump height every 5 seconds intervals, during CMJ60 test. *: indicates statistical significance between groups.

agree with the differences observed for the FI, clearly indicating considerable differences in performance due to the impact of our protocol training: in other words, our results suggest that the training results for the HYP group are in agreement with the hypothesis of this study, confirming that EST was more effective for the HYP group than for the NOR group.

4. Discussion

Power strength can be divided into three modalities: explosive power, maximal power and endurance power, all supplied by alactic and lactic anaerobic metabolism. This study focused on endurance strength training, by comparing the final performance following the same training protocol conducted in hypobaric hypoxia versus normoxia. Endurance anaerobic power was measured using a well-established test (the 60CMJ test) [31]. The main aim of this study was to analyze the reliability of a new method of sports training using strength endurance training in hypoxia. The rationale behind this study was based on previous reports, which concluded that anaerobic power (15–60 seconds) can be maintained in hypoxia at a similar level as normoxia. This equivalent performance in different environments may be explained by enhanced anaerobic energy release and the contribution this makes to total metabolic cost. However, the workload of specific training in hypoxia has been argued to be less than at sea level due to difficulties in maintaining the same intensity over time [32]. According to several authors, anaerobic performance improves following the implementation of different protocols using hypoxia [5–11,18,33]. However, no consensus currently exists regarding protocols, methodologies, acclimatization or tolerance to training [11]. Furthermore, the wide variability in protocols applied, parameters measured and results obtained [14,34,35] render the possibility of analyzing anaerobic performance in hypoxia and being the acquisition of a rigorous knowledge base for prescription of training even more difficult.

Sports with a high reliance on the anaerobic pathway for primary performance require the production of high

power outputs maintained over a short period. High intensity actions in sports require high levels of anaerobic power and this is directly related to short-term maximal force production. Meanwhile, high intensity exercise in hypoxia enhances the intensity of training when absolute workload is equal to that in normoxia [32]. As a consequence, training at a higher intensity could have benefits for anaerobic performance in high performance sports [15–18]. So, our experimental design was aimed to provoke greater stimulation of the anaerobic pathway during training by means of the simultaneous moderate hypobaric hypoxia exposure. The Bosco 60CMJ test was chosen as the means to assess anaerobic capacity since it offers the possibility of measuring lactic and alactic anaerobic capacity for short-term interval-based work patterns.

As explained above, our results show a clear improvement in T2 for the HYP group when compared to the NOR group in mean height for the 60CMJ test and a lower FI in the final phase of the test (35–60 seconds) (Fig. 1 and Table 2), precisely when blood supply for the glycolytic pathway is essential for sustaining muscle energy. These data provide compelling evidence that the protocol training was effective in improving anaerobic capacity to a greater extent for hypoxia than sea level training. Differences were statistically significant for the HYP group when comparing T1 and T2 performance in mean height during the 60CMJ test ($P=0.029$) and for the FI between groups in the final phase of the test. As can be seen in Figs. 1 and 2 and Table 3, there was a considerable difference in performance between both groups from 30 to 60 seconds. The possible mechanisms responsible for this improvement are unknown, but muscular buffer capacity, a higher tolerance to glycolysis metabolites and waste product removal could account for the higher improvement observed in the HYP group at the end of the training program. We can consider that such improvement would be based on several concomitant physiological adjustments:

- improved muscular buffer capacity by altitude training has been previously reported [36,37]. It has been also well established that during maximal exercise in acute hypoxia there is a deficit of energy supply by the aerobic pathway, with a higher O_2 deficit and higher muscle lactate concentrations, compensated by higher anaerobic production of energy [11,38];
- improved economy of energy production and utilization, through cell acclimatization to higher molecular stress [39] or improved endurance power following EST training [40];
- an improved efficiency of the cardiovascular system, reflected in a quicker heart rate recovery following maximal exercise. In a previous study with the same experimental design, heart rate recovery was faster in the group trained in hypoxia than in the group trained in normoxia [41];
- improved efficiency of the respiratory system since respiratory muscles must work more intensively during hypoxia exposure due to the hyperventilatory response, thus producing a certain extent of respiratory muscle training [42,43]
- it has been also recently reported that the use of glucose through glycolytic pathways during maximal exercise

in hypoxia is higher in comparison with that for a same workload in normoxia [44].

When comparing the performance of the two experimental groups during the final interval (45–60 seconds), statistically significant difference was found, with the HYP group achieving a higher mean height in this phase, thus indicating a higher endurance capacity for explosive strength in such group. The 60CMJ test is recommended in the literature in order to evaluate subject involvement during test execution. We found that both groups performed the test with a sufficient level of involvement as denoted by a similar decay in height jump curves, thus indicating that a possible “to keep back” behavior was avoided (Fig. 2). As indicated earlier, training under new conditions may elicit a higher degree of motivation, and thus could also be a means for enhancing performance. The subjective perception of effort under hypoxia also improves the capacity and motivation to train. Recently have been reported increased hormonal changes [45] and improved muscle force and resistance [46] by applying hypoxic stimulus in similar ways as we used it in the present study. Consequently, we consider that this methodology can be a good method to renew motivation in high performance athletes who require new training stimuli.

Several studies have described problems in the quality of motor tasks during the execution of a specific sport movement (technique) performed under hypoxia [32]. One of the aims of this study was to assess the possibility of enhancing anaerobic capacity by means of intermittent hypoxia training without affecting motor task performance or technique skills. During protocol training, no problems in maintaining the equal intensity prescribed were observed.

In conclusion, the present study provides data showing a significant improvement in anaerobic capacity after 12 EST training sessions at simulated altitude (2500 m) compared to identical training at sea level. A significant difference in performance just in the final phase of the 60CMJ test, precisely when glycolytic metabolism is essential to maintain effort intensity has been found. However, further studies are required to identify the physiological mechanisms underlying this enhancement in anaerobic capacity.

5. Conclusions and practical applications

The present study provides data showing a significant improvement in anaerobic capacity after 12 EST training sessions at simulated altitude (2500 m) compared to identical training at sea level. A significant difference in performance just in the final phase of the 60CMJ test, precisely when glycolytic metabolism is essential to maintain effort intensity has been found. However, further studies are required to identify the physiological mechanisms underlying this enhancement in jumping performance. The main limitations of this pilot study are a) the low number of subjects and b) the lack for physiological parameters classically associated to anaerobic capacity. As a consequence, the impact of a training program using this methodology on specific sports (running, cycling, swimming, rowing, etc.) needs to be validated in further studies before establishing this kind of protocol as a new standard method of training for high performance athletes. Nevertheless, we can conclude

that the use of high intensity physical activity under moderate hypobaric hypoxia (whether specific to a particular sport/specialty or not) could be a valid method for improving anaerobic capacity. Additionally, it is necessary also to clarify if hypobaric (natural or simulated altitude) and normobaric (gas mixtures, “hypoxicators”) methods of hypoxia exposure are equivalent for eliciting the same physiological responses here described.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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