Acute Physiological and Performance Responses to High-Intensity Resistance Circuit Training in Hypoxic and Normoxic Conditions

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Abstract

Ramos-Campo, DJ, Rubio-Arias, JÁ, Freitas, TT, Camacho, A, Jiménez-Diaz, JF, and Alcaraz, PE. Acute physiological and performance responses to high-intensity resistance circuit training in hypoxic and normoxic conditions. *J Strength Cond Res* 31(4): 1040–1047, 2017—The aim of this study was to analyze physical performance and physiological variables during high-intensity resistance circuit training (HRC) with the addition of 2 levels (moderate and high) of systemic hypoxia. Twelve resistance-trained young male subjects participated in the study. After a 6 repetition maximum testing session, participants performed 3 randomized trials of HRC: normoxia (NORM: fraction of inspired oxygen [FiO_2] = 0.21; ~0 m altitude), moderate hypoxia (MH: FiO_2 = 0.16; ~2.100 m altitude), or high hypoxia (HH: FiO_2 = 0.13; ~3.800 m altitude), as controlled by a hypoxic generator. Bench press force, heart rate and heart rate variability, rating of perceived exertion, resting metabolic rate, energy cost, and countermovement jump were assessed in each session. Heart rate variability in HH was significantly lower (standard deviation of all normal NN intervals [intervals between two "normal" beats] = 111.9 vs. 86.7 milliseconds; standard deviation of the difference between consecutive NN intervals = 19.5 vs. 17.0 milliseconds; $p \leq 0.05$) in comparison with NORM. There were significant differences in rating of perceived exertion between NORM and HH (11.6 vs. 13.8 points). Peak and mean force on the bench press were significantly lower ($p \leq 0.05$) in HH when compared with MH (peak: 725 vs. 488 N; mean: 574 vs. 373 N). Energy cost was significantly higher ($p \leq 0.01$) in both hypoxic conditions compared with NORM (NORM: 10.4; MH: 11.7; HH: 13.3 kJ·min^{-1}). There were no differences between conditions in heart rate and countermovement jump variables.

These results indicate that hypoxic stimuli during HRC exercise alter physical performance and physiological variables and affect how strenuous the exercise is perceived to be. High-intensity resistance circuit training in hypoxia increases the stress on the performance and physiological responses, and these differences must be taken into account to avoid an excessive overload.

Key Words force, countermovement jump, HRC, resistance training, heart rate variability

Introduction

Developing the most effective and efficient method to maximize strength has been the focus of scientists and coaches for a long time. In recent years, endurance and team sports coaches have paid special attention to strength training because it leads to adaptations related to superior aerobic performance, such as increments in maximal strength, mechanical power, muscle hypertrophy, and rate of force development (RFD) (19,21).

In this sense, one of the most specific strength training protocols for this kind of sports is the high-intensity resistance circuit training (HRC). This type of resistance training has a beneficial impact on the cardiorespiratory and neuromuscular systems and also on body composition (1,2). In fact, HRC has been shown to increase muscle hypertrophy, strength, and power output and to decrease fat mass because of a higher metabolic impact and cardiovascular response (1,2). High-intensity resistance circuit training has positive effects on physical performance similar to those of a concurrent strength and endurance training method, but with shorter session durations (~30–40 minutes) (2). Moreover, it involves both the aerobic and anaerobic metabolisms and improves the resting metabolic rate (RMR) and energy cost (EC) after training more than a traditional strength training session (18).

Another typical strategy used to improve athletic performance in both endurance and team sports is altitude or hypoxic training. These types of training methods produce

structural and functional adaptations of the skeletal muscle (15). Most recently, different studies (3,13,27) have applied strength training in hypoxic environments to enhance muscular performance. Resistance training in hypoxia produces beneficial changes in the musculoskeletal system and increases strength and muscular endurance (26). Research has also shown that hypoxic environments improve intramuscular metabolic stress (28), increasing hypertrophic signaling, muscular hypertrophy (31), and hormonal concentrations (29). In addition, low-intensity resistance hypoxic training results in an increase of motor unit recruitment (29) and muscular endurance (14,17) and maintains maximal anaerobic power capacity measured with a countermovement jump (4). Reeves et al. (24) demonstrated that exercise under hypoxia conditions causes an increase in respiratory and cardiovascular mechanisms and induces a sympathetic activation that can be noninvasively evaluated by studying heart rate variability (HRV) (22). Based on current evidences, performing HRC training with different levels of hypoxia can be a good method to improve athletic performance with shorter volume and duration of the session.

Although the physiological responses that are produced by the effects of hypoxia on strength training adaptations are known, the acute effects of this stressful resistance training in trained athletes on physiological and performance responses are unclear. To our knowledge, no research has investigated the effects of adding systemic hypoxia to HRC. Therefore, the aim of this study was to analyze physical performance and physiological and metabolic variables during HRC training with the addition of 2 levels (moderate and high) of systemic hypoxia.

METHODS

Experimental Approach to the Problem

A comparative, double-blind (no participant or supervisor know the normoxic or hypoxic situation), randomized crossover design was applied to examine whether different levels of hypoxia affect HRC training performance. The subjects completed a HRC protocol randomized under 3 conditions: (a) normoxia (NORM; fraction of inspired oxygen [FiO$_2$] = 0.21; ~0 m altitude); (b) moderate hypoxia (MH; FiO$_2$ = 0.16; ~2.100 m altitude); and (c) high hypoxia (MH; FiO$_2$ = 0.13; ~3.800 m altitude). During each session, subjects breathed through a mask connected to a hypoxic generator (GO2 Altitude hypoxicator; Biomedtech, Moorabbin, Australia).
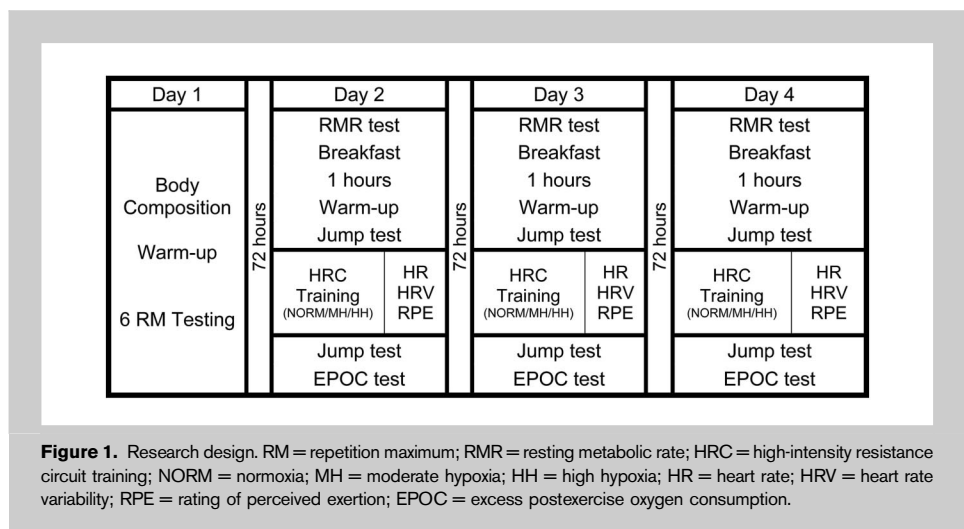
Subjects

Twelve healthy, nonsmoking, male subjects (age: 25.1 ± 4.8 years; age range: 20–29 years; height: 174.6 ± 5.3 cm; weight: 70.3 ± 6.8 kg; fat mass: 12.1 ± 1.8%; bench press 6 repetition maximum [6RM]: 57.1 ± 12.8 kg; half-squat 6RM: 95.9 ± 21.6 kg) participated in this study. Participants had at least 4 years of resistance training experience and exercised 3 times per week. None of the subjects had any musculoskeletal disorder or reported exposure to altitude 3 months before the study. All experimental procedures were explained to the participants, and a written consent was obtained from each subject. The present research was approved by the Institutional Science Ethic Committee.

Procedures

All testing sessions took place in the laboratory during a 3-week period and were carried out at the same time of day. In total, subjects had to report to the laboratory 4 times. During the first visit, body composition was assessed with a segmental multifrequency bioimpedance analyzer (Tanita BC-601; Tanita Corp., Tokyo, Japan) with measurements obtained as described by the manufacturer. Moreover, the 6RM loads were determined for the 6 exercises of the HRC protocol. After 3 days of rest, subjects performed the first training session (second visit) in 1 of the 3 training conditions. Then, after at least 72 hours of rest, the second training session (third visit) was conducted. Finally, again after at least 72 hours of rest, the last training session (fourth visit) was carried out. The 3 HRC training sessions were performed in randomized order (Figure 1). The participants were instructed to maintain their regular dietary consumption during the study and to avoid ingesting caffeine or alcohol at least 24 hours before each visit. The participants agreed not to take ergogenic aids, supplements, or medications that might influence performance.

Six-Repetition Maximum Determination. Before testing, a warm-up consisting of 5 minutes of cycling at 75 W

Figure 1. Research design. RM = repetition maximum; RMR = resting metabolic rate; HRC = high-intensity resistance circuit training; NORM = normoxia; MH = moderate hypoxia; HH = high hypoxia; HR = heart rate; HRV = heart rate variability; RPE = rating of perceived exertion; EPOC = excess postexercise oxygen consumption.
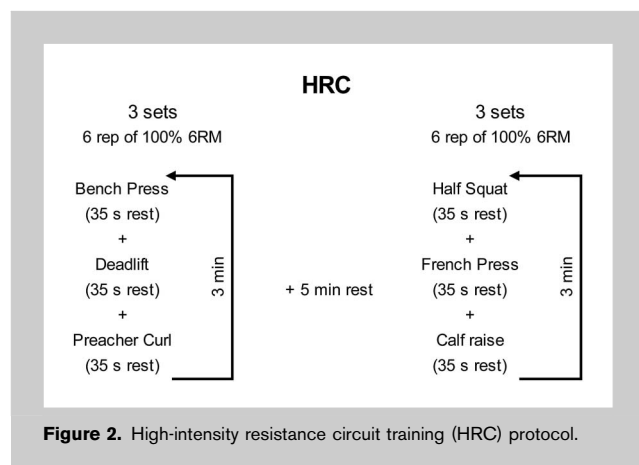
Figure 2. High-intensity resistance circuit training (HRC) protocol.

followed by active stretching was carried out. To calculate the 6RM loads, participants performed 3 sets of each exercise using the following sequence: 10 repetitions at 50% of estimated 6RM, 1-minute rest, 8 repetitions at 75% of estimated 6RM, 2-minute rest, and 1 set of the exercises to volitional fatigue at 100% of estimated 6RM (2). If a participant performed ±1 repetition, the training load was adjusted by approximately ±2.5 and if a subject completed ±2 repetitions, the training load was adjusted by ±5% (5). The participants were allowed to do 5 attempts as maximum with 5-minute rest between each attempt. Bench press, deadlift, elbow flexion (preacher curl), half-squat, elbow extension (french press), and ankle extension (calf raise) 6RM loads were assessed.

Training Protocol. A general warm-up that involved 5 minutes of submaximal cycling at 75 W and 75–100 rpm followed by 5 minutes of active stretching of all major muscle groups was performed before the workout. Also, a specific warm-up consisting of 3 sets of the exercises of the first block was completed using the following sequence: 10 repetitions at 50% of 6RM for each exercise, 1-minute rest, 8

repetitions at 75% of 6RM, 2-minute rest, and repetitions to failure with the 6RM load. The training load ensures that subjects lifted loads that allowed only 6 repetitions (∼85–90% of 1 repetition maximum [1RM]). If participants performed ±1 or ±2 repetitions, the training load was adjusted as described above. To standardize the dynamics of the exercises, the eccentric phase of each exercise was performed in 3 seconds (controlled by a digital metronome), whereas the concentric phase was performed at maximum velocity. The exercises were chosen to emphasize both major and minor muscle groups using single- and multijoint exercises, based on recommendations of the American College of Sports Medicine (ACSM) (10). Subjects were supervised by an experienced lifter to ensure that volitional fatigue was achieved safely and rest periods were strictly controlled.

The HRC protocol was based on the one proposed by Alcaraz et al. (2), and it consisted of 2 short circuits (blocks) completed with a 35-second rest between exercises (which allowed enough time to move safely from one exercise to the next), a 3-minute rest between each series of 3 exercises within a block, and a 5-minute rest between blocks. The protocol was completed with 6 repetitions at 100% of 6RM in each exercise. Each series was performed 3 times. The first block consisted of bench press, deadlift, and elbow flexion (preacher curl) exercises, and the second block consisted of half-squat, elbow extension (french press), and ankle extension (calf raise) (Figure 2).

Testing Procedures. **Heart Rate and Heart Rate Variability.** Heart rate (HR) and HRV were recorded during the entire session. Heart rate data were recorded by a Polar RS800 (Polar, Polar Electro OY, Kempele, Finland) HR monitor. Heart rate variability was examined with the software Kubios HRV (University of Kuopio, Kuopio, Finland). The following parameters of time-domain were analyzed: (a) average of NN intervals (in milliseconds) (variation in the time interval between normal heart beats);

TABLE 1. Heart rate and RPE values of high-intensity resistance circuit training in the 3 environment conditions.*†

	Heart rate (b·min⁻¹)			RPE		
	NORM	MH	HH	NORM	MH	HH
Basal	66.7 ± 8.2	66.9 ± 10.3	64.4 ± 8.6	6.0 ± 0.0	6.0 ± 0.0	6.0 ± 0.0
Block 1	150.9 ± 15.4	151.7 ± 11.4	153.0 ± 24.0	12.1 ± 1.8	12.6 ± 2.0	14.2 ± 3.1
Block 2	146.3 ± 15.4	149.3 ± 14.7	149.7 ± 17.3	11.6 ± 1.2‡	11.9 ± 1.9	13.82 ± 2.5§

*NORM = normoxia; MH = moderate hypoxia (0.16% fraction of inspired oxygen); HH = high hypoxia (0.13% fraction of inspired oxygen).
†Data are presented as mean ± SD.
‡Significant differences between NORM and HH.
§Significant differences between MH and HH ($p \leq 0.05$).

TABLE 2. Heart rate variability of high-intensity resistance circuit training in the 3 environment conditions.*†

Variable	Heart rate variability		
	NORM	MH	HH
Average NN (ms)	529.9 ± 98.7	537.2 ± 83.0	553.2 ± 93.4
SDNN (ms)	111.9 ± 43.4	101.4 ± 48.1	86.7 ± 37.3‡
SDSD (ms)	19.5 ± 4.5	17.6 ± 3.5	16.9 ± 4.0‡
PNN50 (%)	1.1 ± 1.1	0.7 ± 0.6	2.4 ± 2.3
RMSSD (ms)	12.8 ± 4.7	12.5 ± 4.9	12.2 ± 4.5

*NORM = normoxia; MH = moderate hypoxia (0.16% fraction of inspired oxygen); HH = high hypoxia (0.13% fraction of inspired oxygen); SDNN = standard deviation of all normal NN intervals; SDSD = standard deviation of the difference between consecutive NN intervals; PNN50 = percentage of the number of differences between adjacent normal NN intervals higher than 50 milliseconds; RMSSD = square root of the mean of the sum of the squared differences between adjacent normal NN intervals.
†Data are presented as mean ± SD.
‡Significant differences between NORM and HH ($p \leq 0.05$).

(b) standard deviation of all normal NN intervals (in milliseconds); (c) standard deviation of the difference between consecutive NN intervals (in milliseconds); (d) percentage of the number of differences between adjacent normal NN intervals higher than 50 milliseconds (in percentage); and (e) square root of the mean of the sum of the squared differences between adjacent normal NN intervals (in milliseconds).

Resting Metabolic Rate and Excess Postexercise Oxygen Consumption. Before (RMR) and after (excess postexercise oxygen consumption [EPOC]) each training session, RMR and EPOC tests were carried out during 10 minutes (RMR) and 20 minutes (EPOC) respectively, using a breath-by-breath gas analyzer (Metalyzer 3B; Cortex-Medical, Leipzig, Germany). The gas analyzer system was calibrated before each test using the manufacturer's recommendations. Subjects reported to the laboratory fasted and were resting supine during both tests. After the RMR test, participants had a breakfast consisting of a sandwich and a glass of juice. One hour later, they started the training session. Values of $\dot{V}O_2$, RER, and EC were continuously recorded and averaged every minute. Later, averaged values of $\dot{V}O_2$ and EC during the 10 minutes (RMR) or 20 minutes (EPOC), respectively, were used.

Bench Press Force. Force values (in Newton) obtained when performing the bench press exercise were monitored during each set with a linear position transducer (Chronojump, Barcelona, Spain) that was attached to the bar. Later, force values of each block of 6 repetitions were averaged to determine the mean force of each block of 6RM. Moreover, the peak force (in Newton) of each block was analyzed.

Countermovement Jump. Countermovement jump was assessed 1 hour after the RMR and after each training session and immediately before the EPOC test (we assume that this exercise can disturb the EPOC analysis; however, we did the jump in all the situations, so all the conditions were stable). The jump was performed on a Kistler 9286BA portable force platform with a sampling rate of 1,000 Hz (Kistler Group, Winterthur, Switzerland). Subjects were instructed to perform the eccentric phase of the movement as fast as possible and to keep the hands on the hips throughout the execution to minimize any contribution of the upper body to jump impulse. All participants had experience in these types of actions. Three attempts were carried out, and the best result was considered. A 2-minute rest was allowed between jumps to diminish the effects of
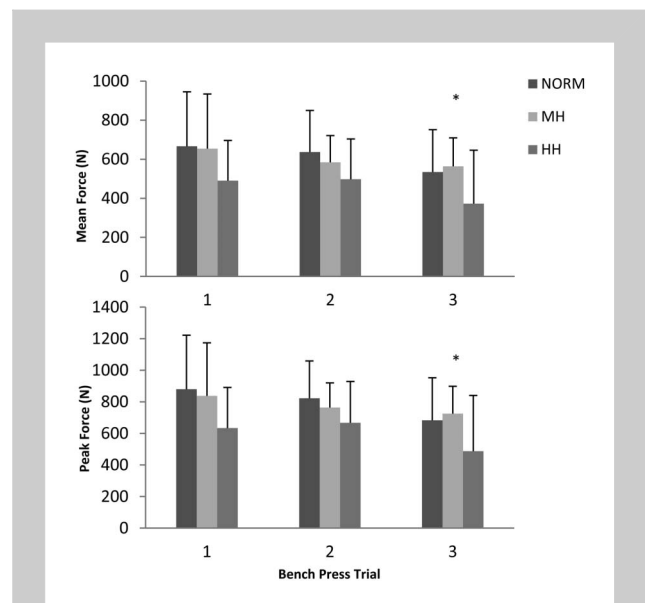

Figure 3. Peak and mean force during bench press (mean ± SD). NORM = normoxia; MH = moderate hypoxia; HH = high hypoxia. *Significant differences between MH and HH ($p \leq 0.05$).

TABLE 3. Mean and peak force during each set of bench press of high-intensity resistance circuit training in the 3 environment conditions.*†

	Mean force (N)			Peak force (N)		
	NORM	MH	HH	NORM	MH	HH
Set 1	666.9 ± 278.2	654.5 ± 205.5	490.5 ± 205.5	879.9 ± 342.0	837.7 ± 335.9	633.9 ± 256.9
Set 2	636.7 ± 213.2	584.7 ± 136.6	497.7 ± 206.3	822.7 ± 236.0	763.5 ± 156.3	666.7 ± 262.2
Set 3	534.7 ± 216.6	563.5 ± 146.0	372.5 ± 274.2‡	682.6 ± 269.7	724.9 ± 173.9	487.5 ± 352.8‡

*NORM = normoxia; MH = moderate hypoxia (0.16% fraction of inspired oxygen); HH = high hypoxia (0.13% fraction of inspired oxygen).
†Data are presented as mean ± SD.
‡Significant differences between moderate and high hypoxia ($p \leq 0.05$).

fatigue. Jump height (in centimeters), maximal power output (in Watts per kilogram), and RFD (in Newton per second) were determined. Jump height (h) was calculated from the take-off vertical velocity (vt) using the following equation: $h = vt^2 \cdot 2\ g^{-1}$. Power was calculated from the data extracted from the force platform as the product of vertical force by instantaneous vertical velocity of the system's center of mass. Rate of force development was determined as the rate of rise on vertical force. In addition, the change between basal values and after-training values of jump variables was analyzed.

Rating of Perceived Exertion. Rating of perceived exertion (RPE) was assessed immediately after each block using a 6–20 RPE scale to determine the stress of HRC training. Participants had previous experience in the use of this scale.

Statistical Analyses
Data collection, treatment, and analysis were performed using the SPSS for Windows statistical package (version 20.0; SPSS, Inc., Chicago, IL, USA). Descriptive statistics (mean and *SD*) were calculated. Before using parametric tests, the assumption of normality and homoscedasticity were verified using the Shapiro-Wilks *W*-test. A 2-way analysis of variance test with repeated measures and Bonferroni post hoc test were used to investigate differences in variables. For all procedures, a level of $p \leq 0.05$ was set to indicate statistical significance.

RESULTS

The results presented in Table 1 showed no significant differences in HR values among the 3 conditions. There were no significant differences between the pretest values for all variables analyzed. Regarding RPE, significant differences ($p \leq 0.05$) were observed between NORM and high hypoxia (HH) and between MH and HH in the last block. No significant differences were observed in other parameters. Furthermore, significant differences ($p \leq 0.05$) between NORM and HH session in standard deviation of all normal NN intervals and standard deviation of the difference between consecutive NN intervals (in milliseconds) variables were found (Table 2).

Figure 3 and Table 3 showed significant differences ($p \leq 0.05$) in mean and peak force between MH and HH in the third set of bench press.

TABLE 4. Values of energy cost and $\dot{V}O_2$ after each session of high-intensity resistance circuit training.*†

	Energy cost (kJ·min⁻¹)			$\dot{V}O_2$ (ml·kg⁻¹·min⁻¹)		
	NORM	MH	HH	NORM	MH	HH
Basal	8.2 ± 1.7	8.2 ± 1.4	8.4 ± 1.1	5.6 ± 1.1	5.6 ± 0.8	5.7 ± 0.7
After training	10.4 ± 1.8	11.7 ± 2.2‡	13.3 ± 2.8§	7.1 ± 0.9	7.9 ± 1.2‡	9.1 ± 2.1§

*NORM = normoxia; MH = moderate hypoxia (0.16% fraction of inspired oxygen); HH = high hypoxia (0.13% fraction of inspired oxygen).
†Data are presented as mean ± SD.
‡Significant differences between NORM and MH ($p \leq 0.01$).
§Significant differences between NORM and HH.

TABLE 5. Change in height jump, relative and absolute power, and rate of force development (%) between before and after the session.*†

Variable	Jump performance		
	NORM	MH	HH
Height jump (%)	-5.7 ± 6.2	-0.4 ± 5.3	-3.3 ± 5.8
Relative power (%)	-3.2 ± 4.2	-2.9 ± 5.7	-2.3 ± 5.1
Absolute power (%)	-3.7 ± 3.9	-3.3 ± 5.5	-1.8 ± 3.8
Rate of force development (%)	8.3 ± 3.3	4.5 ± 3.0	-1.3 ± 6.4

*NORM = normoxia; MH = moderate hypoxia; HH = high hypoxia.
†Data are presented as mean $\pm$ SD.

Significant differences in $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$) and the energy consumption ($kJ \cdot min^{-1}$) during the 20 minutes after the session between NORM and MH ($p < 0.01$) and between NORM and HH ($p < 0.01$) were found (Table 4). No significant differences were observed between MH and HH.

On the other hand, no significant before-after session differences were observed in decrement of absolute and relative power output, RFD, and jump height (%) among conditions (Table 5).

DISCUSSION

To our knowledge, this is the first study that examined physical performance and cardiovascular, perceptual, and metabolic responses during HRC under normoxia and 2 levels of hypoxia conditions in resistance-trained athletes. The main findings of this investigation demonstrated that HRC in HH affected autonomic modulation of the participants during exercise and, in the first 20 minutes after the session, higher energy consumption was needed. High-intensity resistance circuit training in HH produced a significantly higher decrease in mean and maximum forces in bench press when compared with NORM or MH. However, jump performance and HR remain unchanged. Finally, HH significantly increased the RPE of the exercise when compared with NORM and MH.

The influence of resistance training on HRV under acute hypoxia has not been described. The results of this study showed that HRC under HH causes an additional decrease in HRV compared with exercising in MH or NORM. The decrement in HRV can be explained by an increased sympathetic activity during hyperventilation [22], suggesting a reduced vagal control of the heart [8]. An increase in sympathetic and a decrease in parasympathetic activity in submaximal exercise at high altitude have been reported in some studies [8,22]. In this regard, changes in HRV could be an indicator of an imbalance related to resistance training and environment-induced stress [8]. Furthermore, HRC in hypoxia represents 2 types of stress that cause modifications in the sympatho-vagal balance. Thus, HRV may be used as a tool to monitor the stress caused on the athlete's body and can be applied to determine the acclimatization effect of a hypoxia program.

On the other hand, there are no significant differences in HR values. However, it is observed an increase tending to significance in HR with the hypoxic situations. Similar results were obtained by Scott et al. [27]. These findings likely show an increment in cardiac output because of hypoxia in response to muscular oxygen deprivation [12]. This fact can improve the aerobic resynthesis of phosphocreatine [11], which is crucial for performance during subsequent bouts [20]. In this regard, HR is not sensitive enough to detect changes after hypoxic conditions. Therefore, in future studies, researchers should use other intensity variables more related to strength training protocols, i.e., lactate. According to our results, RPE seems to be a better indicator for controlling the load training.

Another notable finding in this study was that the environment where the training session was performed affects energy consumption during the next 20 minutes after training. Hence, hypoxia increases the EC and the $\dot{V}O_2$. The rapid component of EPOC after training is thought to reflect the oxygen cost of phosphocreatine resynthesis [30]; therefore, the increased EPOC after hypoxic HRC training may indicate increased phosphocreatine turnover during the sets. Furthermore, $\dot{V}O_2$ can be attributed to replacement of O_2 in circulation and in muscle, elevated ventilatory rate, elevated heart activity, oxidation of lactate, glycogen resynthesis, and sodium-potassium pump activity [9]. These results were similar those reported by Marín-Pagán et al. [18] for EC in a study applying HRC compared with traditional circuit weight training. These authors showed that EC and $\dot{V}O_2$ values were greater when the intensity of the circuit was increased. This fact may decrease the athlete's mass and optimize body composition after a hypoxia training program [23]. In fact, there are some studies using HRC protocols with both trained participants [2] and older adults [25] that produced significant decrements in fat mass (absolute and

relative values). Thus, HRC in hypoxia conditions may be an effective method to increase the EC after the session and decrease body fat mass.

Exercise under acute systemic hypoxia influences muscular performance (peak and mean force during bench press). Previous studies have shown that acute exercise performed in hypoxia reduces anaerobic performance (6,7). However, other studies have demonstrated no change (15,27). In this study, significant differences were observed in peak and mean force in the last trial of bench press between HH and MD. Thus, exercise with HH condition might produce more fatigue because of the changes in autonomic modulation and in metabolic stress than produces resistance exercise in NORM or MH environment. This fact may be explained by an accumulation of neuromuscular and metabolic fatigue and a decrease in HRV. From a performance point of view, coaches should carefully manipulate the magnitude of the load imposed by HRC protocol under HH, because this kind of effort is more stressful than MH or NORM and can affect the training stimuli or physical target to achieve during the session.

As expected, at the end of the HH training session, RPE values were significantly greater than during the MH and NORM conditions. In this sense, HH was perceived as more difficult than MH and NORM, with the last set of the session considered the heaviest. These results are in accordance with the study by Alvarez-Herms et al. (4), who obtained significant differences in RPE scores between HH (FiO$_2$ = 13.5%) and NORM environments during a series of 6 consecutive jumps, lasting for 15 seconds with an intervening rest period of 3 minutes. However, Scott et al. (27) showed no significant differences in RPE values during a high-intensity resistance training session (5 × 5 repetitions at 80% 1RM, with 3 minutes rest between sets) at the same hypoxic levels as in our study (MH = 16% FiO$_2$ and HH = 13% FiO$_2$). These discrepancies may be because of the type of training protocol (traditional vs. circuit training; at an intensity of 80 vs. 85% 1RM, respectively). Furthermore, a relationship between volume and intensity of a training session and RPE values exists, correlated with physiological variables, intensity parameters, muscle activation, and metabolic stress markers (16).

PRACTICAL APPLICATIONS

The results of this study indicate that coupling systemic hypoxia with HRC exercise significantly affects physical performance. Furthermore, hypoxic conditions modify physiological variables and alter the perception of this type of strenuous exercise. High-intensity resistance circuit training exercise with systemic hypoxia may be useful for resistance-trained athletes, as it produces added stress on the physiological responses and on performance. Coaches may find this type of specific training useful to increase endurance and strength adaptations while reducing the time devoted to resistance training. However, using HRC on HH environ-

ment can adversely affect the imposed physical training dosage, which should be adjusted appropriately to optimize performance. Performance and body composition may also improve in endurance athletes or team sports players using shorter session duration. Coaches should bear in mind that it is possible to produce the same performance outcomes at the sea level by using a simulated hypoxic environment with 0.16% of FiO$_2$ (~2.100 m altitude) in combination with HRC. Our findings show that exercise intensity can be monitored with RPE, which is extremely useful in the field or in artificial rooms to control the load in HRC session under hypoxic conditions.

This research opens a new perspective in the optimization of future resistance training protocols with hypoxic conditions, in an effort to develop the most effective and efficient method to maximize strength performance, metabolic adaptations, body composition, and time spent on resistance training. More research is needed to elucidate the chronic morphological, metabolic, and strength adaptations and the neural and endocrine responses to HRC under hypoxic conditions.

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