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Performance Of Altitude Acclimatized And Non-Acclimatized Professional Football (Soccer) Players At 3,600 M

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TOM D. BRUTSAERT, HILDE SPIELVOGEL, RUDY SORIA, MAURICIO ARAOZ, ESPERANZA CACERES, GILIANE BUZENET, MERCEDES VILLENA, MARIO PAZ-ZAMORA and ENRIQUE VARGAS. **Performance of altitude acclimatized and non-acclimatized professional football (soccer) players at 3,600m. JEP**online, 3(2):28-37, 2000. European football (soccer) matches frequently are played at the international level in mountainous regions of South America. In this study, the exercise response during cycle ergometry and the rate of football match energy expenditure (RFE) were measured in two groups of professional football players at high altitude (3,600 m) and near sea level (420 m). Subjects either resided at high altitude and were therefore altitude acclimatized (n= 9) (HA), or resided near sea level and were non-acclimatized to high altitude (n=11) (LA). Both study groups showed a large decrement in the RFE (0.187 kcal/kg/min, or a 16% decrease) and peak oxygen consumption (VO_2peak) at altitude (10.78 mL/kg/min for HA and 6.27 mL/kg/min for LA). This VO_2peak decrement with altitude was larger in LA versus HA players (20% vs. 13%). The LA players also showed higher ventilatory equivalents for oxygen, lower arterial oxygen saturations, and higher arterial lactate concentrations during submaximal exercise. Because aerobic capacity is an important determinant of football match performance, these results may have some relevance to the debate over an advantage to altitude acclimatized teams for football matches played at moderate to high altitude.

Key words: energy expenditure, Bolivia, high altitude, hypoxia, VO_2peak

INTRODUCTION

International level football matches at high altitude are common in South America where events are frequently held above 2,500 meters (e.g., La Paz, Bolivia, 3,600 m; Oruro, Bolivia, 3,800 m; Cuzco, Peru, 3,300 m; and Quito, Ecuador, 2,800 m). Recently, before the South American qualifying round for the 1998 World Cup, the *Sport Medicine Commission of the Federation of International Football Associations (FIFA)* recommended that football matches above 3,000 m be played only on the condition that "an acclimation period of 10 days is respected". This concern is related to the physiological effect of acute altitude exposure on exercise performance. In addition to the well known decrement in maximal oxygen consumption (1,2,3,4), for a given level of submaximal oxygen consumption (VO_2) compared to sea level, the general stress of exercise in hypoxia is documented by a lower arterial oxygen saturation (SaO_2) (3), a higher heart rate (HR), a higher ventilatory equivalent for oxygen (V_E/VO_2) (5,6), increased lactate production (7,8), and higher levels of circulating catecholamines (9,10). Often mild symptoms of acute mountain sickness (AMS) are present during the first few days of moderate altitude exposure, including headache, anorexia, nausea, dizziness, abnormal tiredness, and breathlessness (11). These symptoms may be exacerbated by exercise, and may contribute to the increased rate of perceived exertion during exercise that has been reported for non-acclimatized subjects compared to moderate altitude natives during acute (2-day) exposure to 4,270 m (12).

In this paper we report findings from an exercise study of altitude acclimatized (HA) and non-acclimatized (LA) professional football players in Bolivia. Each of these subject groups was tested at altitude (La Paz, Bolivia, 3,600 m) and also near sea level (Santa Cruz, Bolivia, 420 m) using a cross-over study design. The performance difference with altitude exposure was measured during submaximal and maximal exercise on a cycle ergometer, and heart rates were monitored in a subset of these players during football matches played in the two environments. The heart rate (HR) monitoring technique can be used to obtain an estimate of the rate of energy expenditure during a football match (13). The data presented here provide insight into the question of whether non-acclimatized teams are at a significant physiological disadvantage when playing against acclimatized teams during matches of international importance at HA.

METHODS

Subjects

This study was reviewed by the Institutional Review Board of the *Instituto Boliviano de Biología de Altura,* in La Paz, Bolivia, concerning the use of human subjects. All subjects were informed of the risks and benefits of the study and gave informed consent. All subjects were professional male football players from the professional football league in Bolivia, divided into two study groups: (1) altitude acclimatized (HA) and (2) low altitude non-acclimatized (LA). HA acclimatized players came from professional teams living and training in La Paz, Bolivia at 3,600 meters. LA players came from teams living and training in Santa Cruz, Bolivia at 420 meters. As is the nature of the Bolivian football league, players frequently made trips between the highlands and the lowlands. Inclusion into the study was based on residency in the home environment, as well as a hemoglobin (Hb) level consistent with the altitude of residence. For the majority of players (>90%), uninterrupted time in their home environment prior to the study exceeded 1 month and previous trips to higher or lower altitude were not longer than 2 days. None of the non-acclimatized players had been to moderate to high altitude for at least one month prior to the study. The majority of the players were born and raised near sea level, with only two HA acclimatized players born at an altitude above 2,000 meters. Pulmonary function testing was used to confirm the overall similarity between study groups in forced vital capacity (FVC), as individuals born and raised at moderate to high altitude have larger lungs which may contribute to an increased capacity for pulmonary gas exchange (14). An equal distribution of player positions was selected in each study group (defender, midfield, and forward).

Study design

A total of 20 players participated in the study (11 HA and 9 LA players). All players were tested in two environments: (1) La Paz, Bolivia (3,600 m) and (2) Santa Cruz, Bolivia (420 m). Each player was tested in his home environment first. Testing in the non-home environment took place within 1 month of testing in the home environment. All subjects were tested at the same time within 48 hours of arrival to the non-home environment. Thus, with respect to the LA players, testing at altitude occurred prior to a full ventilatory and renal acclimatization which generally is complete after more than 6 days (15). Because the study took place during the middle of the Bolivian professional football season, training level was constant over the duration of the study.

Anthropometry and hematology

All subjects were measured using standard anthropometric techniques in order to establish the general similarity between LA and HA groups. Measurements included height, weight, chest width (transverse chest diameter), chest depth (anterior-posterior chest diameter), elbow breadth, biceps skin fold, triceps skin fold, and subscapular skin fold. From skin fold measurements, body density was calculated according to equations given by Durnin and Womersley (16). The Siri equation (17) was used to calculate percent body fat, and from this value fat free mass (FFM) was calculated for each individual. Pulmonary function was assessed with a Collins 9 liter survey spirometer (Warren Collins, Braintree, MA). Each subject performed a maximal inspiration, followed immediately by a forced maximal expiration while in a seated position. From this procedure, the FVC was determined based on the best of at least two efforts. FVC was corrected for BTPS. Blood hemoglobin (Hb) concentration was measured prior to exercise from finger prick capillary blood using a Hemocue blood hemoglobin analyzer (Angelholm, Sweden).

Cycle ergometer testing

Exercise tests in the laboratory were given on a mechanically braked cycle ergometer, and consisted of continuous exercise with increasing work rates at approximately 60, 90, 125, and 160 watts for 4 minutes each, followed by 30 watt increments every 3 minutes until subject exhaustion. The initial workloads at 4 minutes each ensured a steady state of O_2 consumption. During exercise testing subjects inspired room air through a low resistance breathing valve. Expired fractions of O_2 and CO_2 were measured continuously from a mixing chamber using an Applied Electrochemistry S-3A O_2 analyzer and a Beckman LB-2 CO_2 analyzer, respectively. Gas analyzers were calibrated to gas standards prior to each test. Inspired minute ventilation (V_E-ATPS) was measured by a dry gas meter (Rayfield Electronics), which was calibrated with a 3 liter calibration syringe. These data were processed by an automated expired gas analysis indirect calorimetry system (Rayfield Electronics, REP-200B) to produce 30 second interval calculations of VO_2, carbon dioxide production (VCO_2), and minute ventilation (V_E-BTPS). The respiratory exchange ratio (RER) and ventilatory equivalent for oxygen (V_E/VO_2) were calculated from these data. Heart rate (HR) and arterial oxygen saturation (SaO_2) were continuously monitored during exercise using a Vantage XL Polar Heart Rate Monitor (Electric Oy, Sweden) and a Criticare Systems SO1+ pulse oximeter (Criticare Systems Inc., Waukeshau, WI). VO_2peak was defined as the peak oxygen consumption at the point of volitional fatigue. Finger prick blood samples were obtained at rest, during work levels 3 and 4, and 1 minute after maximal exercise in micro-capillary tubes for immediate analysis of blood lactate (Accusport portable lactate analyzer, Boehringer-Mannheim). For La Paz, the mean barometric pressure during the study was 498 mmHg, with a mean temperature of 19 °C and a relative humidity of 35%. For Santa Cruz, the mean barometric pressure was 725 mmHg, with a mean temperature of 28 °C and a relative humidity of 80%.

Football match measurements

Nine of the 20 participating players agreed to wear HR monitors during match play in both testing environments (6 non-acclimatized and 3 acclimatized players). Matches were either a part of regular league competition or were played as exhibitions. Prior to entering a match, players were fitted with a Polar Vantage XL heart rate monitor with the capacity to record cardiac frequency every 5 seconds. Players were measured during the first half of football match play only. The heart rate monitor was left on until player injury, substitution, or the end of the half.

HR data were used to estimate the rate of football match energy expenditure (RFE) as follows. The steady state VO_2-HR relationship was established in a given environment for each individual player from submaximal exercise data collected during the first 4 work loads on the cycle ergometer. VO_2 (L/min) was converted into energy expenditure (EE) (kcal/min) based on the standard energetic equivalent for O_2 consumption at a given level of the RER (18). The resulting EE-HR relationship was used as a standard curve to estimate football match energy expenditure per unit time from HR measurements during the football match. The general validity of this approach has been shown previously (19), and the method has been used to estimate EE in football players during match play (13). It should be emphasized that the EE-HR relationship established for each player was specific to the environment in which the football match was

Table 1. Characteristics of non-acclimatized and acclimatized football players.

Variable	Non-acclimatized	Acclimatized
Age (yr)	22.3 ± 3.6*	27.4 ± 3.6
Hemoglobin (g/dL)	13.6 ± 2.7*	17.9 ± 1.8
Height (cm)	172.6 ± 5.3	171.6 ± 5.4
Body mass (kg)	64.5 ± 6.0*	70.1 ± 6.0
FFM (kg)	55.3 ± 3.3	56.9 ± 4.8
Percent body fat (%)	14.3 ± 3.0*	18.7 ± 3.0
Elbow breadth (cm)	6.7 ± 0.3	6.8 ± 0.3
Arm circumference (cm)	26.7 ± 1.7	28.0 ± 1.5
Calf circumference (cm)	36.0 ± 2.0	37.8 ± 2.1
Chest depth (anterior-posterior) (cm)	198.7 ± 14.0	205.2 ± 13.8
Chest width (lateral) (cm)	298.4 ± 13.0	293.1 ± 12.9
FVC (L/min-BTPS)	4.99 ± 0.56	5.44 ± 0.54

*Significantly different from acclimatized players ($p \leq 0.05$)

played. That is, laboratory VO_2 and football match HR measurements took place within 24 hours of one another in the same environment. The RFE was normalized to body weight (kcal/min/kg) to take into account the relationship between body mass and the absolute rate of EE. The RFE presented here is the average per minute RFE over a 20 minute playing time, as this was the longest uninterrupted period of play obtained from all participating players.

Statistical analyses
Analysis of variance (ANOVA) or covariance (ANCOVA) was used to test for exercise response differences between environments and between subject groups. The interaction between environment and subject group was used to formally test for differences between subject groups in a given environment. All statistics were performed with the Systat Statistical Software, Version 5.2 (Evanston, IL). An effect was considered significant if $p \leq 0.05$, and highly significant if $p \leq 0.01$. All values in tables and figures are reported as means±standard deviations.

RESULTS

Subject characteristics
HA players were slightly older and heavier than the LA players (Table 1). While stature and FFM did not differ between study groups, the HA players had a significantly higher percent body fat to account for the body weight difference. There were no significant differences between subject groups for measures of chest morphology or FVC to indicate differences in either developmental and/or ancestral exposure to high altitude (14). The HA players had a significantly higher mean Hb level consistent with a full hematological acclimatization to high altitude (20).

Maximal cycle ergometer exercise
Maximal exercise response variables are given in Table 2. VO_2peak was significantly lowered for both HA and LA players at high altitude compared to low altitude. In addition, both HA and LA players had lower values for SaO_2, higher V_E/VO_2, and higher values for RER at maximal exercise at altitude compared to low altitude. While peak lactate concentration tended to be higher and maximal HR lower at high altitude, these differences did not reach statistical significance. Within a given environment (La Paz or Santa Cruz), there were no significant differences between HA and LA players in maximal exercise response measures. However, compared to the HA players, the LA players had a larger VO_2peak decrement from low to high altitude. This significant interaction (between subject group and testing environment) is presented in Table 2 as the difference between subject groups in the percentage change of VO_2peak from low to high altitude.

Submaximal response
Submaximal exercise response differences in VE/VO_2, SaO_2, and blood lactate concentration were tested at each of four different steady state work levels (Figures 1-3). Although these work levels were given at a fixed external resistance on the cycle ergometer, variability in pedal frequency between subjects caused variability in the steady state power output over the 1 minute averaging interval. Average power output for all groups combined at exercise intensities 1-4 were 60±7, 92±10, 125±15, and 158±17 Watts, respectively. Corresponding mean VO_2 rates at exercise intensities 1-4 were 1.10±0.11, 1.45±0.17, 1.78±0.19, and 2.15±0.23 L/min, respectively. Small significant differences in power output and VO_2 were apparent between groups at some

Table 2. Maximal exercise response variables for acclimatized and non-acclimatized subjects tested at high altitude (HA, La Paz, 3,600 m), and low altitude (LA, Santa Cruz, 420m). The direction of change from LA to HA (increase or decrease) is indicated as a (+) or (-).

	VO_2 (mL/kg/min)	*RER*	*Lactate (mM)*	*HR (bpm)*	*SaO_2 (%)*	*VE/VO_2*
Non-acclimatized tested at:						
LA (Santa Cruz, 420 m)	52.65±4.15	1.13±0.10	11.07±2.55	178±10	83.78±8.13	36.76±4.91
HA (La Paz, 3,600 m)	41.87±4.15†	1.22±0.10†	12.32±2.69	174±10	78.36±7.36	50.11±4.91†
Acclimatized tested at:						
LA (Santa Cruz, 420 m)	49.85±4.17	1.15±0.12	10.82±2.55	170±9	88.89±7.2	40.04±4.89
HA (La Paz, 3,600 m)	43.58±4.17†	1.26±0.09†	11.07±2.55	173±9	79.33±7.35†	50.35±4.89†
% Change from LA to HA						
Non-acclimatized	20.4 (-)	8.0 (+)	11.3 (+)	2.70 (-)	6.50 (-)	36.3 (+)
Acclimatized	12.6* (-)	9.6 (+)	2.3 (+)	1.6 (+)	10.8 (-)	25.8 (+)

(†)= within group effect where response was significantly different from that seen at LA, $p \leq 0.05$. (*)=between team effect where the response was significantly different from that seen in the non-acclimatized players.

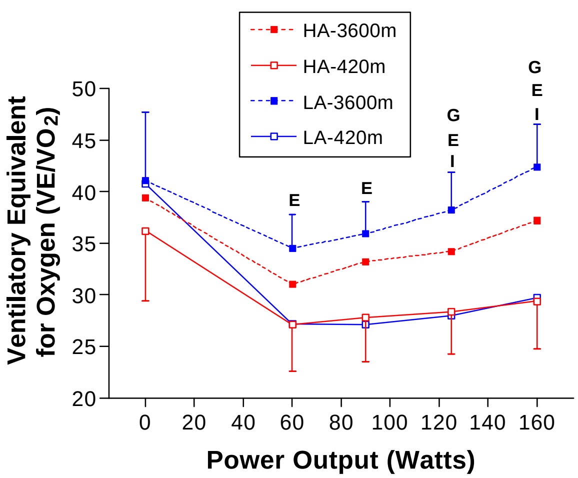

Figure 1. Ventilatory equivalent for oxygen (V_E/VO_2) during submaximal cycle ergometer exercise in acclimatized (red lines) and non-acclimatized (blue lines) football players tested at 3,600 m (La Paz, Bolivia, dotted lines) and near sea level (Santa Cruz, Bolivia, solid lines). E=significant effect of environment (La Paz vs. Santa Cruz), G=significant effect of subject group (acclimatized vs. non-acclimatized), and I=significant interaction between subject group and environment.

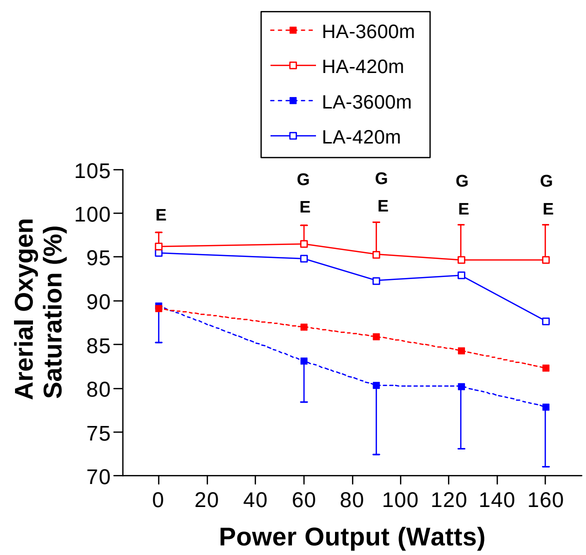

Figure 2. Arterial oxygen saturation (%) by pulse oximetry during submaximal cycle ergometer exercise in acclimatized (red lines) and non-acclimatized (blue lines) football players tested at 3,600 m (La Paz, Bolivia, dotted lines) and near sea level (Santa Cruz, Bolivia, solid lines). E=significant effect of environment (La Paz vs. Santa Cruz), G=significant effect of subject group (acclimatized vs. non-acclimatized).

exercise intensities, but there was no consistent pattern to these differences. Importantly, group differences in VO_2 disappeared when adjusted by covariance analysis for work rate. For this reason, submaximal measures of V_E/VO_2, SaO_2, and arterial lactate concentration were tested by ANCOVA, controlling for work rate (Watts). Thus, values presented in Figures 1-3 are adjusted mean values. The work rate covariate was a significant factor in all models tested. This procedure had little quantitative and no qualitative effect on group mean

Table 3. Rate of football match energy expenditure (RFMEE) in La Paz (3,600 m) and Santa Cruz (420 m) for the subset of 9 football players (Acclimatized = Acclim., and non-acclimatized = Non-acclim.) measured during match play in both environments.

Subject ID	RFMEE (kcal/kg/min) La Paz (3,600 m)	RFMEE (kcal/kg/min) Santa Cruz (420 m)	VO_2peak (kcal/kg/min) La Paz (3,600 m)	VO_2peak (kcal/kg/min) Santa Cruz (420 m)
111 Acclim.	0.233	0.293	46.7	49.7
113 Acclim.	0.205	0.209	41.3	42.8
114 Acclim.	0.211	0.271	49.6	49.8
302 Non-acclim.	0.124	0.169	46.7	49.4
303 Non-acclim.	0.189	0.203	46.1	55.3
305 Non-acclim.	0.196	0.197	41.9	55.0
307 Non-acclim.	0.179	0.199	38.9	61.0
312 Non-acclim.	0.177	0.231	41.6	55.0
314 Non-acclim.	0.172	0.228	44.1	54.0
Mean	0.187±0.03	0.222±0.399	44.1±3.3	52.4±5.1
% change LA-to HA	16%		16%	

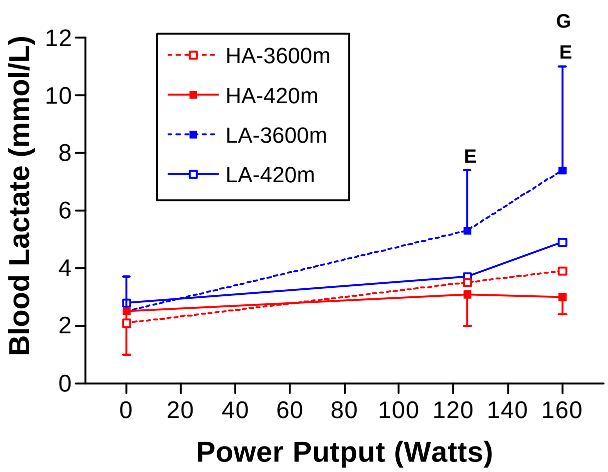

Figure 3. Blood lactate concentration (mM) during submaximal cycle ergometer exercise in acclimatized (red lines) and non-acclimatized (blue lines) football players tested at 3,600 m (La Paz, Bolivia, dotted lines) and near sea level (Santa Cruz, Bolivia, solid lines). E=significant effect of environment (La Paz vs. Santa Cruz), G=significant effect of subject group (acclimatized vs. non-acclimatized).

values, but is considered the correct way to express these data.

The V_E/VO_2 was higher for both HA and LA players at high altitude compared to low altitude (Figure 1). While V_E/VO_2 was similar between subject groups at rest and at all work levels at high altitude, group differences in V_E/VO_2 were apparent at low altitude. That is, significant group main effects and group by environment interactions were detected at exercise intensities 3 and 4 revealing higher V_E/VO_2s in the LA players tested at low altitude versus the HA players. SaO_2 during submaximal exercise was lower at low altitude compared to high altitude for both HA and LA players (Figure 2). The LA players had lower SaO_2s in both environments compared to the HA players. While the LA players tended to show a disproportionately lower SaO_2 at high versus low altitude compared to the HA players (especially at exercise intensity 4), the interaction term did not reach statistical significance.

Lactate concentration increased with increasing power output in all subjects (Figure 3). While there were no differences between subject groups or altitudes in resting lactate levels, differences between groups became apparent with increasing exercise intensity. The LA players had higher lactate levels in both environments. Although the interaction term was not significant at exercise intensity 4, it is clear that most of the group effect at this intensity was due to the disproportionately higher lactate level displayed by LA players when tested at high altitude.

The rate of football match energy expenditure (RFMEE)

RFE and VO_2peak data are presented in Table 3 for the subset of football players tested during football matches in both environments. Sample size is insufficient to test for subject group differences or group by environment interaction effects. However, the combined sample is sufficient to test for an effect of testing environment. All players showed significant decrements in RFE and VO_2peak when tested at high compared to low altitude. While the relative decrease was the same for VO_2peak and RFE, there was no significant correlation between the change in RFE and change in VO_2peak with high altitude exposure.

DISCUSSION

The present study gives exercise response data for HA and LA football players in Bolivia who were studied at both high and low altitude. The cross-over study design and the fact that the subjects were professional football players, make this a unique study with possible relevance to the question of an advantage or disadvantage during football matches played at high altitude by teams differing in acclimatization status. However, as discussed by Bangsbo (13), football match performance is a complex matter depending upon technical, tactical, physiological, and psychological/social factors. Because this study presents only a narrow range of physiological measures, it cannot address the full complexity of this issue.

Both HA and LA soccer players show a significant decrease in peak oxygen consumption (VO_2peak) at high altitude. This is consistent with many previous studies (1,2,3,4). In addition, all players tested showed a decrement in the estimated RFE over 20 minutes of first half match play. Time motion studies have been used in the past to show a significant decline in physical activity level (and presumably EE) near the end of a football match related to player fatigue (21,22). In this study we used a HR monitoring technique, similar to that applied in a previous study of football match performance (13), which should give a better estimate of EE than is possible in a time motion study. However, the RFE estimated in this study was based on a HR-VO_2 curve established from cycle ergometer rather than treadmill exercise. Clearly, treadmill exercise more closely approximates football match activity. Despite this, the estimate appears to have internal validity for EE comparisons between environments. While total match EE was not measured, the significant decrease in the RFE is consistent with the overall decrease in physical work capacity experienced at high altitude. The decrease observed is also consistent with time motion studies that showed a decrease in physical activity during soccer matches played in the heat and at moderate altitude during the 1986 Mexico World Cup (23,24).

Previous studies have demonstrated a significant relationship between maximal oxygen uptake and both the running distance covered during a game (25,26) and the number of sprints attempted by a player (26). Such findings have clear implications for football match performance at high altitude, where a large decrease in aerobic capacity is to be expected for all football players, whether acclimatized or not. What remains difficult to quantify, of course, is the relative disadvantage of playing at high altitude in a non-acclimatized versus acclimatized state. The VO_2peak decrement was large for both player groups, but it was clearly larger in non-acclimatized players (~20% versus ~13%). While the difference between groups in this respect is small compared to the overall effect of high altitude on aerobic capacity, this difference may be important to football match performance. Consider a recent training intervention study of elite junior Norwegian football players (27). This study showed that a 10% increase in maximal oxygen consumption is correlated with a 20% increase in the distance covered during a match, a 100% increase in the number of sprints made during a match, and a 23% increase in the amount of time that a player is involved with the ball (27). While this study may be confounded by increased player motivation after training, the large effects on match performance observed certainly would imply a disadvantage at high altitude until full acclimatization is achieved. The issue of advantage or disadvantage cannot be fully addressed until studies have been conducted to look at the time course of adaptation and football match performance in non-acclimatized football players at high altitude. In the present study we looked at non-acclimatized players within 48 hours of their arrival at high altitude. Because all of these players were tested essentially at the same time it was not possible to gauge the effect of continuing acclimatization on exercise and football match performance.

LA players also accumulated more blood lactate during submaximal work at high altitude, had lower values for SaO_2, and ventilated more per unit oxygen consumption than did HA players. The ventilatory data are particularly interesting as LA players had lower SaO_2 values despite higher levels of pulmonary ventilation during exercise. This indicates an inefficiency of pulmonary gas exchange in the non-acclimatized state, possibly due to ventilation/perfusion inequality or diffusion limitation (28). The lactate data, which show lower levels of lactate accumulation by HA players, even at low altitude, may indicate a sustained lactate paradox in acclimatized subjects when transported to the lowlands. Similar lactate results are reported by Matheson et al. (29) for HA native subjects tested at low altitude.

All of the response differences in the non-acclimatized versus acclimatized state are consistent with acclimatization studies which show improvements in VO_2peak and SaO_2 and decreases in exercise ventilation (30), as well as decreases in the level of blood lactate for a given absolute work output (31). However, it should be noted that improvements in VO_2peak with high altitude acclimatization are generally very small (30). Thus, it is difficult to base a hypothesis of performance disadvantage in the non-acclimatized state on the aerobic capacity measure alone. It should also be considered that other factors can explain the larger VO_2peak decrement at high altitude observed in LA players. Many studies have shown that individuals with a large VO_2peak at sea level have a large VO_2peak decrement when tested at high altitude (32). The LA players in this study started with a slightly higher VO_2peak measured near sea level compared to the HA players. It is not clear why this was the case, but perhaps the LA players were better able to achieve an aerobic training effect during training at low altitude compared to the HA players who trained at high altitude. Such an interpretation provides little support to the hypothesis of a disadvantage in the non-acclimatized state.

The VO_2peak measured at low altitude in this sample of Bolivian professional football players (mean of both teams at LA = 51.2 mL/kg/min) was lower than that measured previously in top level football players from other countries which range between 56-69 mL/kg/min (13,33). One reason for this difference may be because VO_2peak was measured on a cycle ergometer which is not a common exercise modality for a football player. Cycle ergometer measures of VO_2peak are generally ~5% lower than those achieved on a treadmill, especially for runners (34). In addition, our exercise protocol was rather long in order to ensure a steady state of O_2 consumption during the first 4 power outputs. Subjects often complained of local muscle fatigue to signal the end of exercise testing, and data showed that many players did not achieve a true maximum VO_2 based on the criteria of a VO_2 plateau or a maximal HR within 5% of their age predicted maximum. This explains our choice of the term VO_2peak rather than VO_2max. Despite this problem, between team and between environment comparisons of VO_2peak in this study are valid given the self-paired nature of the study design.

CONCLUSIONS

VO_2peak and the RFE decrease significantly at 3,600 m versus 420 m in both HA and LA professional Bolivian football players. Both types of players also show physiological responses during exercise consistent with the increased challenge of exercise in a hypoxic environment, including lower SaO_2 and higher V_E/VO_2 values. However, LA players show a greater decrement in VO_2peak, higher blood lactate levels, and lower SaO_2 values at high altitude compared to HA players. Thus, while the challenge of playing football at high altitude is universal in that it affects the performance of both acclimatized and non-acclimatized football players, the results of this study suggest that non-acclimatized players are at a disadvantage compared to acclimatized players. Unfortunately, we were unable to directly test this hypothesis with a measure of football match performance due to sample size limitations in the RFE measurement.

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