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Soccer activity profile of altitude versus sea-level natives during acclimatisation to 3600 m (ISA3600)

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ABSTRACT

Objectives We investigated the effect of high altitude on the match activity profile of elite youth high altitude and sea level residents.

Methods Twenty Sea Level (Australian) and 19 Altitude-resident (Bolivian) soccer players played five games, two near sea level (430 m) and three in La Paz (3600 m). Match activity profile was quantified via global positioning system with the peak 5 min period for distance ((D_{5peak})) and high velocity running (>4.17 m/s, $HIVR_{5peak}$); as well as the 5 min period immediately subsequent to the peak for both distance (D_{5sub}) and high-velocity running ($HIVR_{5sub}$) identified using a rolling 5 min epoch. The games at 3600 m were compared with the average of the two near sea-level games.

Results The total distance per minute was reduced by a small magnitude in the first match at altitude in both teams, without any change in low-velocity running. There were variable changes in HiVR, D_{5peak} and $HiVR_{5peak}$ from match to match for each team. There were within-team reductions in D_{5peak} in each game at altitude compared with those at near sea level, and this reduction was greater by a small magnitude in Australians than Bolivians in game 4. The effect of altitude on $HiVR_{5peak}$ was moderately lower in Australians compared with Bolivians in game 3. There was no clear difference in the effect of altitude on maximal accelerations between teams.

Conclusions High altitude reduces the distance covered by elite youth soccer players during matches. Neither 13 days of acclimatisation nor lifelong residence at high altitude protects against detrimental effects of altitude on match activity profile.

INTRODUCTION

The activity profile of team-sport athletes alters when matches are played under conditions of environmental stress. For example, the total distance of Australian football players is reduced in matches played under hot compared with cool conditions.[1 2] The reduced total distance may be a result of self-modulation of activity under environmental stress to protect the capacity to perform higher intensity actions,[1] or perhaps it reflects a lack of sensitivity in picking up transient reductions in high-intensity activity during matches. Recently, our group established that the activity profile of soccer players is also altered at moderate altitude (1600 m) compared with that at sea level.[3] Specifically, each of the peak 5 min periods of total distance, high-velocity running (HiVR,>4.17 m/s) distance was reduced after 4 day acclimatisation to 1600 m.[3] Further, the decrease from the peak to the subsequent 5 min stanza was greater than at sea level for total distance, HiVR and maximal accelerations (> 2.78 m/s^2).[3] Thus, at moderate altitude, team-sport athletes had reduced maximal capacity and greater decrement in performance during matches compared with those at sea level, and the players were not able to modulate match activity to preserve high-intensity actions.[3] Matches played at a higher altitude would probably result in greater reductions in running performance compared with those we reported, but this has yet to be established.

The reduced activity capacity of team-sport athletes at high altitude should not be surprising. Athletes in soccer matches operate for sustained periods at approximately 70% of O_{2max},[4] and this capacity is reduced by approximately 7% per1000 m altitude ascended.[5] In fact, in a cohort of non-acclimatised soccer athletes, O_{2max} was reduced by ~20% at high altitude (3600 m).[6] In our previous study, a peak 5 min distance in a soccer match was reduced after 4 days at 1600 m by ~9%, in agreement with the likely reductions in aerobic capacity. It would therefore follow that reductions in the activity profile of soccer players would be greater at a higher altitude. It is not just the average aerobic consumption that is probably limiting the performance of these athletes, but rather the process of phosphocreatine (PCr) resynthesis when recovering from high-intensity efforts that is most affected at high altitude. PCr represents the most immediate substrate to rephosphorylate ATP after high-intensity exercise, and the ability to sustain intermittent exercise performance is affected by PCr availability in working muscles. PCr resynthesis kinetics are sensitive to manipulations of O_2 availability,[7] which occurs during exercise at high altitude. Thus, under conditions of acute hypoxia, PCr resynthesis will be reduced,[8] potentially limiting the intermittent exercise performance typical in soccer matches.

Limitations in oxygen availability do not solely influence metabolic events in the causation of fatigue. Under hypoxic conditions, a lower arterial O_2 availability during repeat-sprints results in lower O_2 consumption and premature fatigue.[9] These findings are further supported by the fact that participants with a higher VO_{2max} consume more VO_2 and exhibit a greater sprint endurance in hypoxia than participants with a poorer aerobic fitness,[10 11] and that O_{2max} is moderately negatively correlated

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with performance decrement during such exercises.[11 12] Strong correlations also exist between arterial O_2 saturation and mechanical work during 10×10 s sprints[9] and 20×5 s sprints.[10] Finally, measurements of tissue oxygenation by near-infrared spectroscopy have revealed that the oxygenation of the cerebral cortex during sprints[9] and the reoxygenation rate of the muscle during recovery intervals between sprints[13] are determinants of repeated-sprint ability.

Six days at moderate altitude was deemed to be insufficient to fully acclimatise and protect against the reduced activity profiles of soccer players,[3] and a 2 week acclimatisation period was recommended.[14] Given that each of the physiological reductions mentioned within the context of fatigue above is adaptable to a hypoxic stimulus, the time course of adaptation to hypoxia and the response of athletes during matches are important to establish. For team sport athletes, the timecourse of adaptation remains unknown.

The aims of this study therefore were to (1) determine the effects of high altitude on the match activity profile of sea level and high-altitude natives and (2) establish the time course of match running performance acclimatisation to high altitude so as to improve our understanding of the optimal timing of arrival before official competition.

METHODS

The general methods of this study are expressed in detail in the companion paper elsewhere in this journal.[15] Please refer to figure 1 of that paper for an overview of the larger study (ISA3600) that this paper forms one part of. Measures on sleep,[16] fatigue, wellness and performance[17] and haematological adaptation[18] have also been discussed elsewhere.

Twenty elite youth male soccer players, lifelong residents at near sea level (Australians, AU), and nineteen elite youth soccer players born at, and lifelong residents of, high altitude (Bolivians, BO) gave written informed consent to participate in this study. The subject characteristics are presented in the companion paper.[15] Almost all of the Bolivian players were 'Mestizos' (mostly a mix between Europeans, Quechua and Aymara). The Australians were of European and Asian descent. The study was approved by the Victoria University Human Research Ethics committee and conformed to the Declaration of Helsinki. Starting 1 week before, and throughout the duration of altitude exposure, each Australian athlete was supplemented daily with oral iron (305 mg ferrous sulfate, 1000 mg vitamin C).

Each field player's activity (ie, goalkeepers were excluded) was monitored individually during 'official friendly' matches at sea level and at high altitude. Two matches were played at Santa Cruz, Bolivia (430 m) over 5 days, and a further three games were played at La Paz, Bolivia (3600 m) on days 1, 6 and 13 of altitude residence. Athletes travelled directly between Santa Cruz and La Paz by aircraft, so travel time and stress were low.

As this study was also a 'training camp' for these athletes, not every athlete played in each match. A total of 13 Bolivian and 14 Australian players were sampled. Five Bolivians and three Australians had files from each match, three Bolivians and four Australians in four matches, and the remainder of the players in three matches. Peak data (see below) were sampled only in the first half of the matches.

Player activity profile was measured via global positioning system (GPS) sampling at 10 Hz (MinimaxX Team Sports 4.0, Catapult Innovations, Melbourne, Australia). The activity profile variables analysed, expressed in metres per minute of match time (m/min), were: total distance; low-velocity running (LoVR, 0.01–4.16 m/s), high-velocity running (HiVR, 4.17–10.0 m/s).[19 20] In addition, the occurrence of maximal accelerations per minute was quantified (Accel ≥2.78 m/s^2).[19–21]

In an attempt to more completely assess the effects of altitude on match running of these players, the peak 5 min periods for distance (D_{5peak}), HiVR ($HiVR_{5peak}$) and Accel ($Accel_{5peak}$) were identified using a rolling 5 min sample period.[3 22] This method is more sensitive for identifying peak periods of activity compared with the traditional method using predefined time periods.[22] In addition to identifying the peak periods of activity as a marker of performance, the 5 min period immediately subsequent to the peak period was also assessed for decrements in total distance (TD_{5-sub}), high-velocity running ($HiVR_{5-sub}$) and maximal accelerations ($Accel_{5-sub}$).

All data were log-transformed to reduce bias arising from non-uniformity error. Between-group standardised differences in all monitored variables were calculated using pooled SDs from the first two matches at sea level. Threshold values were >0.2 (small), >0.6 (moderate) and >1.2 (large). Uncertainty in each effect was expressed as 90% confidence limits and as probabilities that the true effect was substantially positive or negative.[23] These probabilities were used to make a qualitative inference about the true effect as previously described.[23]

RESULTS

In both teams, total distance per minute was reduced by a small magnitude in the first match at altitude, and this was also true for the Bolivians in game 5 (figure 1A). There was no clear difference in the effect of altitude on total distance between teams (figure 1B). Low-velocity running per minute was higher by a small magnitude in Australians than in Bolivians in the second match at near sea level (figure 1C), but there was no clear difference in the effect of altitude between teams (figure 1C,D).

High-velocity running per minute was moderately higher in Australians compared with Bolivians in the second game at near sea level, and higher by a small magnitude in Bolivians compared with Australians in games 3 and 5 (figure 2A). Australian HiVR per minute was moderately lower in game 3 and lower by a small magnitude in game 4 compared with the pooled near sea-level data. Despite this, there was a smaller reduction in HiVR per minute in Australians compared with Bolivians in games 3 and 4 at altitude, and there was no clear difference in game 5 (figure 2B).

Maximal accelerations per minute were higher in Australians than in Bolivians in game 1 at near sea level by a small magnitude, with no other clear differences seem (figure 2C). Bolivian maximal accelerations were higher by a small magnitude in game 5 than for pooled near sea level data, figure 2C. There was no difference in the effect of altitude on maximal accelerations between teams (figure 2D).

Bolivian D_{5peak} was moderately higher than Australians in game 1 at near sea level, and moderately higher for Australians compared with Bolivians in game 5 at altitude (figure 3A). There were moderate within-team reductions in D_{5peak} in each game at altitude compared with at near sea level (figure 3A), and this reduction was greater in Australians than in Bolivians in game 4 (figure 3B).

The $HiVR_{5peak}$ was higher by a moderate magnitude in Bolivians compared with Australians in games 1, 2 and 4, with a large difference in game 3 (figure 3C). Both sides had small–large within-team reductions at altitude compared with at near sea level (figure 3C). The effect of altitude on $HiVR_{5peak}$ was lower by a small magnitude in Australians compared with Bolivians in game 3 (figure 3D).

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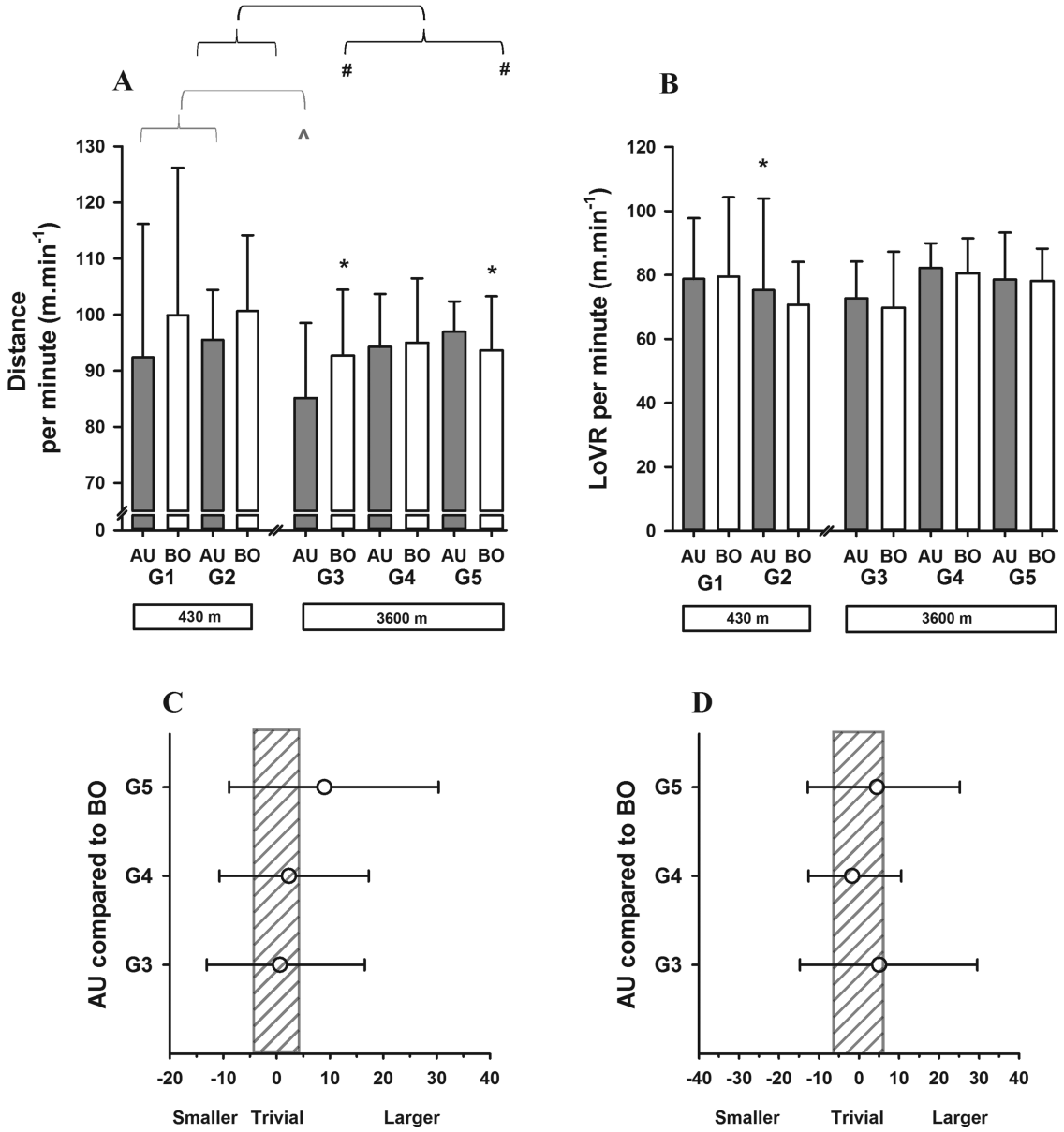

Figure 1 Total distance (A) and low-velocity running (B) per minute of games, each expressed at near sea level (G1, G2) and at altitude (G3, G4, G5, 3600 m). Also, relative change of Australians versus Bolivians at altitude for total distance (C) and low-velocity running per minute (D). 'n' for Australians (Au) and Bolivians (Bo) is in methods. '*' denotes a small standardised difference between teams, '^' a small within-team change for Australians, and '#' a small within-team change for Bolivians.

The $Accel_{5peak}$ was lower by a small magnitude in Bolivians only in games 3 and 4 compared with at near sea level, table 1. There were no other clear differences between groups.

Both teams had substantial decrements in the 5 min stanza subsequent to the peak period for total distance ($D5_{sub}$), HiVR distance ($HiVR5_{sub}$) and $Accel_{5peak}$ in each match, but there were no substantial differences between groups for the effects of altitude on this decrement (figure 4).

DISCUSSION

This is the first study to document the effects of high altitude on the match activity profile of sea level-resident and altitude-resident team-sport athletes. The major findings of this study are: high altitude reduced match running in friendly matches; the altitude-induced reduction in activity profile in soccer matches was variable, but it was similar in sea level and high-altitude natives; thus, neither 13 days of acclimatisation for sea-level natives nor lifelong residence at altitude could protect against reduced output during matches at altitude.

The athletes in this study were well conditioned with similar Yo-Yo intermittent recovery level one scores (see companion paper[17]) to age-matched peers.[24 25] Thus, the results of this study may be transferrable to similar populations of athletes.

The effect of altitude on high-intensity activity during the friendly matches reported in this study was uncoupled from the physical capacity testing data reported in the companion paper.[17] The Australians and Bolivians reduced their D_{5peak} by a similar magnitude at altitude. On initial glance, this may seem a bit surprising, given that the higher relative reduction in high intensity intermittent running capacity of the Australians compared with the Bolivians[17] should contribute directly to reduced movement capacity in matches.[26] The Australians had a greater desaturation at altitude, [17] and each 1% reduction in saturation can cause a concomitant 1% reduction in O_{2max}.[27] The

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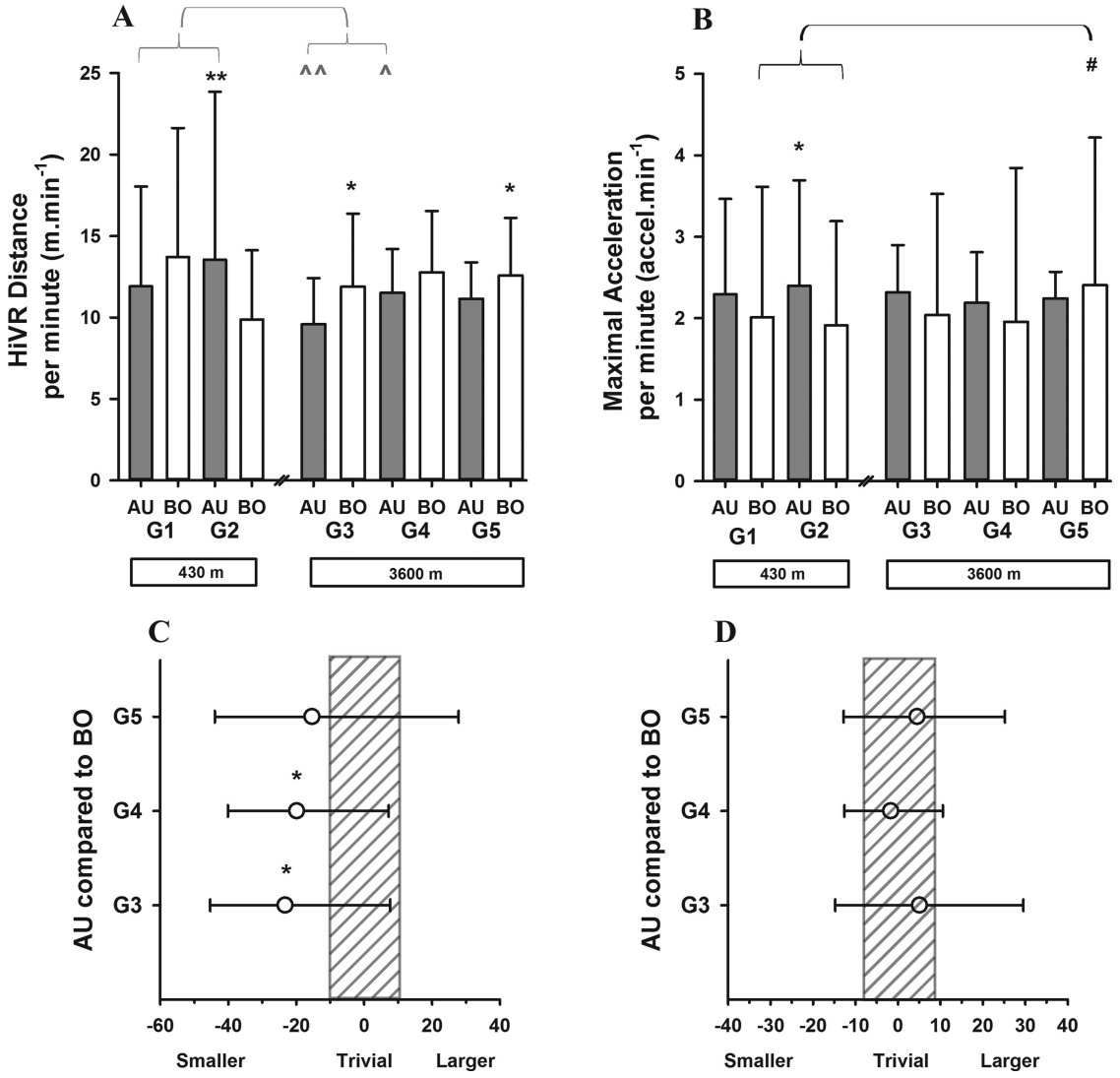

Figure 2 High-velocity running (HiVR, ≥ 4.17 m/s, A) and maximal accelerations (>2.78 m/s^2, B) per minute of games, each expressed at near sea level (G1, G2) and at altitude (G3, G4, G5, 3600 m). Also, relative change of Australians versus Bolivians at altitude for HiVR (C) and maximal accelerations per minute (D). 'n' for Australians (Au) and Bolivians (Bo) is in methods. '*' denotes a small standardised effect between teams, '^' a small within-team effect for Australians, '^^' a moderate within-team effect for Australians, and '#' a small within-team effect for Bolivians.

difference in SpO_2 lessened by the final match,[17] and this coincided with the Australians having a higher D_{5peak} than the Bolivians, indicating a degree of acclimatisation. The reduction at altitude of high-intensity capacity was more marked in the Australians than in Bolivians,[17] yet in matches the opposite was true, with smaller reductions in peak HiVR in the Australians. This is in agreement with the notion that players' physical activity during games is first influenced by tactics[28] and outcomes,[29] which have a greater impact than physical fitness per se. Given the influence of the opposition and team style[30] on the match running of players,[31 32] it is possible that neither of the two teams here were fully taxed physically during matches. These factors need to be considered when opinions on the likely effects of altitude on team-sport athlete performance are formed.[14 33]

It should be acknowledged that the Australian coach instructed his players to play conservatively in the first match at near sea level to avoid potential injury after 30 h of long-haul travel 3 days prior to the first match. This has affected our ability to detect altitude-induced differences between groups, but it reflects a practical reality faced by many teams travelling internationally for competition, especially those from the Southern hemisphere. Equally, it is possible that the Australians' effort reflected travel fatigue[34] and reduced wellness[17] stemming from playing a match on the third day after arrival in Bolivia, after 30 h of long-haul travel and a 10 h time zone change. Long-haul travel is known to reduce counter-movement jump performance,[35] which in turn is related to the amount of HiVR performed by elite team sport athletes in competition.[36]

In accordance with reduced capacity[17] at high altitude,[5 6] the peak 5 min running distance on arrival at 3600 m was 13–16% lower for Bolivian and Australians, respectively, than that reported with the same method at 1600 m.[3] As the magnitude of this standardised effect was evident for both Australians and Bolivians, it is intriguing that lifelong residence at altitude did not offer a protective effect against altitude for the Bolivians. This is especially true when the lower desaturation[17] and higher initial Hb_{mass}[18] of the Bolivians are considered.

The decrement in peak 5 min HiVR in the subsequent stanza was only slightly higher than earlier,[3] but both studies clearly

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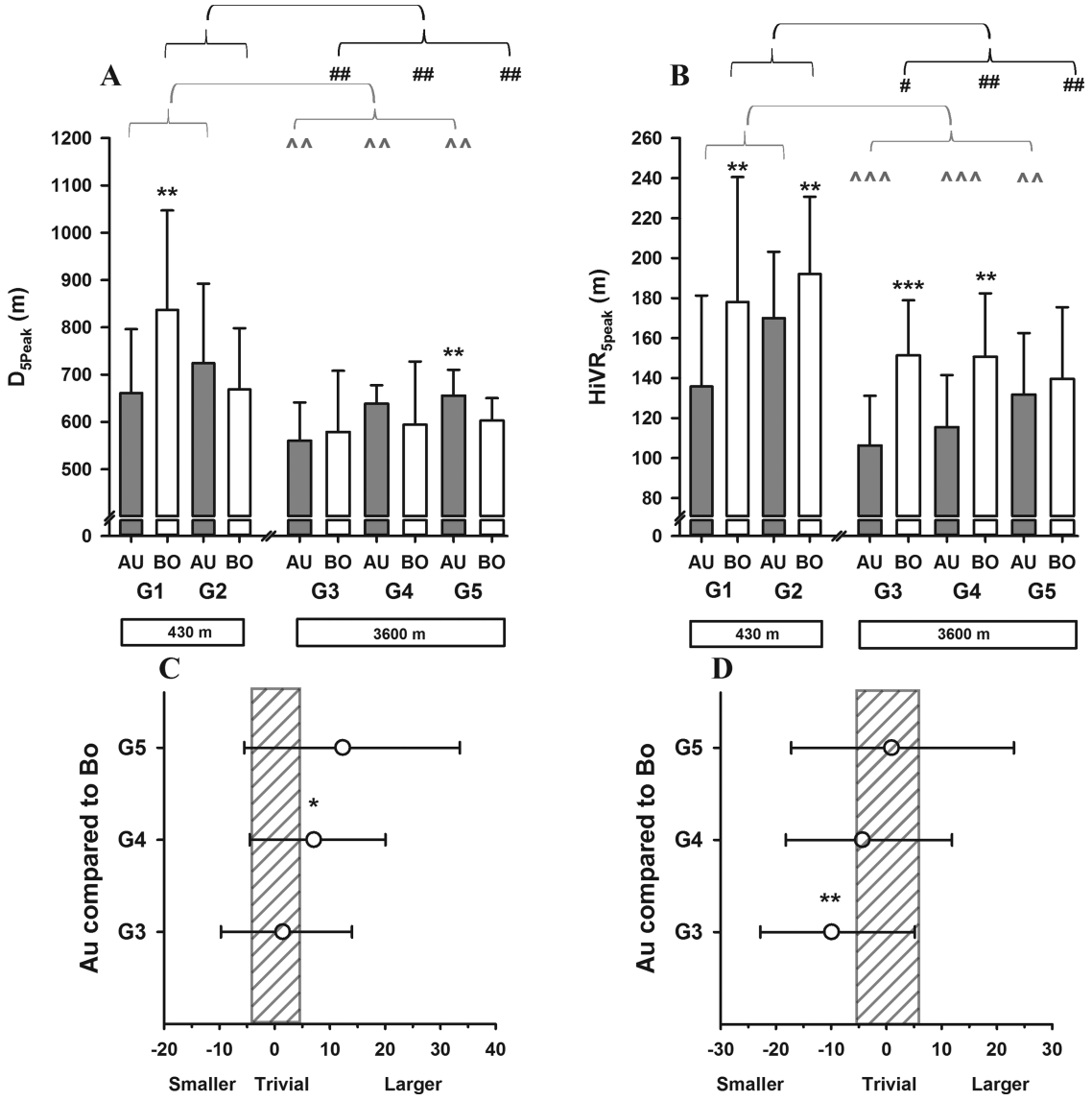

Figure 3 Peak 5 min data for distance (D_{5peak}, A) and high-velocity running ($HiVR_{5peak}$, > 4.17 ms), each expressed at near sea level (G1, G2) and at altitude (G3, G4, G5, 3600 m). Also, relative change of Australians versus Bolivians at altitude for D_{5peak} (C) and $HiVR_{5peak}$ (D). 'n' for Australians (Au) and Bolivians (Bo) is in methods. '*' denotes a small standardised effect between teams, '**' a moderate standardised effect between teams, '***' a large standardised effect between teams, '^^' a moderate within-team effect for Australians, '^^^' a large within-team effect for Australians, '##' a moderate within-team effect for Bolivians, and '###' a large within-team effect for Bolivians.

Table 1 Five-min peak period data for the frequency of maximal accelerations ($Accel_{5peak}$) for games at near sea level and at high altitude

	$Accel_{5peak}$	
Venue	**Australian**	**Bolivian**
Near sea level		
Game 1	11±4	13±6
Game 2	11±3	10±2
Altitude (3600 m)		
Game 3	9±1	10±3#
Game 4	10±5	10±3#
Game 5	11±2	11±3

'#' Denotes a small reduction from sea level.

show a 1.5-fold higher decrement than matches played at sea level.[37 38] This method does not allow for a definitive statement on fatigue in matches, as reduced output may reflect altered tactics[28] or indeed likely match outcomes that can be derived by players from the current score.[29] However, it is not too speculative to suggest that reduced wellness[17] and capacity[5 17 39 40] of athletes at altitude would also cause increased transient fatigue in matches after periods of peak high-intensity activity.

In agreement with previous investigations on the effects of environmentally stressful conditions on team-sport athlete activity profiles, altitude had little clear effect on the capacity of players to maximally accelerate in matches.[1] This is perhaps due in part to this being the least reliable measure derived from GPS,[41 42] but also due to the nature of where these accelerations typically occur. Players typically perform maximal accelerations when in the vicinity of the ball, or when they are trying to get

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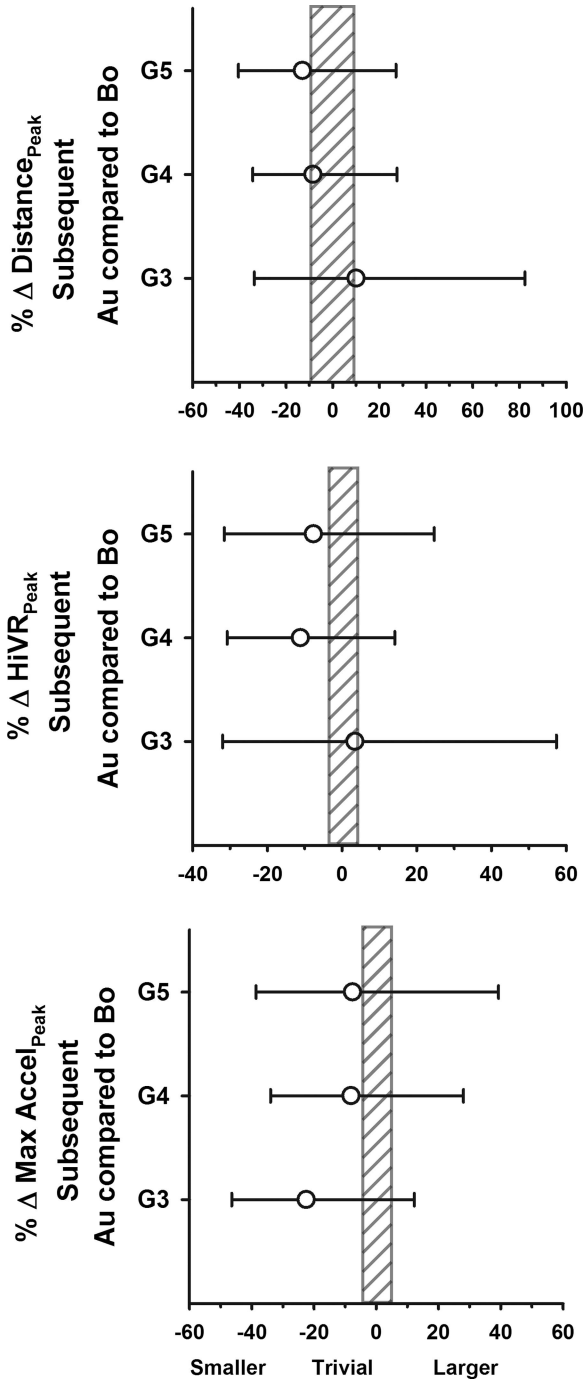

Figure 4 Mean relative decrement in distance (D_{peak}), and high-velocity running ($HiVR_{peak}$, > 4.17 m/s^{1}) from the peak 5 min period to the subsequent 5 min epoch at sea level (SL) games at altitude (G3, G4, G5, 3600 m) for Australians versus Bolivians. 'n' for Australians (Au) and Bolivians (Bo) is in methods. Error bars represent the 90% CIs of the mean change; the hatched bar represents the smallest worthwhile difference and thus the magnitude of a trivial change.

in position to receive or intercept the ball. Players are very likely to therefore protect the capacity to perform these metabolically demanding actions[43] by modifying lower intensity actions—a form or pacing strategy. It is also possible that the short nature of these tasks, even though conducted at a high-metabolic power,[43] makes them less susceptible to limitation by hypoxia.

LIMITATIONS

This study has attempted to quantify adaptation of match running performance to high altitude in sea level-resident natives and high altitude-resident natives. Using the activity profile of players in matches as a tool to assess adaptation is fraught with danger. For example, the activity profile of players can be influenced by match score[44] or the relative skill of opposing teams,[45] and is inherently variable.[46] It is also difficult to make conclusions on the effect pacing strategy[1 47] has on mitigating fatigue of these athletes at altitude. Furthermore, the positional differences were not investigated. The use of more sensitive activity profile analytical methods[22] rather than blunt descriptions of average match activity helps identify the true effect of altitude on these players. In further defence of this study, we have attempted to provide a comprehensive analysis of haematological,[18] wellness, fatigue and physical capacity,[17] and sleep[16] of these athletes to contextualise the activity profile changes in matches.

CONCLUSIONS

High altitude probably reduced match running of elite youth soccer players in friendly matches; the altitude-induced reduction in activity profile in soccer matches was variable, but it was similar in sea level and high-altitude natives; thus, neither 13 days of acclimatisation for sea-level natives nor lifelong residence at high altitude could protect against reduced output during matches at high altitude. Sea-level teams can thus travel to high altitudes confident that the reductions in match running they experience will be similar to those experienced by high-altitude natives.

What is known on this subject

- Moderate altitude reduces the activity profile and increases transient fatigue in elite youth soccer players.
- Six days residence at moderate altitude is insufficient to return activity profiles to sea-level norms.

What this study adds

- High altitude reduces the distance covered by elite youth soccer players during matches for sea level and high-altitude natives.
- Match activity profile is uncoupled from physical capacity decrement at high altitude.
- Neither thirteen days of acclimatisation nor lifelong residence at high altitude protects against the detrimental effects of altitude on match activity profile.

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