Effects of acute exposure to high altitude in acclimatized and non-acclimatized professional soccer players

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Summary

Objective: To evaluate the cardiopulmonary response, gases and acid base balance in a cardiorespiratory maximal test applied to professional football players of first division of Bolivia living at low altitude, during the first six hours after arrival to the high altitude of 3,600 meters.
Methods: Eleven Bolivian players living at an altitude of 150 m (lowlanders, LL) and ten highlanders (HL), living at an altitude of 3,600 m, performed the Yo-Yo endurance test with ergospirometry. Base excess (BE), pH, blood gases and capillary blood lactate were determined at 150 m and at 3,600 m seven days later.
Results: VO_2max ($L{\bullet}min^{-1}$) decreased at 3,600 m in both groups, without differences in slopes or interaction between the factors residence and altitude. In LL (p <.001), 3.52±0.46 *vs* 2.92±0.38. In HL (p <.001), 4.02±0.5 *vs* 3.41±0.45. The distance covered in the test was lower at 3,600 m in both groups: 1358.2±210.6 *vs* 1903.64±202.55 m in LL (p <.001) and 1605.0±281.17 *vs* 2096.0±272.4 m in HL (p <.001). Pre-exercise at 3600 m, LL had a higher pCO_2 (38.3 ± 3.0 *vs* 30.69 ± 1.78 mmHg; p <.001) and a lower $satO_2$ (83.1± 2.7 *vs* 88.1 ± 1.1%; p <.01). Exercise performed at high altitude produced in LL a higher decrement in pH (-0.258 ± 0.06 *vs* -0.206 ± 0.03; p <.05) and in BE (-18.73±2.83 *vs* -12.62±2.13) with no differences in blood lactate (10.8 ± 2.09 *vs* 9.43 ± 2.1 mmol/L for LL and HL, respectively).
Conclusion: During the first six hours at 3,600 m, aerobic performance decrease is similar in LL and HL, although a lower ventilatory response and resting oxygenation of the LL group is found. LL group also showed a greater metabolic acidosis in both altitudes during exercise.

Key words:
Acid-base equilibrium. Physical performance. Hypobaric hypoxia. Soccer players. Acute mountain sickness.

Efectos de la exposición aguda a gran altitud en jugadores profesionales de fútbol aclimatados y no aclimatados

Resumen

Objetivo: Evaluar la respuesta cardiopulmonar, equilibrio ácido base y gases en una prueba cardiopulmonar máxima en futbolistas profesionales de primera división de Bolivia residentes de altitudes bajas, medidos durante las primeras seis horas de llegada a la gran altura de 3.600 m.
Métodos: A once futbolistas bolivianos residentes a 150 m (lowlanders, LL) y diez residentes a 3.600 m (highlanders, HL) se les realizó el Yo-Yo endurance test con ergoespirometría, determinación de pH, exceso de bases (EB), gases y lactato en sangre capilar a 150 m y a 3.600 m una semana después.
Resultados: El VO_2max ($L{*}min^{-1}$) disminuyó a 3.600 m en ambos grupos estudiados, sin diferencia entre el lugar de residencia y altitud. En LL (p <0,001), 3,52±0,46 *vs* 2,92±0,38. En HL (p <0,001), 4,02±0,5 *vs* 3,41±0,45. La distancia máxima recorrida (metros) fue menor en altura (3.600 m) en ambos grupos, 1.903,64±202,55 *vs* 1.358,2±210,6 (p <0,001) en LL, y 2.096,0±272,4 *vs* 1.605,0±281,17 (p <0,001) en HL. Pre-ejercicio a 3.600 m, los LL tuvieron mayor pCO_2 (38,3±3,0 *vs* 30,69±1,78 mmHg; p <0,001) y menor $satO_2$ (83,1± 2,7 *vs* 88,1 ± 1,1%; p <0,01). El ejercicio en altura generó en LL mayores decrementos de pH (-0,258±0,06 *vs* -0,206±0,03; p <0,05) y de EB (-18,73±2,83 *vs* -12,62±2,13) sin diferencias en lactato sérico (10,8 ± 2,09 *vs* 9,43 ± 2,1 mmol/L para LL y HL respectivamente).
Conclusión: En las primeras seis horas a 3.600 m, la caída del rendimiento aeróbico es similar en LL y HL, a pesar de una menor respuesta ventilatoria y oxigenación en reposo del grupo LL, además en ejercicio se genera una mayor acidosis metabólica en LL en ambas alturas.

Palabras clave:
Equilibrio ácido-base. Rendimiento físico. Hipoxia hipobárica. Jugadores de fútbol. Mal agudo de montaña.

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Introduction

Playing soccer (football) at high altitudes is an interesting scientific, sports and logistics challenge for sea-level teams. Thus, consideration has been given both to health risks and impaired physical performance and to the root causes of the disadvantage of competing in these conditions[1-4]. Despite this, the FIFA (Fédération Internationale de Football Association) has raised the point that there is still insufficient information on this matter, particularly for altitudes of more than 3,000 m[5-7].

In 2000, Brutsaert *et al*[8] studied the cardiopulmonary and metabolic response to exercise of altitude acclimatized professional players (or highlanders; HL) and non-altitude acclimatized players from near sea level (or *lowlanders*; LL) measured after a 48-hour stay at 3,600 m. At the end of the cardiopulmonary effort, both teams showed increased oxygen ventilatory equivalents (VE/VO_2), high concentrations of blood lactate and low oxygen arterial saturation levels (SaO_2), with no differences between LL and HL. Moreover, both groups had lower VO_2max values in relation to measurements taken at 430 m, with a greater effect observed in the LL, indicating that this group is at a physiological disadvantage with regard to the acclimatized players[8]. Recently, similar results were reported for non-altitude acclimatized young soccer players[2,9].

Regardless of the acclimatization strategy, the lower atmospheric pressure causes a reduction in the alveolar (PAO_2) and arterial (PaO_2) oxygen pressures and also in the arterial oxygen content (CaO_2), thereby reducing aerobic performance in relation to sea level[10]. Therefore, hypobaric hypoxia increases the ventilatory response regulating PaO_2, while the CaO_2 is determined by the displacement of the haemoglobin dissociation curve[11] and particularly by the concentration of haemoglobin. Consequently, changes in the blood volume and in the erythropoietic response will directly affect the CaO_2[12,13]. For its part, the hyperventilation characteristic of hypoxia reduces the CO_2 arterial pressure ($PaCO_2$), which subsequently involves the restoration of the acid-base balance (ABB) through the renal excretion of bicarbonate[14-17]. The mentioned changes form part of altitude acclimatization and require approximately 2 to 3 weeks to adapt[18,19], thereby creating considerable logistics problems for their implementation in sports competitions. In view of this problem, many teams choose to arrive, play and return on the same day as the high altitude match, a strategy termed *"fly-in, fly-out"* [1] or playing in "immediate acute hypoxia" (IAH). The main justification for the use of this strategy is to avoid the symptoms of "acute mountain sickness" which appear from 6 hours onwards, with a peak between 24 and 48 hours, in view of the associated performance impairment[15,19,20]. Taking an empirical approach, a number of clubs and national teams in South America have used this strategy. However, there is no scientific information on this subject with regard to professional soccer players. Therefore, the aim of this study is to ascertain the effects of exposure to IAH at a high altitude (3,600 m) on the maximal cardiopulmonary response, the ABB and the capillary blood gases in high altitude acclimatized and non-acclimatized professional soccer players.

Material and method

Subjects

21 professional soccer players from two Bolivian first division teams took part in the study. One team came from a low altitude and was non-altitude acclimatized (n = 11, Trinidad, Bolivia, 150 m), named *lowlanders* (LL) while the other team comprised altitude acclimatized subjects, having remained for at least six months at a high altitude (n =10, La Paz, Bolivia, 3,600 m) named *highlanders* (HL). None of the subjects of the HL group were native to the highlands, however all had been permanent residents at high altitude for a minimum acclimatization period of 6 months. All the subjects taking part in the study were professional players and were also members of their respective teams, with daily training sessions and soccer matches over the weekends. All the subjects involved had at least 5 years of systematic training. Table 1 summarises the characteristics of the sample. All the subjects were informed of the tests to be made and gave their written consent to voluntarily take part in the study. The study protocols were designed following the guidelines of the Declaration of Helsinki.

Protocol

The assessments were conducted during the first division national championship of Bolivia. Initially both teams were assessed at low altitude (150 m). One day after this measurement, the HL team returned to a high altitude, to be measured six days later in this condition. The LL team travelled to the high altitude one week after the first measurement and, after a 60 minute journey by plane, they went immediately to the Hernando Siles soccer stadium (3,600 m). Less than 6 hours (3 to 5 hours of IAH) elapsed between the players' exposure to high altitude and the assessment. Figure 1 shows the implementation of the measurements.

Procedure

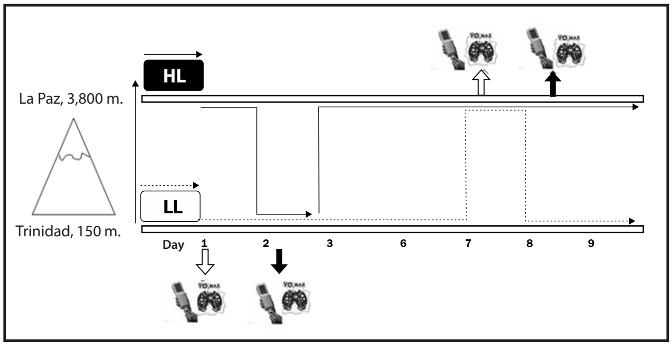
On the day of the assessments, early in the morning, the *Yo-Yo Endurance Test* (YYET)[21] was conducted. This maximum effort field test was used to make the cardiopulmonary assessment. Each player performed the test wearing an ergospirometric device to record the cardiopulmonary changes. At rest (pre-exercise), and at the end of the

Table 1. Anthropometric data, age and time spent at altitude.

	***Lowlanders* (n=11)**	***Highlanders* (n=10)**
Age (years)	21.8±3.4	25.2±3.2*
Height (cm)	172.7±0.07	174.6±0.05
Body mass (kg)	68.6±9.7	72.2±6.3
BMI kg/m²	22.9±2.1	23.7±1.6
Time spent at altitude (months)	0	24.9±32.6*

The data are presented as means ± SD. (*) p<0.05.

Figure 1. Description of the experiment.



The lines represent the travel between 150 and 3,600 m during the experiment. Dotted line for LL and a solid line for HL. The arrows show the measurement times, white for LL and black for HL. Lowlanders (LL), highlanders (HL)

test, during the first 30s of recovery (post-exercise), a capillary blood sample was taken and then used to make the ABB and gas measurements.

YYET field test

The YYET endurance level 1 was used[21-23], with the direct and simultaneous determination of the cardiopulmonary function. The test was conducted on a natural turf soccer field, and with soccer boots. The test is a continuous progressive test, starting at low speeds and with running speed increments of 0.5 km/h per minute in order to achieve the maximal cardiopulmonary effort. The physical performance of each subject was obtained as the maximum distance achieved in the YYET.

The players did not perform any demanding exercise during the 48 hours prior to the YYET test. Before starting the test, they performed a 10 minute warm-up, jogging at 6-8 km/h, as well as joint flexibility and mobility exercises.

Measurement of the cardiorespiratory parameters

To rate the maximal cardiopulmonary response, a portable Metamax 3B (Cortex, Germany) unit was used. This was calibrated before each measurement using factory gases and ambient air for the analysers and a 3 litre certified syringe for the calibration of the flow meter. Likewise, the barometric pressure was recorded.

The achievement of a VO_2max plateau was taken as the criterion for maximal cardiopulmonary effort. In the event of no plateau, then the test was considered valid when 2 of the following criteria were met: 1) an RER ≥1.15; 2) reach at least 95% of the maximal theoretical HR (220 – age); 3) blood lactate concentration of more than 8 mmol/L[24]. The subjects were motivated to achieve the maximal cardiopulmonary effort. At the final stage of the YYET, the maximal uptake of oxygen (VO_2max), maximal pulmonary ventilation (VEmax) and the maximal ventilatory equivalent for oxygen (VE/VO_2max) were obtained. These cardiopulmonary parameters were obtained breath by breath and were subsequently exported to an Excel worksheet at 15 second intervals. The maximum values were determined as those pertaining to the interval in which VO_2max was obtained

Measurement of capillary blood gases and ABB

The ABB and gases were measured in rest conditions (5 minutes sitting down) before starting the warm-up (pre-exercise) and in the 30 seconds following the end of the maximal cardiopulmonary effort (post-exercise). Measurements were made of the pH and the pCO_2 and calculations were made of the HCO_3-, base excess (BE) and SaO_2 in 100 µL of arterialized capillary blood obtained by ear lobe puncture. The samples were analysed with an I-Stat (Abbot, USA) portable unit using specific cartridges (CG4)[25,26]. The concentration of lactate in the blood was determined by a 5 µL blood sample also drawn from the same ear lobe and using a portable analyser (Lactate Pro1, Arkray, Japan).

Statistical analysis

The normality of the distributions was evaluated with the Saphiro-Wilk Test while the homogeneity of variance was determined with the Levene test. As a hypothesis contrast test, a factorial ANOVA was used, considering the principal factors to be the permanent place of residence of the athletes (*Lowlanders* or *Highlanders*) and the place of measurement (altitude of 150 or 3,600 metres). Whenever any significant differences were found in any of the principal factors, the Bonferroni post-hoc test was used. The correlations were analysed through the Pearson test. For all the tests described, a p value of less than 0.05 was used as the cut-off for significance. All the data are presented as mean and standard deviation.

The analysis was performed using the GraphPad Prism 6.0 statistical program.

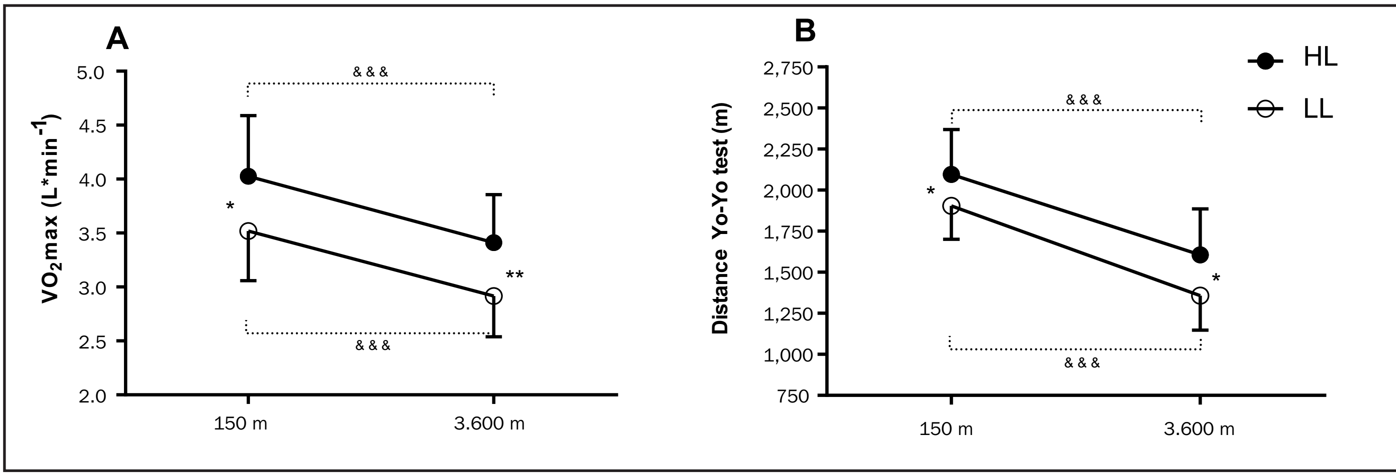
Results

Physical performance

With regard to the physical performance, a reduction in absolute VO_2max ($L*min^{-1}$) was observed at altitude for both groups. For LL this parameter decreased from 3.52 ± 0.46 to 2.92 ± 0.38 $L*min^{-1}$ ($p < 0.001$) while for HL it decreased from 4.02 ± 0.5 to 3.41 ± 0.45 $L*min^{-1}$ ($p < 0.001$) (Figure 2A). Likewise, for the LL, the relative VO_2max ($ml*min^{-1}*Kg^{-1}$) decreased with altitude from 51.48 ± 3.92 to 42.77 ± 3.67 ($p < 0.001$) while, for HL, it decreased from 55.65 ± 4.47 to 47.76 ± 3.53 ($p < 0.001$). For the distance travelled (meters) in the YYET, a decrease in measurements at altitude was also observed, from 1,903.64±202.55 to1,358.2±210.6 m ($p < 0.001$) in the LL group and from 2,096.0±272.4 to 1,605.0±281.17 m ($p < 0.001$) in the HL group (Figure 2B). For both parameters, the LL group showed lower values than the HL group, at 150 m and 3,600 m alike.

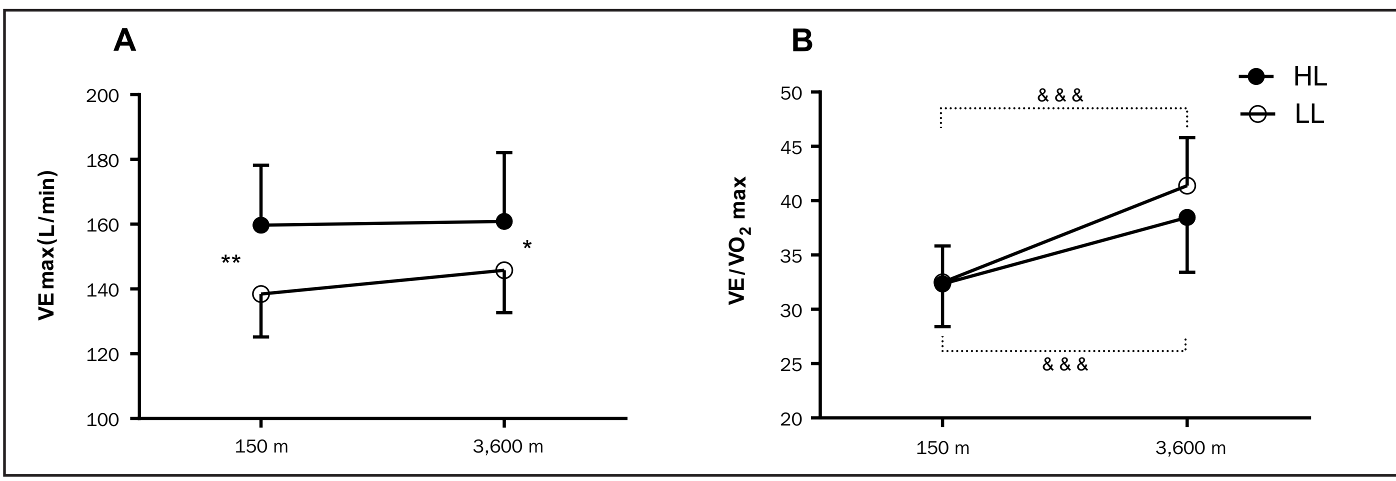
VEmax (L/min) showed no variation ($p = 0.42$) due to altitude change for either group (138.44 ± 13.23 *vs.* 145.83 ± 13.08 for LL and 159.72 ± 18.51 *vs.* 160.84 ± 21.32 for HL) (Figure 3A). The HL group showed higher values for VE both at 150 m ($p < 0.01$) and at 3,600 m ($p < 0.05$). With regard to VE/VO_2max (Figure 3B), this increased from 32.49 ± 3.34 to 41.39 ± 4.41 ($p < 0.001$) for LL, and from 32.35 ± 3.95 to 38.47 ± 5.03

Figure 2. Absolute VO_2max (A) and maximum distance Yo-Yo Test (B) measured at 150 m and 3,600 m in soccer players, *lowlanders* (LL) and *highlanders* (HL). The values are presented as means ± SD.



*Differences between groups at the same altitude: *p <0.05; **p <0.01. (&) Differences between 3,600 m and 150 m: (&&&) p <0.001.

Figure 3. Maximal ventilation (VE max) (A) and maximal ventilatory equivalent of oxygen (VE/VO_2max) (B) measured at 150 m and 3,600 m in soccer players: *lowlanders* (LL) and *highlanders* (HL). The points represent the means ± SD.



*Differences between groups at the same altitude: *p<0.05; **p<0.01. (&) Differences between 3,600 m and 150 m: (&&&) p <0.001.

(p <0.001) for HL, when comparing 150 m with 3,600 m respectively. No differences were found between groups at the same altitude (p = 0.25).

Pre-exercise ABB

Table 2 shows the data for the ABB and gases. With regard to the pre-exercise ABB, the pH did not change for the LL group, however it did increase for the HL group at 3,600 m (p< 0.01). HCO_3-did not change in either group at 3,600 m (p = 0.76) but higher values were found for LL subjects at both 150 m (p <0.001) and at 3,600 m (p <0.001). The pCO_2 (Figure 4A) decreased in altitude for the HL group (p <0.001) with lower values for the HL team at both 150 m (p <0.001) and 3,600 m (p <0.001). The BE (Table 2) did not change with altitude for either team (p = 0.44). However, the HL group showed the lowest values compared to LL, at both 150 m (p <0.001) and 3,600 m (p <0.001). Lactate increased at 3,600 m for LL (p <0.01) and HL (p <0.05), finding higher lactate at 3,600 m for LL compared to HL (p <0.05). Finally, with regard to SaO_2 (Figure 4B) altitude had a different effect on the LL and HL groups. Thus, at 150 m, there is no difference between the groups, decreasing in altitude for both cases (p <0.001) yet with a greater value for the HL group (88.1 ± 1.1 *vs*. 83.1± 2.7; p <0.01).

Post-exercise ABB

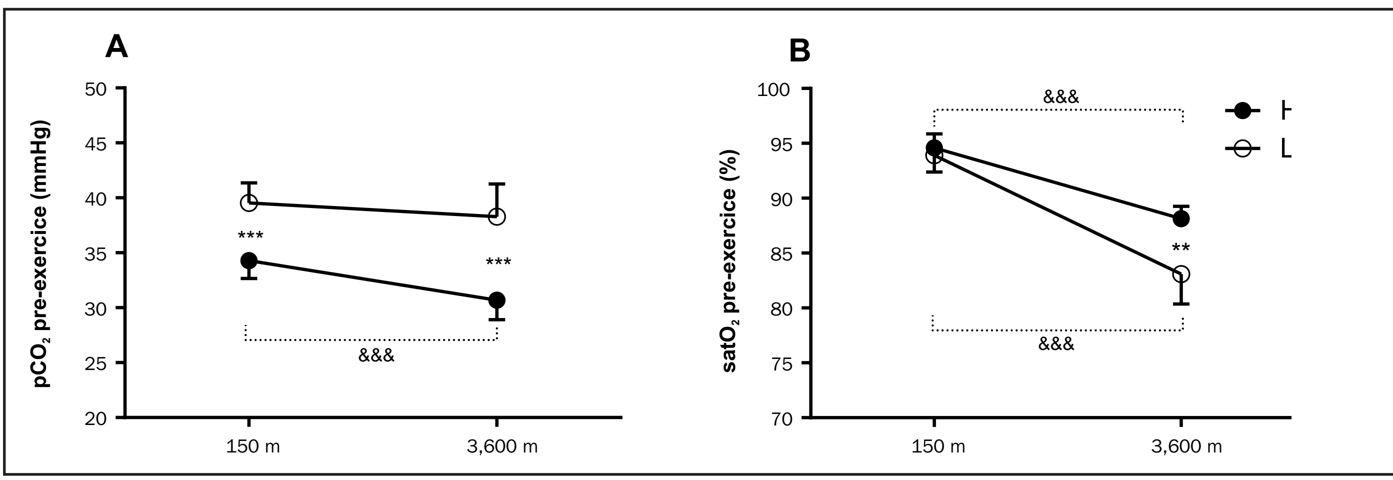
With regard to the post-exercise ABB parameters, it was found that the pH did not change at 3,600 m in either group, with the HL group showing higher values at both 150 m (p <0.05) and 3,600 m (p <0.01).

Table 2. Acid-base balance and capillary blood gases pre and post maximal exercise, in professional soccer players, measured at altitudes of 150 m and 3,600 m.

	Lowlanders (n=11)		Highlanders (n=10)	
	150 m	3,600 m	150 m	3,600 m
pH pre	7.425±0.02	7.440±0.03	7.416±0.01	7.454±0.02b
pH post	7.192±0.05	7.182±0.05	7.230±0.04*	7.248±0.04**
ΔpH -0.234±0.05	-0.258±0.06	-0.185±0.04*	-0.206±0.03*	
HCO3- pre (mmol/L)	25.93±0.74	26.07±2.25	22.01±0.97***	21.59±1.49***
HCO3- post (mmol/L)	14.05±1.80	11.53±1.92[b]	13.95±1.87	12.15±1.38
Δ HCO3- (mmol/L)	-11.93±2.25	-14.55±2.15[b]	-8.1±1.73***	-9.44±1.78***
pCO2 pre (mmHg)	39.5±1.83	38.3±3.0	34.3±1.62***	30.69±1.78 ***,c
pCO2 post (mmHg)	36.6±4.5	30.5±2.8[b]	33.1±2.25*	27.65±2.64 *,c
Δ pCO2 (mmHg)	-2.9±4.7	-7.8±2.4[b]	-1.2±2.38	-3.0±2.57***
BE pre (mmol/L)	1.64±0.92	2.09±2.47	-2.60±1.17***	-2.25±1.39***
BE post (mmol/L)	-14.10±2.33	-16.64±2.77[a]	-13.5±2.64	-14.88±2.42
Δ BE (mmol/L)	-15.8±2.86	-18.73±2.83[b]	-10.9±2.38***	-12.62±2.13***
Lactate pre (mmol/L)	1.89±0.48	2.87±0.81[b]	1.64±0.53	2.1±0.46*,a
Lactate post (mmol/L)	11.7±1.93	13.72±2.40[b]	10.7±1.85	11.53±2.12*
Δ Lactate (mmol/L)	9.76±1.82	10.8±2.09	9.06±1.88	9.43±2.1

The absolute changes (Δ) were calculated as the post-pre exercise values. The values are presented as a mean ± SD.
(*)Differences between groups at the same altitude: (*) p (a, b and c). Differences between 3,600 m and 150 m: (a) p<0.05; (b) p<0.01; (c) p<0.001.

Figure 4. pCO_2 (A) and SaO_2 (B) pre-exercise, measured at 150 m and 3600 m in soccer players: *lowlanders* (LL) and *highlanders* (HL). The points represent the mean ± SD.



*Differences between groups at the same altitude: **p<0.01; ***p<0.001. (&) Differences between 3,600 m and 150 m: (&&&) p <0.001.

With regard to post-exercise HCO_3- a lower concentration was found at 3,600 m for both the LL subjects (p<0.01) and for the HL subjects (p <0.05) with no differences between both groups (p = 0.66). The post-exercise pCO_2 also decreased at 3,600 m for the LL group (p <0.01) and HL group (p <0.001) with lower values for the HL group at both altitudes (p <0.05). The post-exercise BE only decreased significantly for the LL subjects at 3,600 m (p <0.05) with no changes found in the HL group (p = 0.16). Finally, the post-exercise lactate only increased in the LL subjects at 3,600 m (p <0.01) while lower values were found for the HL group at altitude (p <0.05).

Absolute changes in ABB per exercise

As can be observed in Table 2, the decreases in the pH, HCO3-, BE and pCO_2 after exercise were greater for the LL group at both altitudes. The increase in Lactate showed no differences within the groups, or comparing one group with another.

Correlations and regression analysis

At rest, we found a negative correlation (r = -0.85 p <0.001) between SaO_2 and pCO_2 for LL and HL measured at 3,600 m (Figure 5). For LL, we

Figure 5. Ratio between the absolute values of SaO_2 (%) and pCO_2 (mmHg) in capillary blood, pre-exercise in soccer players: *lowlanders* (LL, n=11) and *highlanders* (HL, n=8) measured at La Paz (Bolivia) at 3,600 m.

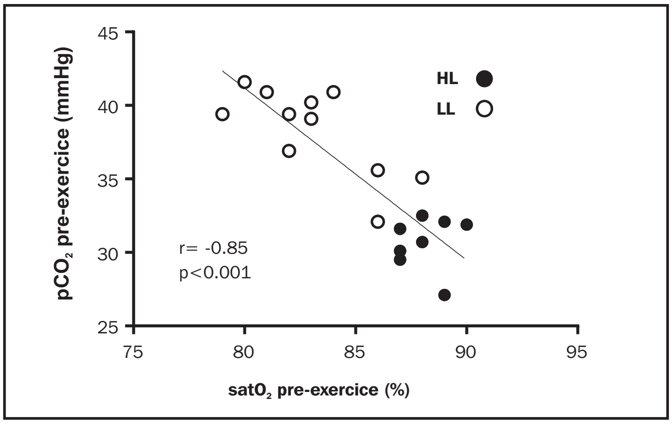
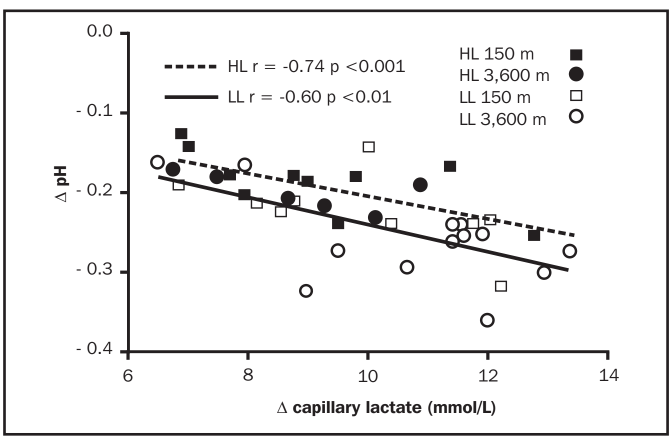


Figure 6. Ratio between the absolute changes in lactate and pH in capillary blood (Δ = post – pre exercise) in soccer players: lowlanders (LL) and highlanders (HL). The dotted line corresponds to the HL (n=11) and the solid line to the LL (n=8).



found a greater pCO_2 and lower SaO_2, while the HL subjects showed a lower pCO_2 and greater SaO_2.

Finally, Figure 6 shows two different straight lines for LL (r =-0.60 p <0.01) and HL (r = -0.74 p <0.001) when relating the lactate increases with the pH increases.

Discussion

Physical performance

As far as we are aware, this work is the first assessment to be made on the effect of IAH on professional soccer players. The most important finding in the study was the reduction of VO_2max at altitude and the reduction in the maximum distance for YYET for HL and LL subjects alike. This suggests that the effect of exposure under an IAH condition would equally affect the physical and cardiopulmonary performance of altitude acclimatised and non-altitude acclimatised subjects alike.

The results of Brutsaert[8], obtained at La Paz with professional soccer players after 48 hours of exposure, are in keeping with our own results, in that both groups show a reduction in VO_2max. However, in Brutsaert's study, the reduction is greater in LL subjects than HL ones (-20% and -13% respectively). In our results, this reduction in VO_2max is similar (-17% and -15% respectively), which is certainly due to the duration of exposure and allows us to affirm that acute exposure to hypoxia in the first 6 hours equally affects the performance of LL and HL. However, when this exposure is extended to 48 hours, it affects the LL subjects to a greater extent.

Our study shows an increase in VE/VO_2max at altitude with no apparent differential effect of this medium on either group, which is in line with other studies[8,27]. The greater VE/VO_2max at altitude is rather the result of the reduction in VO_2max, as no changes were found in the VEmax between 150 m and 3,600 m for either group.

Pre-exercise ABB and $satO_2$

The reduction in pCO_2 at rest in the HL group at 3,600 m (Figure 4A) suggests a greater ventilatory response which is related to greater SaO_2 at altitude, as shown in Figure 5. One possible explanation is that the LL group takes longer to adequately activate the hyperventilation mechanism that is characteristic of hypobaric hypoxia[15,28]. Hyperventilation offers the advantage of increasing the availability of oxygen, in accordance with the alveolar gas equation, but it also has the disadvantage of causing respiratory alkalosis[28] with contradictory effects on performance[28,29]. For its part, alkalosis causes a displacement of the haemoglobin dissociation curve to the left (the opposite to the Bhor effect), increasing the affinity of haemoglobin for O_2[14,28] and is associated with "acute mountain sickness"[19,30,31]. This situation has previously been reported for soccer players acutely exposed to altitude (a stay of 2 to 3 days) producing general discomfort and dyspnoea, affecting performance[32].

The results of ABB at rest, summarised in Table 2, indicate that there are no changes in the pH and HCO_3- for group LL at 3,600 m. Similar findings have been found for young non-professional players also exposed to IAH[20]. For their part, the changes observed in the HL players (Table 2) suggest a respiratory alkalosis compensated by the renal excretion of HCO_3-, a situation that is characteristic of subjects acclimatised to altitude[14,15,17]. Therefore, HL subjects achieve a greater hyperventilation at rest with greater SaO_2 and with a slight alteration of the pH, in contrast to the LL subjects who, probably due to the limited time of exposure to hypoxia, do not change their ABB, achieving a lower ventilatory response and lower SaO_2.

Post-exercise maximal ABB

In relation to physical exercise, the absolute changes in pH are greater for the LL group at both altitudes, implying greater metabolic acidosis or else a lower buffer capacity in this group (Table 2). The same behaviour is observed for HL players at both altitudes, yet less intense.

The acute exposure time to the new altitude conditions makes it impossible to completely compensate the ABB for both groups. Therefore, the acute modifications per exercise are similar to those found in their normal native environment (Figure 6).

The lactate at rest is greater at a high altitude for both groups, with the greatest change experienced by the LL subjects (Table 2). The post-exercise lactate is greater for the LL subjects at 3,600 m. However, when comparing the absolute changes for lactate, no differences were found. Although the correct interpretation of lactate is complex in these conditions[33], this response is consistent with the modifications observed in the pH as shown in Figure 6, where it appears that acclimatization generates less acidosis per exercise for the same change of lactate.

We know that a condition of metabolic acidosis makes it possible to increase the availability of tissue-level oxygen during exercise, due to the Bhor effect, in both normoxia and hypoxia[34,35], although this situation has recently been questioned with high intensity exercise in hypoxia[36]. On the other hand, there is evidence that, under normoxia conditions, metabolic alkalosis (by oral administration of bicarbonate) causes a reduction in VO_2max and physical performance[37]. In this present study, under IAH conditions, the LL players would achieve greater post-exercise metabolic acidosis, which could favour a greater availability of oxygen at the muscle level, which could compensate for the considerable decrease in PAO_2 due to hypoxia.

In conclusion, the present findings make it possible to consider exposure to IAH as a reasonable physiological strategy to address high altitudes in sports such as soccer (which do not allow for long acclimatization periods) given the fact that the decrease in aerobic performance is similar in LL and HL, therefore creating no disadvantages for players coming from lower altitudes.

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