ACUTE PHYSIOLOGICAL RESPONSES TO "RECOVERY INTERMITTENT HYPOXIA" IN HIIT

RESPOSTAS FISIOLÓGICAS AGUDAS À "HIPÓXIA INTERMITENTE DE RECUPERAÇÃO" NO HIIT

RESPUESTAS AGUDAS A LA "HIPOXIA INTERMITENTE DE RECUPERACIÓN" EN EL HIIT

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Yan Figueiredo Foresti[1]
(Physical Education Professional)
Carlos Dellavechia De Carvalho[2]
(Physical Education Professional)
Felipe Alves Ribeiro[1]
(Physical Education Professional)
Julia Causin Andreossi[1]
(Physical Education Professional)
Gabriel Luches-Pereira[1]
(Physical Education Professional)
Danilo Rodrigues Bertucci[3]
(Physical Education Professional)
Fúlvia de Barros Manchado-Gobatto[4]
(Physical Education Professional)
Marcelo Papoti[1,2,3]
(Physical Education Professional)

1. Universidade de São Paulo, School of Physical Education and Sport of Ribeirão Preto, Ribeirão Preto, SP, Brazil.
2. Universidade de São Paulo, Ribeirão Preto Medical School, Ribeirão Preto, SP, Brazil.
3. Universidade Estadual de São Paulo, Department of Physical Education, Rio Claro, SP, Brazil.
4. Universidade de Campinas, School of Applied Sciences, Laboratory of Applied Sport Physiology, Limeira, SP, Brazil.

Correspondence:
Yan Figueiredo Foresti
Universidade de São Paulo, School of Physical Education and Sport of Ribeirão Preto. 3900, Bandeirantes Ave, Vila Monte Alegre, Ribeirão Preto, SP, Brazil.
yan.foresti@alumni.usp.br

ABSTRACT

Introduction: Traditional intermittent hypoxia training improves sport performance after short periods of exposure, but acute exposure to intermittent hypoxia leads to decreased training intensity and technical quality. The solution to overcome these negative effects may be to perform efforts in normoxia and the intervals between efforts in hypoxia, maintaining the quality of training and the benefits of hypoxia. Objective: This study aimed to evaluate the acute physiological responses to hypoxia exposure during recovery between high intensity efforts. Materials and methods: Randomized, one-blind, placebo-controlled study. Sixteen men performed a graded exercise test to determine their maximal intensity and two sessions of high-intensity interval training. The training intervals could be in hypoxia (HRT), FIO2: 0.136 or normoxia (NRT), FIO2: 0.209. During the two-minute interval between the ten one-minute efforts, peripheral oxygen saturation (SpO_2), heart rate (HR), blood lactate ([La]), blood glucose ([Glu]) were constantly measured. Results: There were differences in HR (TRN = 120 ± 14 bpm; TRH = 129 ± 13 bpm, p < 0.01) and SpO_2 (TRN = 96.9 ± 1.0%; TRH = 86.2 ± 3.5%, p < 0.01). No differences in [La] and [Glu] TRN (4.4 ± 1.7 mmol.l-1; 3.9 ± 0.5 mmol.l-1) and TRH (5.2 ± 2.0 mmol.l-1; 4.0 ± 0.8 mmol.l-1, p = 0.17). Conclusion: The possibility of including hypoxia only in the recovery intervals as an additional stimulus to the training, without decreasing the quality of the training, was evidenced. ***Level of Evidence II; Randomized Clinical Trial of Minor Quality.***

Keywords: Oxygen Saturation; Lactate; High-Intensity Interval Training; Hypoxia.

RESUMO

Introdução: O treinamento de hipóxia intermitente tradicional melhora o desempenho esportivo após curtos períodos de exposição, porém a exposição aguda à hipóxia intermitente leva à diminuição da intensidade do treinamento e da qualidade técnica. A solução para superar esses efeitos negativos pode ser realizar esforços em normóxia e os intervalos entre os esforços em hipóxia, mantendo a qualidade do treinamento e os benefícios da hipóxia. Objetivo: Este estudo teve como objetivo avaliar as respostas fisiológicas agudas à exposição de hipóxia durante a recuperação entre esforços de alta intensidade. Materiais e métodos: Estudo aleatório e one-blinded, com efeito placebo controlado. Dezesseis homens realizaram um teste de exercício graduado para determinar sua intensidade máxima e duas sessões de treinamento intervalado de alta intensidade. Os intervalos de treinamento podem ser em hipóxia (TRH), FIO2: 0,136 ou normóxia (TRN), FIO2: 0,209. Durante os dois minutos de intervalo entre os dez esforços de um minuto, foram medidos constantemente a saturação periférica de oxigênio (SpO_2), frequência cardíaca (FC), lactato sanguíneo ([La]), glicemia ([Glu]). Resultados: Houve diferenças na FC (TRN = 120 ± 14 bpm; TRH = 129 ± 13 bpm, p <0,01) e SpO_2 (TRN = 96,9 ± 1,0%; TRH = 86,2 ± 3,5%, p <0,01). Sem diferenças em [La] e [Glu] TRN (4,4 ± 1,7 mmol.l-1; 3,9 ± 0,5 mmol.l-1) e TRH (5,2 ± 2,0 mmol.l-1; 4,0 ± 0,8 mmol.l-1 , p = 0,17). Conclusão: Evidenciou-se a possibilidade de incluir a hipóxia apenas nos intervalos de recuperação como um estímulo adicional ao treinamento, sem diminuir a qualidade do treinamento. ***Nível de Evidência II; Estudo Clínico Randomizado de Menor Qualidade.***

Descritores: *Saturação de Oxigênio; Lactato; Treinamento Intervalado de Alta Intensidade; Hipóxia.*

RESUMEN

Introducción: El entrenamiento tradicional en hipoxia intermitente mejora el rendimiento deportivo tras cortos periodos de exposición, sin embargo, la exposición aguda a la hipoxia intermitente conduce a una disminución de la intensidad del entrenamiento y de la calidad técnica. La solución para superar estos efectos negativos puede ser realizar los esfuerzos en normoxia y los intervalos entre esfuerzos en hipoxia, manteniendo la calidad del entrenamiento y los beneficios de la hipoxia. Objetivo: Este estudio pretendía evaluar las respuestas fisiológicas agudas a la exposición a la hipoxia durante la recuperación entre esfuerzos de alta intensidad. Materiales y métodos: Estudio aleatorizado, a ciegas y controlado con placebo. Dieciséis hombres realizaron una prueba de ejercicio graduado para determinar su intensidad máxima y dos sesiones de entrenamiento por intervalos de alta intensidad. Los intervalos de entrenamiento podían ser en hipoxia (HRT), FIO2: 0,136 o normoxia (NRT), FIO2: 0,209. Durante el intervalo de dos minutos entre los diez esfuerzos de un minuto, se midieron constantemente la saturación periférica de oxígeno (SpO_2), la frecuencia cardiaca (FC), el lactato en sangre ([La]) y la glucemia ([Glu]). Resultados: Hubo diferencias en

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la FC (TRN = 120 ± 14 lpm; TRH = 129 ± 13 lpm, p < 0,01) y la SpO_2 (TRN = 96,9 ± 1,0%; TRH = 86,2 ± 3,5%, p < 0,01). No hubo diferencias en [La] y [Glu] TRN (4,4 ± 1,7 mmol.l-1; 3,9 ± 0,5 mmol.l-1) y TRH (5,2 ± 2,0 mmol.l-1; 4,0 ± 0,8 mmol.l-1 , p = 0,17). Conclusión: Se evidenció la posibilidad de incluir hipoxia sólo en los intervalos de recuperación como estímulo adicional al entrenamiento sin disminuir la calidad del mismo. ***Nivel de Evidencia II; Ensayo Clínico Aleatorizado de Baja Calidad.***

Descriptores: *Saturación de Oxígeno; Lactato; Entrenamiento de Intervalos de Alta Intensidad; Hipoxia.*

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INTRODUCTION

Intermittent hypoxia training (IHT) consists of performing continuous or repeated efforts generally in hypoxia and spending intermittent periods of the day in hypoxia.[1-3] The use of IHT as an additional stimulus for training has been a common practice in sports training in different cyclic modalities.[3]

Studies show the efficacy of IHT in improving sports performance in short periods (i.e. 3-5 weeks of training), providing evidence of anaerobic improvements,[4] changes in pH, greater carbonic anhydrase, glucose transport, and HIF1α activity into muscle.[3] Furthermore, IHT is effective for improving movement economy, maximum oxygen uptake, and repeated sprint ability.[4-7]

Despite IHT being efficient in promoting positive adaptations, performing training in hypoxia cause a reduction in training intensity and loss of movement quality, reducing the capacity to generate power and decrease the number of efforts performed. The decrease in exercise intensity caused by hypoxic over time could explain the absence of positive results or even reduced performance in some research.[8-10]

IHT results in a paradoxical effect, it can promote additional adaptations due to hypoxia exposure; on other hand, the exposure may decrease the training intensity. The negative effects can "dilute" the possible positive effects on performance.[1]

Because of this, performing IHT with efforts at normoxia and pauses between efforts in hypoxia may be an alternative to maintain intensity and technical/mechanical quality during training. This strategy would probably generate positive adaptations from both regular training and hypoxia exposure, avoiding the harmful effects of hypoxia during exercise. However, to the best of our knowledge, no study to date has investigated this possibility under real training conditions. Thus, the present study aimed to assess the acute physiological responses to hypoxic during intervals between high-intensity efforts and compare with normoxia. Our hypothesis was that method could generate physiological alterations on traditional exercise markers as [La], HR and rate of perceived efforts (RPE) great than in normoxia training without decrease the number of efforts performed.

MATERIALS AND METHODS

Participants

Sixteen men participated in this study (age= 23±4 years, height= 180±10 cm, weight= 78.4±11.9 kg). The participants signed a consent form agreeing to participate in the study. All procedures adopted by the study comply with the university's human research ethics committee (CAAE: 32220020.0.0000.5659) and the Helsinki declaration.

Experimental Design

The participants came to the laboratory on 3 different days, with a minimum 48-hour interval. They were advised to maintain the same diet, to eat regular meals at least two hours before the interventions, and to avoid caffeine/alcohol. All procedures were performed at the same time of day. The laboratory was located at an altitude of 531 meters above sea level, with a controlled temperature of 22 °C. None of the participants had traveled to altitudes above 1,500 m in the previous 6 months. All experiments were performed on a treadmill (Super ATL, Imbrahmed, Brazil).

On the first day, height and body weight were measured, the participants were familiarized with the treadmill and the unidirectional face mask used during the study. Before each intervention, a 5-minute treadmill warm-up was performed at an intensity of 7 $km.h^{-1}$. The subjects performed a graded exercise test (GXT) until exhaustion, to estimate the peak speed achieved (V_{PEAK}). On the other two days, the participants realized a repeated high-intensity effort training session, with recovery between stimuli being performed in normoxia (T_RN) or hypoxia (T_RH). These executions were carried out at random, with the participants unaware of the situation they were being exposed to.

Graded Exercise Test (GXT)

The GXT started at 8 $km.h^{-1}$, increments of 1 $km.h^{-1}$ every 3 minutes, until voluntary exhaustion. Between each stage, there was a 30-second interval to collect blood samples and record HR and RPE. The following exhaustion criteria was adopted: a) [La] > 8.0 $mmol.l^{-1}$; b) maximum HR predicted by age (HRpred = 208 – (0.7 * age); c) RPE > 9 on an RPE scale from 0-10 points.[11]

The V_{PEAK} was the highest velocity achieved in the GXT; when exhaustion occurred before completing the stage. V_{PEAK} was adjusted using the equation:[12]

$$V_{PEAK} = SLC + (TI/TE) * I$$

Where SLC is the last complete stage speed; TI is the time performed in the last stage; TE is the stipulated time per stage; I was the increase in intensity.

Hypoxia Instrumentation

An Air San unidirectional mask (Air Safety, Brazil) was connected to a 3-meter flexible hose (IVPU, air vacuum PU 1.1/2), the opposite end was connected to a tent (CAT, TentTM, USA) with air capacity of 12,000 liters, connected to a hypoxia generator (CAT-430TM, Altitude Control Technologies, USA). The system remained online throughout the experiment. The F_IO_2 selected to hypoxia was of 0.135. The FIO_2 was monitored using an O_2 sensor (Oxygen Senor R-17MED, Teledyne Analytical Instruments, USA). The participants performed the same procedures for the normoxic, however received ambient air (F_IO_2: 0.209).

Training Session

Both training sessions with recovery in normoxia (T_RN) and hypoxia (T_RH) consisted of ten 1-minute efforts at 100% V_{PEAK}, with 2-minute of passive pauses. In both sessions, the participants carried out their efforts exclusively in normoxia. However, during the intervals, the participants breathed air with either 0.209 or 0.136 F_IO_2. RPE, [La], [Glu] were measured after the end of each effort, the HR, and SpO_2, were collected each ten seconds, until 120 seconds of interval. (Figure 1)

Hypoxic Dose Calculation (HD)

The HD was estimated as the exposure time in hours (t) multiplied by the reduction in SpO_2, assuming a resting SpO_2 value of 98%. Thus, HD = (98 - SpO_2) x t.[13]

Calculation of the Arterial Partial Pressure of Oxygen (PaO_2)

The SpO_2 values were converted to PaO_2 values using the equation:[14]

$$PaO_2 = \left(\frac{23400}{\frac{1}{SpO_2} - 0.99} \right)^{\frac{1}{3}}$$

Blood Sample Analysis

The blood samples were collected using heparinized and calibrated capillary tubes to collect 25µl of blood from the earlobe. The samples were dropped into Eppendorf tubes containing 50µl of 1% sodium fluoride. These tubes were frozen at -20°C for posterior analysis in a blood analyzer to determine [La] and [Glu] (YLS, model 2700, Ohio, USA).

Statistical Analysis

Data normality, homogeneity, sphericity were checked using the Shapiro-Wilk test, Levene test, and Mauchy test, respectively. The Greenhouse-Gesser correction was applied when necessary. The data were expressed in mean ± SD. To compare two means the Student t-test was used for dependent samples. To compare normoxia and hypoxia in different periods the repeated measures ANOVA was used. In the case of significant F values, the Sidak post-hoc test was used. The effect size (ES) and its 95% confidence interval (C.I.) was interpreted following: trivial <0.2, small 0.2–0.6, moderate 0.6–1.2, large 1.2–2.0, and very large >2.0. Only the RPE variable was analyzed using the Wilcoxon signed rank non-parametric f test, considering the value of the rank-biserial correlation (r_b) as the ES. A p-value of 0.05 was used for all tests. The JASP software (version 0.13.1.0, Amsterdam, Netherlands) was employed.

RESULTS

Figure 2, panel (A) shows the SpO_2 values in intervals, panel (B) shows the SpO_2 responses during an interval. The SpO_2 values of all the sessions were T_RN (96.9 ± 1.0%) and T_RH (86.2 ± 3.5%, $p < 0.01$, ES = 3.04 C.I. = 1.85, 4.22). The decrease in SpO_2 was 1.1 ± 1.0% for T_RN and 11.8 ± 3.5% for T_RH ($p < 0.01$, ES= 3.04 C.I. = 1.85, 4.22).

As expected, the HD for T_RN (0.35 ± 0.34%.h) was lower than the one for T_RH (3.89 ± 1.17%.h, $p < 0.01$, ES= 3.04, C.I.= 1.85, 4.22). The SpO_2 transformed into PaO_2 are presented in Figure 3. T_RN presented a higher PaO_2 value compared to T_RH ($p<0.01$, ES= 3.991, C.I= 2.488, 5.479).

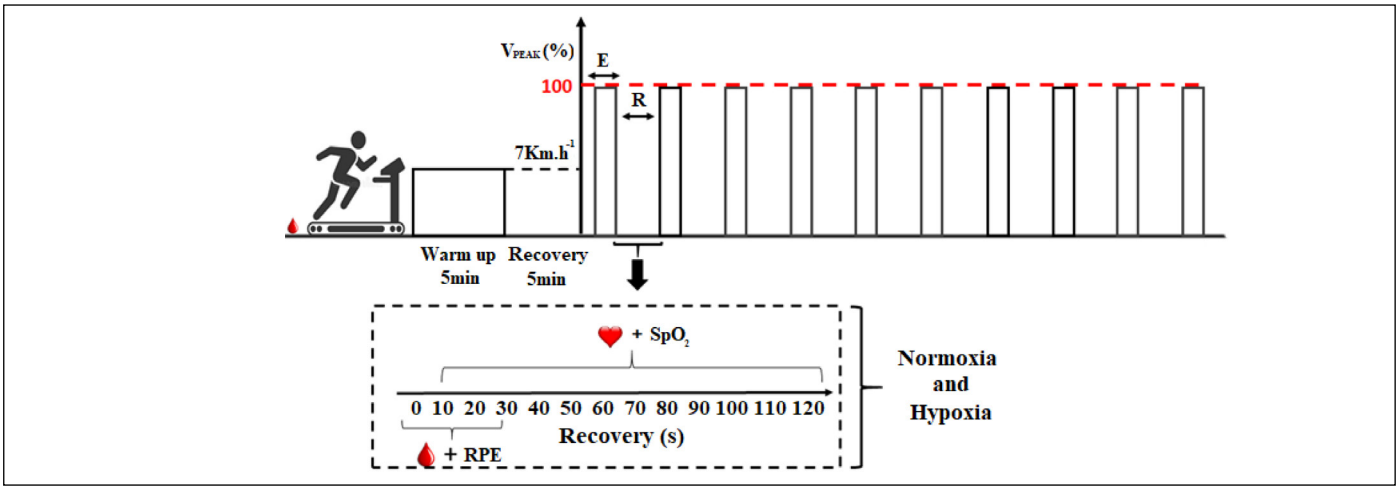

Figure 1. Representation of the dynamics of the high-intensity intermittent training session with recovery intervals in hypoxia or normoxia. VPEAK - maximum speed reached in the incremental test; E - effort period; R- the interval between efforts; RPE- the subjective perception of effort; SpO2- partial pressure of oxygen, ▯ represents a measurement of heart rate; 🩸 represents a measurement of blood lactate concentration.

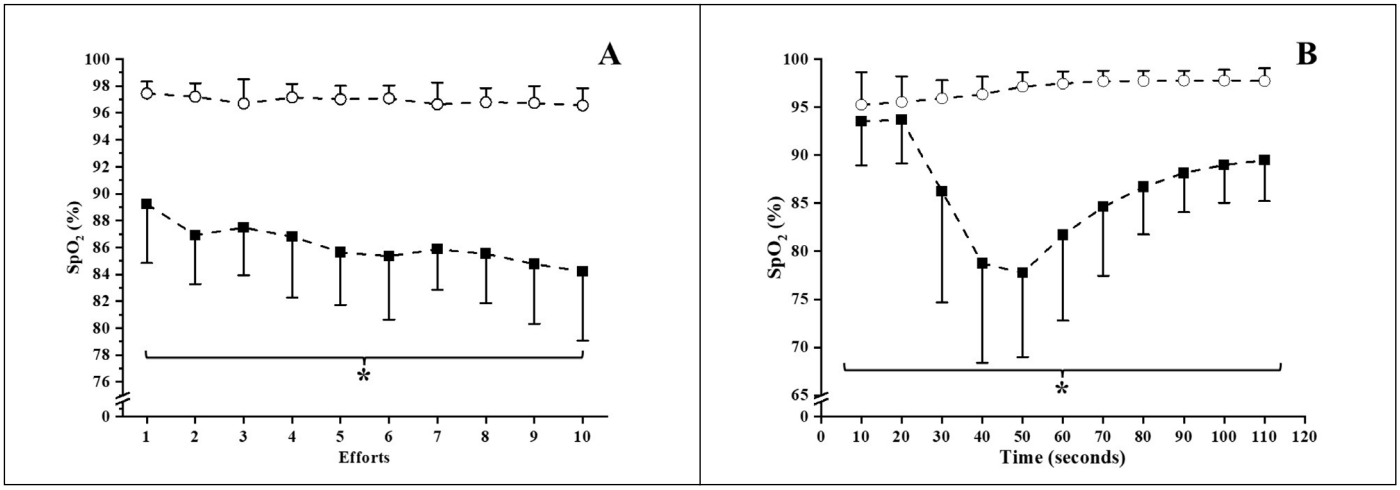

Figure 2. Comparison of the average blood oxygen saturation behavior during the recovery intervals, in the different training sessions; panel A - The comparison between the SpO2 average from each series, panel B - SpO2 behavior during the 120 seconds interval. ■ represents training performed with intervals in hypoxia; ○ represents training performed with intervals in normoxia. * means the statistical difference from normoxia with hypoxia situations ($p < 0.05$).

The HR responses during the recovery are presented in Figure 4. The mean HR of T_RN (120 ± 14 bpm) was lower than that of T_RH (129.1 ± 12.7 bpm, p < 0.01, ES= 1.35, C.I.= 0.65, 2.02).

No statistical differences were observed in the [Glu] between groups (T_RH= 4.0 ± 0.8 mmol.l^{-1}, T_RN= 3.9 ± 0.5 mmol.l^{-1}), although no statistical differences were observed in the [La] was slightly higher in T_RH (5.2 ± 2.0 mmol.l^{-1}) than in T_RN (4.4 ± 1.7 mmol.l^{-1}). (Figure 5)

The RPE showed no difference between T_RN (5.68 ± 2.12 pts.) and T_RH (6.06 ± 2.35 pts, p= 0.54, ES= 0.24, C.I = -0.451, 0.775).

DISCUSSION

The main finding was that training session with hypoxia during the intervals between high-intensity efforts was efficient in causing acute physiological changes in SpO_2 and HR levels compared to normoxia. Thus, the inclusion of hypoxia represents an additional training stimulus, confirming our hypothesis. It is important to highlight that this intervention did not alter the physical efforts, which were all performed in normoxia. The manipulation of the PaO_2 conditions only occurred in the intervals between the maximum 1-minute stimuli, thus not impairing the evaluated individual's motor gestures.

We are unaware of any other studies that investigate the effect of intermittent hypoxia only in the intervals. There is only one study that verifies the effect of hypoxia exposure during recovery after a training session.[15] The aforementioned authors applied a continuous submaximal training and used a 30-minute recovery after the end of the exercise.[15] Thus, we consider the data original.

Hypoxia decreases body oxygen supply, causing acute changes such as decrease in alveolar pressure, PaO_2, capillary pressure, intramuscular oxygen pressure (PiO_2).[16,17]

A reduction in PiO_2 below to 8.00 mmHg is sufficient to stabilize HIF1α.[18] In normoxic, the PHD hydroxylates HIF1α, enabling coupling with the von Hippel-Lindau protein and marking the E3 ubiquitin ligase complex, for degradation of HIF1α in the 265 proteasomes. With the decrease in PHD due to the decrease in PiO_2, HIF1α stabilizes, increasing its concentration inside the cell's cytosol, causing the MAPK protein to phosphorylate HIF1α. This protein translocates to the cell nucleus, connecting with HIF1β, forming the HIF1α/HIF1β complex. This complex connects to the HRE domain, increasing the transcription of several other proteins that are responsible for the positive adaptations resulting from exposure to hypoxia.[19-21]

A study using 0.100 F_IO_2, which is lower than the level used in this study (F_IO_2: 0.136), the PaO_2 values at rest were 46 ± mmHg, with respective PiO_2 values of 23 ± 6 mmHg.[16] These values were above what was necessary for HIF1α stabilization, indicating that passive hypoxia does not leads to adaptations in the HIF-1α pathway. In corroboration, a review showed that only passive hypoxia was not efficient in causing aerobic or anaerobic changes.[22]

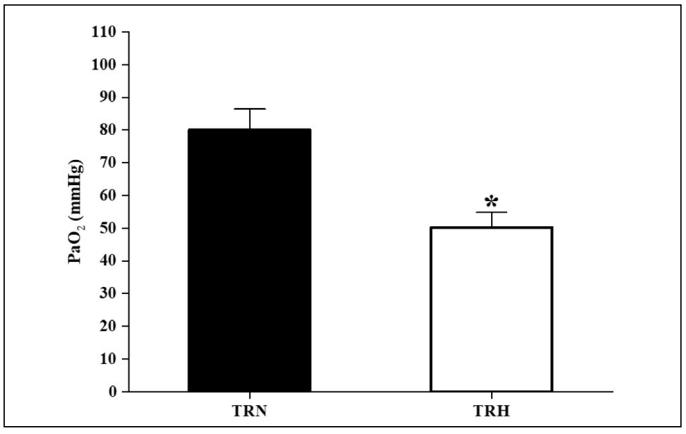

Figure 3. Comparison between arterial oxygen pressure (PaO2) in interval training performed with intervals in hypoxia (TRH) and interval training performed in normoxia (TRN) situation of exposure to hypoxia at rest and situation of hypoxia with high--intensity interval training. * represents statistical difference (p<0.05).

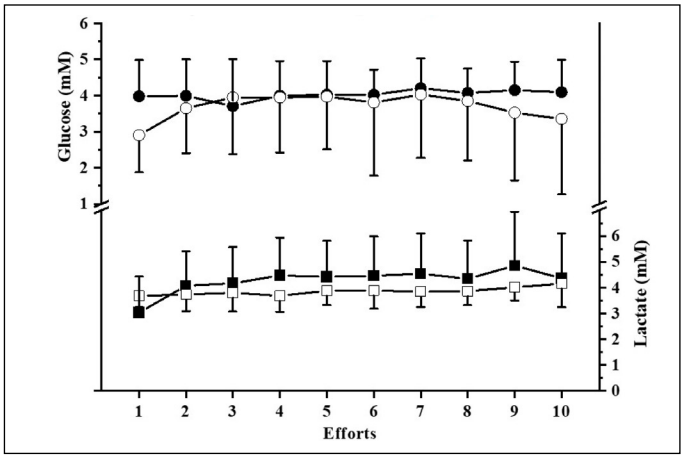

Figure 5. Comparison between blood lactate and glucose concentrations during the ten 1min efforts in the different training sessions. White symbols represent normoxia situation; black symbols represent hypoxia situation.

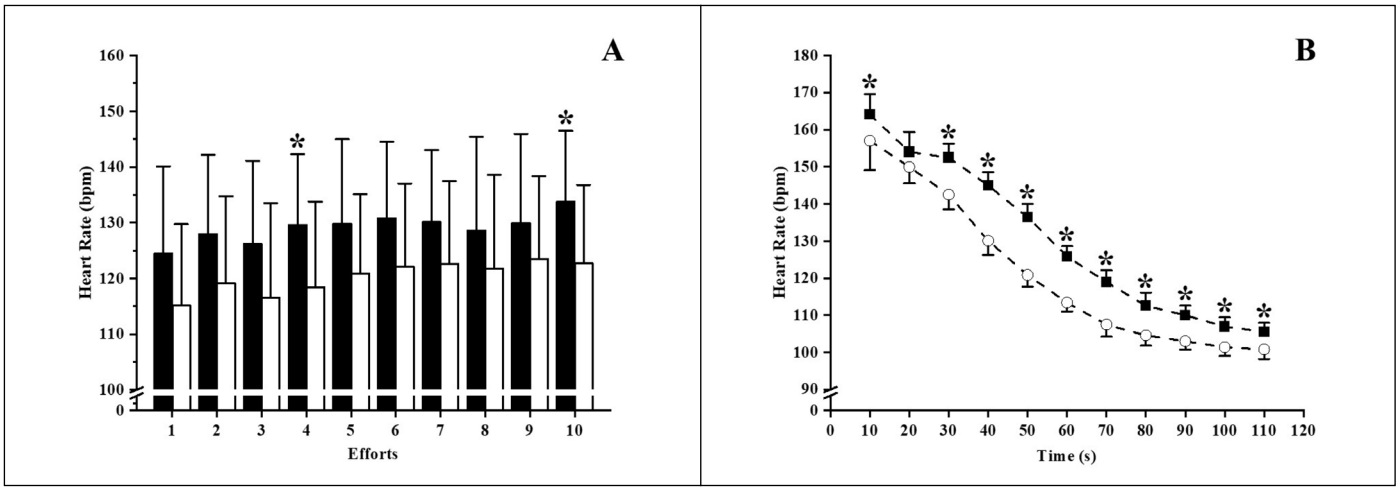

Figure 4. Panel A- Comparison between the average frequency during the intervals between efforts. Panel B- Comparison of heart rate behavior during recovery time. Represents training session in normoxia with recovery between intervals in hypoxia; □ represents the training session held in normoxia at maximum intensity. * represents the statistical difference between situations (p<0.05). ■ represents training performed with intervals in hypoxia; ○ represents training performed with intervals in normoxia.

Other studies show that physical exercise in normoxia performed at high-intensity can decrease PiO_2 values from 35 mmHg to 3.1 mmHg, thus exercise at high-intensity seems to be enough to stabilize this pathway.[16,17,23]

Studies report PaO_2 values of 46 mmHg and PiO_2 values of 2.3 mmHg when high-intensity exercises are combined with hypoxia, being enough for HIF1α stabilization.[17,18] In the present study, when hypoxia was added during the recovery intervals, we found PaO_2 values of 50.26 ± 4.57 mmHg.

We are unable to say whether the decrease in oxygen supply in the proposed session was sufficient to stabilize HIFα, since we did not perform muscle biopsies to determine its concentration or expression. The mean SpO_2 value during the intervals was similar to or lower than observed in studies that have demonstrated improved performance with IHT, compared to training performed in normoxia.[3,6,24] Based on the aforementioned information, it can be speculated that the hypoxia addition during interval is an additional stimulus to optimize physiological gains, with the advantage of maintaining the "quality of effort," since the efforts can be performed in normoxia.

The HD was higher in the recovery periods in hypoxia, however, literature provides limited information concerning the HD required to trigger positive adaptations.[25] The HD for a given activity seems to be dependent on both exposure time and the variation in SpO_2 values. This variation seems to be influenced by several factors, such as age, training level, and ability to maintain oxygen uptake at altitude and during the ventilatory response to hypoxia. The ventilatory response can alter the entire oxygen consumption cascade from alveoli to muscle PiO_2.[16,26]

There was a tendency for [La] to increase in T_RH compared to T_RN, however no differences were found. This was similar to observed in IHT.[5] The increase in [La] due to hypoxia can be explained in part, by the greater use of anaerobic pathways to generate energy, since the aerobic pathway is compromised when less oxygen is transported to cells.[27] In this study, the [Glu] maintained stable during training, suggesting that hypoxia only in the recovery was not enough to increase the lactic demand to generate energy. However, some authors have reported no changes in [La] after hypoxia, a phenomenon known as the "lactate paradox".[28]

Hypoxia can cause reduction in [Glu] accelerating the fatigue and decreasing performance.[29] During this study, the participants performed efforts without any decrease in intensity or increase other parameters associated to fatigue.

The HR was frequently used to determine internal training load, it is noted that T_RH was effective in changing HR during recovery, showing a greater internal load for T_RN, Internal load manipulation was associated with improved performance.[30] Thus, add hypoxia in training seems to be alternative to raise internal load, without increase the external load. This hypothesis still needs to be confirmed in future chronic studies. Besides, studies that manipulate training loads during hypoxia have consistently reported additional benefits in performance-related parameters.[4,5]

The present study has limitations: the subjects did not carry out a training session entirely in hypoxia or other combinations, although our objective was to prevent the entire session from being performed with low O_2 availability for the reasons previously reported. No muscle biopsy was performed to determine biomolecular parameters.

CONCLUSION

We conclude that hypoxia during the intervals between efforts can be an additional and innovative stimulus for high-intensity interval training, without hindering the execution of physical efforts and external training load, maintaining the intensity of efforts, furthermore, this acute model proved to be effective in promoting substantial acute physiological alterations.

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All authors declare no potential conflict of interest related to this article

AUTHORS' CONTRIBUTIONS: All authors contributed individually and significantly to: a) Substantial contribution in the conception or design of the work, acquisition, analysis or interpretation of data for the work – Writing of the work or critical review of its intellectual content; b) Final approval of the version of the manuscript to be published; c) Agree to be held accountable for all aspects of the work, in order to ensure that any matter relating to the completeness or accuracy of any part of the work is properly investigated and resolved. YFF, CDC, FAR, JCA, GLP, DRB, FBMG and MP.

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