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Position statement—altitude training for improving team-sport players' performance: current knowledge and unresolved issues

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Accepted 30 September 2013

ABSTRACT

Despite the limited research on the effects of altitude (or hypoxic) training interventions on team-sport performance, players from all around the world engaged in these sports are now using altitude training more than ever before. In March 2013, an *Altitude Training and Team Sports* conference was held in Doha, Qatar, to establish a forum of research and practical insights into this rapidly growing field. A round-table meeting in which the panellists engaged in focused discussions concluded this conference. This has resulted in the present position statement, designed to highlight some key issues raised during the debates and to integrate the ideas into a shared conceptual framework. The present signposting document has been developed for use by support teams (coaches, performance scientists, physicians, strength and conditioning staff) and other professionals who have an interest in the practical application of altitude training for team sports. After more than four decades of research, there is still no consensus on the optimal strategies to elicit the best results from altitude training in a team-sport population. However, there are some recommended strategies discussed in this position statement to adopt for improving the acclimatisation process when training/competing at altitude and for potentially enhancing sea-level performance. It is our hope that this information will be intriguing, balanced and, more importantly, stimulating to the point that it promotes constructive discussion and serves as a guide for future research aimed at advancing the bourgeoning body of knowledge in the area of altitude training for team sports.

PREAMBLE

Team sports are activities that enjoy worldwide participation with large numbers of players training and competing at all levels. As skill proficiency increases, it is clear that overall technical and tactical effectiveness—rather than (competitive) physical performance per se—have a greater impact on winning.[1] Over the last two decades, however, it is indisputable that team sports have experienced a tremendous increase in the tempo of play and energy demands imposed on players during matches. In this context, coaches and their staff are continuously looking for innovative ways to improve match outcomes, and moderate altitude training (~2000–3000 m)[2] has emerged as a popular ergogenic aid. Precompetition acclimatisation while residing at altitude (eg, training for 1–2 weeks at the competition venue elevation) versus using altitude training to improve players' 'trainability' and competition performance in the days and weeks following return to sea level (eg, 2–3 weeks of living high and training low during the preseason) are two distinct forms of altitude interventions that were debated by the expert panel. Despite altitude training being an area of interest for many sporting organisations—for example, *Fédération Internationale de Football Association* (FIFA), symposium on playing football at altitude[2] and the *International Olympic Committee* (IOC), consensus statement on thermoregulatory and altitude challenges for all high-level athletes[3]—research on the impact of altitude training for team sports is still in its infancy.

An *Altitude Training and Team Sports* conference was held in Doha, Qatar on 24–25 March 2013. The original aims of the conference were to present cutting-edge research on the basic and applied aspects of altitude training and its impact on the physical performance of team-sport players. To this end, a panel of international experts (Australia: 7; Belgium: 1; Canada: 1; Germany: 1; Qatar: 4; Switzerland: 1; the USA: 2) was invited to address specific issues (detailed in the different review papers of this supplement) related to this topic. This position statement provides an overview of research and practical issues that may be of importance to consider when intending to use altitude training with team-sport players.

The basic principles that governed the conduct of the discussions during the meeting are summarised below.

A broad-based, independent panel was assembled to give balanced and evidenced-based attention to the present topic.

Panel members included researchers in exercise physiology, medical doctors, coaches and performance/research scientists. Panellists did not represent organisations per se, but were selected for their expertise, experience and understanding of this field. They were also required to sign a form to *Disclose any Potential Conflicts of Interest*.

A number of specific questions were prepared to define the scope and guide the direction of the

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To cite: Girard O, Amann M, Aughey R, *et al*. *Br J Sports Med* 2013;**47**:i8–i16.

position statement. The principle task of the panel was to provide responses to the questions outlined below.

This position statement is intended to serve as the scientific record of the conference, and it is our hope that it will be widely disseminated to achieve maximum impact on both future practice and research.

While agreement may exist pertaining to the principal messages conveyed within this document, the authors acknowledge that the science of altitude training as it applies to team sports is a rapidly growing field and therefore the decision to use altitude training remains in the realm of professionals working closely with players.

This position statement paper is broken into a number of sections

1. Hot topics
2. Methodological issues
3. Implications for implementation
4. Where to now?
5. Summary and conclusion

The expert panel systematically addressed these issues and provided research and practical recommendations, based on their experiences and the latest scientific and coaching evidence.

Section 1: Hot topics

For players of which team sports (eg, disciplines, playing position) might altitude training be relevant?

The physical (total distance covered, high-speed running or sprinting) and physiological (cardiovascular load, blood lactate concentration) demands of major team (football,[4] rugby[5] or Australian football[6]) and racket sports (tennis and squash[7]) during training and competition have been described by using miniaturised smart sensor devices (eg, Global Positioning System technology, video tracking, portable gas analysers). In many team sports, the running distance during matches has considerably increased in recent years due to new tactical approaches having been adopted by many teams, thereby increasing the importance of endurance capacity. Team sports share the common feature of high-intensity, intermittent exercise patterns with continuously changing pace and also experience marked variability of game characteristics between sports,[8] between playing positions[9] and playing styles[10] within the same sport and even from one match to the next.[11] This creates a diversity of physiological challenges and performance needs across team-sport players.

While elite team-sport players do not exhibit the specific physical/physiological capacities of elite endurance and sprint athletes, they generally possess an efficient combination of 'aerobic' and 'anaerobic' potential, though the relative contribution of oxidative versus glycolytic component varies widely across players and sports. Although aerobic metabolism dominates the energy delivery during most team sports, decisive actions (eg, sprints, jumps and tackles) are covered by means of anaerobic metabolism.[4 12] As a result, the demands of team sports lend themselves towards a potential gain from adaptations to hypoxia from aerobically (maximal oxygen uptake (VO_{2max}), economy and PCr resynthesis) and anaerobically (muscle buffer capacity) derived mechanisms. However, because the extent to which a player may benefit from different altitude-training methods may differ according to both their general and specific training focus (more aerobic vs anaerobic type of adaptations), no uniform recommendations can be made across all team sports. Nonetheless, it is anticipated that those activities displaying shorter exercise-to-rest ratios and/or requiring prolonged time spent at a high relative exercise intensity are more likely to benefit from altitude training.

Panel members agreed that the effectiveness of any altitude-training programme might be worthwhile for some, but certainly not all, team members. For instance, it is intuitive that altitude training may have greater benefits for players covering large distances (>100 m/min) with high-intensity repeated efforts (ie, 'invasion' sports), as Australian football players do, compared with volleyball players, who run relatively less (distance covered generally <50 m/min) during a match.[8] It is worth noting that since the impact of fitness on match running performance is likely player-dependent, playing style-dependent and position-dependent,[13–16] the possible performance benefits of altitude training for team sports might not be as straightforward as for individual sports, where physical capacities strongly determine final performance. Considering soccer for instance, while it is appealing that altitude training may positively affect midfielders' or attackers' activity patterns, less evident is its possible impact for central defenders and goalkeepers. However, these assumptions await scientific evidence.[17] Although it is difficult to derive sound conclusions based on the limited literature available, it is proposed that incorporating information in accordance with time-dependent metabolic and match profiling (exercise-to-rest ratios[18]), along with supplemented data from position-specific and player profile-related requirements could enable more informed judgements of the relevance of altitude training for a given player.

It has been acknowledged that in elite endurance[19] as well as team-sport[20] athletes the effect of altitude training on red cell mass may depend on the initial haemoglobin mass (Hbmass). The proposed rationale is that an initial high Hbmass will not allow Hbmass to increase substantially following altitude training, whereas an initial low value will likely lead to meaningful enhancements in Hbmass.[21] Noteworthy, however, is the observation that meaningful increases in Hbmass also occur in highly trained endurance athletes—that is, with some of the highest reported pre-intervention Hbmass values—from different sports and after various forms of altitude training.[22] In team sports, where a high Hbmass is not necessarily a pre-requisite in all positions, players are generally characterised by a low to moderate Hbmass (or VO_{2max} values usually ranging from 55 to 65 mL/min/kg)[23 24] in comparison with endurance athletes,[25] whose performance is largely related to aerobic capacity.[26] There remains considerable controversy about the extent to which Hbmass increases in response to altitude training[27] and two recent meta-analyses[28 29] also offer somewhat conflicting viewpoints.

In elite junior soccer players, the potential for altitude training to increase Hbmass was 3% after 12 days at 3600 m,[24] and it is likely also present at the lower altitudes usually used for altitude-training camps by team-sport players.[20] The rationale for attempting to increase Hbmass in team-sport players would be to increase their VO_{2max} and enhance blood buffer capacity, and thereby decrease relative exercise intensity during games and increase tolerance for repeated-sprint exercises, respectively.[16 30–34] While it is noted that, in some players, those values might already be near the upper limit of aerobic power, the expert panel agreed that any improvement in blood oxygen carrying capacity needs to be balanced so as not to limit explosive-type performance gains.[35 36]

What type of altitude-training interventions should be recommended for team-sport players?

Contemporary altitude-training practices among athletes include: living high and training high (LHTH), living high and

 Girard O, et al. Br J Sports Med 2013;47:i8–i16. doi:10.1136/bjsports-2013-093109

training low (LHTL) as well as living low and training high (LLTH).[37 38] These paradigms can be achieved with natural altitude, simulated altitude or a combination,[39] but it is important to note that the physiological responses to natural and simulated altitude may be quite different and controversy still exists as to what is the most efficient hypoxic exposure.[17 40] In a 2009 meta-analysis of sea-level performance after hypoxic exposure,[41] it was found that in elite endurance athletes, an enhancement of maximal aerobic power output was only possible with natural LHTL (4.0%; 90% confidence limits±3.7%), and unclear with LHTH (1.6%;±2.7%) and LLTH (0.6%;±2.0%). While it is arguably easier to accumulate hours of hypoxia with LHTH, a recent meta-analysis concluded that Hbmass increases at approximately 1.1% per 100 h of altitude exposure regardless of the type of exposure (ie, LHTH (>2100 m) or LHTL (~3000 m)).[29]

Owing to possible inter-individual variability (eg, individual responsiveness is approximately half the group mean effect in professional football players completing an LHTH training camp),[20] when it comes to improving player's fitness, one may question whether having all the team members residing and training at the same natural altitude is a sound approach if no individual adjustments in training content are made. Another recognised concern of hypoxic exposure is the large and individual decrease in maximal aerobic power (VO_{2max}, ~7% per 1000 m altitude ascent),[42] which may slow down the process of phosphocreatine resynthesis when recovering from high-intensity efforts.[43 44] Compared to sea-level, VO_{2max} was reduced by 20% in a cohort of non-acclimatised soccer players at a natural altitude of 3600 m,[45] while at the same simulated altitude a single 5 s treadmill sprint performance was preserved (Brocherie *et al* unpublished observations). However, after repetitive efforts of short duration a larger fatigability is commonly observed in hypoxia,[43 46–48] this effect may also be dependent on other factors such as training background,[49] work-to-rest ratio[50] and hypoxia severity.[51]

In order to maintain high-intensity training effectiveness (ie, prevent premature fatigue), which represents a significant portion of competitive teams' training content, regular training practices of LHTH altitude camps may need to be modified.[52] These modifications could be avoided by descending the whole squad to lower training venues but the logistical constraints and extended travel times may actually result in additional fatigue. Alternatively, work : rest ratios could be altered during sessions also taking into account the altitude of the training venue and players' background. Practically, this requires adjusting distance or time of efforts and/or recovery times in order to modify the intensity or duration of practice bouts at altitude.[33 53] Only with these adjustments can dramatic reductions in training quality along with accompanying negative alterations in mechanical and neuromuscular stimuli be avoided.[54] Another solution could be to live in a natural, hypobaric hypoxic environment, but train at or near 'simulated' sea level with the aid of supplemental oxygen.[55] While scientific evidence is still lacking, training with oxygen cylinders requires a stationary training situation, which is clearly unpractical for training sport-specific, technically complex activities commonly associated with team sports.[4] Conversely, artificial altitude models (LHTL) may be more convenient for the team-sport players with the possibility of remaining in one training venue, while individualising the 'altitude dose' and training contents in line with their characteristics and field positioning.

Exercise capacity during high-intensity intermittent exercise not only depends on the blood oxygen-carrying capacity, but also on molecular adaptations in the skeletal muscle and the efficiency of the neuromuscular system. Although not a consensus,[56] LLTH altitude training regimes including near or maximal-intensity efforts (repeated sprint training in hypoxia) have proved superior to training at sea level in enhancing peripheral adaptations (ie, oxidative capacity, capillary density and muscle glycolytic potential as well as increased expression of hypoxia inducible factor 1α (HIF-1α) and downstream genes to oxygen and transport)[57–60] and, thereby, high-intensity intermittent performance.[57 61 62] Likewise, resistance training combined with systemic hypoxia has been reported to further increase muscle strength,[63–65] although other studies have shown no additional effect of hypoxia on strength gains.[66] With only two known studies recruiting team-sport players,[62 65] it was recognised that there needs to be more research to determine which form of LLTH altitude-training intervention may be more effective for maximising strength gains and multiple-sprint performance, while taking into account the specific characteristics of the different team sports and of the player for a given activity.[33]

There was unanimous agreement by the panel that altitude training could also be implemented for rehabilitation purposes. Here, we alert the reader to recent findings demonstrating that the HIF-1α pathway is activated during bone repair and can be manipulated genetically and pharmacologically to improve skeletal healing.[67] The past decade has seen impressive strides in our understanding of the effects that an exposure to intermittent hypoxia might have on improving metabolic risk factors in pathological populations. Although irrefutable scientific support is lacking, altitude training may possibly be implemented upon return to training in some team-sport players, after sustaining an injury, in order to increase the cardiovascular and perceived intensity of the session without a corresponding increase in the mechanical load imposed on the musculoskeletal system.[33]

What are the most relevant performance tests to provide ecologically valid data of the benefits of altitude training in a population of team-sport players?

Assessment of the physiological determinants of physical performance is an integral part of sport science support for elite teams. At present, however, virtually all performance tests commonly used to judge the efficacy of any altitude-training intervention have been based on indicators of endurance-like performance (eg, time trials). As such, the extent to which altitude training affects anaerobic performance is largely unaccounted for in the available literature. While altitude training is thought to improve some aspects of performance by only a small amount, high reliability (ie, typical errors of 1–2% with the tested-dependent variable having an error of measurement smaller than the smallest important effect) is a fundamental criterium guiding the selection of a particular field-based or laboratory-based test in the plethora of tests available today.

It would be worthwhile to centre the test battery on the key elements of aerobic-type and anaerobic-type performance meant to be improved by the altitude-training intervention in question. As a single performance test cannot address the full complexity of team-sport performance, a broad suite of tests is expected. It was agreed that, in a population of team-sport players, relevant tests would at least include an evaluation of acceleration/peak sprinting and maximal aerobic velocities, while jump, repeated-sprints (with or without agility sequences) and running economy (eg, 10–12 km/h for 5 min) tests can elegantly complete the test battery. In the absence of a 'gold-standard' for repeated-sprint testing for instance, coaching teams should adjust sprint distances, frequency, recovery time/type according to their players and sport requirements, ensuring that the tests are valid and reliable.[68]

Sport scientists have been tempted to directly measure the acute effects of an altitude exposure or the efficacy of a period of altitude acclimatisation on the occurrence of repeated high-intensity actions (frequency of maximal accelerations) and match running performance, as recently garnered from total distance covered or distances completed across different preselected time intervals.[52 69 70] However, given the numerous confounding factors such as temporal changes in a team, opposition's tactics and playing system and/or the contributions of substitutions, it must be questioned whether time motion analysis data can realistically be used in isolation to identify the benefits of any altitude-training intervention on athletic performance.[1 10] In other words, one should proceed cautiously when inferring physical performance of team-sport players from their activity profiles since distances covered only reflect the 'external physical output' of players.[1] Importantly, high-intensity activity in professional soccer is not always related to team success,[71] while those players performing more high-intensity work are also often covering lower total distances.[72] Practically, it was therefore recognised that it is important to simultaneously measure the external (eg, distance covered within different velocity zones) and internal loads (eg, heart rate, perceptual responses)—irrespective of whether total distance covered has increased or not in response to altitude training—in order to objectively determine if a player is working easier physiologically to produce the same 'external physical output'.[16]

Controlled experimental simulations of match-play activity performed on the field such as the Yo-Yo Intermittent Recovery test (level 2)[73] and the 30–15 Intermittent Fitness Test[74] or simulating team-sport running performance on a non-motorised treadmill in the laboratory environment[51 75] are recommended to evaluate altitude training usefulness. Standardised drills in the form of small-sided games that replicate to a certain extent the physical intensity, movement (running performance) patterns and the technical requirements (skill component) of competitive match play for instance, with a simultaneous evaluation of total distance covered and distance ran at high speed, are also likely suitable.[76 77]

Section 2: Methodological issues

Current practices and trends in altitude training: What is the 'optimal' altitude dose to be used?

In individual athletes, the success of altitude training requires living high enough (>2000 m), for enough hours/day (>14–16 h/day), for a sufficient period of time (>19–20 days) in order to sustain an erythropoietic effect of hypoxia; that is, the so-called altitude dose (~300–400 h).[37 55 78] The time course of the erythropoietic response to altitude training is highly individual ranging from no response until 15% after 3–4 weeks.[79 80] Training camps as short as 2 weeks have also been shown to increase Hbmass substantially in elite youth soccer (ie, LHTH),[24] elite water polo (ie, LHTL[81]) and Australian football players (ie, LHTL[82] and LHTH[20]). Limited data currently exists regarding the time course of non-haematological adaptations, which may also be potentially beneficial for team-sport performance, during and after an altitude-training camp,[83] thereby limiting the possibility to offer scientifically based recommendations about these adaptations.

Most altitude-training venues around the world, which are equipped with the necessary facilities to suit team-sports (ie, comfortable rooms and playing fields), are in the 1800–2500 m range. In the majority of research studies moderate altitudes (2000–3000 m) have been used arguably because at those heights robust and reliable erythropoietin (EPO)-induced expansion of red cell mass is usually observed, with athletes suffering from only minor side effects.[84] Limited data are available on how these entities should be balanced and how far the boundaries of hypoxic exposure can be extended. At present, the optimal altitude for a team to reside at is unknown, but there is a widespread belief that elevations higher than ~3000 m should be used with caution because of the excessive loss of training intensity and the characteristics of ball flight will change substantially due to the thinness of the air.[85] On the one hand, the degree of hypoxia determines the magnitude of the induced physiological changes in a 'dose–response' relationship, with higher altitudes triggering larger/faster increases in red cell mass.[28 78] On the other hand, exposure to chronic (several days to several weeks) hypoxia using elevations >3000–3500 m can be unproductive for some individual players as the stress on their body and the resultant side effects—for example, loss of appetite, inhibition of protein synthesis, muscle wasting, prevalence and severity of acute mountain sickness, excessive ventilatory work and/or metabolic compensation—from such high altitude could outweigh any erythropoietic benefits and thereby impair performance gains.[35 54 86] Reportedly, however, sleep quality is rapidly increased with acclimatisation[87] and may not even be adversely affected by acute (1–2 days) or chronic (1–2 weeks) exposures to high altitudes (>3500 m).[88] This reinforces the potential value of individualising altitude-training 'prescription' with artificial exposures as a prerequisite in order to maximise the performance of each player, and thereby reduce some of the individual responses seen today.

Players who have had previous hypoxic exposure may adapt sooner to hypoxic conditions due to an increase in the magnitude of hyperventilation in the first few days of re-exposures.[89] Although absolute mean changes in physiological capacities (ie, Hbmass) appear to be repeatable after both LHTL[90] and LHTH,[20 24] individual athletes do not exhibit consistency in altitude-induced Hbmass changes from year-to-year, that is, the magnitude of the correlations between Hbmass changes are only small ($r=0.21$)[20] to moderate ($r=0.47$),[90] with differences in the individual responses to each intervention as large as 8%[90] to 10%.[20] More importantly, subsequent physical performance benefits may be even more variable from an intervention to another one (unclear to small relationships, ie, $r<0.1$, with up to 4% of difference in the individual responses). However, even though altitude training (at least in elite endurance athletes) results in an increase in VO_{2max} of more than half the magnitude of the increase in Hbmass, the weak (but significant) correlation found between these factors suggests that other non-haematological factors are also likely to be important.[22]

Specific timing-related issues of altitude training in team sports: Does a player benefit the same from a given altitude block in precompetition and in-season? Would a combination of methods be the optimal approach?

Although irrefutable scientific support is lacking, the effects of altitude training on some of the determinants of physical performance in team players may depend on the training phase of the competitive season.[91] Importantly, altitude training needs to fit within the busy competition schedule of a team, without compromising the quality of the technical and tactical training. With the advent of hypoxic facilities (hypoxic chambers and/or altitude dormitories) in a growing number of high-level professional clubs and sport institutes, the prospect of implementing altitude interventions in a congested calendar is no longer as daunting. Larger physiological changes are generally expected for altitude training conducted preseason compared to in-season, likely due to lower initial fitness levels. Preseason generally provides a window of about a month or two to embark on a 2-week to 4-week sojourn at a natural or simulated altitude aiming to primarily enhance convective oxygen transport.[82 92] The increased oxygen transport capacity of blood in response to altitude training may allow training at higher intensities during subsequent training in normoxia (improved lactate metabolism), thereby optimising the training stimuli by enhancing some neuromuscular and cardiovascular determinants of team-sport performance.

Today, the busy competition schedules of major team sports often makes prolonged (>2 weeks) stays at altitude (at least for natural altitude exposure) unrealistic for anything other than preseason camps and the most important international tournaments. During the competition period, a 2-week camp implemented during the mid-season break for instance—be it LHTL or LLTH—may boost physical performance; nevertheless, longer exposures are certainly required to maximise the magnitude of these responses.[29] Coaching teams involved in sports (eg, water-polo and rugby) with a competition calendar targeting major international tournaments (ie, Olympics and World Cup) in addition to regular league matches could accommodate an LHTL intervention during the competition preparation phase to maximise physiological adaptations of their squads.[81] With minimal travel, modest expense and relatively minor disruption of training and daily life, a few blocks of LLTH altitude intervention (simulated altitude of 2500–3500 m; 2–3 sessions/week for 2–4 weeks; supra-maximal intensity workouts) could also be included in their yearly programme in order to add variety to training and help maintain in-season sprint speed and maximise explosive power/maximal strength capacity.[17 38]

Upon removal of the hypoxic stimulus, a reversal of some altitude-specific adaptations can occur relatively quickly (within few weeks; ie, neocytolysis, red blood cell destruction).[93] Nevertheless, with a typical exposure of ∼300–400 h, the increase above prealtitude Hbmass values persists for ∼2–3 weeks,[24 29 80] which does not support the proposal of short-term neocytolysis after altitude descent. Accordingly, the ability of the players to train at a high level for several weeks on return to sea level, due to the positive acclimatisation responses to altitude, may allow them to achieve a higher level of fitness (ie, one that may last longer than the acclimatisation effects themselves) and more importantly performance. While the entire physiological acclimatisation is mostly undetectable 4 weeks of post-descent, performance gains seem to be more resilient and may last up to 4 weeks after the altitude camp.[92] However, coaches should not expect any altitude-induced physiological changes to be maintained throughout the entire duration of a team-sport season if no additional hypoxic stimulus is added thereafter to the training programme.

Although this awaits stronger scientific evidence, it was recognised that some of the side effects (decrease in Na^+/K^+ ATPase activity and decreased plasma volumes) of each of the individual altitude-training interventions could potentially be attenuated when using combined (or mixed) methods. For players and coaches looking to elicit 'aerobic' and 'anaerobic' benefits to improve sea-level performance, living high and training low and high is an attractive altitude intervention for team sports.[38] Proposed LHTL modifications which involve interspersing 'blocks' of nightly exposure to hypoxia, with several nights of normoxia ('intermittent' LHTL), to lessen any adverse psychological[94] and physiological (eg, minimising the detrimental effects of chronic hypoxic exposure on muscle Na^+/K^+ ATPase activity, especially in athletes undertaking heavy training)[95 96] impacts of prolonged (>20 h/day) room confinement. Reportedly, a combined approach of LHTL plus additional hypoxic training sessions resulted in greater enhancement in the physiological capacities (VO_{2max} and Hbmass) that underpin endurance performance (3 km time trial) compared with LHTL or LLTH.[90] Currently, however, the optimal characteristics of exercise in hypoxia or the combination of the various methods are unclear. Although altitude-training interventions combined with other challenging environmental conditions (eg, heat exposure to increase plasma volume)[82] could potentially be useful to improve selected aspects of team-sport performance, at this stage, there is insufficient evidence to recommend such innovative mixed methods.

Does the reduced air resistance with terrestrial altitude (hypobaric hypoxia) significantly modify match-related performance and the aerodynamics of the ball compared to exposure to simulated altitude (normobaric hypoxia)? What is the impact on training or competition?

LHTH altitude has been, and will remain, widely used by teams to acclimatise before matches at altitude. This approach is supported by the lack of direct transfer of the benefits induced by a normobaric acclimation to the hypobaric situation and, in comparison, larger ventilatory acclimatisation, minimised acute mountain sickness prevalence and improved performance using terrestrial altitude or hypobaric chambers.[97–99] As a general recommendation, suitable strategies to maximise physiological acclimatisation (oxygen transport and acid–base balance) should last 3–7 days for low altitude (500–2000 m),[69 100] 1–2 weeks for moderate altitude (2000–3000 m) and at least 2 weeks if possible for high altitude (>3000 m).[80] When designing acclimatisation strategies it is of utmost importance to consider the altitude of residence of the team and the ultimate competition altitude.[101] The expert panel agreed that for squads who must compete at a moderate altitude within 2 weeks of ascent, living at the competition altitude (whenever possible at the competition venue) and not higher is advisable.[102] Practically, shorter recovery periods before players can repeat high-intensity efforts and improved willingness to possess the ball can be viewed as signs of positive physiological acclimatisation.

Because it does not simulate the reductions in air density, which affect motor ball trajectory and consequently motor skill proficiency,[103] using normobaric hypoxia is not optimal for preparation for competition at a natural altitude. The major determinants of air density are barometric pressure, temperature and, to a lesser extent, humidity. Upon ascent to natural altitude, changes in these variables will have a proportionate effect on air density (air density reduces by about 10% for every 1000 m increase in altitude) and, consequently, physical performance and player behaviour. This is a serious concern in team sports where performance relies directly on repeated high-intensity activities such as sprinting and involves a large technical skill component essential for training and competition.[104] At natural altitude, any potential advantage associated with reduced air resistance (increased single sprint performance)[105] is offset by the increased metabolic challenge in hypoxic conditions (impaired repeated sprint ability).[106] Regarding the effects of moderate altitude exposure on activity profiles during actual soccer match play, not only is total distance covered reduced above 1200 m,[70] but also, a larger reduction in match running performance is seen at 1600 m for higher intensity tasks such as high velocity running or maximal acceleration.[69] Thirteen days of acclimatisation nor life-long residence at high-altitude (3600 m) protected against detrimental effects of altitude on match activity profile.[52] Additionally, for sea-level players a significant number of repetitions are arguably necessary to make the appropriate motor skill adjustments required for competitive success in a reduced air density environment.

The decreasing air density associated with increasing altitude also results in changes in the drag and lift forces acting on the flying object (ball, missile), thereby altering its flight characteristics.[103 107] This is typically manifested as a reduction in the lateral deflection or 'curve' of the projectile and an increased flight, as the projectile will travel more easily through the thinner air.[85] As a result, a soccer player's technical skills may be impacted when shooting, controlling long passes and clearing the ball using punted and long kicks out of defence. Undoubtedly, the goalkeeper could also be deceived by shots at goal, owing to the faster flight of the ball and its altered trajectory. However, those effects have yet to be quantified, and whether a technical acclimatisation to altitude takes place, beyond physiological acclimatisation, needs to be researched, with a careful monitoring of the extent and the time course of these adaptations for a range of heights. Despite the absence of scientific evidence, it is reasonable to suggest that extra time and practice is probably required to allow adequate adjustments in motor skills and movement timing as the terrestrial altitude where teams reside, train and compete increases. Because physiological and aerodynamic (also likely to be highly individual) adaptations may not necessarily share the same time course, it is advised that teams experience these responses in a training camp setting well ahead of the competitive event. Arguably, when a team prepares for competition at one altitude but has to contest games at various altitudes during the tournament (eg, 1986 and 2010 FIFA World Cups), without a suitable time period to readjust to the biomechanical constraints, the coach may need to make tactical changes. Likewise, teams will also have to readjust upon return to sea level and whether LHTH should not be recommended when competing at sea level in a short window (<7–10 days) requires research.

Section 3: Implications for implementation

What would be the benefits of a careful player screening and a preacclimation period before prolonged exposure to hypoxia? What physiological markers would be worthwhile monitoring to identify altitude 'responders' and 'non-responders'?

At present, there is no 'gold-standard' test battery to facilitate the detection of team members who are unlikely to cope well with the stress of altitude or who will respond positively. As a general rule, however, preascent evaluations should ensure that players are free of illness, injury and fatigue.[20 24] A comprehensive initial assessment would also include other measures such as 'normal' iron and nutritional-hydration status, body mass and psychological attributes. Only players who fulfil these criteria should add the stress of hypoxia to their training. A conservative approach might be prudent for at-risk players—those who are currently unfit and not coping well with altitude stress—to ensure that they are not worked too hard at hypoxia until fully recovered.

Arterial oxyhaemoglobin saturation (SpO_2) in hypoxia is largely controlled by the hypoxic ventilatory response.[108] An enhanced resting ventilatory response to hypoxia, which is mediated primarily by the peripheral chemoreceptors in the carotid bodies,[109] is arguably beneficial as the body responds to the hypoxic stimulus more quickly. Reportedly, the ability to maintain SpO_2 during heavy exercise at sea level has a strong influence on the ability to maintain VO_{2max} and exercise performance with acute altitude exposure.[110] As such, although their mode of evaluation (rest vs exercise; hypoxic dosage) is still debated, determining chemosensitivity parameters (ie, desaturation and ventilatory response to hypoxia) may help detect at-risk players before a sojourn to altitude.[111 112] Although irrefutable scientific support is lacking,[97] coaches and support staff can also be proactive by implementing short-term, intermittent normobaric hypoxia exposures (30–60 min at altitude ranging 3000–4500 m) before travel for those with a blunted hypoxic ventilatory response in order to reduce the prevalence and severity of acute mountain sickness.[113]

Another explanation proposed to account for the lack of adaptation to altitude training is depleted iron stores prior to and as a result of altitude exposure.[114] In iron deficient athletes (serum ferritin <35 ng/mL for females and <50 ng/mL for males) the likelihood of an altitude-induced increase in Hbmass is minimal, suggesting that normalisation with oral (ferrous sulfate) supplements and monitoring iron status of each team member is an absolute necessity before exposure to hypoxia.[54] Iron-deficiency per se could result in decreased training potential or physical performance in team-sport players, not only because of blunted erythropoiesis but also due to its negative impact on other iron-dependent physiological processes at the mitochondrial level and in myoglobin content. We recommend that iron deficient players receive iron supplementation, in order to normalise serum ferritin stores before departing for altitude, and maintenance of iron supplementation for all players while at altitude in order to prevent bias arising from iron deficiency.

As with any other training stimulus, there is considerable variation in the response to altitude training. This is evidenced by decreased sympathetic activity and strong erythropoietic responses to altitude in some participants, while others see little or no changes in such variables with chronic exposure.[115] Likewise, most players experience significant impairment of training velocities and oxygen uptake at a moderate altitude, while few would be able to maintain training and oxygen flux near what they would be able to at sea level. The concept of 'responders' and 'non-responders' was created without offering plausible mechanisms.[115] While factors influencing the magnitude of individual response to hypoxia may be genetically inherited traits (ie, HIF-1α functions as a master regulator of many genes, notably of erythropoiesis, pH regulation and glycolysis),[116 117] it remains possible that certain psychosociological concerns, not physiological ones, may also determine how specific team members will respond. For some players leaving their family (spouse and parents) and regular training environment for the duration of a camp can be problematic. This may partly explain the within and between years variability observed in the response of an individual athlete.[20 24 29 118] As such, it may not be appropriate to divide team members into 'responders' and 'non-responders' but rather to question whether the intervention had a measurable impact on player performance. A proposition would be to identify those who will respond with a fast/high, moderate/medium and slow/low response compared to the group mean response. Importantly, in the same individuals, changes in physiological and performance measures (ie, the former to a higher extent than the latter) after two virtually identical altitude-training camps are not necessarily consistent.[20 80 90] This reinforces that altitude training-related gains may not only be dependent on positive physiological adaptations but also on a complex interaction of other factors including fitness, training status and fatigue. Substantially increased

 Girard O, et al. Br J Sports Med 2013;47:i8–i16. doi:10.1136/bjsports-2013-093109

feelings of fatigue (players' perception of how hard they are training along with their fatigue, stress and muscle soreness levels), submaximal heart rates, poorer training quality and disrupted sleep structure, as measured from validated tools also give the coach invaluable insight to help delineate those players who are coping well with the stress of hypoxia from those who are not.[35 88]

The majority of training benefits at sea level are accrued with adequate attention given to consistent training, suitable recovery/nutrition and skill development. How are these factors taken into account when training at altitude?

It was recognised that disrupted training and recovery are expected at altitude, especially for novice players, and therefore require careful management.

Training

A factor of importance to the outcome of an altitude-training programme is the training undertaken during the intervention period. The severity of altitude, time spent training at altitude, history of altitude training and timing of training leading into competition represent important factors to consider when designing a training programme at altitude. A considerable interindividual variability in the reduction of aerobic power at altitude exists, and this should be considered.[42 119–122] Consequently, individual adjustments of training intensity and periodisation of training at altitude are required to avoid over-reaching and/or detraining. The proposed actions to individualise the 'altitude dose' and training content should include daily assessment of sleep quality, mood state and frequent monitoring of the changes in HR-derived measures.[35 69] Training load during the altitude sojourn should also be carefully monitored. Ideally, this can be achieved by quantifying the duration and the intensity (CR-10 Borg scale) for each training session.[123] Although monitoring perceived training load and wellness using psychometric[124] and the Lake Louise acute mountain sickness[125] questionnaires are also useful to help prevent the risk of negative adaptations. Careful daily monitoring of indirect measures of cardiac autonomic activity such as heart rate variability or heart rate responses, together with ratings of perceived exertion (RPE) responses to a submaximal run (eg, 4–8 min at 10–12 km/h over 20–40 m shuttles) can help predict/prevent sickness and maintain the training process.[69 86]

In addition to the higher physiological stress, some critical aspects of sport-specific decision-making processes together with skill execution (short-passing ability) and perceived wellbeing are likely to be negatively affected by acute moderate altitude exposure as a result of exacerbated fatigue levels.[126] When 28 international male football players belonging to the English national squad were tested in preparation of the 2010 FIFA World Cup, exposure to a simulated altitude of 1800 m compromised their ability to sustain work output during 10 min of constant-load cycling at 85% of maximum heart rate, and was also associated with higher RPE values.[127] Cognitive function (as measured during the last 5 min of the 10 min constant-load test) was also impaired by acute altitude exposure with a 9% reduction in simple reaction time. As such, careful monitoring of decision-making responses (ie, ideally assessed daily in the initial stages during a hypoxic intervention) undoubtedly has merit.[128]

Recovery

During an altitude sojourn the whole squad should be carefully monitored to try to avoid over-reaching, dehydration or upper respiratory tract infection, taking into account that hypoxia may impact on sleep quality/quantity and therefore player recovery.[35 88 129] Avoiding illness is not always possible; however, by allowing adequate rest (first 1–2 days) and easing into training at altitude (following 2–3 days) before taking up regular training a player's immune system is not placed under excessive stress from both hypoxia and hard training.[53 54 101] Higher heart rates and lower SpO_2 values reflect the inadequate ability of a player to adjust to the hypoxic environment.[24] Practically, we encourage monitoring a range of haematological and immune function parameters including iron status, vitamins, oxidative stress, as well as self-reported wellness and session RPE, before leaving for altitude, particularly during the early phase of chronic altitude training (within the first 2 days of ascent/exposure) and if possible every week thereafter.[35 130 131]

As training sessions in hypoxia increase the use of carbohydrates during exercise, appropriate nutrition is important. Reportedly, a high-CHO meal consumed prior to moderate exercise in hypoxic conditions reduced oxygen desaturation compared with a high-protein meal.[132] Further, football players competing in the 2008 European Championships (Switzerland-Austria with venues elevation <600 m) experienced a decrease in extracellular and body mass (indicating fluid loss),[133] which may be caused by a loss of appetite, dehydration or a change in energy balance (energy expenditure or food availability). In team-sport players, a diet high in carbohydrate could therefore improve tolerance to intense and stressful hypoxic training sessions, which is important when looking at increasing sport-specific fitness. At altitude, respiratory alkalosis during the first few days of exposure initiates a chronic loss of bicarbonate, which may be restored in order to help effectively buffer acidosis during high-intensity exercise and thereby maximise the potential for interval-training quality.[134 135]

Dehydration is common at altitude (diuresis) and may also be caused by sweating and fluid loss through the upper airways (low humidity) due to increased ventilation to defend the immediate fall in SpO_2 due to the reduction in the partial pressure of oxygen at altitude. Because the combination of hypoxia and a strenuous training programme could lead to the development of a chronic state of hypohydration, checking hydration status and electrolyte balance before, during and after training or the game is recommended. Practically, quantifying urine osmolality (>700 mOsm/kg), urine specific gravity (>1.020 g/mL) and/or body mass change (>2% body mass loss from water deficit) can be used as index of dehydration.[136] Because sweat rates and sweat electrolyte content vary greatly among individuals, the development of individualised fluid and electrolyte replacement strategies is required for the preservation of performance and protection of player health.[137]

Global sleep quality (number of arousals and awakenings) can ideally be monitored using polysomnography, but alternatives including actigraphy, sleep questionnaires and other sleep monitoring devices are available in situations where this tool is not practicable.[138–140] Sleeping at moderate altitude does not cause major disruption to players' sleep in general, but it does cause minor to moderate disruption to rapid eye movement sleep, which is important for mental recovery.[141] These symptoms, present in ~25% of the players in a team when sleeping at moderate altitude, should improve over 2–3 nights. Depending on the altitude and the individual, sleep disturbance can be caused by periodic breathing resulting from the interplay between hypercapnia and hypoxia leading to central sleep apnoea. Nearly 40–50% of the members of a team may experience moderate/severe disordered breathing at high altitude (3600 m).[88] This disruption is unavoidable in terrestrial altitude, but it could be avoided in simulated altitude with the use of a 'rest high, sleep low, train low' paradigm for affected individuals. If this new paradigm is used, the potential benefit associated with avoiding disordered breathing during sleep should be considered against the potential cost of spending less time at altitude. Finally, when considering the effects of altitude training on sleep, it is also important to consider any potential effects of travel fatigue (caused by sleep loss, dehydration, immobility) and jetlag due to trans-meridian travel.[142 143]

Section 4: Where to now?

What recommendations can be formulated to overcome some of the limitations of the current studies?

It was commonly agreed that the current level of evidence for the efficacy of hypoxic methods to improve acclimatisation at moderate or high altitude is well established, but rather low when it comes to improved sea level exercise performance. Part of this inconsistency is linked to the fact that various hypoxic methods (hypobaric vs normobaric hypoxia), training modalities or training states of the players have been employed within as well as between studies with discrepancies between measuring methods frequently seen (eg, Hbmass).[144–147] In addition, performance changes resulting from altitude training are not that reproducible even when the mean improvements in underlying physiology are more consistent.[90] Furthermore, the ability to detect a relatively small signal is swamped by the noise of the range of factors that can impinge on individual performance, let alone that of a team.

Important methodological limitations of some of the current literature also include uncontrolled trials, non-randomised study protocols and neither single-blinded nor double-blinded designs.[101] Lack of blinding in interventions, leading to expectation (placebo and nocebo) effects, should be avoided wherever possible (ie, double-blinding natural LHTH studies is impossible), especially in a population of team-sport players where team connection has a widespread effect on performance. Future studies should avoid methodological shortcomings such as absence of lead-in period, undefined training cycle or players' recent training history. Such trial specifications are standard in many other exercise physiology fields and need to be adhered to in the area of altitude-training research in order to move this growing field forward. In addition, it would be worth recording through questionnaire the players' belief in the efficacy of altitude training before they go to the camp to further clarify if expectation is any way associated with benefit. When possible it is also encouraged to use double baseline measures, and carefully documenting training content/load before, during and after the altitude-training intervention will allow a more systematic comparison of various hypoxic methods.

Performance changes should not only be monitored shortly (ie, few days) after the intervention but also for few weeks after the last day of exposure to distinguish the short from middle/long-term (or delayed) effects. Ideally, players would need to be accustomed to performing similar (if not identical) performance tests as part of their usual battery of team fitness testing in order to facilitate this process. It is also important to report eventual dropouts, which indirectly reflect how players coped with the altitude intervention. Further, the level of adherence of the players to the intervention must be measured: "How do the players think the intervention worked for them?" Finally, there is a need for consensus between practitioners and researchers to define what difference in magnitude, in terms of peak sprint or maximal aerobic velocities for instance, after any altitude-training intervention can realistically be considered a meaningful 'improvement' (ie, greater than the 'smallest worthwhile change' or the typical error of measurement) relevant for competitive team-sport performance. In this context, developing a long history of standardised performance tests is important to obtain an indication of each player's sensitivity to a given altitude-training intervention. Only then meaningful recommendations for team-sport players could be derived.

Unresolved performance-led and mechanistic issues, and future directions

While research scientists are inevitably interested in the underlying mechanisms for any changes in performance (and focusing on the mean response where statistical significance is often the critical consideration), these become of secondary importance for applied sport scientists who directly deal with professional team players, as performance optimisation and competition outcome are the driving factors. Equally though, so that applied sport scientists can make evidence-based decisions, it is critical that any performance tests are valid and reliable and that studies are well-designed to avoid placebo/nocebo effects and too many confounding variables. The panellists recognised that some of the key research gaps in the field of altitude-training methods relevant for team sports can be addressed by.

Performance-led investigations

- Determining whether performance and physiological changes induced by altitude-training protocols are actually transferred to competitive match outcomes: how to accurately measure these effects?
- Verifying the usefulness of new hypoxic training methods (eg, live high and train low and high interspersed, repeated sprints in hypoxia, live high—train low under heat stress or altitude training combined with blood occlusion) in a range of professional team sports, to determine whether the capacities meant to be improved actually are.
- Evaluating the combination of altitude-training methods and the effect that they have on the magnitude and time course of several aspects of match-related performance and adaptive responses during isolated or periods of intensified competition.
- Validating the efficacy of LLTH methods when attempting to improve sea-level performance, preacclimation, prevention of detraining during off-season/injury periods or to prolong the beneficial effects of an extended altitude-training block.
- Determining whether the breathing abnormalities that occur during sleep at high altitude by many players, and the accompanying sleep fragmentation, affect the efficacy of altitude training.
- Clarifying how increased oxygen delivery/utilisation conferred by hypoxic interventions improves match-related performance, prevents premature and excessive neuromuscular fatigue and improves recovery processes in team-sport-related activities.
- Determining under which circumstances altitude exposure can be used either as a substitute to reduce the inevitable detraining effect seen in long-term injured players or to further stimulate the cardiovascular and metabolic systems, while keeping training load lower than at sea level.
- Clarifying some of the jet lag-related methodological (circadian rhythms) issues, and establish whether teams should train or be tested at the new destination or at the origin time, also taking into account the delay before competition and the details of the altitude stress.

Mechanistic studies

- Understanding whether the cellular and molecular basis of hypoxic adaptations (downstream targets of HIF-1α) differ between the various altitude-training interventions, and the impact of titrated 'hypoxic doses'.

- Shedding more light on putative adaptive mechanisms (eg, running economy, lactate metabolism and muscle/blood buffer capacity along with compensatory vasodilation associated to reduced oxygen content and potential on fibres behaviour and fatigability) and signalling pathways (eg, mitochondrial efficiency and biogenesis, capillarisation and sodium/potassium handling) of non-haematological adaptations important for team-sport physical performance.
- Identifying physiological (with a particular emphasise on genetic and ventilatory responses) and psychosociological factors of primary influences affecting individual player responses to hypoxic training.
- Quantifying the extent of biomechanical/skill-based adaptations associated with hypobaric hypoxia, and the optimal dosing and timing of those aerodynamics and neuromuscular control adjustments in regards to physiological ones.
- Measuring the magnitude and rate of changes and the underpinning physiological (Hbmass, oxygen cost of breathing) and biomechanical (neural activation strategies, kinetic/kinematic adjustments) adaptations when altitude-resident players descend from altitude and when sea-level players live high and train low.
- Investigating if hypobaric and normobaric hypoxia hold the same potential for improvement in match-specific fitness and share similar underlying physiological mechanisms, and therefore determining whether they can be used interchangeably.

Section 5: Summary and conclusion

The field of altitude training represents a good example of how a better understanding of the acute/chronic effects of hypoxia, as well as the best practices to acclimatise, can help teams to better prepare their players. At present, most of our understanding, and information on altitude-training methods, have been focussing on endurance (individual) athletes. Based on this literature, there is little question as to the benefits of training at altitude for the purpose of improving performance at altitude (acclimatisation). However, the benefits of using a LHTH, LHTL and LLTH altitude-training intervention or a combination of those methods to improve team-sport-related physical performance upon return to sea level are not as definitive. The approach that consists of extrapolating existing data obtained with individual athletes to understand the effects of altitude training on complex team-sport performance is limited. The question of whether altitude/hypoxic training—be it natural or artificial—is relevant to improve team-sport performance (and its putative underlying mechanisms) has not yet been convincingly proven. Nevertheless, it is undeniable that no single recommendation is likely suitable for all players in a team, or across all team sports, requiring the development of optimised interventions at the individual player level. This theoretically implies that not all the members of a team should be exposed to the same hypoxic conditions, but rather that an optimal dose/time/type be established for each player. Finally, considering that team sports require high levels of skill, decision-making and tactics, it still remains to be ascertained whether individual enhancements in high-intensity running and involvements with the ball during competitions would also positively impact a team's game result.

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Contributors The manuscript was written by OG based on the discussions held during the *Altitude Training and Team Sports* conference. The manuscript that was read and approved by all authors reflects a range of ideas and concepts.

Competing interests None.

Provenance and peer review Commissioned; internally peer reviewed.

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Position statement––altitude training for improving team-sport players' performance: current knowledge and unresolved issues

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Br J Sports Med 2013 47: i8-i16
doi: 10.1136/bjsports-2013-093109