Original article

# Rating of perceived exertion and physical performance changes after one circuit training session in hypoxia or normoxia

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**Summary**

The aim of this study was to analyze the rating perceived exertion and physical performance changes after one session of circuit training in hypoxia ($FiO_2$= 0.16) or normoxia ($FiO_2$= 0.21). Eleven resistance-trained young male subjects participated in the study. They performed two circuit training session (hypoxia or normoxia) in randomized order. Three days before the first training session, a familiarization and 6RM test session was performed. After 72 hours of rest, the subjects performed the last training session. The circuit training consisted of two blocks of three exercises (Block 1: bench press, deadlift and elbow flexion; Block 2: half-squat, triceps extension, and ankle extension). Each exercise was performed at 6RM. Rest periods lasted for 35 s between exercises, 3 min between sets, and 5 min between blocks. Rating of perceived exertion (RPE) and peak and mean force, velocity, power and acceleration and time to perform peak power and velocity were determined during all the sets half-squat and bench press exercises. No differences were observed in RPE values between hypoxia and normoxia. Moreover, significant differences were observed in the first trial of half squat in peak acceleration (normoxia = 2.9 ± 0.7 m/s$^2$; hypoxia = 2.2 ± 1.1 m/s$^2$; $p$ = 0.037) and peak power (normoxia = 1577.1 ± 587.5 W; hypoxia = 1227.2 ± 636.3 W; $p$ = 0.039) between hypoxia and normoxia. In conclusion, these results indicate that simulated hypoxia during circuit training exercise decreases peak power and peak acceleration but maintains rating perceived exertion of the exercise. These differences must be taken into account to avoid an excessive fatigue.

**Key words:**
Altitude. Resistance training. Hypoxia. Perceived exertion.

## Percepción de esfuerzo y cambios en el rendimiento producidos por una sesión de entrenamiento en circuito en hipoxia o normoxiaia

**Resumen**

El objetivo del presente estudio fue analizar los cambios en el rendimiento de fuerza y en la percepción de esfuerzo (RPE) producidos por una sesión de entrenamiento de fuerza en circuito en hipoxia ($FiO_2$= 0,16) o normoxia ($FiO_2$= 0,21). Once deportistas entrenados en fuerza realizaron dos sesiones de entrenamiento en circuito de forma aleatoria en hipoxia o normoxia. Tres días después de una primera sesión de familiarización en la que se determinaron las cargas, se llevó a cabo la primera sesión de entrenamiento. La última sesión se llevó a cabo 72 horas después. La sesión consistió en dos bloques de tres ejercicios (bloque 1: *press* banca, peso muerto y *curl* de bíceps; bloque 2: media sentadilla, *press* francés y extensión de tobillos) realizando 3 series de 6 repeticiones al 6RM con un descanso de 35 segundos entre ejercicio, 3 minutos entre serie y 5 minutos entre bloques. Se analizó la percepción de esfuerzo (RPE) después de cada serie y los valores medios y máximos de velocidad, aceleración, fuerza y potencia, así como los tiempos obtenidos hasta la máxima velocidad y la máxima potencia en media sentadilla y *press* de banca. Los resultados no muestran diferencias significativas en el RPE entre condiciones. Se observan diferencias significativas entre ambas condiciones en la primera serie de sentadilla en la variable aceleración pico (normoxia = 2,9 ± 0,7 m/s$^2$; hypoxia = 2,2 ± 1,1 m/s$^2$; p = 0,037) y en la variable potencia pico (normoxia = 1577,1 ± 587,5 W; hypoxia = 1227.2 ± 636,3 W; p = 0,039). En conclusión, la adición de hipoxia a la sesión de entrenamiento de fuerza afecta a la potencia y a la aceleración pico desarrollada en el ejercicio de sentadilla pero no modifica la percepción de esfuerzo que tiene el deportista.

**Palabras clave:**
Altitud. Entrenamiento de fuerza. Hipoxia. Percepción de esfuerzo.

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## Introduction

Training programs aim to improve the physical condition of athletes. To do so, a range of methodologies[1] are used. Trainers and scientists aim to optimise performance by applying the most effective training methods. In this regard, strength training is becoming increasingly important, both for improving performance and for preventing injuries in any sports discipline[1,2].

Circuit training is a popular working method amongst trainers. This method is characterised by the use of low loads with high volumes in order to achieve improvements in performance based on increased strength and muscle adaptations such as muscular strength or the improvement of the cardiovascular system[3]. Specifically, over the last few years, research is being carried out on high resistance circuit training (HRC), which is a training method that uses higher intensities (6 repetitions maximum (RM) with relatively short recovery times (35") and a greater cardiovascular load than traditional circuits. HRC offers the possibility to work on different types of exercises at a moderate-high intensity of 6-RM with no decrease in muscle power[4]. Therefore this training method offers similar performance effects to other workout methods, while optimising the training time and applying shorter sessions[5].

Hypoxic training is another very common physical training strategy to improve performance in different individual and group sports. This type of training, in hypoxia conditions, causes greater stress on the anaerobic metabolism[6-8]. In this respect, numerous studies on strength training in hypoxia[9-14] are verifying the impact of these metabolic factors and other mechanisms such as greater fibre recruitment, cytokine production or an increase in hormones to improve strength and generate a greater muscle hypertrophic response through an increased muscle cross-sectional area. Together with these studies, which analyse the physiological responses to IHRT training, another variable which is given great consideration in the studies is the participant's perceived exertion[12,15]. In these studies, no differences in perceived exertion have been found between the different training sessions in hypoxia or normoxia, using traditional training sessions: 3-4 sets of 8-12 repetitions at 70% of 1RM.

Focussing on strength performance, prior studies observed no effect of reduced $FiO_2$ on jump performance[16] following a jump session in hypoxia ($FiO_2$ = 13.5% and 16.5% *vs*. 20.9%) or the power and strength generated[17] during a bodyweight squat and deadlift workout (5 sets x 5 reps at 80% of 1RM ($FiO_2$ =13% and 16% *vs*. 20.9%). Moreover, in the sessions used by these authors, they continue to apply traditional training parameters[17] or through jumps[16].

Based on current evidence, circuit strength training, together with a hypoxic environment, could be a good method to improve performance in shorter training sessions. Even so, further investigation is necessary in order to determine the acute effects and the physiological responses produced by training in hypoxia, given the fact that there are no studies in the literature that consider the added effect of the use of circuit training together with the application of low $FiO_2$. Therefore, this study was directed at analysing the acute effects on strength performance and on the rating of perceived exertion (RPE) produced by a strength circuit training session in either hypoxia ($FiO_2$=0.16) or normoxia ($FiO_2$=0,21).

## Material and method

### Design

A double-blind comparative crossover study was conducted to determine the cause-effect relationship of the dependent variables and the strength training in hypoxia. The participants completed the circuit training under two conditions: normoxia (N) where the fraction of inspired oxygen ($FiO_2$) was 0.21 (0 m altitude); and hypoxia (H) where the $FiO_2$ was 0.16 (2,100 m altitude). During both sessions, the participants breathed through a mask connected to a hypoxia generator ($GO_2$ Altitude hypoxicator, Biomedtech, Australia).

### Participants

Eleven men with prior adaptations to strength training (ages: 24.1 ± 3.6 years; height: 176.6 ± 4.2 cm; weight: 71.1 ± 6.4 kg; fat mass: 12.1 ± 1.6%; 6-RM bench press: 57.6 ± 12.5; 6-RM squat: 96.2 ± 21.2 kg). Participants had no muscle injuries and no altitude exposure in the three months prior to the study. The experimental procedures were explained to the subjects and they signed their informed consent. This study was approved by the ethics committee of the Universidad Católica San Antonio (Catholic University of St. Anthony), Murcia.

### Procedure

All sessions were held at the laboratory at a controlled temperature of 21 ± 2 ºC over a 3 week period and were conducted at the same time of day. Participants attended for a total of 3 times. On the first day, the 6-RM test was carried out in order to determine the weights for the various exercises to be performed during the training sessions, based on guidelines from prior studies[4]. During this session, participants were also familiarised with the exercises and tests to be made. Furthermore, a body composition analysis was made with a bioimpedance analyser (Tanita BC-601, TanitaCorp, Tokyo, Japan). Following a 3 day rest, the subjects started to perform the first circuit session, randomly in one of the two conditions (normoxia or hypoxia). After a 72 hour recovery, the participants performed the next session in the other condition (third session). The participants in the study were told to maintain a balanced diet for the duration of the study and they were forbidden to consume caffeine or alcohol at least during the 24 hour period prior to each session.

### Experimental protocol

#### *Warm-up*

Prior to the training session, the participants were familiarised with the face mask, for 10 minutes. The warm-up session then started, consisting in 5' on a 75w exercise bike, following by 5 minutes of active stretching exercises. This was followed by the specific warm-up based on the following sequence: 10 repetitions at 50% of 6-RM for each exercise with 1 minute recovery; 8 repetitions at 75% of 6-RM with a two minute recovery time, and repetitions to failure with a load of 6-RM. The 6-RM load was adjusted approximately by ±2.5% if the subject performed ± 1 repetition, and was adjusted approximately by ± 5% if the subject performed ± 2 repetitions[18]. The eccentric phase of each movement was controlled using a digital metronome, while the concentric phase was performed at the maximum speed possible. The subjects rested for 5 minutes before starting the circuit.

### *High intensity circuit*

The circuit comprises two blocks of three exercises. 3 sets were performed in the first block, which included bench press, deadlift and biceps curl exercises with a 35 second rest between exercises and 3 minutes between sets. Following a 5 minute recovery period, the second block was started, consisting in half squat, French press and ankle extension (with identical recovery times). The subjects were supervised by an experienced lifter to ensure that voluntary fatigue was safely achieved and with strict technical control[19] (Figure 1).

### Measurement protocol

After performing each set, the subjective rating of perceived exertion (RPE) of the subject was measured using the Borg 6-20 scale. Prior to this, the functioning and utility of the scale was explained and all subjects had experience using it. Moreover, measurements were taken of the performance values for the bench press exercises (block 1) and the half squat (block 2), in each set, through a linear encoder (Chronojump, Barcelona, Spain) mounted on the bar. The performance variables analysed were: mean and maximum values for speed, acceleration, strength and power, as well as the times obtained up to the maximum speed and the maximum power.

### Statistical analysis

The data set was analysed using the SPSS software, a statistical package for Windows (version 20.0: SPSS, Ine. Chicago, Il., USA). A descriptive analysis was made, obtaining mean values and standard deviation. Shapiro-wilk was then used to perform normality tests. A general linear model analysis was performed, and repeated measurements and pair comparisons (Bonferroni Test). For non-parametric variables, we used the Wilcoxon signed rank tests and the Mann-Whitney U test. The statistical significance cut-off was set at p ≤0.05.

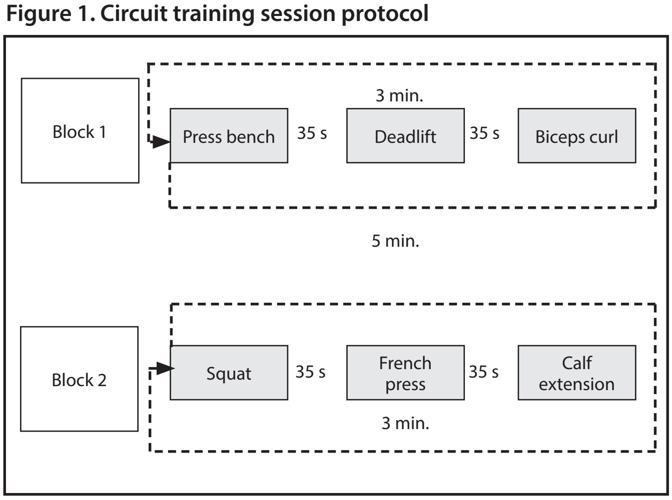
## Results

The results shown in Table 1 offer no significant differences in RPE between conditions.

Then, Table 2 shows the mean and peak speed values (m/s), acceleration (m/s$^2$), strength (N) and power (W) for the press bench and half squat exercises recorded for each set. The time values (s) to reach the power and peak speed can also be observed.

The data show a downward trend in the performance variables for the condition of hypoxia in relation to the condition of normoxia, yet with no statistically significant differences. It is only possible to observe differences between both training conditions in the first squat set for the peak acceleration variable (p = 0.037) and the peak power variable (p= 0.039).

**Figure 1. Circuit training session protocol**




## Discussion

The primary aim of this study was to analyse the acute effects caused by a circuit strength training session in hypoxia ($FiO_2 = 0.16$) on physical performance variables and the subjective rating of perceived exertion. The main finding of this investigation is that the addition of hypoxia to the strength training session affects the power and the peak acceleration achieved in the squat exercise, yet it does not change the athlete's perceived exertion.

With regard to the RPE variable, our results are in line with the literature that analyses the said variable. Prior studies[12,15,17] observe that there are no differences in the perceived subjective effort, even when the cardiovascular demands are increased. In this study it was possible to observe trends towards greater increases in the variable for perceived exertion following the first HRC block, although with no significant di-

**Table 1. Rated perceived exertion values (RPE). Mean (Standard Deviation).**

| | | Block 1 | | | Block 2 | | |
|---|---|---|---|---|---|---|---|
| Variable | Condition | Set 1 | Set 2 | Set 3 | Set 1 | Set 2 | Set 3 |
| RPE | N | 10.0 (2.3) | 11.0 (1.6) | 12.3 (1.7) | 10.7 (0.7) | 11.5 (1.4) | 12.0 (1.7) |
| | H | 11.8 (3.0) | 12.4 (2.6) | 14.1 (3.8) | 12.4 (2.3) | 13.7 (3.1) | 13.1 (2.6) |

RPE: Rating of perceived exertion; N: normoxia; H: hypoxia.

**Table 2. Values for the performance variables on the press bench and squats in normoxia and hypoxia. Mean (Standard Deviation).**

| Variable | Condition | Block 1 | | | Block 2 | | |
|---|---|---|---|---|---|---|---|
| | | Set 1 | Set 2 | Set 3 | Set 1 | Set 2 | Set 3 |
| Mean speed (m/s) | N | 0.4 (0.1) | 0.4 (0.1) | 0.3 (0.1) | 0.5 (0.1) | 0.5 (0.1) | 0.4 (0.2) |
| | H | 0.4 (0.2) | 0.4 (0.2) | 0.3 (0.2) | 0.4 (0.1) | 0.4 (0.2) | 0.3 (0.2) |
| Mean acceleration (m/s$^2$) | N | 1.4 (0.5) | 1.3 (0.3) | 1 (0.5) | 2.4 (0.8) | 2.5 (0.9) | 2.4 (1.1) |
| | H | 1.2 (0.7) | 1.3 (0.7) | 1 (0.9) | 1.9 (1) | 2.1(1.3) | 1.9 (1.1) |
| Mean strength (N) | N | 671.5 (292.8) | 638.1 (224.6) | 525.9 (226.2) | 1587.9 (340.8) | 1618.4 (354.1) | 1525.8 (560.4) |
| | H | 493.4 (216.4) | 501.3 (217.1) | 379.7 (287.9) | 1354.1 (583.7) | 1297.2) (701.7) | 1303.6 (700.6) |
| Mean Power (W) | N | 279.3 (118.3) | 247.9 (104.4) | 180.5 (76.1) | 744.3 (230.8) | 760.2 (221.4) | 728.1 (300.6) |
| | H | 201.1 (89.4) | 208.1 (90.3) | 159.9 (119.6) | 596.4 (280.8) | 619.9 (342.2) | 599.6 (327.3) |
| Mean Power (W) | N | 0.6 (0.2) | 0.6 (0.1) | 0.5 (0.2) | 0.8 (0.2) | 0.9 (0.2) | 0.8 (0.3) |
| | H | 0.6 (0.3) | 0.6 (0.3) | 0.4 (0.4) | 0.7 (0.3) | 0.7 (0.4) | 0.6 (0.4) |
| Peak acceleration (m/s$^2$) | N | 3.3 (1.5) | 3.2 (1.2) | 2.5 (1.1) | 2.9* (0.7) | 3 (0.7) | 2.6 (1.1) |
| | H | 2.7 (1.2) | 3.2 (1.8) | 2.2 (1.8) | 2.2* (1.1) | 2.3(1.3) | 2.1 (1.2) |
| Peak strength (N) | N | 883.2 (360.3) | 827.9 (248.1) | 673.2 (282.5) | 2016.9 (401.3) | 2082.8 (449.2) | 1926.1 (713.2) |
| | H | 637.2 (270.6) | 670.9 (276.1) | 497.5 (370.2) | 1695.5 (705.1) | 1666.1 (887.8) | 1656.3 (882.4) |
| Peak power (W) | N | 472.8 (207.1) | 404.6 (133.8) | 296.6 (119.7) | 1577.1* (587.5) | 1664.3 (587.8) | 1597.6 (670.3) |
| | H | 321.3 (168.5) | 335.3 (167.2) | 261.1 (209.3) | 1227.2*(636.3) | 1301.1 (750.1) | 1254.8 (726.5) |
| Time to maximum speed (s) | N | 0.7 (0.2) | 0.8 (0.2) | 0.8 (0.4) | 0.5 (0.1) | 0.5 (0.1) | 0.5 (0.2) |
| | H | 0.7 (0.3) | 0.7 (0.3) | 0.5 (0.4) | 0.5 (0.2) | 0.4 (0.2) | 0.4 (0.2) |
| Time to maximum acceleration (s) | N | 0.7 (0.2) | 0.7 (0.2) | 0.8 (0.4) | 0.5 (0.2) | 0.5 (0.2) | 0,4 (0.2) |
| | H | 0.6 (0.3) | 0.6 (0.2) | 0.5 (0.3) | 0.4 (0.2) | 0.3 (0.2) | 0.3 (0.2) |

Block 1: Values of press banca; Block 2: Values of half-squat; *statistically significant differences between H and N p≤0.05; N: normoxia; H: hypoxia.

fferences. One of the possible reasons for the lower values obtained in the second block could be due to the exercises used and to the greater demand of the exercises in the first block in relation to the second one. Exercises involving a greater number of muscle groups increase oxygen consumption and the muscles' capacity to extract oxygen from blood, causing decreased saturation and an increase in the heart rate[20]. In this respect, in the first block, the exercises used (bench press, deadlift and biceps curl) involve the mobilisation of major muscle groups, while the exercises selected in the second block (half squat, French press and ankle extension) have a lower demand as they only use a single multi-joint exercise. In contrast to these results, other studies do find differences in the RPE between training conditions[21,22]. These contradictory results could be explained by the different training methodology; traditional compared to the high intensity circuit. Therefore, the RPE variable is a good indicator for training in hypoxia, as it provides valuable information on the intensity of the exercise and allows us to control the training load in this environmental condition[23,24].

With regard to the maximum performance values, the results of this study show significant differences in the first half squat set. Prior studies have observed that, in conditions of hypoxia, there is an increase in the concentration of lactate in the blood, the blood pH decreases as does the availability of oxygen[25]. These findings appear to suggest a greater metabolic involvement of anaerobic glycolysis, required to maintain the resynthesis of ATP. So, when the aerobic metabolism is unable to meet the demand for ATP, the breakdown of phosphocreatine and the greater involvement of anaerobic glycolysis help to provide the energy required[26]. On the other hand, the increased metabolic stress and acidosis associated with training in hypoxia[9] together with the short recovery times that we used in the HRC, affect the capacity of the muscles to maintain a balance between ATP utilisation and resynthesis, limiting muscle recovery[27]. This physiological response, as suggested by the studies, could explain this drop in performance observed in our study. However, it is necessary to make an analysis of the said variables, which were not studied in our work. Therefore, the results appear to indicate that the proposed training in hypoxia has a negative impact on the capacity to produce strength peaks in half squats. Therefore, these results should be taken into account when planning strength training in hypoxia, given the fact that muscle power and speed are factors that are modified with hypoxia and this may modify the response to the training[28].

The results obtained in the variables for mean strength, power and acceleration and the times necessary to reach the maximum speed and maximum power show that there are no significant differences between the conditions studied. Even so, the data obtained in the condition of hypoxia tended to be lower than for normoxia. In this respect, our results, despite the clear differences in the tasks proposed between both workouts, appear to be in line with the study by Scott *et al*.[17] who found no significant differences, although they did find lower values in the strength and power variables between hypoxia and normoxia in one session with squat and deadlift exercises with 5 sets of 5 repetitions at 80% of 1RM at 0.16 or 0.13% of $FiO_2$. This drop in the mean performance variables is associated with an accumulation of products that generates metabolic fatigue and neuromuscular fatigue as well as a drop in phosphocreatine reserves[29]. Moreover, training in hypoxia[30] is also associated with a greater involvement of anaerobic glycolysis which increases the intracellular acidosis and contributes to fatigue[31]. Therefore, the mean performance values for a circuit training session in hypoxia are similar to those for a session in normoxia, which suggests that it can be used without adverse effects and take advantage of the benefits of working in an environment with a low availability of oxygen, which prior studies related to greater muscle hypertrophy[12,15].

This study contributes to the understanding of the acute responses to a circuit training session in hypoxic conditions. It provides evidence as to the potential applicability in endurance sports that use strength training in their training programs. Circuit sessions in hypoxia do not produce the same acute responses in performance variables as the same training under conditions of normoxia. These differences must be taken into account when designing and optimising the training loads. Moreover, it should be borne in mind that the subjects in this study were well-trained athletes and with experience in strength training. Therefore, the results are applicable to athletes seeking to improve their performance in this quality. Due to the high demand for anaerobic glycolysis that this training condition appears to produce, the results of the study can also be applied to team sports players, sprinters or endurance athletes who may want to optimise their strength training sessions so that these are shorter.

To conclude, the results of this study show that a circuit training session in hypoxia ($FiO_2 = 0.16$) does not reduce the mean physical performance of the session or the athlete's perceived exertion, however it does affect the peak acceleration and power achieved during the squat exercise in comparison with the same training in normoxia. It is necessary to continue to investigate strength training in hypoxia and, specifically, circuit training, in order to understand the chronic adaptations in strength, as well as metabolic and morphological adaptations. If the findings of future investigations continue to be in line with our study, then we could be looking at a new strength training methodology, given the fact that it does not reduce the mean physical performance of the session and, on the other hand, the exercise is not perceived as being more intense. Therefore, athletes would benefit from improved performance provided by the medium with the diminished availability of oxygen and in a shorter training time.

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