Methods of the international study on soccer at altitude 3600 m (ISA3600)

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ABSTRACT

Background We describe here the 3-year process underpinning a multinational collaboration to investigate soccer played at high altitude—La Paz, Bolivia (3600 m). There were two main aims: first, to quantify the extent to which running performance would be altered at 3600 m compared with near sea level; and second, to characterise the time course of acclimatisation of running performance and underlying physiology to training and playing at 3600 m. In addition, this project was able to measure the physiological changes and the effect on running performance of altitude-adapted soccer players from 3600 m playing at low altitude.
Methods A U20 Bolivian team ('The Strongest' from La Paz, n=19) played a series of five games against a U17 team from sea level in Australia (The Joeys, n=20). 2 games were played near sea level (Santa Cruz 430 m) over 5 days and then three games were played in La Paz over the next 12 days. Measures were (1) game and training running performance—including global positioning system (GPS) data on distance travelled and velocity of movement; (2) blood—including haemoglobin mass, blood volume, blood gases and acid–base status; (3) acclimatisation—including resting heart rate variability, perceived altitude sickness, as well as heart rate and perceived exertion responses to a submaximal running test; and (4) sleep patterns.
Conclusions Pivotal to the success of the project were the strong professional networks of the collaborators, with most exceeding 10 years, the links of several of the researchers to soccer federations, as well as the interest and support of the two head coaches.

INTRODUCTION

In May 2007, for the third time in 11 years, the Fédération Internationale de Football Association (FIFA) vetoed international soccer games above 2500 m. The reasons given each time were (1) to avoid potential risks to players' health and (2) decreased performance and therefore injustice to the lowland team. These FIFA decisions affected the South American countries of Colombia (Bogota at 2600 m), Ecuador (Quito at 2800 m) and Bolivia (La Paz at 3600 m), which are the highest locations in the world where World Cup soccer is played. The 2007 ban was withdrawn shortly after its declaration until sufficient scientific data are available.

In October 2007, FIFA convened a meeting in Zürich of scientists/clinicians, representatives from Bolivia, the FIFA Medical Assessment and Research Committee and of the 'Association de Footballeurs professionels'. The meeting generated a consensus statement,[1] with recommendations about soccer performance at different altitudes, preparation to play soccer at altitude and mitigation of acute mountain sickness (AMS). These recommendations were gleaned from the existent altitude literature, which was largely derived from either endurance athletes or from studies on mountain climbers because there is a dearth of studies that have described the performance of team-sport athletes at altitude.[2] Even now, there are relatively few studies on team-sport athletes using altitude training[3–7] or the time course of acclimatisation.[8]

In 2000, Brutsaert *et al*[7] described no substantial differences in maximum aerobic power (VO_{2max}) of elite soccer players from near sea level within 2 days of arrival at 3600 m compared with lifelong altitude-adapted players. After ascent, there was a greater decrement in performance of soccer players from sea level than for altitude-adapted players, as well as higher ventilatory equivalents for oxygen, higher blood lactic acid concentrations and lower oxygen saturation. Brutsaert *et al*[7] concluded that soccer at 3600 m is a challenge for sea level and altitude teams and that non-acclimatised players are at a disadvantage compared with acclimatised players.

In La Paz, the Instituto Boliviano de Biología de Altura (IBBA) conducted a study during early 2007 on health status, performance and physiological changes in soccer players from sea level (Asunción, Paraguay, 60 m) within 48 h after arrival at high altitude, compared with players resident in La Paz. In the resultant publication,[5] data on AMS collected in 2002–2003 were also included. The empirically developed system whereby teams arrive at and depart from high altitude as soon as possible before and afterwards, respectively, seemed to be supported by a 2010 study financed by the Bolivian Football Association (unpublished report authored by I Eterovic). It demonstrated that for lowland soccer players there was an 18% decline in VO_{2max} within 6 h after arrival in La Paz, which expanded to 24% after 72 h. Because the altitude-induced decrease in VO_{2max} after 6 h was equal in both soccer players native to altitude and to near sea level, the Bolivian Football Federation concluded that there is a 'physiological window' allowing play at altitude within 6 h after arrival without disadvantage for the sea level team. Neither of these studies has been published in international journals and apparently little notice was taken of this information by the scientific community.

A recent retrospective analysis of the 2010 World Cup concluded that technical skills were not compromised at 1200–1750 m compared with sea level but that running performance was reduced by ~3%.[4] Garvican *et al*[6] is the only other soccer-specific study that we could locate, but it dealt with preparation of soccer players at 1600 m, which is also classified as low altitude.[1] Hence, soccer-specific data are warranted from moderate to high altitude given that the North/South American rounds of the World Cup (under the Confederation of North, Central American and Caribbean Association Football and the Confederacion Sudamericana de Futbol) can be played at these altitudes. In addition, high-altitude residents frequently report malaise and dizziness when they descend to low altitudes and anecdotal reports describe the need for bigger boots due to peripheral oedema when soccer players from altitude perform at sea level. Thus, there is also a need to systematically study soccer players who are normally resident at high altitude as well as sea-level residents who need to compete at high altitude.[9] Indeed, retrospective analysis of 104 years of games suggests that soccer players from high altitude are at a greater disadvantage when playing near sea level than the converse, that is, sea-level residents competing at high altitude.[9]

During the October 2007 FIFA meeting in Zürich, the need for soccer-specific studies to be conducted at altitude was suggested. Nearly 5 years later, in September 2012, the current international collaborative group succeeded in conducting a study of soccer preparation in La Paz, Bolivia. This paper summarises the steps that led to the completion of the International study on Soccer at Altitude 3600 m (ISA3600), whereas previous attempts by notable altitude researchers (Hans Hoppeler 1994–1995; Ben Levine 2008; Bengt Saltin and Peter Bärtsch 2008–2009—personal communications) were not successful.

The aims of project ISA3600 were twofold. First, to quantify the extent to which running performance would be altered at 3600 m compared with near sea level; and second, to characterise the time course of acclimatisation of physical performance and the underlying physiology to training and playing at 3600 m. These two aims mirrored two of the three major aspects of the FIFA consensus statement.[1] Project ISA3600 also examined the incidence and time course of AMS in soccer players exposed to 3600 m. In addition, project ISA3600 provides, for the first time, information on physiological changes and on performance of high altitude-adapted soccer players playing at low altitude.

METHODS

Subjects and design

The project design (figure 1) was a time series measurement of Bolivian (n=19) and Australian (n=20) soccer players during 6 days near sea level (Santa Cruz, Bolivia; 430 m), followed by 12 days in La Paz (3600 m). The player characteristics are shown in table 1. The Bolivian group was selected from 'The Strongest' club, which had won their national soccer league for the past 2 years, and comprised U20 players who were anticipated to provide an even contest for the Australians during games. Altitude baseline measurements were also made on the Bolivian soccer players in La Paz, in the 5 days before they travelled to Santa Cruz, since there is evidence of neocytolysis in altitude residents descending to sea level.[10] The Australian group was the U17 National team, called The Joeys, with half from the Australian Institute of Sport (AIS) and the other half selected from state-based programmes in Australia. All players, or their guardians if under 18 years, provided written consent.

Study themes

The major measurements of project ISA3600 fall into four themes:

- *Game and training running performance measures*—including global positioning system (GPS) data (miniMaxX—10 Hz, Catapult Innovations, Melbourne, Australia) on distance travelled, speed of movement and the associated heart rate (HR, Polar Team system 2, Polar, Kempele, Finland); sprints using electronic timing gates (Fusion Sport, Coopers Plains, Queensland, Australia) and the Yo-Yo IR1 test[11]; as well as ratings of perceived exertion (RPE, CR-10 Borg scale[12])
- *Blood measures*—including haemoglobin mass (CO-rebreathing method[13]), haemoglobin concentration, blood volume, blood gases and acid–base status.
- *Acclimatisation measures*—Lake Louise Questionnaire assessment of AMS,[14] HR and RPE responses to a submaximal running test,[15 16] morning (resting) HR variability[17] and perceived wellness measures.[18]
- *Sleep*—including assessments of sleep quantity and quality using wrist activity monitors (Actical Z-series; Philips Respironics, Inc, Pennsylvania, USA) and polysomnography (Siesta V1 and V802; Compumedics Limited, Victoria, Australia).

While each of the four companion papers to this parent paper will describe their salient methods in detail,[19–22] it is relevant to provide an overview of the entire project ISA3600 to understand why additional measures were not made within each theme. A key overarching principle of project ISA3600 was to provide a good preparation of The Joeys who were attempting to qualify for the U17 World Cup via the U16 Asian Football Cup in Iran, approximately 2 weeks after being in Bolivia. Consequently, the research team could not afford to sour the relationship with The Joeys programme and its parent body, the Football Federation of Australia (FFA). Thus, the total number of measures and their sequencing had to fit around The Joeys' coach requirements of sufficient time for skill development, fitness training and team bonding, in addition to adequate rest, meals and sleep. The programme of games, research testing and training was developed collectively between the coaches and key researchers. A satisfactory balance was achieved, but it was at the limits of what was tolerable by an experienced research team with coaches receptive to the science and young players who were compliant. To this end, all players from both teams were given a 'day off' from testing on day 7 at altitude. More invasive measures such as muscle biopsy assessment of muscle mitochondrial function,[1 2 23] which would have been of great interest, were not tenable for the Australian or the Bolivian players.

Staffing

In addition to 39 soccer players (table 1), there were 21 support staff to assist with the project (table 2). Thus, a total of 60 players, scientists, coaches, medical and technical staff were in Bolivia for project ISA3600.

Challenges

One of the challenges faced by the Australian players was the initial trip from Australia to Bolivia. The trip involved a 10 h eastward time zone change between Sydney (GMT +10 h) and Santa Cruz (GMT −4 h). In Santa Cruz, the Australian group followed a schedule of exposure to, and avoidance of, sunlight using the principles described in Eastman and Burgess.[24] This schedule was designed to aid their acclimatisation to the new

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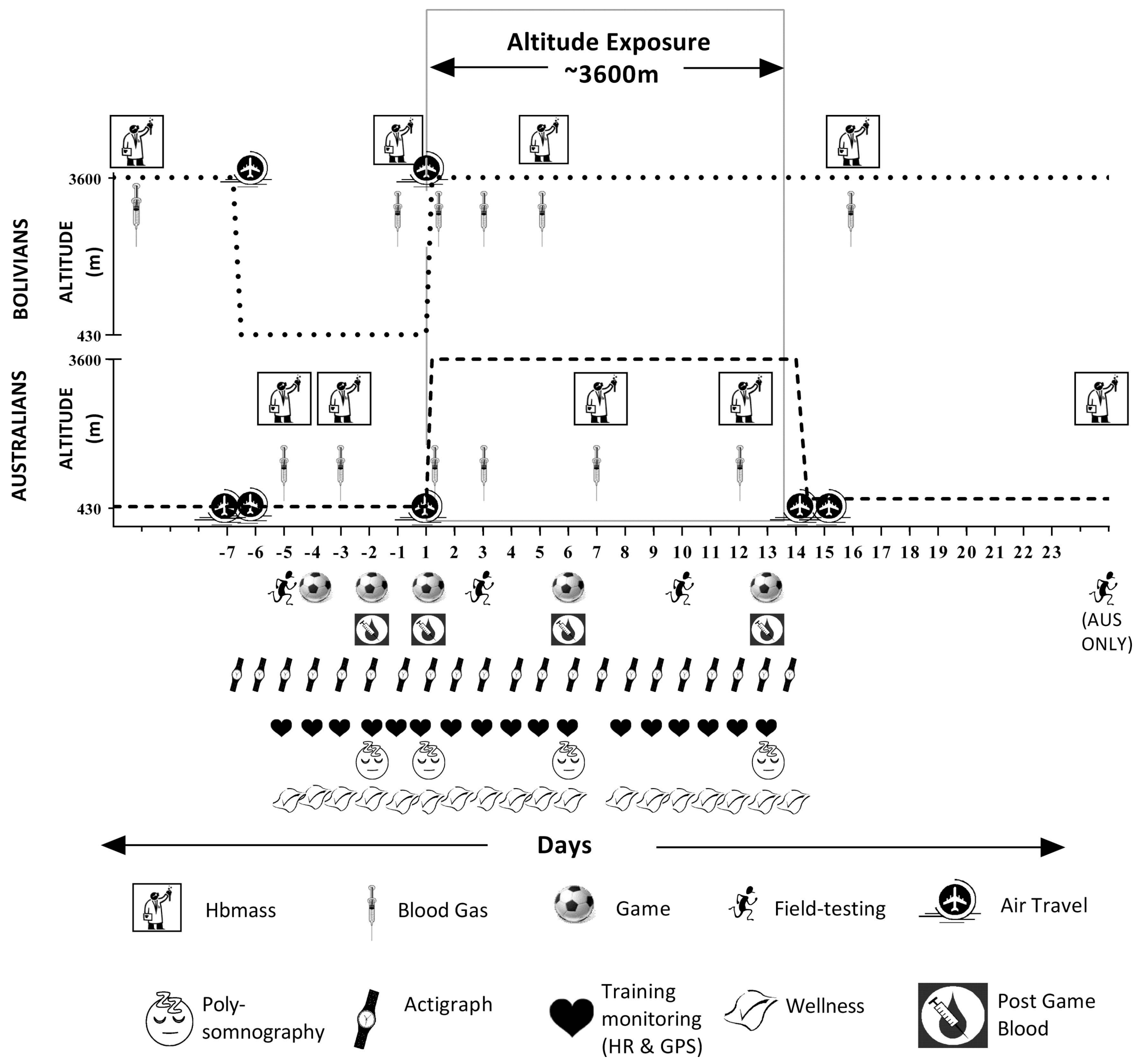

Figure 1 Study design showing the game, training, blood, acclimatisation and sleep measures. Hbmass—haemoglobin mass measured via CO-rebreathing; blood gas—capillary sample for oxyhaemoglobin (Hb-sO_2), partial pressure of oxygen (Po_2), partial pressure of carbon dioxide (Pco_2) and acid–base status; Game—The Strongest versus The Joeys official game; field testing—included Yo-Yo intermittent recovery level 1 and 40 m sprint; air travel—domestic and international air travel, the double plane symbol indicates long-haul travel between Australia/Bolivia or return (~30 h of travel each way); polysomnography; and actigraph—sleep monitoring; training monitoring—heart rate (HR) and global positioning systems (GPS), HR responses to a 5 min submax run before each session; wellness—morning wellness monitoring, including Lake Louise Questionnaire and HR variability; post game blood—venous blood sample within 90 min postgame for measurement of blood markers of changes in erythropoiesis.

time zone by a 10 h advance of their body clock. Baseline testing of The Joeys in Santa Cruz thus occurred after 30 h of travel plus one night of sleep.[19] Thus, The Joeys' baseline measures are potentially compromised. But this means that any running performance decrement at altitude (La Paz) would be a robust decrease compared with a potentially lowered baseline in Santa Cruz.

Data analysis

A combination of conventional and contemporary statistical techniques was used by the different theme papers. With two groups of nearly 20 players and large magnitude effects likely due to the high altitude, the project had mostly adequate statistical power.

Using conventional statistics for sample size estimates, 12 participants in each group (n=24 in total) would be required to make clinically decisive inferences on differences in total haemoglobin mass assuming a typical error of 2%, a reference threshold of 3% and types I and II errors of 5% and 20%, respectively. Using magnitude-based inferences, seven participants in each group are needed (n=14 in total), for the same assumptions for typical error and the reference threshold, and for setting the chances of detrimental effects to 0.5% and the chance of benefit to 25%. For distance covered from GPS data, the anticipated changes based on the decrease in VO_{2max} at this altitude[25] will more likely be of the order of 25%, but even with a typical error of ~30%, a sample size of 17 per group (n=34 in total) is also sufficient for magnitude-based inferences for this parameter during training. But with only 11 players allowed on the field during a game, the study is potentially underpowered for GPS data.

CONCLUSIONS

The interpretation of results of each theme was contained in the companion papers[19–22] and will not be considered here. Instead, perhaps of most relevance for the discussion of this

Table 1 Participant characteristics

	Groups	
	Australian (N=20)	Bolivian (N=19)
Age (years)	16.0±0.4	18.1±1.0
Height (cm)	178.6±4.6	171.1±6.3
Age from peak height velocity (years)[26]	+2.4±0.5	+2.9±0.8
Mass (kg)	66.7±5.6	63.6±7.2
Lean body mass (kg)	60.8±4.5	57.4±6.1
Altitude of birth (m)	22±8	3333±554
Haemoglobin concentration (g/dL)	15.0±0.9	18.2±1.0
Haemoglobin mass (g)	797±75	833±104
Ferritin (μg/L)	79±51	52.9±19.1

Values are mean±SD.
Data for age, height, age of peak height velocity, mass and lean body mass are as determined on day 10 at altitude. Initial haemoglobin concentration, haemoglobin and ferritin were determined at the normal altitude of both groups (ie, Australians in Santa Cruz at 430 m and Bolivians in La Paz at 3600 m).

(Methods) paper is the consideration of why project ISA3600 was successful, whereas previous attempts to quantify soccer competition at high altitude were not. Contributing factors include the personal networks of the researchers and a realistic research agenda that did not impact excessively on player preparation for games.

Networks

At the October 2007 FIFA meeting in Zürich, among the representatives from high altitude countries were HS and Dr Vargas (a former Director of IBBA who had good relations with the Bolivian soccer authorities and who had conducted several scientific studies on soccer players at low and high altitudes). Also in attendance were WFS and CJG, who had a long-standing professional relationship (figure 2). These networks were the foundation for conducting a successful soccer study in La Paz.

In mid-2009, collaborators WFS and CJG decided to vigorously pursue the concept of project ISA3600; however, it took more than 3 years of planning and negotiation to conduct the study in September 2012. In 2010, an application to AIS for funding was rejected because the altitude of La Paz was much higher than that to which the Australian team sport players might be subjected, since Australia competes in the Asian confederation of the FIFA World Cup qualifying rounds, where Kunming (1900 m), China is most likely the highest stadium.

Table 2 The 21 scientific and soccer support staff from the partner organisations who travelled to Bolivia

Organisations	Number	Role
Australian Institute of Sport (AIS)	1	Scientist
AIS Soccer Programme	2	Coach
	1	Team manager
	1	Physiotherapist
ASPIRE Academy for Sports Excellence	3	Scientist
Central Queensland University	2	Scientist
Football Federation of Australia	1	Doctor
	2	Coach
Instituto Boliviano de Biología de Altura	2	Scientist
The Strongest	2	Coach
University of Bayreuth	3	Scientist
Victoria University	1	Scientist

More than a year later (November 2011), collaborators CJG and RJA (figure 2) won a grant of ~$A50 000 from the AIS and Victoria University to study soccer at high altitude. The grant collaborators included WFS, Dr Vargas and the head of medical services for the FFA, whom CJG and RJA had been able to assist with the U20 Young Socceroos team preparing to play the 2011 U20 World Cup in Colombia at moderate altitude.[6] This interaction with the FFA, coupled with CJG's long-standing relationship with FFA's Head of National Teams and Development, opened the door to further collaboration on the effects of altitude on soccer performance. WFS's seed funding of €10 000 as part of the AIS/Victoria University grant was a critical catalyst to project ISA3600, as was the promise of in-kind support from Vargas. During early 2012, via Bourdon (figure 2), an additional ~$A50 000 grant was secured from the ASPIRE Zone Foundation (AZF) because of AZF's nascent interest in altitude research and their strong focus on developmental soccer players. Thus, based on cash grants exceeding $A115 000, the project team was able to approach the FFA in 2012 for endorsement and financial support to fund a team doctor and two coaches (table 3).

One of the last but most critical aspects of project ISA3600 was finding soccer teams who would not only comply with the scientific rigour of the project, but would also benefit from multiple games played at altitude. 'The Strongest' team, one of the three professional clubs from La Paz with a history spanning >100 years, was identified as the likely opponent, due to the existing relationship between staff from IBBA (RS) and 'The Strongest'. In 2012, the AIS soccer programme comprised an U17 cohort, approximately half of whom were likely to make The Joeys team. Because an altitude training camp in late August to early September 2012 could potentially provide strong preparation for the 2012 U16 Asian Football Cup in Iran (the qualifying tournament for the 2013 U17 World Cup),[3] the FFA was also supportive of project ISA3600. Importantly, the

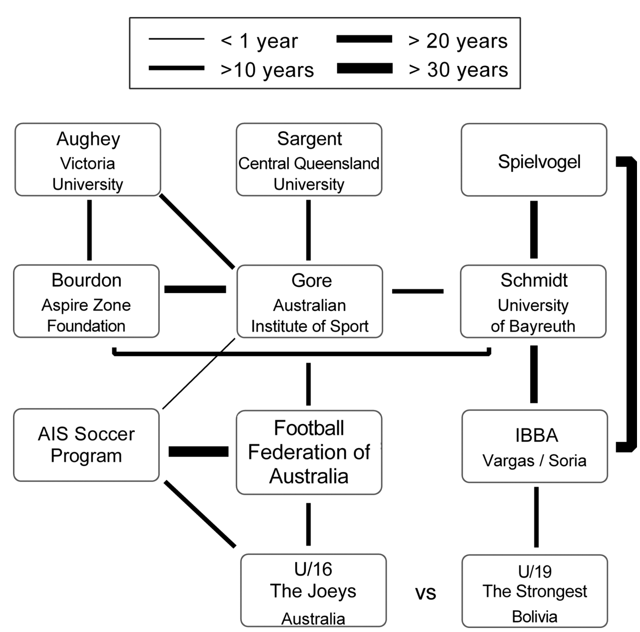

Figure 2 Relationships underpinning project ISA360, with cash and/or in-kind contributions from all organisations. The line thickness indicates the duration of the relationship. AIS, Australian Institute of Sport; IBBA, Instituto Boliviano de Biologia de la Altura; ISA360, International study on Soccer at Altitude 3600 m.

Gore CJ, *et al*. *Br J Sports Med* 2013;**47**:i80–i85. doi:10.1136/bjsports-2013-092770

Table 3 The cash and in-kind contributions (in Australian dollars) of the partner organisations

Organisations	Cash or grant	Additional funding support (cash or in kind)*	Total
AIS including AIS Soccer programme	$A60 000	$A15 000	$A75 000
ASPIRE Zone Foundation	$A50 000	$A65 000	$A115 000
Central Queensland University	$A5000	$A20 000	$A25 000
FFA	–	$A10 000	$A10 000
IBBA	–	$A5 000	$A5000
University of Bayreuth	$A14 000	$A41 000	$A55 000
Victoria University	$A35 000	$A2000	$A37 000
		Grand total*	$A322 000

*The cost of equipment such as of 22 miniMaxX global positioning systems (GPS, ~$A90 000), 40 Actical Z-series wrist activity monitors (~$A32 000), 2 Radiometer CO-oximeters (~$A30 000) and 6 Compumedics Siesta polysomnography systems (~$A93 000) has not been included as in-kind support.
AIS, Australian Institute of Sport; FFA, Football Federation of Australia, IBBA—Instituto Boliviano de Biología de Altura.

head coach of The Joeys was open-minded and supportive of the project, as was the coach of The Strongest.

Scoping visits

In April 2010, WFS undertook an initial scoping visit of ~1 week to IBBA in La Paz and to Santa Cruz. His aim was to ensure the collaboration of IBBA and of the chief administrators of the relevant departments of La Paz and Santa Cruz to provide access to stadiums in each city. In early June 2012, three members of the project team undertook a second scoping visit to Santa Cruz and La Paz. They confirmed the suitability of playing fields and rooms for testing the athletes, verified the quality of training facilities, accommodation and dining arrangements. The group also met the President of the Bolivian Football Federation to confirm the Federation's support for project ISA3600, as well as the representatives and coaches from 'The Strongest'. Both scoping visits were vital for project ISA3600. They ensured that the main project started in a timely fashion and helped to circumvent most issues beforehand.

On the ground

The five games were played under the supervision of official FIFA referees in the Ramon Tahuichi Aguilera (Santa Cruz, 430 m) and Hernando Siles (La Paz, 3600 m) stadiums with international soccer rules applying. In Santa Cruz and during the first week in La Paz, all players, coaches and scientists resided in the same hotels, which were located directly across from the stadiums. Owing to budget restrictions the Bolivian players had to reside in their own homes during the second week in La Paz. In Santa Cruz, the stadium was available for daily training; however, in La Paz, the training facilities had to be arranged outside the game venue. All training venues in La Paz were >3500 m, except for the field testing venue at Lipari (3000 m), which is 16 km from La Paz. Lipari was used because it provided excellent test conditions, whereas an adequate training surface could not be located in the centre of La Paz on the required days at times that suited the coaches. In Santa Cruz and La Paz, hotel rooms were set up as temporary laboratories for all measurements outside of those made on the soccer field. Blood centrifugation and storage were arranged at a local medical laboratory in Santa Cruz and in the IBBA laboratory in La Paz.

Several other temporary problems, such as delays in releasing equipment from Bolivian Customs, damaged medical equipment and transportation (eg, a city wide traffic ban was applied in La Paz on the day of the last game), were all circumvented effectively by RS and his colleagues. Consequently, the study was conducted largely as initially planned.

Conclusions

This attempt to quantify the acute and chronic effect of 3600 m altitude on the soccer running performance, haematology, training, sleep and well-being of adolescent soccer players was successful as a result of alignment of a group of well-networked researchers with a long history of collaboration as well as relevant connections to soccer associations in Bolivia and Australia. However, such applied research can only be successful in the long term if the scientific and soccer groups find this type of project worthwhile.

What are the new findings?

- The main findings are summarised in the four companion papers in this supplement. These address game and training running performance, acclimatisation, haematology, and sleep of national level junior soccer players competing at high altitude (3600 m), respectively.
- Other researchers attempting to examine soccer played at high altitude in South America will also most likely need to have a parsimonious research agenda agreed to by the coaches and participating soccer federations.
- The logistical and political constraints of research at altitude in South America are far more challenging than the scientific measurements.

How might it impact on clinical practice in the near future?

- The collective results from the four studies may be considered by the Fédération Internationale de Football Association (FIFA) to provide the best available data about soccer played at high altitude.
- This study could encourage other researchers to investigate the acclimatisation of international calibre adult soccer players at high altitude.
- The combined results are also relevant to individual and team-sport athletes seeking to compete at high altitude.

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Contributors CJG contributed to the conception and design, as well as the interpretation, drafting of the manuscript and final approval. RJA contributed to the conception and design, interpretation, manuscript review and final approval. PCB, RS, CS, GDR, MB, KH and NW were responsible for the project design, data collection and interpretation, manuscript review and final approval. LAGL was involved in the project design, data collection and interpretation, drafting of the manuscript and final approval. JCJC, BMS and MK contributed to the project design, data collection, manuscript review and final approval. MP, AE, DC and TV contributed to the project design, intervention oversight, data collection, manuscript review and final approval. HS and WFS were involved in the conception and design, data collection and interpretation, as well as the drafting of the manuscript and final approval.

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Competing interests None.

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Data sharing statement Any data sharing relates more appropriately to the four companion papers Refs. 19–22.

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