

Research article

Increased Hypoxic Dose after Training at Low Altitude with 9h per Night at 3000m Normobaric Hypoxia

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Abstract

This study examined effects of low altitude training and a live-high: train-low protocol (combining both natural and simulated modalities) on haemoglobin mass (Hb_{mass}), maximum oxygen consumption (VO_{2max}), time to exhaustion, and submaximal exercise measures. Eighteen elite-level race-walkers were assigned to one of two experimental groups; lowHH (low Hypobaric Hypoxia: continuous exposure to 1380 m for 21 consecutive days; $n = 10$) or a combined low altitude training and nightly Normobaric Hypoxia (lowHH+NHnight: living and training at 1380 m, plus 9 h.night⁻¹ at a simulated altitude of 3000 m using hypoxic tents; $n = 8$). A control group (CON; $n = 10$) lived and trained at 600 m. Measurement of Hb_{mass} , time to exhaustion and VO_{2max} was performed before and after the training intervention. Paired samples t-tests were used to assess absolute and percentage change pre and post-test differences within groups, and differences between groups were assessed using a one-way ANOVA with least significant difference post-hoc testing. Statistical significance was tested at $p < 0.05$. There was a 3.7% increase in Hb_{mass} in lowHH+NHnight compared with CON ($p = 0.02$). In comparison to baseline, Hb_{mass} increased by 1.2% ($\pm 1.4\%$) in the lowHH group, 2.6% ($\pm 1.8\%$) in lowHH+NHnight, and there was a decrease of 0.9% ($\pm 4.9\%$) in CON. VO_{2max} increased by ~4% within both experimental conditions but was not significantly greater than the 1% increase in CON. There was a ~9% difference in pre and post-intervention values in time to exhaustion after lowHH+NH-night ($p = 0.03$) and a ~8% pre to post-intervention difference ($p = 0.006$) after lowHH only. We recommend low altitude (1380 m) combined with sleeping in altitude tents (3000 m) as one effective alternative to traditional altitude training methods, which can improve Hb_{mass} .

Key words: Hypoxia; hemoglobin mass; live high: train low; athletic performance; peak oxygen uptake.

Introduction

For many athletes, it is common practice to live and train at venues of moderate altitude (i.e. 2000-3000 m) (Millet et al., 2010) for periods of time, in order to achieve continuous exposure to hypoxia with the intent of improving sea-level performance (Bonetti and Hopkins, 2009; Hahn et al., 2001; Wilber et al., 2007). This 'classical' mode of altitude training is often performed by living and training at moderate altitude for several weeks at a time (Millet et

al., 2010).

For Australian endurance athletes, Thredbo, New South Wales, Australia, is a venue often used for training camps. The 1380 m elevation at Thredbo is comparable to some other training camp venues used by athletes internationally (Millet et al., 2010); albeit that this elevation is in the 'low altitude' range of 500 – 2000 m as defined by Bartsch et al (2008). Performance improvements have been reported after use of this altitude training method (Wilber et al., 2007). However, it has been suggested that the low altitude (Bartsch et al., 2008; Levine and Stray-Gundersen, 1997) at such venues is insufficient to stimulate red blood cell production and increase hemoglobin mass (Hb_{mass}) (Levine and Stray-Gundersen, 1992; Rusko et al., 2004; Wilber, 2007), which is one of the key mechanisms associated with improvements in VO_{2max} (Schmidt and Prommer, 2010), and performance gains after altitude training (Bonetti and Hopkins, 2009). In an early study (Weil et al., 1968), it was reported that exposure to 1600 m is insufficient to increase red cell mass. More recently however, continuous exposure to 1800 m elevation (Garvican-Lewis et al., 2015) was shown to significantly increase haemoglobin mass, compared to a control condition. Collectively, these results suggest that the threshold for haematological changes after altitude training may be above 1600 m, and at or below 1800 m.

Live-high: train-low (LHTL) altitude training is an alternative to the classical method that has been widely investigated (Bonetti and Hopkins, 2009), whereby athletes continue to spend a set period of time during the day and night at moderate altitude, but perform training sessions at much lower altitude or near sea level. LHTL can be achieved naturally, a method known as hypobaric hypoxia (HH) (Millet et al., 2013) or by simulating elevated altitudes, referred to as normobaric hypoxia (NH) (Millet et al., 2013) using methods such as nitrogen chambers or hypoxic tents (Wilber, 2007), and has been shown to enhance performance in various exercise modalities, including running (Stray-Gundersen et al., 2001) and cycling (Hahn and Gore, 2001). LHTL has the advantage of preventing a compromise to training intensity, which can occur during continuous altitude exposure (Wilber, 2007). Furthermore, providing that the daily and total exposure to altitude is sufficient (Clark et al., 2009; Gore et al., 2013), LHTL also stimulates erythropoiesis result-

ing in gains in Hb_{mass} . Indeed, one study reported a 6% increase in haemoglobin mass after an 18-day period of LHTL where altitude was progressively increased from 2500 m to 3500 m. (Robach et al., 2006). Within our research group, we have demonstrated improvements in Hb_{mass} , as well as a ~4% improvement in treadmill performance, in elite-level race walkers following simulated LHTL training (Saunders et al., 2010).

Conducting LHTL at natural altitude venues is often impractical (Hahn and Gore, 2001) because the travel involved to training venues may interfere with athletes' training schedules (Wilber, 2007). An alternative is to combine methods of hypoxic training (Millet et al., 2010). Specifically, the use of normobaric altitude tents may increase the hypoxic dose sufficiently to elicit haematological and physiological effects. Neya et al. (2013), suggested that a more practical approach to conventional LHTL at natural altitude was to combine three weeks of living and training at 1300-1800 m, with 10 hours of nightly exposure to 3000 m simulated altitude. Therein, travel to low altitude training venues was eliminated, with altitude tents used to provide the additional hypoxic stimulus at night. However, such an approach has not been applied to the investigation of increases in Hb_{mass} and maximum oxygen consumption (VO_{2max}) in elite athletes, when comparing modified LHTL to both low altitude training, and a control group training near sea level. Other studies have used venues of similar topography and simulated altitude (Brugniaux et al., 2006; Tiollier et al., 2005; Povea et al., 2005; Cornolo et al., 2006; Robach et al., 2005; 2006), and effects of repeated exposure to low altitudes for several weeks at a time has also been investigated (Frese and Friedmann-Bette, 2010). However, within these studies, the optimised CO rebreathing method (Schmidt & Prommer, 2005) was not used to measure changes in haemoglobin mass; and hypoxic rooms, rather than tents were used to achieve the simulated altitude. Therefore, the purpose of this investigation was to assess changes in Hb_{mass} (g), VO_{2max} ($mL \cdot min^{-1} \cdot kg^{-1}$) and time to exhaustion (min) in elite athletes, using a combined low-altitude training and simulated altitude exposure protocol (combining 21 days at 1380 m with 9 hours per night of 3000-m simulated altitude), compared with a matched period of low altitude training at 1380 m, and with a control group.

Methods

Subjects

Eighteen elite-level race walkers (competitive nationally or internationally), volunteered to participate in the study (12 males and 6 females; body mass 62.9 ± 7.5 kg; VO_{2max} 63.2 ± 6.9 $mL \cdot min^{-1} \cdot kg^{-1}$; age 25 ± 4 years). A further 10 elite-level race-walkers from a previous study (Saunders et al., 2010) were used as a control group (CON) comprising 5 males and 5 females; body mass 62.5 ± 10.1 kg; VO_{2max} 60.8 ± 8.1 $mL \cdot min^{-1} \cdot kg^{-1}$; age 24 ± 5 years. Written consent was obtained from all participants, after the experimental procedures and potential risks were explained. Approval for the investigation was obtained from the Australian Institute of Sport (AIS)

Human Ethics Committee.

Experimental design

Participants were assigned to one of two independent experimental groups or the control group, and the groups were matched for performance ability, training history and training volume. Participants were not blinded to their experimental condition.

The training completed by participants was performed during an annual training camp of national and internationally competitive race walkers, and was consistent across the two groups, but was monitored and adjusted by the AIS race walking coach based on the requirements of individual athletes. Each week, participants completed 3-4 continuous light aerobic walking sessions (which included two hill sessions), 1-2 light aerobic runs or cross-training sessions, 2 interval-based sessions at or above race pace intensity, and two strength and conditioning sessions. The training described above was also consistent with that completed by the control group, which was also conducted over a 21-day period, as the data were collected during the same training phase in a previous year and supervised by the same coach.

Participants in the low altitude-training group (lowHH, $n = 10$) lived and trained at a training camp in Thredbo (New South Wales, Australia, 1380 m) for 21 consecutive days. In the combined low-altitude and simulated altitude group (lowHH+NHNight, $n = 8$), participants were also based at the training camp in Thredbo (1380 m) for the 21-day duration, but they spent 9 hours overnight at a simulated altitude of 3000 m using hypoxic tents (Colorado Altitude Training, Louisville, Colorado, United States of America), to decrease the percentage of oxygen in the air. The time each athlete entered and left their altitude tent was recorded each day, to ensure each athlete in this group experienced 9 hours of exposure. The fraction of inspired oxygen in the hypoxic tents was approximately 17.0%. Data from the lowHH and lowHH+NHnight groups were compared to data collected in a former study, from matched control race-walkers (CON, $n = 10$) who lived and trained in Canberra (Australian Capital Territory) near sea level (600 m) (Saunders et al., 2010).

All treadmill, VO_{2max} and performance testing was conducted at the AIS physiology laboratory (600 m) prior to and following completion of the 21-day intervention. To prevent iron-deficient anemia, every participant, across the three groups, ingested daily 105 mg elemental iron (Abbott Pharmaceuticals, Botany, NSW, Australia). The baseline ferritin (mean \pm SD) across the three groups was 72.0 ± 50.2 $ng \cdot L^{-1}$, and haemoglobin concentration was 14.4 ± 1.1 $g \cdot dL^{-1}$.

Methodology

A treadmill test was used to assess VO_{2max} , walking economy, velocity at VO_{2max} (vVO_{2max}) and lactate threshold on a custom-built motorized treadmill (Australian Institute of Sport). The test involved continuous walking for 4 min at 4-5 incrementally faster speeds ranging from 9-15 $km \cdot h^{-1}$ at 0% gradient with 1 min of standing recovery

between each speed. The starting speed was individualised based on each athlete's recent 20 km race performance time. Submaximal heart rate (HR, Polar Electro, Kempele, Finland) was taken as the average of values recorded during each of the 4-5 submaximal treadmill test stages. Five minutes after the final submaximal walking speed, an incremental test to exhaustion was performed, to determine $\text{VO}_{2\text{max}}$, as well as the time to exhaustion. The incremental test started at $8\text{--}11 \text{ km}\cdot\text{h}^{-1}$ (0% gradient) and increased by $0.5 \text{ km}\cdot\text{h}^{-1}$ every 30 s until 4 min was reached (equivalent to the final speed of the submaximal test), thereafter speed remained constant and the gradient increased by 0.5% every 30 s until volitional exhaustion. The number of submaximal stages completed, and the starting speed for both the submaximal stages and test to exhaustion was decided by the experimenter, and was based on the athlete's recent 20 km race time.

During the treadmill test, heart rate and expired ventilation samples were recorded continuously, with blood lactate (La) concentration (Lactate Pro, Arkray, Japan) measured at the completion of each of the 4-min submaximal race walking periods and one minute following the incremental test to exhaustion. Expired ventilation samples were collected by a custom built open-circuit indirect calorimetry system with associated in-house software for determination of oxygen uptake described in full previously (Saunders et al., 2004). Gas analyzers were calibrated before each test, and the treadmill calibrated at the start of each day of testing. Submaximal walking economy was indicated by mean oxygen uptake during the last minute of each of the submaximal speeds. The speed ($\text{km}\cdot\text{h}^{-1}$) at which 4 mM lactate concentration was reached via the speed-versus-lactate curve.

Total Hb_{mass} was measured pre and post intervention using the optimised 2 minute carbon monoxide (CO) rebreathing test adapted from Schmidt and Prommer (2005). Briefly, a CO dose of $1.2 \text{ mL}\cdot\text{kg}^{-1}$ body weight was administered and rebreathed for 2 min. Capillary fingertip blood samples were taken before the start of the test and at 7 min post administration of the CO dose. Blood samples were measured a minimum of five times for determination of %HbCO using an OSM3 hemoximeter (Radiometer, Copenhagen, Denmark). Hb_{mass} was calculated from the mean change in HbCO before and after rebreathing CO. The test was performed prior to the intervention period and within 1 week after the completion of the intervention period. The typical error for this method in the hands of the researcher who conducted these measures has recently been quantified as 1.4% (Garvican-Lewis et al., 2015).

Prior to and after the 21-day training intervention, 6mL of venous blood was obtained at rest from an ante-cubital forearm vein. Samples were analysed for ferritin using an immunoturbidimetric assay run on an Hitachi 911 Automatic Analyzer (Boehringer Mannheim, Germany), in order to confirm the initial iron stores of the participants.

Statistical analysis

Results were presented as the absolute and percentage change in each variable between the pre and post-intervention values. Absolute and percentage change

values were presented for Hb_{mass} , time to exhaustion, $\text{VO}_{2\text{max}}$, $v\text{VO}_{2\text{max}}$, maximal blood lactate concentration, maximal HR, submaximal VO_2 , submaximal HR, and the speed at which 4 mM lactate concentration was reached. Paired t-tests were used within conditions to analyse pre to post-intervention differences. After checking the data for normality (Shapiro-Wilk test), differences between groups for the pre-post changes were analysed using a one-way analysis of variance (ANOVA). Following each ANOVA, a Fisher's Least Significant Difference post-hoc test was performed, in order to examine difference between specific conditions. The aforementioned analyses were used for all variables except time to exhaustion, where independent samples t-tests were used. For all statistical tests, significance was set to $p < 0.05$. Testing was performed using the SPSS statistical package (IBM, New York, USA).

Results

Haemoglobin mass

There was a significant ($p = 0.02$) 3.7% increase in Hb_{mass} for the lowHH+NHnight group (within group change $2.6 \pm 1.8\%$, mean \pm SD) compared with the CON group (within group change $-0.9 \pm 4.9\%$). However, the change in Hb_{mass} for the lowHH group ($1.2 \pm 1.4\%$) was not significantly different compared with either the lowHH+NHnight ($p = 0.47$) or CON groups ($p = 0.13$).

$\text{VO}_{2\text{max}}$

There was a significant, $4.0 \pm 2.5\%$ ($p = 0.02$) increase in $\text{VO}_{2\text{max}}$ within the lowHH and a non-significant, $4.4 \pm 5.6\%$ improvement within the lowHH+NHnight group ($p = 0.08$). The change within the CON group was $1.3 \pm 3.7\%$. However, the change in $\text{VO}_{2\text{max}}$ when compared between groups was non-significant ($p = 0.23$).

Time to exhaustion

Time to exhaustion increased by $8.9 \pm 5.6\%$, ($p = 0.03$) within the lowHH+NHnight group, and by $7.7 \pm 7.8\%$ ($p = 0.01$) within the lowHH group; an increase that was not statistically different between these two groups ($p = 0.55$). Unfortunately, a dissimilar treadmill test protocol was used for the CON group, so we were unable to make a comparison for time to exhaustion between the CON data and the two experimental conditions.

Submaximal HR and VO_2

No significant differences for submaximal HR were observed between the three conditions ($p = 0.37$; Table 1). The average submaximal VO_2 in the CON group was significantly reduced compared with both lowHH+NHnight ($p = 0.01$) and lowHH ($p = 0.01$), with no significant difference in the change scores between the two experimental groups ($p = 0.83$).

Discussion

This study evaluated a combined low altitude training and simulated altitude exposure protocol, in comparison with an existing low altitude training protocol used by elite-level Australian athletes, as well as control data. Our key

Table 1. Post minus pre-intervention changes for each measure, for LowHH (low altitude training), LowHH+NHnight (combined low altitude training and simulated altitude exposure) and control (CON). Values are expressed as mean (\pm standard deviation).

Variable	LowHH (n = 10)	LowHH + NHnight (n = 8)	CON (n = 10)
Hbmass (g)	9.8 (10.7)	22.5 (17.6)	-10.2 (42.9)
VO _{2max} (mL·min·kg ⁻¹)	2.5 (2.6)	2.5 (3.1)	.61 (2.1)
Time to exhaustion (min)	.7 (.6)	.8 (.5)	NA
Lactate threshold (km·h ⁻¹)	.3 (.4)	.1 (.3)	.8 (1.1)
Submaximal VO ₂ (mL·min·kg ⁻¹)	-.2 (1.4)	-.4 (1.3)	-2.2 (1.5)
Maximal HR (bpm)	-3.8 (3.8)	-3.1 (2.0)	-3.0 (4.8)
Maximal La (mmol·L ⁻¹)	.1 (1.4)	1.1 (2.0)	-.4 (3.5)
vVO _{2max} (km·h ⁻¹)	.5 (.3)	.7 (.7)	.7 (4)
Submaximal HR (bpm)	-6.6 (3.8)	-9.20 (6.1)	-12.0 (12.4)

finding was that 21 days of 1380 m low altitude exposure combined with 9 h of simulated 3000 m exposure per day (lowHH+NHnight) was sufficient to elicit a significant ~3% improvement in hemoglobin mass when compared to the CON group. A secondary finding was that within both the low altitude protocol and the combined low altitude training and simulated altitude protocol, there were improvements in time to exhaustion compared with baseline measures for each of the experimental conditions, and significant improvements in VO_{2max} within the low altitude group, compared with baseline.

Haemoglobin mass

The most important benefits found with our combined protocol were those associated with changes in Hb_{mass}, as it has been concluded that small increases in Hb_{mass} elicit improvements in endurance performance (Levine and Stray-Gundersen, 1997). While performance was not directly measured in the current investigation, the ~3% increase in Hb_{mass} after the 21-day training intervention, compared with the baseline measure, was significantly greater than the slight decrease (-0.9 %) recorded for our control group. The amplitude of the improvement in Hb_{mass} observed is consistent with other studies from our laboratory that have incorporated simulated exposure of 3000 m, including a 3.3% improvement in trained male cyclists (Clark et al., 2009) and a 2.8% increase in highly trained runners (Robertson et al., 2010). The current findings are also consistent with the results of a 2013 meta-analysis investigating the relationship between improvements in haemoglobin mass and VO_{2max} after hypoxic exposure (Saunders et al., 2013). Saunders et al. (2013) reported that each 1% improvement in haemoglobin mass is expected to be associated with a 0.6-0.7% increase in VO_{2max}. Our finding that in the lowHH+NHnight group, compared with the CON group, there was a 3.7% improvement in haemoglobin mass, and a 3% improvement in VO_{2max}, is consistent with the correlation reported by Saunders et al.

Importantly, in the aforementioned studies, participants completed altitude exposure for 21 days (as in the current investigation), but for a longer daily duration (14 hours) at 3000 m. In contrast, however, the remainder of each day was spent in near sea level (600 m) as opposed to 15 h per day at 1380 m in the present study. It has been suggested that the threshold for hypoxia-induced erythropoietin (EPO) release is 2100-2500 m above sea level

(Ge et al., 2002), which may provide some explanation for our observation that in our low-altitude training group (at 1380 m) the increase in hemoglobin mass of 1.2% \pm 1.4% was non-significant and within the imprecision of the method. Although we did not measure EPO in the present study, the combination of simulated and natural altitude appears to have provided a sufficient hypoxic dose to stimulate erythropoiesis. Indeed, recent studies that have used different methods to increase hypoxic dose, including modified LHTL using a similar protocol (Neya et al., 2013) and repeated exposure to low altitude (Frese and Friedmann-Bette, 2010) have reported significant increases in EPO.

An important implication of our study is that we elucidated benefits associated with athletes' physiology and performance after 9 h per day simulated altitude at 3000 m. Consistently, it has been recommended that a minimum of 12 h daily exposure is required in order to achieve the benefits of hypoxic exposure at altitude (Millet et al., 2010; Rusko et al., 2004). Potentially, the combination of the continuous, 21-day exposure to the low altitude of 1380m, with the addition of daily, simulated altitude contributed to a cumulative altitude exposure that equated to an adequate dose of hypoxic exposure. If so, our study demonstrates a method of achieving the required hypoxic dose, which has been established as the most important variable when implementing altitude training (Mazzeo, 2008; Wilber et al., 2007). Therefore, our findings suggest an altitude training method that requires a reduced daily requirement for time spent in an altitude tent or chamber. Such a finding is of considerable importance to athletes and their coaches seeking to implement an altitude training strategy that would be feasible during an altitude training camp in preparation for major competitions, as competition and training schedules can often heavily influence altitude training protocols used (Garvican et al., 2012). The method used in this study can also provide a means for athletes to increase their altitude dose when completing training camps in countries in which the topography is less than 2000 m, via the use of altitude tents.

Time to exhaustion

We observed increases in time to exhaustion of ~9% and ~8% in the combined low-altitude training and simulated altitude group, and the low-altitude training group, respectively. While there was no statistically significant

difference between the two groups, the increase between pre and post-intervention measures within each group were statistically significant, suggesting the potential for a performance benefit when spending 21 days at ~1400m, with or without the addition of 3000 m simulated altitude each night. While time to exhaustion results are not proportional to time trial or race performance, a recent meta-analysis (Bonetti and Hopkins, 2009) suggested that multiplying time to exhaustion results by a factor of (1/15) can indicate likely time trial performance. Applying the formula to our experimental groups yields a 0.6% improvement in the lowHH+NHnight group, and a 0.5% improvement in the lowHH group. Improvements of 0.5% - 1.0% have been modelled to increase athletes' medal-winning chances in international competition (Hopkins and Hewson, 2001). It has been suggested performance enhancement after altitude training can be partially due to the 'training camp effect', (when improvements are observed when athletes live and train together for a period of time) (Saunders et al., 2010). This phenomenon may provide partial explanation for our observed effects after both low altitude and combined low altitude training and simulated altitude exposure.

The results of our investigation are similar to those of a recent study investigating the effects of combined classical and simulated altitude exposure. Neya et al. (2013) reported a 3.5% increase in Hb_{mass} after well-trained middle distance runners lived and trained for 21 days at 1380 m, with an additional 10 hours' daily exposure to 3000 m simulated altitude per day, in the experimental group. The authors also found an 8.6% improvement in VO_{2max} after combined classical and simulated altitude exposure compared with control data. In the current investigation however, we found no statistical difference in the increase in VO_{2max} between the three groups. We did however find a significant improvement within our lowHH group, when comparing our pre and post-intervention values. The improvements in VO_{2max} in our low altitude training group may be related to the effects of competitive athletes completing the study within a well-structured training camp (Bonetti and Hopkins, 2009).

Overall, the results of the current investigation and that by Neya et al. suggest that low altitude training, incorporating a relatively short (9-10 hours) daily exposure to 3000 m simulated altitude can elicit haematological and physiological benefits, in both well-trained and elite athletes.

Limitations

A limitation of this study was the lack of a control group completing training at normoxia, concurrent with that completed with the two experimental groups. The scenario is related to the difficulty of recruiting additional, elite athletes, and ensuring that training in a different location to the other groups, is consistently conducted. The Australian Institute of Sport coach prescribed and monitored training for the two experimental groups, who were based at Thredbo, and substantial logistical challenges would be presented if an additional group were simultaneously based in Canberra or a nearby location near sea level. Also associated with the allocation of our participants to

experimental groups was our inability to blind participants to their experimental condition, which has been suggested to influence results (Lundby et al., 2012). A further limitation was the lack of a true performance test that was representative of the performance capabilities of the athletes who completed the study (as opposed to time to exhaustion in the VO_{2max} test). While some indication of participants' performance capacity was provided by their time to exhaustion results, this measure does not provide an optimal indication of competition or race performance, as races are

completed over a set distance (Hopkins et al., 2001). In previous studies from our laboratory, we have been able to develop some understanding of participants' performance abilities by analyzing the performances of participants shortly after study completion. However, in the Australian 20 km championships, which were held several weeks after the completion of this study, high temperatures on the day of competition presented confounding environmental influences that make the effect of an altitude intervention on performance difficult to ascertain.

Conclusion

Our study demonstrates that the combination of low and moderate altitude exposure facilitates physiological and performance-related benefits. These findings indicate that, for elite athletes undertaking altitude training, our combined low altitude training plus simulated altitude method is an effective alternative to conventional camps at moderate altitude. While we do not suggest that combined low altitude training plus simulated altitude exposure should replace conventional altitude training, it is a method that may provide an alternative method that allows athletes to increase their hypoxic dose, within an existing training camp. Furthermore, the method we recommend is especially relevant in countries in which the topography is less than 2000 m. We recommend that low altitude (~1400 m) combined with sleeping in altitude tents (3000 m) is a time efficient method to improve Hb_{mass} , with the advantage of less compromised training intensity compared with traditional altitude methods typically conducted at higher altitudes of 2000-3000m.

Practical applications

In this study, we have investigated a novel approach to altitude training that can be implemented by elite race-walkers and other endurance athletes at low altitude venues in order to improve Hb_{mass} and time to exhaustion. The results of this study demonstrate that it is possible to attain benefits of altitude training, by travelling to relatively low altitude venues of ~1400 m and increases in Hb_{mass} , provided that a portable hypoxic tent is used to simulate higher altitudes (~3000 m). Furthermore, we have demonstrated that shorter, daily durations of altitude exposure than previously recommended, in combination with a continuous exposure to ~1400m, can elicit performance benefits. Overall, the altitude training protocol we have developed is conducive to athletes maintaining their existing training camp protocols, with minor adjustments that should not interfere with training or competition schedules.

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Key points

- In some countries, it may not be possible to perform classical altitude training effectively, due to the low elevation at altitude training venues. An additional hypoxic stimulus can be provided by simulating higher altitudes overnight, using altitude tents.
- Three weeks of combined (living and training at 1380 m) and simulated altitude exposure (at 3000 m) can improve haemoglobin mass by over 3% in comparison to control values, and can also improve time to exhaustion by ~9% in comparison to baseline.
- We recommend that, in the context of an altitude training camp at low altitudes (~1400 m) the addition of a relatively short exposure to simulated altitudes of 3000 m can elicit physiological and performance benefits, without compromise to training intensity or competition preparation. However, the benefits will not be greater than conducting a traditional altitude training camp at low altitudes

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