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Acute physical exercise under hypoxia improves sleep, mood and reaction time

Valdir de Aquino-Lemos [a], Ronaldo Vagner T. Santos [a,e], Hanna Karen Moreira Antunes [e], Fabio S. Lira [c], Irene G. Luz Bittar [d], Aline V. Caris [a], Sergio Tufik [a,e], Marco Tulio de Mello [b,*]

[a] Departamento de Psicobiologia, Universidade Federal de São Paulo (UNIFESP), Brazil
[b] Departamento de Esportes, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil
[c] Departamento de Educação Física, Universidade do Estado de São Paulo (UNESP), Presidente Prudente, São Paulo, Brazil
[d] Departamento de Fisiologia, Universidade Federal de São Paulo, Nutrição, (UNIFESP), Brazil
[e] Departamento de Biociências, Universidade Federal de São Paulo (UNIFESP), Brazil

HIGHLIGHTS

- Hypoxia impairs sleep, reaction time and mood.
- Hypoxia may increase the risk of accidents.
- Acute physical exercise under hypoxia improves sleep, mood and reaction time.

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ABSTRACT

This study aimed to assess the effect of two sessions of acute physical exercise at 50% VO_{2peak} performed under hypoxia (equivalent to an altitude of 4500 m for 28 h) on sleep, mood and reaction time. Forty healthy men were randomized into 4 groups: Normoxia (NG) (n = 10); Hypoxia (HG) (n = 10); Exercise under Normoxia (ENG) (n = 10); and Exercise under Hypoxia (EHG) (n = 10). All mood and reaction time assessments were performed 40 min after awakening. Sleep was reassessed on the first day at 14 h after the initiation of hypoxia; mood and reaction time were measured 28 h later. Two sessions of acute physical exercise at 50% VO_{2peak} were performed for 60 min on the first and second days after 3 and 27 h, respectively, after starting to hypoxia. Improved sleep efficiency, stage N3 and REM sleep and reduced wake after sleep onset were observed under hypoxia after acute physical exercise. Tension, anger, depressed mood, vigor and reaction time scores improved after exercise under hypoxia. We conclude that hypoxia impairs sleep, reaction time and mood. Acute physical exercise at 50% VO_{2peak} under hypoxia improves sleep efficiency, reversing the aspects that had been adversely affected under hypoxia, possibly contributing to improved mood and reaction time.
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1. Introduction

Atmospheric pressure and, consequently, the partial pressure of inspired oxygen (PO_2) decrease at high altitudes. As a result, a reduction in the PO_2 of arterial blood and body tissues is classically described. Accordingly, physiological and behavioral changes can occur in both animal models and humans [1].

A study performed by Gao et al. [2] showed that individuals living at an altitude of 4500 m for five years exhibited an impairment of mood, sleep quality and cognitive functions, and exposure to hypobaric hypoxia (3700–5100 m for five days) was found to promote negative changes in mood and reaction time [3]. Roach et al. [4] conducted a study on a mountain at 5000 m and demonstrated that exposure to hypoxia for 16 days impaired reaction time. Such chronic impairments may occur within the first few hours after exposure. Reductions in sleep efficiency, slow-wave sleep and REM sleep were observed under simulated altitude in a normobaric chamber for 24 h. Several mood parameters were impaired, with depressed mood, anger, fatigue, and vigor scores being observed [5]. It is clear that hypoxia causes physiological and behavioral impairments, which may increase the risk of accidents and death [6]. Furthermore, hypoxia can cause health problems such as hypertension and cardiovascular diseases [7].

Therefore, different strategies are employed to minimize the damage caused by hypoxia, which include dietary supplements, medications and the use of oxygen [8,9,10,11,12,13,14]. However, physical exercise was the strategy used in the present study.

* Corresponding author at: UFMG, Av. Presidente Carlos Luz, 4664, Pampulha, Belo Horizonte, MG 31310-250, Brazil.
E-mail address: tmello@demello.net.br (M.T. de Mello).

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Physical exercise performed under normoxia has been described as an approach that improves many body functions, including sleep, mood and cognition [15,16,17,18,19,20]. To our knowledge, however, the effects of physical exercise performed under hypoxia on sleep, mood and cognition have not been simultaneously evaluated.

Therefore, this study aimed to evaluate the effect of two sessions of acute physical exercise at 50% VO_{2peak} performed under hypoxia equivalent to an altitude of 4500 m for 28 h on sleep, mood and reaction time. Based on the knowledge that acute physical exercise performed under normoxia benefits health in general, we hypothesized that the two sessions at 50% of VO_{2peak} performed under hypoxia might reverse the impairment of sleep, mood and reaction time.

2. Methods

2.1. Participants

Before participating in the study, the volunteers were informed about all possible risks associated with the experimental procedure. The study was approved by the Research Ethics Committees of the Federal University of São Paulo - São Paulo Hospital (Universidade Federal de São Paulo - Hospital São Paulo) (# 1110-1108) and followed the guidelines established in the Declaration of Helsinki of 1964. Data were collected at the Psychobiology and Exercise Research Center (Centro de Estudos em Psicobiologia e Exercício-CEPE) between 2012 and 2014.

The study was advertised by electronic and print media. Interested individuals came into contact with the researcher, who recruited personally.

The sample consisted of 40 healthy male volunteers who were randomized into 4 groups: Normoxia (NG) (n = 10); Hypoxia (HG) (n = 10); Exercise under Normoxia (ENG) (n = 10); and Exercise under Hypoxia (EHG) (n = 10). The characteristics of the sample were described as the mean ± standard deviation, as shown in Table 1. All volunteers performed specific activities, which included strength training, cycling and running two or three times a week for at least 6 months. The volunteers typically went to bed at approximately 22:00 pm and woke up at 07:00 am. All participants were males aged 20 to 30 years. The exclusion criteria were as follows: the use of tobacco, alcohol, illicit drugs, or any others drugs; exposure to hypoxic conditions in the last 12 months; and heart problems or sleep disorders, including obstructive sleep apnea, periodic limb movement disorder (PLMD), or any other alterations that could increase sleep fragmentation.

Of the 40 volunteers, 38 completed the study. One subject was excluded due to the presence of acute mountain sickness symptoms during the experiment, including severe headache and nausea [21]; these complaints were substantiated according to the Lake Louise consensus criteria [22].The other subject was excluded because of the occurrence of obstructive sleep apnea, detected through polysomnography.

2.2. Experimental design and procedures

During the first visit to the laboratory, the volunteers underwent a resting and effort electrocardiogram. On the second visit, they underwent a spirometry test to determine $VO_{2peak.}$ On the third visit, the volunteers were subjected to the experimental procedure corresponding to the group to which they were randomly assigned.

The entire experiment was conducted in a double-blind manner for the hypoxic condition. The time at which sleep, mood and reaction time were assessed in all groups as well as the time of hypoxia exposure are shown in Fig. 1. Exposure to hypoxia was initiated at 8 am on the first day at an FiO_2 of 20.9% O_2, equivalent to sea level. This fraction was gradually reduced for 1.5 h until reaching an FiO_2 of 13.5% O_2, corresponding to a simulated altitude of 4500 m. The simulation was completed on the second day at 12:10 am, when FiO_2 was returned to sea level conditions.

One week after the first adaptation polysomnography was performed, the volunteers arrived in the laboratory to sleep, after which the second polysomnographic assessment was conducted under normoxia.

On the first day, the volunteers awoke at 7:00 am, and after 40 min, the mood and reaction time assessments were conducted. The ENG and EHG groups performed one physical activity session. The third polysomnographic evaluation was carried out on the second night, 10 h after the first acute physical exercise session and 14 h after the initiation of hypoxic conditions.

On the second day, the volunteers awoke at 7:00 am after remaining under hypoxia for 23 h, and the second acute physical exercise session began after 27 h. The second mood and reaction time assessment was performed immediately after the end of the second acute physical exercise session. This timeline was employed to observe the response of mood and reaction time after the second standardized exercise session under the same conditions as the first day.

At the end of the experiment, the volunteers were dismissed when no clinical symptoms that might prevent them from leaving the laboratory were observed.

Throughout the experiment, each volunteer remained alone in the adapted room with a bathroom for 28 h after the initiation of hypoxic conditions at sea level. The volunteers had free access to television, the internet, books, magazines and a cell phone during the experimental period [5]. The investigators observed the volunteers from outside the room using a closed-circuit camera system to ensure that the volunteers did not nap during the day.

Four meals were served in the course of the experiment: breakfast (7:10 am to 7:30 am), lunch (12:20 pm to 1:20 pm), afternoon snack (4 pm to 4:20 pm) and dinner (7:20 pm to 8:20 pm), totaling 1784.80 ± 227.0 kcal/day. The Harris–Benedict equation [23] was

Table 1
Descriptive statistics for the sample.

Measure	Normoxia Mean ± (*SD*)	Hypoxia Mean ± (*SD*)	Exercise under normoxia Mean ± (*SD*)	Exercise under hypoxia Mean ± (*SD*)	*P*
Age (years)	22.2 ± (3.1)	23.3 ± (2.2)	26.1 ± (3.2)	24.1 ± (2.4)	0.06
Body Weight (kg)	69.2 ± (1.4)	67.5 ± (8.2)	71.4 ± (10.3)	72.1 ± (11.2)	0.83
Height (m)	1.78 ± (0.05)	1.75 ± (0.08)	1.75 ± (0.07)	1.78 ± (0.07)	0.83
BMI (kg/m^2)	21.1 ± (7.3)	22.3 ± (2.1)	23.1 ± (1.2)	22.1 ± (1.3)	0.56
$HR_{Max.}$	191.2 ± (3.1)	194.3 ± (8.2)	186.3 ± (11.2)	197.3 ± (6.2)	0.30
$VO_{2Max.}$	47.1 ± (4.2)	47.4 ± (6.2)	44.4 ± (5.4)	49.1 ± (3.1)	0.39
Educational level (years)	15.00 ± (1.9)	16.4 ± (1.26)	15.30 ± (1.76)	16.5 ± (1.19)	0.11
Energy expenditure (kcal)	1757.2 ± (141.1)	1718.1 ± (158.2)	1751.1 ± (160.5)	1858.5 ± (140.1)	0.30
Carbohydrate (%)	61.5 ± (1.2)	62.3 ± (1.0)	60.8 ± (1.5)	63.3 ± (1.7)	0.20
Protein (%)	23.6 ± (0.5)	24.2 ± 0.6)	24.9 ± (0,7)	23.3 ± (0.5)	0.60
Fat (%)	14.2 ± (0.69)	13.9 ± (0.4)	14.7 ± (0.8)	14.0 ± 0.52	0.40

Results are reported as the mean ± (standard deviation). Comparisons were performed using one-way ANOVA. BMI = body mass index; HR = maximum heart rate. The significance level was set at $p \leq 0.05$.

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