Original research

Live-high train-low improves repeated time-trial and Yo-Yo IR2 performance in sub-elite team-sport athletes

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1. Introduction

Australian Football (AF) athletes cover high distances, 3 often at high-velocities (>4.17 m·s⁻¹), 2 suggesting that a high physical capacity is important for these athletes.

Despite this, higher aerobic capacity may not translate into improved match running performance. 3 However, better performing teams and individuals cover more distance in matches, 4, 5 and have superior time trial (TT) 6 and Yo-Yo intermittent recovery test level 2 (Yo-Yo IR2) performance. 7, 7 The resynthesis of phosphocreatine (PCr) is oxygen-dependent, 8 with the rate of muscle re-oxygenation after a maximal effort critical for subsequent performance. 9 Therefore, a highly developed aerobic system is crucial for performing both the lower-intensity movements and repeated high-intensity activities during matches. As increased fatigue reduces technical skill performance, 10 minimizing fatigue may help maintain skill efficiency. Therefore, altitude training that increases aerobic capacity can potentially improve team-sport athlete running performance and skill efficiency.

With live-high train-low (LHTL) altitude training, participants live at real or simulated altitude (2000–3000 m) for more than 12 h per day and train at or near sea level. 11 Although not unanimous, the majority of literature points to improved sea-level performance or haematological changes following LHTL. For example, elite endurance athletes have improved running economy, 12 and haemoglobin mass (Hbmass), 13 compared to groups living and training at sea-level. 12

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An increased Hbmass appears beneficial for performance in repeated aerobic efforts. In elite female cyclists following LHTL, Hbmass was clamped in one group and free to adapt in a second.14 Both groups improved 4-min mean power, although the clamp group could not match the group with improved Hbmass for performance during a subsequent aerobic effort.14 This indicated Hbmass is important not only to improve oxygen carrying capacity during sustained efforts, but also to improve the rate of recovery, allowing greater performance in subsequent efforts. This has critical relevance to team-sport athletes, and thus a repeated TT performance test should be used to ascertain team-sport specific performance changes through LHTL.14

Twelve to 14 h per night is recommended to increase Hbmass and performance.15,16 Thus, bouts of LHTL of less than 12 h may be insufficient to increase Hbmass,17 due to the break between altitude bouts being too long to allow a sustained release of erythropoietin to stimulate Hbmass changes. As an increase in Hbmass of 1–1.5% per week has been shown, exposure of more than 14 nights is required to see meaningful changes.15,16 Many team-sport athletes play competition matches each week, so an unbroken block of >14 nights in-season is difficult to administer. Blocks of five nights of LHTL separated by two days at sea level have been successfully used in elite runners to improve running economy and race performance,12 and are more realistic for team-sport athletes due to matches and training in-season. Therefore, investigation is required to determine whether intermittent LHTL is effective for team-sport athletes and the minimum time course for adaptation.

This study therefore investigated the effects of LHTL on aerobic performance measures that correlate to team-sport athlete running performance (Yo-Yo IR2 and short-duration time trials).2 and the time-course of adaptation using sub-elite team-sport athletes.

2. Methods

A pre-post, parallel-groups controlled trial study design was undertaken during the latter stages of pre-season immediately before practice matches. For these athletes, this is a medium-to high-volume period of pre-season training, with the primary focus on skill and tactical development, with a secondary goal of continuing to improve physical capacity.18 As such, small gains in aerobic capacity are expected during this period; therefore, testing the efficacy of LHTL in producing additional gains was established through a pair-matched control group with matched internal training load. Ethical approval was obtained through the institutional Human Research Ethics Committee.

Sixteen male semi-professional Australian Footballers from the same Victorian Football League (VFL) team volunteered for the study. The VFL is a sub-elite AF competition; it is a feeder league to the Australian Football League (AFL). At the beginning of the study, all participants were injury free, living at sea level, and had not been exposed to high altitude for at least 12 months. After baseline testing, the eight participants from LHTL were pair-matched with another squad member with similar Yo-Yo IR2 performance who acted as a control (CON). One subject from LHTL did not reach the required minimum altitude exposure, with his data removed from analysis; therefore 15 participants completed the study (LHTL n = 7, 20.1 ± 1.2 years, 83.2 ± 6.8 kg, 182.7 ± 7.8 cm, CON n = 8, 20.2 ± 1.4 years, 83.6 ± 11.7 kg and 184.2 ± 8.5 cm). All LHTL subjects were given a single daily oral iron supplementation (305 mg ferrous sulphate, 1000 mg Vitamin C) throughout the study.

The LHTL group was exposed to 19 nights (3 × 5 nights, and 1 × 4 night block) of simulated altitude exposure (FIO2 0.142 simulating 3000 m altitude, humidity 40%, temperature 21°C). Each altitude block was separated by two nights at sea level. Participants were required to spend 12 h night−1 at altitude (average of 12 h 10 min night−1).

The Yo-Yo IR2 was used to test intermittent running performance of the participants. This test consists of 2 × 20-m shuttles performed to an audible beep at increasing speeds, interspersed with 10 s of active recovery, performed until exhaustion.13 It is a valid test for determining aerobic and anaerobic capacity for team-sport athletes.20 The Yo-Yo IR2 was performed on the same indoor court on both groups at baseline, after 5, 15, and 19 nights LHTL. Due to participant availability, not all athletes performed the Yo-Yo IR2 weekly, however all subjects performed the Yo-Yo IR2 pre and post.

Both groups performed the 2- and 1-km time trial (TT) two days following the pre and post Yo-Yo IR2. On the same outdoor 400-m running track, participants first performed a 2-km TT, after a 5-min break, a 1-km TT was undertaken. Two maximal aerobic efforts were used as multiple efforts require a greater reliance on aerobic metabolism.14,21 This is both for enhanced oxygen transport and improved recovery rates, through the removal of metabolic by-products accumulated from the first effort.14 Further, due to the intermittent nature of many team-sports, repeated efforts may be more important for team-sport athletes than a single TT. This repeated aerobic test, combined with the Yo-Yo IR2 helps determine the running capacities that are important for team-sport athletes. Both tests were performed at the same time of day, after a standardized warm up before training, with participants instructed to maintain a consistent diet before each test. Apart from the iron supplementation, participants were instructed not to begin taking supplements, or those on supplements were asked to maintain the same dosage as prior to the study.

Haemoglobin mass was measured by the same experienced assessor using the carbon monoxide (CO) rebreathing technique.22 This involves rebreathing 1.0 mL kg−1 of CO for 2 min. A 3 mL venous blood sample was taken pre and 7 min post initial CO inhalation, to measure percent carboxyhaemoglobin (OSM-3 Hemoximeter, Radiometer Medical, Copenhagen). Haemoglobin mass was calculated by the change in percent carboxyhaemoglobin from these two measures. Duplicates were taken to increase precision. If duplicates were more than 0.1% different, a third measure was taken, with the average of the two nearest measures used for analysis. This technique has a typical error of 1.7%.22

Haemoglobin mass was measured in LHTL at baseline, after 5, 10, 15, and 19 nights. All seven participants from LHTL had Hbmass measured pre and post LHTL, although due to participant availability, only five participants had Hbmass measured after 5, 10, and 15 nights.

Training load was determined using the product of session duration and rating of perceived exertion (RPE) following each session.23 Weekly load was determined using the sum of daily load. As both groups performed the same training throughout the study, the CON group is a true control, with the LHTL intervention being the only difference between groups. Training load was also gathered on participants in the seven weeks prior to LHTL to ensure all participants presented in the same training state at the beginning of the study. This prior monitoring of training load ensured we were able to determine the effects of LHTL on the performance tests undertaken confident it was not due to a difference in training between groups.

Means, standard deviations, and percentage changes were calculated at each testing session. A contemporary statistical approach,24 using effect size (ES) and confidence limits was used to measure changes between groups. Differences between, and within groups were determined, with an ES of 0.20 set to evaluate the smallest worthwhile change.25 Standardised effects were classified as small (0.2–0.59), or moderate (0.6–1.2). Ninety percent
Fig. 1. Weekly training load shown in arbitrary units for CON (black bars) and LHTL (clear bars) for the 7 weeks prior to (pre-intervention), and the 4 weeks of intervention phase of the study.

confidence limits (CL) were expressed for changes compared to pre for all measures.

3. Results

There were no meaningful differences in training load prior to, or throughout the study (LHTL 1.2% greater load, ES 0.44, 90% CI 0.43; 1.31) Fig. 1).

Fig. 2 displays percentage change for Hbmass in LHTL at each time point. In comparison to pre, percentage change in absolute Hbmass was not meaningfully different after 5 (0.2% change, ES 0.01, 90% CI 0.03; 0.05) or 10 nights (1.6%, 0.8, –0.16; 0.32), possibly higher after 15 nights (3.8%, 0.19, 0.05; 0.33), and a likely small effect after 19 nights (6.7%, 0.35, 0.19; 0.52).

Group means and the number of athletes tested at each time point for Yo-Yo IR2 are displayed in Fig. 3A. Differences in the change between groups compared to baseline at each time point are shown in Fig. 3. Groups were not different for Yo-Yo IR2 performance at baseline (LHTL 3.0% lower, –0.12, –1.18; 0.94). The LHTL change compared to CON was not clearly different after 5 nights, possibly greater after 15 nights, and likely greater after 19 nights (5.5%, 0.21, –0.26; 0.67, 10.2%, 0.37, –0.29; 1.04, and 13.5%, 0.49, –0.16; 1.14 after 5, 15, and 19 nights, respectively).

At pre, LHTL was not meaningfully different to CON for either 2-km, (0.9% faster, 0.09, –0.76; 0.93, Fig. 3B) or 1-km TT (1.5% faster, 0.21, –0.64; 1.07, Fig. 3C). At post, both groups improved 2-km TT, with LHTL improvement possibly greater than CON (1.9%, 0.22, –0.18; 0.62, Fig. 3E). Only LHTL improved 1-km TT from pre to post, with LHTL change greater than CON (4.6%, 0.56, –0.08; 1.04, Fig. 3E).

4. Discussion

The main finding was that 19 nights of LHTL implemented during pre-season training increased intermittent running performance in sub-elite team-sport athletes more than sea-level training alone. While both groups improved 2-km TT performance at post, only LHTL improved 1-km TT when performed 5 min post 2-km TT. Therefore, increased performance after LHTL appears to be more evident in a second aerobic challenge.

As the study was undertaken in pre-season, it is expected that changes in physical performance will occur through normal training. As expected, both groups improved Yo-Yo IR2 performance; however changes in Yo-Yo IR2 were likely greater in LHTL compared to CON. Therefore LHTL on top of normal pre-season training can increase physical performance. This change in Yo-Yo IR2 for LHTL became more apparent the greater the time spent at altitude. As there were increases in Hbmass, improved aerobic capacity may have contributed to a greater Yo-Yo IR2 performance.

The increased Yo-Yo IR2 after LHTL may be important for team-sport athlete match running performance. Yo-Yo IR2 performance can discriminate between playing levels in team-sport athletes, with International level soccer players outperforming division 1 and 2 players, while elite players performed 41% better than sub elite. Therefore, a higher Yo-Yo IR2 performance appears important to team-sport athletes. However, despite the high aerobic demand of team-sport matches and the relationship between Yo-Yo IR2 performance and playing level, it is yet to be determined if changes in Yo-Yo IR2 performance translate directly into better match-running performance. Therefore, caution should be taken to assume the change in Yo-Yo IR2 in the LHTL group translates into better running performance and chances of success in matches. Even though improved Yo-Yo IR2 may not relate directly to better match-running performance, improved aerobic capacity results in a decreased relative running intensity when running at the same absolute speed. In turn decreasing peripheral muscle fatigue, possibly negating any decrease in skill efficiency seen through fatigue.

Increased Yo-Yo IR2 has occurred in hypoxic studies. Combining heat and hypoxia in elite Af athletes increased Yo-Yo IR2 by 25% after six, and 44% after 14 days of LHTL. However this was in combination with heat and IHT training making it difficult to isolate the effect of LHTL on Yo-Yo IR2. As IHT has improved Yo-Yo IR2 by 27% more than a control group after only six sessions, it is possible that this greater change in Yo-Yo IR2 in the LHTL + Heat study was through the IHT component of training. Further, both groups completed IHT, and there was no difference between the LHTL group and the control group for change in Yo-Yo IR2, again supporting the thought that IHT may be more beneficial than LHTL for increasing Yo-Yo IR2. However, in a separate study there was no difference in the change in Yo-Yo IR2 performance between a LHTL + IHT and a LHTL only group, with both groups improving more than a control.

Although 2-km TT improved in both groups at post, importantly only LHTL improved subsequent 1-km TT, with a likely greater improvement from baseline compared to CON. It is possible that
LHTL was able to increase 1-km TT performance through increased aerobic capacity, as shown through increased Hbmax. Alternative mechanisms, including increased contribution of anaerobic metabolism may be why CON still improved 2-km TT. However, fatigue does not allow improved performance during the 1-km TT. The increased Hbmax not only enhances oxygen delivery during the 2-km TT, but may also improve the rate of recovery, allowing improved performance during the subsequent 1-km TT through decreased accumulated fatigue.\(^{14}\)

The finding of a greater performance in a second effort is novel for team-sport athletes, but as stated earlier is not unique among elite endurance athletes.\(^{14}\) Considering team-sport competition can last up to 120 min, with breaks in play, repeated aerobic efforts are required by team-sport athletes. Therefore, the finding of LHTL improving repeated efforts more than a single bout is extremely relevant for team-sport athletes.

It is important to ensure the testing protocol is designed to detect any changes seen through the altitude exposure employed.
For example, a group of similar sub-elite team-sport athletes undertaking Intermittent Hypoxic Training (IHT) have used the same performance tests as the current study, however, the performance response was different. There was no difference in 2-km TT between groups post training, while the control group improved 1-km TT more than the IHT group post testing. However for the Yo-Yo IR2, the IHT group had a 27% greater change than the control group after only 6 sessions of IHT. As the repeated TT design used is predominantly an aerobic test, and there is a large anaerobic contribution to the Yo-Yo IR2, it is likely that different mechanisms were at play. Therefore, study design is crucial to determine the performance outcomes from an altitude intervention. If the IHT study presented above had only used an aerobic type of test, important intermittent running performance changes for team-sport athletes would not have been detected, and the conclusion would have been markedly different. It is possible that true changes in performance in altitude studies are missed due to the design and selection of tests being unable to detect these performance changes. Therefore the conflicting findings between LHTL studies are perhaps in part due to differences in testing protocol.

An important factor often overlooked with training studies is the training status prior to the commencement of the study. Most training studies only have the participants for the duration of the study; making it difficult to monitor activity prior to the study. However, it is important to do this to determine whether athletes present at the beginning of the study are in the same training state. For example, if an athlete begins the study in an over-trained state, the result of a performance test may be sub-optimal. Knowing that changes in performance after altitude can be similar to that seen in a taper, determining the training load prior to a LHTL intervention is crucial. By using a single team in the present study, we were in the unique position to be able to monitor training for seven weeks prior to the study commencing. Therefore participants were matched, not only for testing performance at the start of the study, but also on pre-study training load.

It appears that if increased aerobic capacity and Hbmass are the aim for team-sport athletes, LHTL offers a viable option to achieve this. However, if changes in repeated high-intensity efforts as measured through the Yo-Yo IR2 are the primary goal, team-sport athletes are better advised to undertake IHT, with this method showing large increases in Yo-Yo IR2 performance in a relatively short time frame.

A limitation was not taking Hbmass from CON. This made it impossible to determine if CON also increased Hbmass, and if the clear changes in Hbmass in LHTL were induced through the altitude or adaptations to normal training. However, team-sport athletes with a similar Yo-Yo IR2 performance showed no changes in Hbmass through normal training alone, indicating large increases in Hbmass from CON would be unlikely. Secondly, a placebo effect may have been present as there was no blinding of altitude. However, as Hbmass changed, there were physiological adaptations to the intervention, and not just a placebo effect.

5. Conclusions

In team-sport athletes, 19 nights of intermittent LHTL is effective at increasing Hbmass. Further, LHTL improves Yo-Yo IR2 and repeated TT performance more than sea-level training alone. Importantly, this alternate design allows sub-elite team-sport athletes to take part in effective altitude training during the season. Before LHTL is undertaken in season, further research is required to determine the optimal timing for LHTL to finish prior to matches.

6. Practical implications

- Live-high train-low improves aerobic running performance in sub-elite team-sport athletes.
- Live-high train-low can be used to increase Hbmass in sub elite team sport athletes.
- Appropriate selection of tests is crucial for detecting performance changes seen through altitude training, with a time-trial design important for detecting aerobic changes through altitude.

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