IMPROVING TEAM-SPORT PHYSICAL PERFORMANCE

LATEST HYPOXIC TRAINING PROPOSALS

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Highlights

1. *Performing 'all-out' efforts in hypoxia (Repeated Sprint training in Hypoxia or RSH) may provide additional activation of anaerobic and neuromuscular pathways beyond that observed in normoxia.*
2. *Combining 'traditional' altitude methods (Live High-Train Low) and 'innovative' methods (Repeated Sprints training in Hypoxia), the so-called Live High Train Low and High or LHTLH, would boost both aerobic fitness and repeated-sprint ability in team sports.*

INTRODUCTION

Historically, altitude training for endurance athletes emerged in 1960s and was limited to the "Live High-Train High" (LHTH) method for those looking to increase their oxygen (O_2) transport. This 'classical' method was complemented in 1990s by the "Live High-Train Low" (LHTL) method, where athletes benefitted from the higher intensity of training at lower elevations whilst simultaneously residing at altitude. The development of new research directions are usually derived from problems encountered in the field by practitioners.

UPDATED PANORAMA OF HYPOXIC METHODS

Recently, innovative "Live Low-Train High" (LLTH) methods have emerged as "Resistance Training in Hypoxia" or "Repeated-Sprint training in Hypoxia" (RSH) with the belief that up-regulated non-haematological peripheral adaptations may further improve high-intensity intermittent performance compared to normoxic controls[1]. "Resistance Training in Hypoxia" for instance, was proposed with or without vascular occlusion with the purpose of promoting hypertrophy and power production, yet with unclear benefits in the available literature[2]. A combination of hypoxic methods also represent an attractive solution. For example, "Live High-Train Low and High" (LHTLH) is a method whereby athletes "live high and train low except for few intense workouts at altitude"[3]. By combining LHTL and RSH, for instance, larger repeated-sprint ability (RSA) gains have been reported in team-sport players[4]. Similarly, the usefulness of the combination of LHTH and high-intensity training near sea-level ("Live High-Train High and Low"; LHTHL) was demonstrated in swimmers[5]. The scope of hypoxic training methods is now wider than in the past as it distinguishes RSH from traditional "Intermittent Hypoxic Training" (IHT) methods (Table 1) and the use of altitude training is no longer restricted to endurance athletes.

ALTITUDE TRAINING AND TEAM SPORTS

Team-sport players are required to repeatedly produce skilful actions at maximal or near-maximal intensity (e.g., accelerations, changes in pace and direction, sprints, jumps and kicks), interspersed with brief recovery intervals (consisting of rest or low- to moderate-intensity activity), over an extended period of time (1–2 h). Imperative performance characteristics of team-sport players are excellent RSA and large distance covered during the Yo-Yo intermittent recovery (Yo-Yo IR) test, both being associated with in-match physical performance[6]. High-intensity training under hypoxia likely improves buffering capacity, lactate exchange and removal, tissue O_2 extraction, glycolytic enzyme activity, citrate synthase activity and myoglobin content. Despite a lack of strong scientific evidence, a growing number of team-sport athletes are using altitude training in the belief that it can promote greater physiological adaptations useful to improve in-game physical performance. Because of the limited time allowed in a competitive season to employ hypoxic interventions, it is therefore not surprising that LLTH methods, causing minimal disruption to technical and tactical training, encounter a large popularity in the team-sport community. As little as four "in season" RSH sessions, using either a cycle[8] or a double-poling[9] exercise mode, were beneficial to enhance repeated power production in World-level Rugby Union players during the short-term preparation to a major competition.

BEYOND INTERMITTENT HYPOXIC TRAINING: REPEATED SPRINTS IN HYPOXIA

The development of hypoxic facilities (O_2-filtration chambers/tents or breathing hypoxic mixtures with a mask) within the last two decades has prompted the implementation of LLTH interventions. A thorough analysis of 20 studies including IHT leads to strikingly poor benefits for sea-level performance improvement, with only four studies bringing additional benefits in performance-related variables compared with similar training in normoxia[10]. To overcome some of the inherent limitations of IHT (e.g., lower training stimulus due to hypoxia), a new hypoxic training method was developed in Lausanne against the observation of an up-regulation of several genes mRNA only when exercise was performed at high-intensity and high altitude (and not at lower intensity)[11]. This model differs from IHT since the intensity of the training stimulus is maximal and therefore would allow one to maintain high fast twitch muscle fibre recruitment, so that positive results can be expected when adding hypoxia to training. RSH training is based on the repetition of short (<30 s) 'all-out' sprints with incomplete recoveries (<60 s) in hypoxia[10,12]. A lower rate of O_2 delivery to the muscles increases the stress on glycolytic flux, which may stimulate the up-regulation of this energy pathway. Compared with repeated-sprint training in normoxia (RSN), RSH could induce beneficial adaptations at the muscular level, along with improved blood perfusion, which may lead to greater improvements in RSA[10].

Table 1

Methods	*Date*	*Sports*
Live High – Train High (LHTH)	*1960s*	*Endurance*
Intermittent Hypoxic Training (IHT)	*1960s*	*Endurance*
Live High – Train Low (LHTL)	*1997*	*Endurance*
Resistance Training in Hypoxia (RTH)	*2000s*	*Power*
Repeated-Sprint in Hypoxia (RSH)	*2013*	*Team/racket*
Live High – Train Low and High (LHTLH)	*2015*	*Team/racket*
Live High – Train High and Low (LHTHL)	*2015*	*Endurance*
RSH with Voluntary Hypoventilation at Low lung volume (RSH-VHL)	*2017*	*Team/racket*

Table 1: Historical summary of altitude/hypoxic training methods (adapted from Millet et al 2019).

REPEATED-SPRINT TRAINING IN HYPOXIA AND PERFORMANCE IMPROVEMENTS

In our pioneer study, 40 trained male cyclists completing four weeks of RSH or RSN (against a control group with no specific repeated-sprint training) were tested before and after training for the determination of endurance performance, anaerobic capacity and RSA[13]. Whereas performance during a 3 min "all-out" time trial was not improved, RSN and RSH improved the average power output during 10 s sprints and a 30-s Wingate test post-intervention. A major finding of this study was that RSH delays fatigue during a repeated-sprint test to exhaustion (10-s sprints, 20-s recovery period until peak power output declined by 30%). Hence, the number of sprints completed increased by ~40% (from 9 to 13) in the RSH group, whilst the RSN group showed no such improvement (9 sprints before and after the intervention). A 2017 meta-analysis featuring nine controlled studies (over 200 individuals) indicated that RSH induces greater improvement for mean repeated-sprint performance during sea-level repeated sprinting than RSN[12]. In the altitude training area, RSH is of interest with 25 studies published by seven research groups in the past 5 years, with only two studies demonstrating no beneficial effects[14]. Practically, RSH benefits have been demonstrated for a large range of team- (rugby, football, LaCrosse, Australian Football, field hockey), endurance (cycling, track and field, cross-country ski), racket (tennis) or combat (Jiu-Jitsu) sports.

In soccer, Gatterer et al[15] showed that sport specific shuttle-run sprint training is feasible in hypoxic chambers of limited size

(4.75 x 2.25 m) and is associated with a better running speed maintenance during a RSA test (lower fatigue slope) when compared to normoxia training. In highly-trained youth football players (Aspire Academy), the addition of 10 repeated-sprint training sessions performed in hypoxia vs normoxia to their regular football practice over a five-week in-season period was more efficient at enhancing repeated-agility ability (including direction changes), whereas it had no additional effect on improvements in lower-limb explosive power, maximal sprinting, RSA performance and maximal aerobic speed[16]. Interestingly, an additional benefit on in-game physical performance-related variables of RSH compared to RSN is present in all currently available studies.

In a group of elite rugby players, Galvin et al[17] found that four weeks of maximal RSH training induced a ~19% greater improvement in Yo-Yo IR1 performance compared with matched controls completing the same training under normoxic condition. Players also tended to cover more distance with a smaller speed decrement during the RSA test after hypoxic training, while 5-m sprint performance and RSA total time improved similarly in both training groups. RSH where hypoxia is induced by voluntary hypoventilation at low lung volume (named VHL) may also improve repeated-sprint performance more largely than with an unrestricted breathing pattern, as demonstrated by ~60% more sprints on average during an 'open loop' test carried out until a predefined exhaustion criteria in highly-trained rugby players[18].

"A typical normobaric RSH training performed on ergocycle last ~30 min with RSH blocks of 4 to 6 min. This is generally performed at the end of a 30-40 min strength training session."

"A good example would consist of 3 sets of 7 s maximal effort (at a pedaling rate of 140) with 23 s passive rest and 3 min between sets."

– Didier Reiss

"Wales rugby players performed short RSH blocks (15-days period) including 4-6 sessions with upper- and lower-body exercises."

"For the 2015 Rugby World Cup, we used 15-days hypobaric LHTLH and 10-days normobaric LHTL in addition to in-season RSH training."

"I am convinced of the effectiveness of RSH training to enhance repeated-sprint performance and power output in rugby players."

"We successfully applied this RSH method during several 6 Nations Championships."

– Adam Beard

Figure 1: Testimonial of world-class strength and conditioning coaches regarding their use of repeated-sprint training in hypoxia.

ADDITIONAL CONSIDERATIONS

Overall, larger improvements in team-sport athletes' ability to repeatedly perform predominantly aerobic high-intensity work (Yo-Yo IR and RSA tests) after hypoxic repeated-sprint training together with the lack of greater performance improvement during isolated maximal 'all-out' efforts of short duration (<30 s) would indicate that muscular oxidative activity rather than non-oxidative metabolism might be influenced by such training. The larger efficiency of RSH could relate to an increased muscular perfusion, an enhancement of growth hormone response, an ameliorated cerebral deoxygenation, a changed pH regulation and enhancement of the glycolytic capacity (PFK activity) and/or an increased expression of genes relating to O_2 transport[10,12,14].

The exercise-to-rest ratio likely plays an important role in the putative benefits after RSH because it modifies the energetic contribution of glycolysis and the fast twitches recruitment/activation during high-intensity exercise. Various activities and differing positions or playing styles within the same team sport creates a diversity of physiological challenges[7]. In light of each team-sport athlete needs, specific training focus (more aerobic vs. anaerobic type of adaptations) would imply that the effects of RSH may not be uniform across all players (e.g., larger anticipated benefits for midfielders or attackers compared to central defenders in football). Nonetheless, it is anticipated that players engaged in team sports (e.g., Australian league football) displaying shorter exercise-to-rest ratios and/or requiring prolonged time spent at high relative exercise intensity are more likely to benefit from such training.

At top level, coaches and athletes would be more likely to endorse the efficiency of a given intervention if results have direct relevance to their programmes and can be applied in a sport-specific setting (Figure 1). New technologies such as the mobile inflatable hypoxic marquees[19] now offer advancements of hypoxic training practical applications, notably with the opportunity to train (i.e., repeated sprinting over ~25 m, small-sided games, resistance training in hypoxia) under field-based hypoxic conditions. Training inside these marquees using a RSH paradigm has recently been successfully implemented

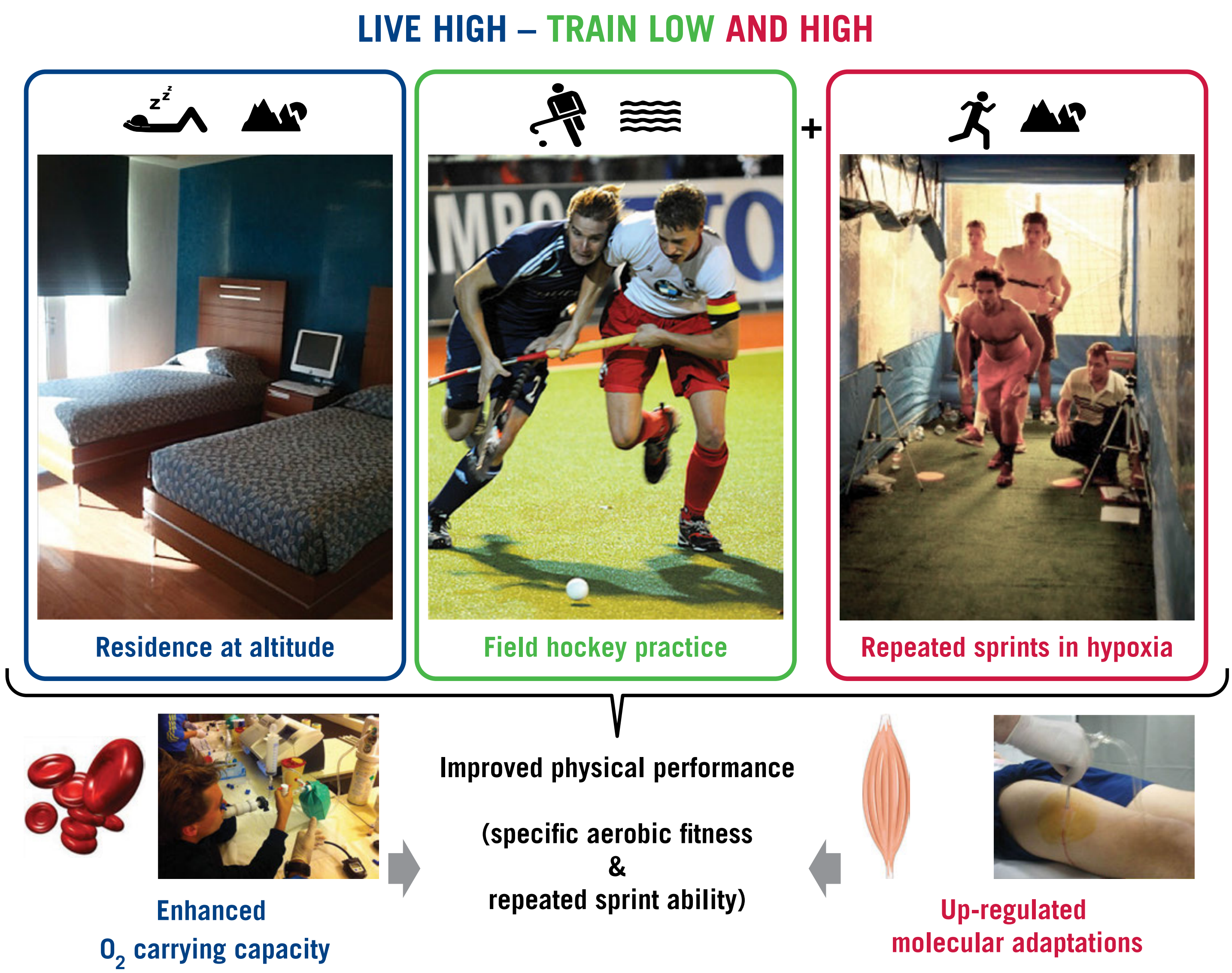

Figure 2: Live High-Train Low and High (LHTLH) altitude training paradigm using the altitude dorm facilities at Aspetar.

with elite field-hockey players during in-season training camp in Doha (Figure 2).

Completing significant amounts of underpinning research is a prerequisite prior any attempts to implement strategies that have the potential to directly impact day-to-day activities in the 'real world'. As a result, the time lag identified for the translation of research into "routine practice" usually exceeds 5-10 years. Only five years after the first published results, however, innovative RSH and LHTLH have already gained considerable popularity in the team-sport community[14]. Many training centres at terrestrial altitude or specialized centres with normobaric altitude dormitories (altitude residence for improved blood carrying capacity) also equipped with a climatic chamber (i.e., RSH for improved muscle factors and/or heat training for improved thermoregulation) now have the facilities for optimal preparation of team-sport players. Aspetar is fortunate to have World-class facilities for training with environmental stress. Through strategic partnerships, Aspetar attracts prestigious national teams for optimal competition preparation. In recent years, French Rugby Federation squads have successfully tested new RSH (female Sevens national team) or LHTLH with heat training (male U20) training regimens for the purpose of refining best practice (Figure 3).

LIVE HIGH-TRAIN LOW AND HIGH

Although aerobic metabolism dominates the energy delivery during most team sports, decisive actions (e.g., sprints and jumps) are covered by means of anaerobic metabolism. As a result, the demands of team sports lend themselves towards a potential edge from hypoxia-derived aerobic and anaerobic adaptive mechanisms. LHTLH has been recently validated as an attractive combination (LHTL + RSH) to elicit concurrent aerobic and anaerobic performance-related physical fitness traits in team sports (Figure 2). With a low hypoxic dose (≥200 h), LHTLH conducted for two weeks during the in-season period of elite field hockey players was efficient to elicit immediate up-regulated haemoglobin mass (+4%) and an increase in Yo-Yo IR2 performance (+20%), yet with similar gains compared to sea-level training (LHTL + RSN)[4]. However, the superiority of the LHTLH over the LHTL + RSN method was demonstrated on the RSA test (8 x 20 m, 20 s rest) with twice larger acute performance gains, those being well maintained at least for

Figure 3: Repeated Sprint training in Hypoxia (a) and Live High-Train Low and High combined with heat training (b) altitude training camps of elite French rugby players at Aspetar.

three weeks post-LHTLH intervention only. Analysis of muscle biopsy samples indicated an overexpression of transcription factors involved in O_2-signaling and O_2-carrying capacity and mitochondrial metabolism enzymes for LHTLH[20].

SUMMARY

Altitude training has traditionally targeted endurance-based athletes, but more recently, the use of LLTH approaches and in particular the emergence of the RSH paradigm used in isolation or combined with 'traditional' methods (the so-called LHTLH), is gaining considerable attention in team sports. It is thought that this practice may maximize high-intensity exercise performance through an improved ability to resist fatigue and eventually greater outcome of crucial situations (preserved technical and tactical behaviour and wise cognitive choice) in the most intense periods of a game or towards the end of a match. By adding hypoxic stress to repeated-sprint training, a large number of studies available to date demonstrate larger, short-term (2-6 weeks) benefits associated with RSH on several indices of repeated-sprint performance enhancement, compared to similar training at sea level. Considering the complexity of match running performance and numerous factors influencing it (pacing strategies, mental fatigue, contextual and tactical factors), determining whether individual post-RSH physical performance enhancements would also positively impact a team's game result remains a considerable challenge.

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