Artículo original

Effects of repeated-sprint hypoxic training on physical fitness of active adults

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Summary

Due to the time is, commonly, a barrier to exercise, the scientific community has paid attention to a new model of training. Repeated-sprint hypoxic training is now considered an effective time-efficient method for improving physical performance in different sport modalities. However, few researchers have studied the effect of this strategy in healthy untrained or moderately trained individuals. Depending of the prior fitness status, different findings may be obtained. Therefore, this study determined the effects of 4 weeks of repeated-sprint in hypoxia on cardiorespiratory fitness and anaerobic capacity in healthy men. Twenty-four physically active males (were randomly assigned to repeated-sprint in normoxia (n=8; 0.20 FiO_2), in hypoxia (n=8; 0.14 FiO_2) or a control group (n=8). Participants of both exercise groups developed eight training sessions consisted of 2 sets of 5 all-out cycling sprints of 10 s with a recovery of 20 s between sprints and 10 min between sets. Repeated sprint ability, vertical jump performance and estimated maximal oxygen consumption were tested at baseline, 7 days and 2 weeks after the last session. Seven days after the last sessions, significant differences ($p<0.05$) between normoxia (+7.8%; $p<0.001$; ES=1.66) and hypoxia groups (+9.9%; p=0.000; ES=1.42) compared with control group were found in estimated maximal oxygen consumption. In the hypoxia group, the number of sprints to exhaustion (7 days Post +55.6%; ES=1.40; 2 weeks Post +10.0%; ES=1.80) improved with a large effect size at 7 days and 2 weeks after the last sessions compared with baseline. Eight sessions of repeated-sprint training in hypoxia conditions could produce improvements and delayed effects on anaerobic capacity.

Key words:
Hypoxia. Sprint interval training. Physical conditioning. Cardiorespiratory fitness. Jump performance.

Efectos del entrenamiento de esprints repetidos en hipoxia sobre la condición física de adultos activos

Resumen

La comunidad científica ha prestado atención en los últimos años a un nuevo modelo de entrenamiento, debido a que la falta de tiempo es comúnmente la principal barrera para la práctica deportiva. En este contexto, el entrenamiento de esprint repetidos en hipoxia es considerado como una prometedora estrategia para mejorar el rendimiento físico en diferentes modalidades deportivas. Sin embargo, existen pocos estudios que investiguen los efectos sobre población moderadamente entrenada o sedentaria. Así, este estudio determina los efectos de un entrenamiento de esprint repetidos en hipoxia sobre la condición física de hombres sanos. Veinticuatro hombres fueron asignados aleatoriamente a un grupo normoxia (n=8; 0.20 FiO_2), hipoxia (n=8; 0.14 FiO_2) o control (n=8). Después de ocho sesiones de esprint repetido en cicloergómetros de 10 s, la habilidad de esprint repetido, el rendimiento en el salto vertical, así como el consumo de oxígeno fueron evaluados en la línea base y a los días y 2 semanas de la última sesión de entrenamiento. A los 7 días, se observaron diferencias significativas entre normoxia (+7,8%; $p<0.001$; ES=1,66) e hipoxia (+9,9%; p=0,000; ES=1,42) comparado con el grupo control en el consumo máximo de oxígeno estimado. En hipoxia, el número de esprint hasta la extenuación (7 días Post +55,6%; ES=1,40; 2 semanas Post +10,0%; ES=1,80) también mejoró con tamaño del efecto elevado a los 7 días y 2 semanas de la última sesión comparado con la línea base. El protocolo de 8 sesiones de esprines repetido en hipoxia podría producir mejoras y retrasar los efectos sobre el rendimiento anaeróbico de hombres sanos.

Palabras clave:
Hipoxia. Sprint repetido. Condición física. Resistencia cardiovascular. Salto vertical.

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Introduction

In the clinical and sport context, improving or maintaining muscular strength, power, and endurance are goals commonly pursued by individuals practice physical training programs[1]. Over last decades, the scientific community has paid attention to high-intensity training such an effective time-efficient training method for improving physical performance in athletes[2]. Due to the most commonly cited barrier to physical activity is lack of time[3], there is today a surge of research interest focused on examining the effects of short sprints and all-out efforts[2]. In this sense, all-out repeated-sprint training has been shown as high-intensity training regimen capable to enhance exercise performance with a lower training volume[4].

Last decades, greater improvements in exercise performance of athletes of different sport modalities have been shown when high-intensity is carried out under hypoxic condition[5]. Innovative 'live low-train high' methods have emerged as 'repeated-sprint training in hypoxia' (RSH), based on maximal "all-out" efforts of short duration (<30 s) with incomplete recoveries[6,7]. Specific adaptations have been attributed to RSH, which differ from intermittent hypoxic training (IHT) adaptations. Maximal intensity accompanied with the drop in arterial oxygen content favour the usage of fast twitch fibers[8] and the compensatory vasodilation[9]. Increasing in muscle mitochondrial, capillary density[10] and stimulation of markers of mitochondrial metabolism and biogenesis[11] may enhance the anaerobic energy system contributing to greater improvements in anaerobic capacity and cardiorespiratory fitness[12].

Recently, it has been shown that RSH led to greater exercise performance than the same training in normoxia in athletes[5-8,13-18], as well as obesity population[19]. However, controversial results are shown and, no additional effect on performance outcomes were found in other reports[20].

On the other hand, the exercise program effectiveness is not only determined by short-term effects, unless the maintenance of the benefits achieved during the detraining period is essential[21]. After high-intensity programs, the beneficial training effects usually return to near resting values within only 2 weeks of detraining after programs[22]. In this sense, adding a hypoxic stimulus may allow for more systemic and muscular adaptations due to elevated hypoxic and oxidative stress in conjunction with pertinent neuromuscular and neuromechanical loading[23,24]. Lasting for at least three weeks post-intervention of RSH training, Yo-Yo performance and repeated-sprint ability of elite field team-sport kept increasing[25]. In obese women, RSH was an effective alternative for improving cardiovascular respiratory fitness when compared to the same normoxic training, even after of 4-weeks the cessation of the training program[19]. However, studies on the maintenance of exercise-induced performance benefits after cessation of training are rare.

Meanwhile RSH has been investigated in different modalities athletes[25], few researchers have investigated the effect of this strategy on performance in healthy untrained or moderately trained individuals. Depending of the prior fitness status, different findings may be found[26]. Therefore, the present study aimed at determining the effects of four weeks of RSH on cardiorespiratory fitness and anaerobic capacity in active adults. We hypothesized that RSH would lead to greater enhancement in aerobic as well as anaerobic parameters performance.

Material and method

Study design

The study was designed as a randomised blinded controlled trial. Participants were randomly assigned to one of the three groups of the study: control (CON; n=8) that completed only testing sessions, normoxic repeated-sprint training (RSN; n=8) or repeated-sprint training in hypoxia (RSH; n=8). One week prior to baseline measurements, participants visited the laboratory for familiarisation with experimental trials and fitness testing. A general questionnaire was completed to collect medical and personal data before entering the study. Subjects in both groups were instructed to maintain their usual physical activities during the study period. All participants were assessed at three time points: at baseline (Pre), in the 7 days after the last session (Post) and 2 weeks after the last session (Det). All time points for evaluations consisted of the same measurements.

Participants

Participants were recruited from the Sports Science Faculty of the University of Extremadura. Inclusion criteria, assessed during a screening visit, were: healthy men, physically active (per week: >75 min moderate-to-vigorous physical activity or 150 min moderate physical activity) and have not been acclimated or recently exposed to altitude (above 1,500 m for more than 6 hours per day (i.e., no overnight sleep at altitude), during the last 3 months). Exclusion criteria included contraindications to exercise and medication that may have affected on their daily activities.

Twenty-four physically active males (age: 23.1±3.6 years; body mass: 72.6±6.7 kg; BMI: 23.6±3.5 kg·m^{-2}) volunteered for this study. Compliance training was calculated as the number of sessions completed divided by the 8 possible sessions available per participant. All the participants should have to complete at least 80% of the sessions. Subjects were informed of the experimental protocol and after signing the informed consent became part of the study. This project was approved by the Bioethics Committee of the Council of Europe of the University of Extremadura and carried out according to the Declaration of Helsinki. Participant's characteristics are shown in Table 1.

Training sessions

Participants started the training protocol 1 week following baseline. During the 8-weeks study period, 8 training sessions were completed over 4 weeks, 2 days per week, supervised by an experienced member of the research group. Sessions were scheduled with at least 1 day of

Table 1. Participant's characteristics at baseline

	CON (n=8)	RSN (n=8)	RSH (n=8)
Age, years	22.8 ± 4.8	24.4 ± 3.5	22.1 ± 2.6
Weight, kg	70.2 ± 6.7	71.4 ± 5.8	69.3 ± 10.4
BMI, kg·m^{-2}	22.3 ± 0.5	23.1 ± 2.7	23.7 ± 2.5

Values are mean ± SEM. BMI: body mass index.

rest between for optimal recovery (Monday and Wednesday or Tuesday and Thursday) and participants were requested to train at the same time throughout the 8 sessions. Each session consisted of repeated-sprint during cycling in a hypoxic chamber (CAT 310, Louisville, Colorado, USA) built in our laboratory (459 m of altitude, 24ºC and 40% relative humidity). RSH group breathed an oxygen fraction (FiO_2) at 0.14 ± 0.003 (simulate an altitude of 3,400 m above sea level) controlled with an electronic device (HANDI+, Maxtec, Salt Lake City, Utah, USA). Oxygen content within the chamber could be reduced by insufflating nitrogen, which was produced from chamber air through a molecular sieve. Normoxic repeated-sprint training group exercised at FiO_2 of 0.20 corresponding to sea level in the laboratory. Blinding of the subjects, the system also ran for normoxic repeated-sprint training with normoxic airflow into the chamber.

Training sessions were performed in a cyclosimulator with an integrated potentiometer (Cycleops 410 pro, Cycleops, Madison, USA). Cycling provides a lower risk of leg muscle injury (by minimal eccentric contraction), which was the most important reason for selecting this exercise mode. After 10 min of warm-up at 60 watts (W), all training sessions consisted in 2 sets of 5 repeated 10 s all-out sprints with a recovery of 20 s between sprints and a recovery period of 10 min at 120W between sets, ending with a 5 min recovery at 120 W. The maximum power of each sprint was registered and monitored by the potentiometer in real time via the potentiometer data screen itself. Between training sessions there were at least 48 hours of rest for an optimal recovery.

Testing sessions

In all time points, assessments were carried out over 2 sessions. On the morning of the first day, body composition and jump performance were measured. Then, after 45 minutes, subjects performed a Yo-Yo Intermittent Recovery Test at level 1. On the second day, the subjects took a Repeated sprint ability (RSA) Test.

- *Body mass index:* height and weight were measured following standard procedures. Body mass index was derived from height and weight using the accepted method (BMI = weight/height^2, kg·m^{-2}).
- *Repeated sprint ability test:* The subjects conducted a repeated sprint test under normoxic conditions, comprising the largest number of 10 seconds all-out sprints (maximal pedalling) with a 20-sec active rest between sprints at 120 W[27]. Subjects were given very strong verbal encouragement and performed as many sprints as possible until exhaustion. A minimum of 70 rpm or less after 5 s of sprinting was set as the criterion to stop the test. The total number of sprints was registered.
- *Jump Performance:* to test the lower limb explosive strength performance an Optojump platform connected to a personal computer were used (OptojumpNext, Microgate, Bolzano, Italia). Jump height of the widely knows squat Jump (SJ) and Counter-movement Jump (CMJ) protocols were registered. Two trials were performed for each of the jumping tests (SJ and CMJ). A 10 s rest within and a 90 s rest between jumping tests were set. The best trial was retained for analysis and the jumping height was calculated from the flight time[28].
- *Yo-Yo Intermittent Recovery Level 1 Test:* participants performed twenty-meters shuttle runs with increase of the velocity until the exhaustion. Periods of 10 s of active recovery were developed between runs. Total distance covered (including the last incomplete shuttle) was registered and used to estimate maximal oxygen consumption (VO_{2max}) using the equation: VO_{2max} ml·kg^{-1} min^{-1} = [IR1 distance (m) * 0.0084] + 36.4[29].

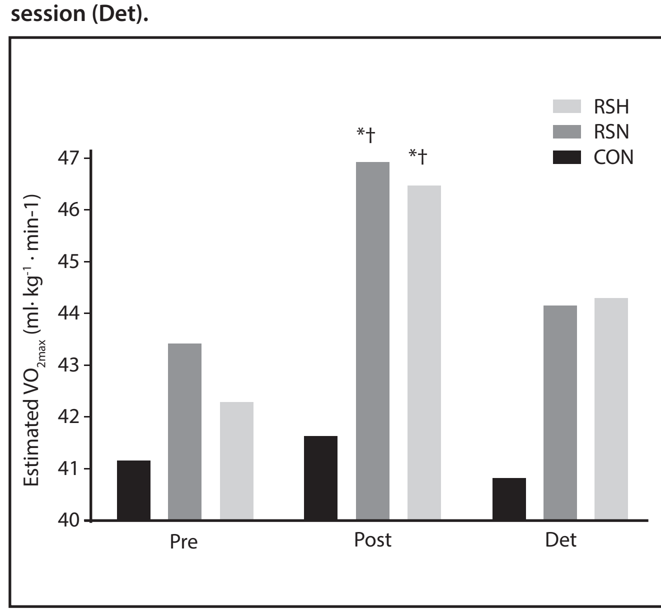
Statistical analyses

The statistical package SPSS v.20 for MAC (IBM, New York, USA) was used for statistical analysis. Before the analysis, the Kolmogorov–Smirnov test and Levene's test were calculated to identify data homogeneity. Then, two-way repeated measures analysis of variance (ANOVA) was used to compare responses in each variable. Bonferroni post hoc analysis was used to identify where changes occurred. To establish statistical significance, $p<0.05$ was used. The effect size was calculated for all variables between pre- and post-testing. The magnitude of the difference was considered as a small (0.2), moderate (0.5) or large (0.8) effect size (ES).

Results

Compliance with training prescription was 100% in the RSH group and 91.39% in the RSN group. Effects of training about estimated VO_{2max} obtained in the Yo-Yo Test are shown in Figure 1. After training, estimated VO_{2max} increased significantly in both RSN ($p=0.02$) and RSH ($p=0.04$) groups compared with control group. Statistically significant differences within groups with a large ES were found in the RSN group

Figure 1. Estimated VO_{2max} with Yo-Yo Test at baseline (Pre), in the 7 days after the last session (Post) and 2 weeks after the last session (Det).



Estimated VO_{2max}: maximal oxygen uptake; CON: Control Group, RSN: Repeated-Sprint Normoxia, RSH: Repeated Sprint Hypoxia. *Significant difference ($p < 0.05$) compared to Pre-. †Significant difference ($p < 0.05$) compared to CON.

Table 2. Repeated sprint and jump ability results before and after intervention.

		Pre (A)	Δ (% A-B)	Post (B)	Δ (% B-C)	Det (C)	d Cohen (A-B)	d Cohen (B-C)
Number of sprints, n	CON	5.5 ± 0.8	-2.7	5.3 ± 1.6	+17.0	6.2 ± 1.2	0.14	0.70
	RSN	5.0 ± 1.2	+24.0	6.2 ± 2.2	-9.7	5.6 ± 0.9	0.71	0.39
	RSH	4.5 ± 1.7	+55.6	7.0 ± 1.8	+10.0	7.7 ± 1.9	1.40	1.80
SJ Height, cm	CON	32.3 ± 6.8	-4.6	30.8 ± 7.1	-6.2	28.9 ± 6.0	0.23	0.28
	RSN	30.1 ± 5.0	+0.7	30.3 ± 6.2	+5.3	31.9 ± 5.6	0.04	0.26
	RSH	29.5 ± 3.0	+2.0	30.1 ± 3.6	+14.3	34.4 ± 5.4	0.19	0.95
CMJ Height, cm	CON	34.2 ± 3.9	+5.3	36.0 ± 4.7	-5.3	34.1 ± 4.6	0.41	0.40
	RSN	35.5 ± 7.6	+0.8	35.8 ± 5.7	-5.3	33.9 ± 5.4	0.03	0.34
	RSH	30.9 ± 4.2	+6.1	32.8 ± 3.8	+10.7	36.3 ± 4.4	0.98	0.88

Values are mean ± SEM. CON: Control Group; RSN: Repeated-Sprint Normoxia; RSH: Repeated-Sprint Hypoxia; Δ: absolute change; d Cohen: Effect size; SJ: squat jump; CMJ: countermovement Jump.

(+7.83%; p=0.001; ES=1.66) and RSH group (+9.95%; p=0.000; ES=1.42) between Pre and Post evaluation.

The training effects on RSA and jump performance are shown in Table 2. The number of sprints until exhaustion and jump performance did not show significant improvements compared with control group. In within group analysis, RSH showed a large ES between Pre and Post (+55.56%; ES=1.40) and Pre and Det (+10%; ES=1.80) in the number of sprints. Increases in SJ and CMJ height were also found in RSH group with a large ES between Pre and Post and between Pre and Det (SJ: +2.03% and +14.3%, ES=0.98 and ES=0.88, respectively; CMJ: +6.15% and +10.7%, ES=1.28 and ES=0.88, respectively).

Discussion

The present study aimed at determining the effects of four weeks of RSH on cardiorespiratory fitness and anaerobic capacity in active adults. The main finding was that the combination of repeated-sprint and hypoxic stimulus could not lead to an additional effect on cardiorespiratory fitness compared with the same protocol in normoxia conditions. After training, significant differences were found in estimated VO_{2max} in RSN group compared with control group, as well as RSH group with respect to the control group. However, the anaerobic capacity, showing through the number of sprints to exhaustion, may tend to increase under hypoxia conditions. The greater large effect sizes found in RSH group leads us to think that significant changes could be obtained from higher sampling. Besides, delayed effects on anaerobic capacity with a large effect size were shown after 2-weeks of cessation of the program. In any case, finding no significant differences, the results must be taken with caution.

Cardiorespiratory fitness

Hypoxic training has been commonly used to improve cardiorespiratory capacity over years. The stress of hypoxic exposure, in addition to the training stress, may increase the adaptations experienced with exercise alone and will lead to greater improvements in performance[30]. Whereas previous studies reported that RSH induced greater improvements on cardiorespiratory capacity in elite athletes[14,18,25] and obese people[19], the present study did not show additional effects of RSH on estimated VO_{2max} through Yo-Yo Intermittent Recovery tests. Despite aerobic field-based protocol may be preferred over laboratory-based protocols due to an increase in ecological validity for performance measurement in sport-field[18], the lack of additional benefits of RSH over RSN is the non-specificity of training relatively to the test implemented[31].

Anaerobic capacity

Based on previous studies, RSH, when compared with that under normoxia, may be more useful for enhancing anaerobic capacity[4], by increases the contribution of the anaerobic energy system during all-out sprint exercise[32]. The results observed in the present study are partially agreed with meta-analysis' aggregated findings[7] that indicated RSH vs. RSN improved in RSA. In contrast, other studies found that RSH equally improved RSA performance compared with RSN[14,18,20,25,33]. Many factors may be contributing to these controversial results[7] such as level of athlete and/or protocol design. Similarly to Hamlin *et al.* (2017) and Beard *et al.* (2019), improvements in RSA performance were reported when a multiple-set protocol of RSH was applied[7]. Although the mechanisms for the anaerobic capacity are still under debate, RSH may induce greater improvements of oxygen utilization by the fast-twitch fibers during 'all-out' maximal repeated sprints performed in hypoxia[8].

Surprisingly, in the present study, anaerobic capacity continued improving after two weeks of detraining in RSH group. These findings are especially relevant in a population where cessation of training is common for holidays[19]. As previous authors have reported, delayed effects on exercise performance could be achieved after RSH protocol[19,25]. Although speculative, this phenomenon could be attributed to higher variations of blood perfusion delaying fatigue in the RSA test and improvements in vascular conductance where fast-twitch fibers are better utilised[8]. In parallel, neural adaptations would increase motor unit synchronization and/or agonist muscle activation[34]. Conversely, skeletal muscle molecular beneficial may elicit higher short-term adaptations with a rapid decay and normalization of molecular adaptations after cessation of the training[7]. However, studies on the maintenance of exercise-induced exercise performance benefits after cessation of training are rare and more research is required.

There are some limitations to this study. We cannot ignore that the present study includes a low hypoxic dose with 8 RSH sessions, 800 s sprinting duration over 28 days (mean of the RSH studies was 9.4 ± 3.1 sessions, 1216 ± 527 s sprinting duration over a 27.3 ± 8.4 days period[7]). A factor of importance to the outcome of an altitude-training program is the exercise regimen undertaken during the intervention period[35]. The severity of altitude, time spent training at altitude or type of training represents important factors to consider when designing a training program at altitude. Thus, this lowest volume could partially explain why no significant changes were shown. The small sample size certainly is a weakness in this study. Despite this, there are significant indications that this type of training could have benefits for this population, as shown by the high effect sizes. Besides, the non-specificity of training relatively to the test implemented establishes another important limitation of the present study. Using a field test (Yo-Yo test) predicting VO_{2max} rather than measuring it with metabolic gas analysis have a considerable error for estimating VO_{2max} in adults. For these reasons, the findings of this study should be confirmed in further investigations.

Conclusions

In conclusion, eight RSH sessions performed over four weeks does not appear to have an additional effect on cardiorespiratory capacity in active adults compared with equivalent training in normoxia. However, it could produce improvements in RSA and lead delayed effects on anaerobic capacity. Further studies with protocols designed for double blind and large sample sizes are needed to support the effectiveness of RSH in this population.

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Conflict of interest

The authors do not declare a conflict of interest.

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