The effects of exposure to acute hypoxia at rest on time trial performance in national category cyclists

Jesús Torres-Pérez[1], Aitor Pinedo-Jauregi[2], Jesús Cámara[3], Oier Moreno, Javier Yanci[3]

[1]Faculty of Education and Sports. Universidad del País Vasco. UPV/EHU. Vitoria-Gasteiz. [2]Department of Physical Education and Sports. Faculty of Education and Sports. Universidad del País Vasco. UPV/EHU Vitoria-Gasteiz. España. Physical Activity and Exercise Group. Instituto de investigación y salud Bioaraba Vitoria-Gasteiz. [3]Society. Sports and Physical Exercise Research Group (GIKAFIT). Department of Physical and Sports Education. Faculty of Education and Sports. Universidad del País Vasco. UPV/EHU. Vitoria-Gasteiz.

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Summary

Objectives: The objectives of the present study were to study the physiological responses of national class cyclists after exposure to acute normobaric hypoxia at rest, to analyze whether performance in a simulated time trial was altered after exposure to acute hypoxia under normoxic conditions. and describe the relationship of physiological responses, after exposure to acute hypoxia at rest, with simulated time trial performance.
Material and method: Nine national class cyclists participated in this study. Metabolic and cardiorespiratory variables were measured before and after resting exposure to acute normobaric hypoxia for 30 min. Subsequently, a simulated time trial cycling test was performed on a cycle ergometer.
Results: Despite the fact that after exposure to hypoxia, significant differences were observed between the pre and post moments in some gas exchange variables such as the equivalent of carbon dioxide consumption ($EqCO_2$, $P = 0.001$, ES = -1.58 high), end-tidal pressure of oxygen ($PetO_2$) and end-tidal pressure of carbon dioxide ($PetCO_2$) ($P < 0.05$, ES = 0.84-0.96, high), no significant difference was observed ($P > 0.05$) in performance variables between exposure to normoxia and hypoxia.
Conclusions: Acute hypoxic exposure did not cause an improvement in cycling time trial performance under normoxic conditions, despite causing a change in some of the immediate physiological responses to hypoxic exposure.

Key words:
Altitude. Hypoxia. Cycling. Physiology. Hypocapnia. Performance.

Efectos de una exposición a hipoxia aguda en reposo en el rendimiento en contrarreloj en ciclistas de categoría nacional

Resumen

Objetivos: Los objetivos del presente estudio fueron estudiar las respuestas fisiológicas de ciclistas de clase nacional tras una exposición a hipoxia aguda normobárica en reposo, analizar si el rendimiento en una prueba contrarreloj simulada sobre cicloergómetro en normoxia se veía alterada tras la exposición a hipoxia aguda frente a condiciones de normoxia y describir la relación de las respuestas fisiológicas, tras la exposición a hipoxia aguda en reposo, con el rendimiento en contrarreloj simulada.
Material y método: En este estudio participaron nueve ciclistas de clase nacional. Se midieron variables metabólicas y cardiorrespiratorias antes y después de la exposición en reposo a hipoxia aguda normobárica durante 30 min. Posteriormente, se realizó una prueba simulada de ciclismo contrarreloj sobre cicloergómetro.
Resultados: A pesar de que tras la exposición a hipoxia se observaron diferencias significativas entre el momento pre y post en algunas variables de intercambio gaseoso como el equivalente de dióxido de carbono ($EqCO_2$, p = 0,001, ES = -1,58 alto), la presión final espirada de oxígeno ($PetO_2$) y la presión final espirada de dióxido de carbono ($PetCO_2$) (p <0,05, ES = 0,84-0,96, alto), no se observó ninguna diferencia significativa (p >0,05) en variables de rendimiento tras la condición de exposición a normoxia y a hipoxia.
Conclusiones: La exposición a hipoxia aguda en reposo no provocó alteraciones de mejora o detrimento del rendimiento en contrarreloj en ciclismo en condiciones de normoxia, a pesar de provocar un cambio en algunas de las respuestas fisiológicas inmediatas a la exposición a hipoxia, además algunas de las respuestas en variables fisiológicas tras exposición a hipoxia en reposo guardan relación con variables fisiológicas durante la contrarreloj.

Palabras clave:
Altitud. Hipoxia. Ciclismo. Fisiología. Hipocapnia. Rendimiento.

Correspondence: Jesús Torres-Pérez
E-mail: jsstorres009@gmail.com

Introduction

Hypoxia has been defined as a situation in which the fraction of inspired oxygen is lower than under normoxic conditions, whether due to a lower partial pressure of oxygen in the atmosphere (hypobaric hypoxia) or a lower concentration of oxygen in the air inspired (normobaric hypoxia)[1]. In both cases, the reduced fraction of inspired oxygen (FiO_2 <150 mmHg)[2] compromises oxygen absorption by tissues and negatively impacts instantaneous physical performance, especially aerobic performance[3]. Hypoxia training helps to produce a series of responses that, in the medium and long term, can lead to adaptations that improve performance in sport[4-8]. Perhaps for this reason, numerous endurance athletes use various methods of exposure to hypoxia to produce suitable physiological responses that manifest through improvements to performance in sport[9].

Numerous scientific studies have been published in recent decades that examine the resulting improved performance in sport from various methods of training and exposure to hypoxia in athletes from various athletic disciplines[5,7,10,11] and, more specifically for this case, in cycling[10,12–17]. One of the methods that appear to improve performance in sport is the so-called "living high-training low" (LHTL) method[5]. This method basically consists of repeated exposure to hypobaric hypoxia at rest (living high) combined with training sessions at sea level (training low). Through this exposure to hypobaric hypoxia (living high), the goal is to induce physiological adaptations that improve performance without modifying any of the training characteristics for altitude reasons (training low)[18,19]. A number of different methodological applications exist based on the desired responses and adaptations[20]. Although this method of exposure to hypoxia and training seems to have positive effects on performance in cyclists[12,13,15,16], continued exposure to hypoxia requires significant logistical and financial resources. These costs make it difficult, or even impossible in some cases, for sports teams to use this method. For that reason, the effects of exposure to (normobaric) hypoxia at rest on performance in cycling has also been examined in recent years[16,17,21,22].

It has been observed that acute exposure to hypoxia at rest can alter the ability to assimilate and distribute oxygen through the body, leading to an acute reduction in performance[23]. This type of exposure seems to produce adaptive responses following a period of time after the intervention (one to two hours up to a maximum of five days)[24]. A number of studies on the impact of acute (normobaric) hypoxia on performance in trained triathletes, cyclists and runners[25] have stated that the reduction to performance can be mainly explained by the acute modification of gas exchange variables, with these corresponding to the specific type of exposure to acute hypoxia. Although the responses to this method of exposure to hypoxia and the effect on performance in sport under these conditions have been studied[22,23], the impact from the responses to exposure to acute hypoxia on immediate performance in cycling under normoxic conditions is unknown for the time being. The responses in gas exchange variables following exposure to acute (normobaric) hypoxia could be associated with performance variables in medium- and long-duration time trial (20-60 min) cycling (oxygen consumption, watts and perceived exertion cardiorespiratory variables)[26] under normoxic conditions. Hence, the hypothesis for this study attempts to compare the effect of exposure to acute normobaric hypoxia against normoxic conditions and physical performance in a 20-minute simulated time trial under normoxic conditions.

Therefore, the objectives for this study were: 1) to study the physiological responses (blood, metabolic and cardiorespiratory variables) in national category trained cyclists following exposure to acute normobaric hypoxia at rest; 2) to analyse whether performance (mechanical and physiological variables) in a 20-minute simulated time trial under normoxic conditions was altered following exposure to acute hypoxia compared with normoxic conditions as a placebo test; and 3) to describe the link between the physiological responses following exposure to acute hypoxia at rest and simulated time trial performance under normoxic conditions.

Material and method

Participants

Nine national category[27] trained cyclists (7 men and 2 women) (aged 26.0 ± 3.4 years, height: 169.3 ± 5.9 cm, mass: 63.9 ± 5.1 kg, training: 9.6 ± 1.0 hours/week, MMP20: 4.6 ± 0.3 W/Kg) took part in the study. The criteria for inclusion in this study were: 1) having at least six years of experience in the practice of competitive cycling; 2) having taken part in national cycling competitions; 3) engaging in a weekly training volume of least eight hours; and 4) not having been previously exposed to normobaric hypoxia, which could lead the participant to distinguish the placebo test from the hypoxia protocol. Before starting the study, all the participants were informed of the risks and benefits of taking part and they were asked to complete an informed consent form. The study was approved by the Ethics Committee for Research with Human Beings (CEISH) of the University of the Basque Country (UPV/EHU) (NoRefCEid: M10/2017/200). This study followed the ethics standards established in the 2013 Declaration of Helsinki.

Procedure

All the participants completed two test sessions on two different days in the laboratory. The second session took place between two and six days after the first. For the 24 hours prior to the test sessions, the participants engaged in no strenuous exercise, consumed no alcohol or stimulant drinks that could alter the test conditions, and reported no discomfort. General data was collected on the number of training hours per week and the best declared power record over 20 minutes in the 2022 season (MMP20). The participants were subjected to a normobaric hypoxia protocol (FiO_2 = 0.09) or a normoxia protocol (placebo). The same measurement and hypoxia apparatus placement procedures were

performed in both protocols, with the exception being that the oxygen supply regulator was kept fully open in the normoxia protocol so that the fraction of inspired oxygen supplied to the breathing mask was equal to atmospheric levels ($FiO_2 = 0.209$). Exposure to acute hypoxia or normoxia was performed in a randomised manner. The participants were therefore unaware of the type of exposure to which they were subjected and the percentage of oxygen (O_2) supplied by the generator after a continuous time (overuse) was not changed, ensuring the same faction of inspired oxygen under the hypoxia conditions. Red blood cell counts were taken when the subjects arrived at the laboratory. Subsequently, after 10 minutes at rest, heart rate (HR) and gas exchange variables were measured constantly.

Furthermore, occasional measurements were taken of glucose, lactate and arterial oxygen saturation (SpO_2) at the end of the 10 minutes at rest. All these variables were measured both before (pre) and after (post) exposure to hypoxia or normoxia. The participants then completed a warm-up period of five minutes that consisted of continuous pedalling at 90 pedal strokes/minute at an intensity of 70% of their MMP20. This was followed by a 20-minute time trial on a cycle ergometer (TT). During the warm-up and TT, the same measurements were taken of the aforementioned variables, as well as perceived exertion variables. The entire study procedure took place in the laboratory under environmental conditions of 20-22ºC in temperature and 30-35% humidity at an altitude of 539 metres above sea level. Figure 1 shows a diagram of the study procedure.

Measurements

Initial measurements

Haematocrit and haemoglobin: a sample of capillary blood was taken from the index finger of the right hand of the participants using a haematocrit and haemoglobin parameter measuring device (Diacare BC-101, Diacare®, Shenzen, China) following the previously established protocol[28]. The erythrocyte count percentage in capillary blood was obtained, as well as the haemoglobin concentration in capillary blood[29].

Measurements "pre and post" exposure to hypoxia and normoxia protocol

Blood glucose concentration: the blood glucose values were obtained using a glucometer (Accu-Chek Aviva, Accu-Ceck®, Barcelona, Spain)[30], based on a capillary blood sample taken after puncture of the previously sterilised index finger of the right hand[28].

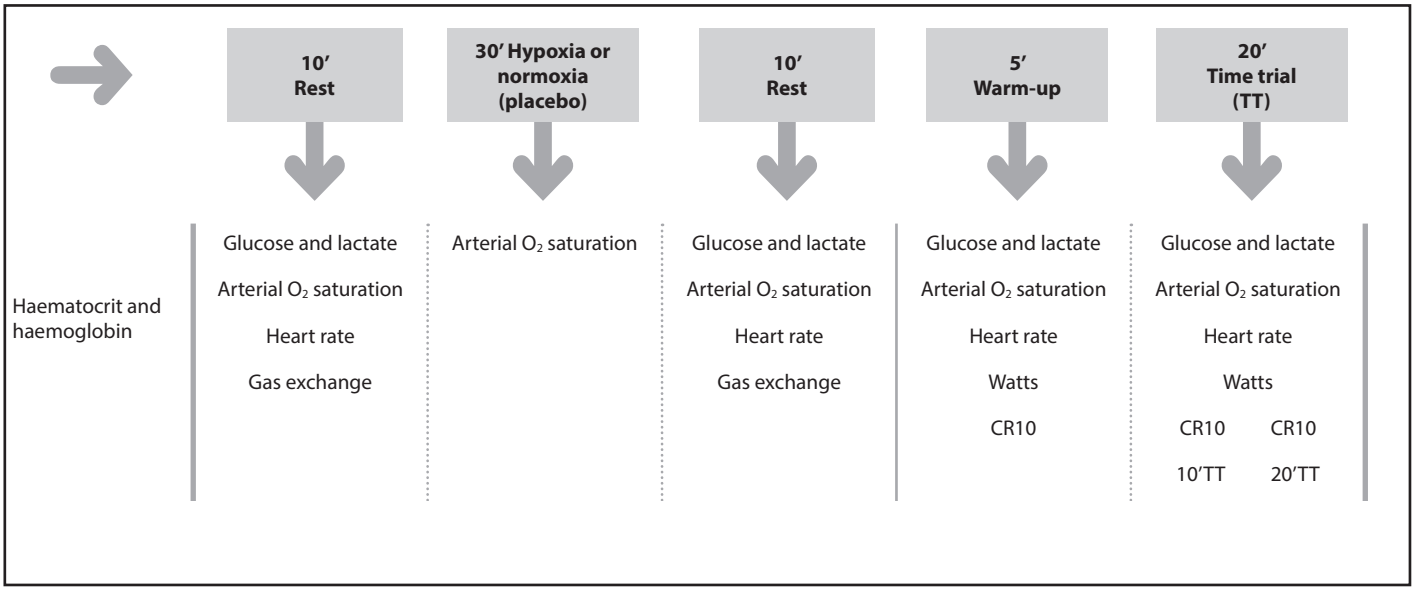
Lactate concentration: the previously sterilised right ear lobe of the participants was punctured[28] to measure the blood lactate value using a lactate meter (Lactate Pro, Arkray, KDK Corporation®, Kyoto, Japan)[31].

Arterial oxygen saturation (SpO_2): a pulse oximeter (300 I, Konica Minolta®, Tokyo, Japan) was used on the index finger of the right hand[32] to determine arterial oxygen saturation.

Heart rate (HR): average HR was recorded both during the rest periods while sat on a chair (pre-exposure and post-exposure) and during completion of the time trial test[33]. An HR measurement band (Polar H10, Polar Electro Oy®, Kempele, Finland)[34] positioned in the middle of the chest of each participant and a data collection device (Garmin 520, Garmin Ltd.®, Olathe, Kansas) were used for this purpose[33].

Gas exchange: a breath-by-breath respiratory gas analyser (Medisoft™ Ergocard, Medisoft Group, Sorinnes, Belgium) was used. The gas analysis system was calibrated before each test for both gas volume and concentration using benchmark gases and a 1 L syringe (nSpire Koko, nSpire Health Inc.®, Longmont, CO, USA). When at rest, the participants were sat on a chair without making any physical effort to ensure that

Figure 1. Diagram of the research procedure and tests conducted.



the gas exchange measurements were representative of their physiological state. Gas exchange was measured at rest, obtaining values for oxygen consumption (VO_2), relative oxygen consumption (VO_{2r}), the ventilatory equivalent for oxygen (EqO_2), the ventilatory equivalent for carbon dioxide ($EqCO_2$), the partial pressure of oxygen at the end of exhalation ($PetO_2$) and the partial pressure of carbon dioxide at the end of exhalation ($PetCO_2$).

Protocol for exposure to hypoxia/normoxia

The randomised exposure to hypoxia or normoxia took place over two sessions. Participants were sat on a chair and a non-rebreather mask (Hypoxico Biolaster, Biolaster®, Andoain, Spain) was put in place and connected to a normoxic altitude generator (Hypoxico, Hypoxico, Inc.®, New York, USA)[35]. Normobaric hypoxia exposure was provided for 30 minutes[36], simulating an altitude of 4,500 metres above sea level and corresponding to an FiO_2 of 0.09. The hypoxic load was controlled using a pulse oximeter[37]. For the normoxia session (placebo), the FiO_2 was 0.209.

Simulated time trial test on a cycle ergometer

The participants performed a 20-minute simulated time trial test[38] on a cycle ergometer (Lode Escalibur, Lode®, Groningen, Netherlands) at the two sessions (hypoxia session and normoxia session) by applying a constant load regardless of cadence (hyperbolic mode). The cycle ergometer measurements were previously adjusted to the preference of the participants. The time trial test was preceded by a 5-minute warm-up at 70% of the MMP20 declared by each cyclist. During the simulated time trial test, each participant could manually increase or decrease the resistance (W) setting on the cycle ergometer to their preference. The resistance was concealed from the participants in order to prevent self-regulation by the participants during the time trial based on the power displayed. They were only shown how much time had passed[26]. The MMP20 from the simulated time trial was recorded[38], both in absolute values (W) and relative to the body mass of the participants (W/kg)[40]. HR and gas exchange variables were also recorded throughout the 20 minutes. Blood glucose and lactate concentration, as well as the SpO_2, were recorded at the start and at minutes 10 and 20 of the time trial test. The subjective perceived exertion was recorded during the time trial test using the Borg CR10 scale[41]. The participants, who were familiar with the use of this scale, were asked to declare their subjective perceived exertion from the time trial test at the moment the record was taken and retrospectively. This cardinal numerical scale from 0 to 10 rates the physical demand perceived by the subject, with 0 being "no effort at all" and 10 being "extremely difficult". The scale was visually available to the participants when they were asked to rate the perceived exertion.

Statistical Analysis

The results from the study are shown as an average with a standard deviation (SD). The Shapiro-Wilk and Levene tests were performed to check data normality and variance equality, respectively. The paired sample t-test was used to analyse the pre vs. post differences in averages from the results obtained at the various moments of the study, the post-test differences between exposure to normobaric hypoxia and normoxia, and the differences in the results from the hypoxia and normoxia simulated time trial tests. The magnitude of the differences found in the variables was calculated using the difference percentage (Dif %) and the Cohen effect size (ES)[42]. The ES was classified as: high (≥0.8), moderate (0.8-0.5), small (0.5-0.2) or trivial (<0.2)[42]. A negative effect size indicates that the result value fell, while a positive result indicates that the result value increased. The Pearson (r) correlation was used to associate the difference percentage (pre *vs*. post) in the various variables analysed with the results from the variables obtained during the simulated time trial, as well as analysis of the links between the post hypoxia or normoxia protocol values and the results obtained during the simulated time trial test. The levels of correlation were classified as: perfect (1.0), very high (<1.0-0.9), high (<0.9-0.7), moderate (<0.7-0.4), very low (<0.4-0.2) or nil (0)[43]. The data analysis was performed using JASP statistical analysis software (JASP, JASP Free Project, University of Amsterdam, Amsterdam, Netherlands). Statistical significance was set at P <0.05.

Results

The results from initial (pre) measurement of red blood cell variables were 44.1 ± 2.1% haematocrit and 15.0 ± 0.7 g/dl haemoglobin in the protocol for exposure to hypoxia, and 44.8 ± 4.5% haematocrit and 15.2 ± 1.5 g/dl haemoglobin in the protocol for exposure to normoxia. There were no significant differences (p >0.05) in these pre values between the session of exposure to hypoxia and the session of exposure to normoxia.

The results corresponding to the pre and post exposure moments in the hypoxia protocol and the normoxia protocol are shown in Table 1. Following exposure to hypoxia, significant changes were only observed between the pre and post moments in the $EqCO_2$ (p = 0.001, ES = -1.58 high), $PetO_2$ and $PetCO_2$ (P <0.05, ES = 0.84-0.96) variables. Following exposure to normoxia, significant changes were observed between the pre and post moments in the $PetO_2$ (P <0.05, ES = -1.23, high) variable.

On the other hand, no significant differences were observed in the pre values between the exposure to hypoxia and normoxia. However, in terms of the post values, the participants who underwent the hypoxia protocol showed relatively higher values of VO_2 and VO_2 than those who were exposed to normoxia (P <0.05, ES = 0.924).

Table 2 shows the results obtained from the time trial test following exposure to hypoxia and normoxia. No significant difference was observed (p >0.05) between exposure to normoxia and to hypoxia.

No significant correlations were observed between the difference percentage and effect size in the average variables for pre and post exposure to hypoxia/normoxia and the results obtained in the simulated time trial test, neither under exposure to hypoxia nor under exposure to normoxia. On the other hand, correlations were found with statistically

Table 1. Results obtained before (pre) and after (post) the exposure to hypoxia and normoxia in the variables analysed.

	Pre Exposure	Post Exposure	ES (Dif %)	*P*
Hypoxia				
Glucose (mg/dl)	101.8 ± 17.6	99.2 ± 9.8	0.12 (-2.55)	0.728
Lactate (mmol/dl)	1.5 ± 0.3	1.5 ± 0.3	0.13 (-0.00)	0.708
SpO_2 (%)	97.5 ± 0.8	97.5 ± 2.0	0.25 (0.00)	0.468
HR (bpm)	62.6 ± 11.5	62.6 ± 3.7	0.00 (0.00)	1.000
Gas exchange				
VO_2 (l/min)	0.3 ± 0.0	0.3 ± 0.0	-0.09 (0.00)	0.776
$VO_{2\,r}$ (ml/kg/min)	5.4 ± 1.1	5.5 ± 0.6	-0.05 (1.85)	0.884
EqO_2	33.6 ± 3.7	32.8 ± 4.4	0.49 (-2.38)	0.177
$EqCO_2$	38.3 ± 3.8	42.4 ± 4.7*	-1.58 (10.7)	0.001
$PetO_2$ (mmHg)	96.5 ± 3.6	92.4 ± 4.8**	0.95 (-4.25)	0.021
$PetCO_2$ (mmHg)	35.1 ± 3.4	32.6 ± 3.8**	0.84 (-7.12)	0.035
Normoxia				
Glucose (mg/dl)	91.5 ± 9.2	100.0 ± 15.4	-0.65 (9.29)	0.086
Lactate (mmol/dl)	1.7 ± 0.3	1.4 ± 0.2	0.64 (-15.06)	0.088
SpO_2 (%)	97.2 ± 1.0	97.3 ± 0.8	-0.09 (0.10)	0.782
HR (bpm)	59.3 ± 9.9	59.5 ± 10.1	-0.09 (0.34)	0.777
Gas exchange				
VO_2 (l/min)	0.3 ± 0.0	0.3 ± 0.0#	-0.12 (0.00)	0.709
$VO_{2\,r}$ (ml/kg/min)	4.8 ± 0.4	4.9 ± 0.6#	-0.14 (2.08)	0.666
EqO_2	37.0 ± 4.0	34.5 ± 5.4	0.54 (-6.76)	0.142
$EqCO_2$	38.9 ± 4.9	41.0 ± 5.0	-0.52 (5.40)	0.154
$PetO_2$ (mmHg)	99.4 ± 3.5	95.3 ± 4.6***	1.23 (-4.12)	0.006
$PetCO_2$ (mmHg)	34.4 ± 3.2	32.8 ± 2.2	0.61 (-4.65)	0.100

$EqCO_2$: average values for carbon dioxide ventilatory equivalent; EqO_2: average values for oxygen ventilatory equivalent; HR: heart rate; ES: effect size; Dif %: difference between post and pre values expressed as a percentage; $PetCO_2$: average values for pressure of carbon dioxide at end-tidal breathing; $PetO_2$: average values for pressure of oxygen at end-tidal breathing; Post: moment after exposure to hypoxia or normoxia; Pre: moment before exposure to hypoxia or normoxia; SpO_2: arterial oxygen saturation; $VO_{2\,r}$: average oxygen consumption values standardised by body mass; VO_2: average oxygen consumption values; NS: not significant.
*≤0.001; **P <0.05; ***P <0.01; significant differences regarding the pre exposure values.
#p <0.05 significant differences between exposure to hypoxia and exposure to normoxia.

significant results between the post intervention moment and the time trial test, both under exposure to hypoxia and under exposure to normoxia. These results are shown in Table 3 below.

Discussion

This study analysed the effects in national category cyclists of acute (normobaric) hypoxia at rest on physical performance during an immediately subsequent simulated time trial test on a cycle ergometer. The variables on physiological response and performance following exposure to hypoxia have been extensively described in physical exercise situations[12]. Previous studies[9] show that the mechanisms for improving physical performance may be related to various central or peripheral adaptations based on the type of protocol used for exposure to hypoxia. The aim of this particular study was to observe the effect of exposure to acute hypoxia and its possible influence on immediately subsequent physical performance in national category cyclists under normoxic conditions during a time trial cycling test. This specific aspect had not been studied previously. The results from this study show significant changes between the pre and post moments in certain gas exchange variables under exposure to hypoxia. However, the metabolic variables (glucose and lactate), HR, SpO_2 and those on physical performance during the time trial test were not significantly different following exposure to acute hypoxia or normoxia. Furthermore, following exposure to acute hypoxia at rest, some of the gas exchange variables show a significant correlation to performance variables during the time trial test.

No significant differences were observed in this research between the pre and post values for glucose, lactate, SpO_2 and HR[44], neither under exposure to hypoxia nor normoxia. Nonetheless, differences were observed in gas exchange variables ($EqCO_2$, $PetO_2$ and $PetCO_2$) between the pre and post moments under exposure to hypoxia. Under exposure to normoxia, only one variable ($PetO_2$) showed a significant reduction. These results coincide with those obtained previously in a study with physically active subjects[45]. In said study, changes were observed in gas exchange variables (ventilation and $PetCO_2$) following exposure to normobaric hypoxia (FiO_2 = 0.142%) for a period of 10 hours at rest. The fact that, in this study, the $PetCO_2$ value showed a change following

Table 2. Results for metabolic variables, gas exchange variables and performance variables during the simulated time trial.

Variable	After exposure to normoxia	After exposure to hypoxia	ES (Dif %)	*P*
Metabolic variables				
GLUCOSE $_{WUP}$ (mg/dl)	95.4 ± 7.9	90.1 ± 12.2	0.57 (-5.56)	0.123
GLUCOSE $_{TT10}$ (mg/dl)	99.5 ± 20.5	96.7 ± 13.3	0.11 (-2.81)	0.740
GLUCOSE $_{TT20}$ (mg/dl)	113.5 ± 17.3	111.7 ± 27.3	0.05 (-1.59)	0.879
GLUCOSE $_{DIF\_WUP\text{-}TT20}$ (mg/dl)	19.3 ± 19.6	24.2 ± 27.7	-0.12 (25.39)	0.719
LACTATE $_{WUP}$ (mmol/dl)	1.9 ± 0.5	1.8 ± 0.6	0.11 (-5.26)	0.733
LACTATE $_{TT10}$ (mmol/dl)	6.3 ± 2.8	8.1 ± 2.2	-0.48 (28.57)	0.184
LACTATE $_{TT20}$ (mmol/dl)	7.8 ± 2.0	9.1 ± 2.7	-0.59 (16.67)	0.114
LACTATE $_{DIF\_WUP\text{-}TT20}$ (mmol/dl)	3.3 ± 1.3	4.5 ± 2.3	-0.65 (36.36)	0.087
$SpO_{2\,WUP}$ (%)	97.2 ± 1.2	95.4 ± 2.2	0.68 (-1.85)	0.687
$SpO_{2\,TT10}$ (%)	92.3 ± 2.5	91.5 ± 1.4	0.35 (-0.87)	0.350
$SpO_{2\,TT20}$ (%)	93.5 ± 1.7	91.4 ± 4.5	0.50 (-2.25)	0.500
HR_{WUP} (bpm)	117.1 ± 14.0	123.7 ± 19.2	-0.28 (5.64)	0.413
HR_{TT10} (bpm)	171.4 ± 9.8	176.4 ± 12.6	-0.48 (2.92)	0.182
HR_{TT20} (bpm)	176.5 ± 11.5	180.4 ± 11.0	-0.37 (2.21)	0.289
HR $_{AVERAGETT}$ (bpm)	165.2 ± 11.4	169.6 ± 13.8	-0.45 (2.66)	0.212
Gas exchange variables				
$VO_{2\,TT}$ (l/min)	3.6 ± 0.3	3.6 ± 0.4	0.10 (0.00)	0.770
$VO_{2\,rTT}$ (ml/kg/min)	57.6 ± 4.2	56.8 ± 4.9	0.13 (-1.39)	0.707
$EqO_{2\,TT}$	31.5 ± 2.9	34.5 ± 6.4	-0.50 (9.52)	0.170
$EqCO_{2\,TT}$	31.3 ± 2.6	33.14 ± 4.3	-0.41 (5.88)	0.252
$PetO_{2\,TT}$ (mmHg)	102.3 ± 3.7	103.4 ± 3.9	-0.30 (1.08)	0.390
$PetCO_{2\,TT}$ (mmHg)	35.2 ± 2.7	34.6 ± 2.9	0.30 (-1.70)	0.387
Performance variables				
$POWER_{TT}$ (W)	273.2 ± 31.8	277.8 ± 33.3	-0.21 (1.68)	0.540
$POWER_{TTr}$ (W/kg)	4.2 ± 0.4	4.3 ± 0.3	-0.21 (2.38)	0.545
$CR10_{WUP}$	3.1 ± 1.5	2.7 ± 0.9	0.21 (-12.90)	0.535
$CR10_{TT10}$	7.0 ± 0.9	7.3 ± 0.6	-0.25 (4.29)	0.464
$CR10_{TT20}$	9.0 ± 1.0	9.1 ± 0.8	-0.17 (1.11)	0.608
$CR10_{TT\ AVERAGE}$	6.3 ± 1.0	6.4 ± 0.6	-0.03 (1.59)	0.923

CR10: perceived exertion values. Dif %: difference between hypoxia and normoxia values expressed as a percentage. DIF_WUP-TT20: difference between the WUP and TT20 values. $EqCO_{2\,TT}$: average values for ventilatory equivalent for carbon dioxide during the time trial. $EqO_{2\,TT}$: average values for ventilatory equivalent for oxygen during the time trial. ES: effect size. HR: heart rate. AVERAGE: average value during the time trial. NS: not significant. $PetCO_{2\,TT}$: average values for pressure of carbon dioxide at end-tidal breathing during the time trial. $PetO_{2\,TT}$: average values for pressure of oxygen at end-tidal breathing during the time trial. $POWER_{TT}$: average power during the time trial. $POWER_{TTr}$: average relative power during the time trial. SpO_2: arterial oxygen saturation. TT10: values at minute 10 of the time trial. TT20: values at minute 20 of the time trial. $VO_{2\,rTT}$: average values for oxygen consumption relative to body mass during the time trial. VO_2: average values for oxygen consumption during the time trial. WUP: values during the warm-up prior to the time trial.

exposure to hypoxia and not following exposure to normoxia may be due to the hypocapnic effect (low concentration of CO_2 in arterial blood), caused by the exposure to hypoxia, with this phenomenon being tied to the change in $PetCO_2$[46]. As described previously[47], the observed change in $PetCO_2$ may also be related to the changes in $EqCO_2$ and $PetCO_2$.

In the case of exposure to normoxia, significant differences were only observed in this study between the pre and post values for $PetO_2$. These differences may be explained to a certain extent by the breathing pattern required of participants involving a breathing bag connected to the hypoxia generator in such a way that provided a positive pressure flow of exhaled air ($FiO_2 = 0.209$). Furthermore, said breathing bag was subject to the condensation of water vapour in the exhaled air, which could have impacted the $PetO_2$ values following exposure to normoxia that, in principle, should not have experienced any variation.

Another of the findings observed in this study was that the VO_2 values (relative and absolute) at the post moment increased following exposure to hypoxia when compared with normoxia. These results could be due to the vasodilatory effect of hypoxia, given that other studies have described exposure to hypoxia possibly causing an increase in the diffusing capacity to tissues of O_2[48–50]. The increased VO_2 (absolute and relative) observed following exposure to hypoxia could be due to an increased cardiac output, of the ventricular contraction strength caused by the exposure to hypoxia[51]. In this case, no significant differences were observed in the heart rate at rest following exposure to hypoxia,

Table 3. Correlations between the post intervention variables and the variables from the time trial test in hypoxia and normoxia.

Post variables	Variables in the time trial	r	*P*
Hipoxia			
Glucose	$LACTATO_{DIF\_WUP\text{-}TT20}$	0.888	0.001*
	$CR10_{WUP}$	0.812	0.008**
	$CR10TT_{AVERAGE}$	0.723	0.028**
HR	$EqO_{2\,TT}$	0.781	0.013**
	$EqCO_{2\,TT}$	0.764	0.016**
VO_2	$VO_{2\,TT}$	0.802	0.009***
	$POWER_{TTr}$	0.903	<0.001*
$VO_{2\,r}$	$VO_{2\,rTT}$	0.675	0.046**
	$POWER_{TTr}$	0.891	0.001*
EqO_2	$EqCO_{2\,TT}$	0.778	0.014**
$PetO_2$	$PetO_{2\,TT}$	0.884	0.002***
	$PetCO_{2\,TT}$	-0.898	<0.001*
$PetCO_2$	$PetO_{2\,TT}$	-0.753	0.019**
	$PetCO_{2\,TT}$	0.770	0.015**
Normoxia			
Glucose	$VO2_{rTT}$	0.726	0.027**
Lactate	$EqO_{2\,TT}$	-0.680	0.044**
EqO_2	$EqCO_{2\,TT}$	0.778	0.014**
$PetCO_2$	$PetO_{2\,TT}$	-0.678	0.045**
	$PetCO_{2\,TT}$	0.846	0.004***

CR10: perceived exertion values. DIF_WUP-TT20: difference between the WUP and TT20 values. $EqCO_2$: average values for carbon dioxide ventilatory equivalent. EqO_2: average values for oxygen ventilatory equivalent. HR: heart rate. AVERAGE: average value during the time trial. $PetCO_2$: average values for pressure of carbon dioxide at end-tidal breathing. $PetO_2$: average values for pressure of oxygen at end-tidal breathing. $POWER_{TTr}$: average values for relative power during the time trial. TT20: values at minute 20 of the time trial. $VO_{2\,r}$: average values for oxygen consumption relative to body mass. VO_2: average oxygen consumption values. WUP: values during the warm-up prior to the time trial.

*$p \leq 0.001$; **$p < 0.05$; ***$p < 0.01$; significant correlation.

which could be explained by a "compensatory" parasympathetic response during the exposure to hypoxia and this prevailing over the sympathetic stimulus following exposure to hypoxia in such a way that the tachycardic stimulus produced by the exposure to hypoxia would be immediately compensated[51].

Previous studies have shown that prolonged exposure to hypoxia has positive effects that improve performance in cycling[12,14,15]. However, there are no studies that have analysed the effect of exposure to acute hypoxia on immediate performance in a time trial test under normoxic conditions in cyclists. No significant differences were observed in this study either in the gas exchange, metabolic and HR variables or physical performance variables in the time trial test between exposure to hypoxia and exposure to normoxia. The continued exposure for 30 minutes to acute hypoxia ($FiO_2 = 0.09$) did not lead to any improvement in time trial performance when compared to exposure to normoxia. Despite the fact that, following the exposure to hypoxia in this study, the values for gas exchange parameters ($EqCO_2$, $PetO_2$ and $PetCO_2$) showed significant changes in pre and post (suggesting a hypocapnic effect that previous studies have shown may have effects on metabolic contribution and the variables representative of said contribution in short maximal efforts (30 seconds) in cycling[52,53]), a link was observed between the response to the hypocapnia and time trial performance over 20 minutes in cycling under normoxic conditions[54]. In the case of this study, the hypocapnia effect induced by the hypoxia did not improve performance in a 20-minute simulated time trial test. These results are similar to those obtained in other studies, also in which no positive effects were observed from the hypocapnia on prolonged time trial performance in cycling (60-90 minutes)[54]. This absence of performance improvements could be explained by the duration of the effort (70 seconds *vs.* 30-90 minutes). Hence, the possible ergogenic responses following exposure to hypoxia seem to have no impact on immediate performance in 30-90 minute tests but do indeed seem to have an impact on shorter efforts[52]. More studies with a methodological design similar to this study may be necessary to attempt to determine the extent to which the immediate effects of acute hypoxia can affect performance in cycling, considering the duration and characteristics of the effort.

Furthermore, this study analysed the relationship between the physiological responses caused by the acute hypoxia at rest and the physiological variables on time trial performance in cycling, a relationship being found between these variables. Specifically, a greater number of significant correlations were found between variables in the hypoxia protocol than in the normoxia protocol. Significant correlations were observed between the variables of: glucose post exposure to hypoxia and $LACTATE_{DIF\_WUP\text{-}TT20}$ (Table 3). This correlation could be due to the sympathetic-adrenal stimulus during the exposure to hypoxia[55], acutely modifying the glycolytic contribution during the exercise[56]. A positive correlation between the glucose in post and $CR10_{WUP}$, showing a correlation between the levels of glucose post exposure to hypoxia and the subjective perceived exertion during the exercise. This could be caused by a greater glycolytic contribution during the exercise following exposure to hypoxia due to said sympathetic-adrenal effect, thereby influencing the perception of exertion[57]. The positive correlation between HR at rest post exposure to hypoxia and $EqO_{2\,TT}$ stands in line with evidence of a correlation between heart rate and gas exchange variables in studies conducted under normoxic conditions[58].

Furthermore, correlations were observed with statistical significance (p <0.05), with a degree of association (high correlation) post exposure to hypoxia between gas exchange variables and these same variables during TT (VO_2 in post with VO_{2TT} and VO_{2r} in post with VO_{2rTT}). A correlation was also observed in gas exchange variables post exposure to hypoxia and performance variables during the simulated time trial (VO_2 in post with $POWER_{TTr}$ and VO_{2r} in post with $POWER_{TTr}$). The correlation in post between VO_2 with VO_{2TT} and VO_{2r} with VO_{2rTT} reveals the association between the starting point for the oxygen consumption variable prior to the exercise (post exposure to hypoxia) and oxygen consumption during the exercise. It could be that the oxygen consumption response following exposure to hypoxia impacts the oxygen consumption taking place during the time trial test in normoxia. Or, on the other hand, it could be that the values for oxygen consumption taking place during the time trial test in cycling under normoxic conditions are related to the response from oxygen consumption values post exposure to hypoxia at rest. The correlation between VO_2 values in post with $POWER_{TTr}$ and VO_{2r} in post with $POWER_{TTr}$, reveals how the response to exposure to hypoxia in oxygen consumption values is related to the values for power produced during the 20-minute cycling time trial test under normoxic conditions. It has been shown that these gas exchange variables with the aforementioned correlations maintain a correlation with increased performance in time trial cycling[26]. However, no evidence was found in this study for improvements in simulated cycling time trial performance following exposure to the hypoxia protocol.

We have not seen any studies with a similar design to this study and related to the responses induced by acute hypoxia at rest and time trial performance under normoxic conditions in cycling. This has made it difficult to compare the results obtained on the correlations between the different variables.

Conclusions

The exposure to acute hypoxia at rest for a period of 30 minutes at a simulated altitude of 4,500 metres above sea level caused significant changes in the cardiorespiratory response (gas exchange variables) when compared to normoxic conditions. Although an acute response was observed in gas exchange variables following exposure to acute hypoxia at rest, this response had no positive effect on simulated time trial performance in the cyclists participating in the study when compared with the protocol for exposure to normoxia. Finally, significant correlations were observed between the response to hypoxia at rest and simulated time trial performance under normoxic conditions in metabolic variables, ventilatory response variables and perceived exertion variables, revealing new findings in the response to acute hypoxia at rest and performance under normoxic conditions in cycling for which no evidence has been shown to date in the literature from studies based on procedures of a similar nature to this study.

Conflicts of Interest

The authors declare no conflict of interest.

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