Does altitude training benefit the sea-level performances of athletes?

BRODIE D. GARDNER

University of the Sunshine Coast, Sippy Downs, Australia

Abstract

GARDNER, B.D. Does altitude training benefit the sea-level performance of athletes? **Purpose**: The review was conducted to provide an insight into the possible benefits altitude training has on sea-level performance and possible ways that altitude training programs can be modified to achieve greatest improvements for particular individual sports utilising either the aerobic or anaerobic energy systems. A review of possible methods to detect responders and non-responders was also included. **Methods:** Limited to articles in English and those located in the University of the Sunshine Coast, Australia library database or available free online, databases "PubMed", "Web of Science" and "Google Scholar" were searched (1992 through 2009) using the search terms: "altitude training", "sea-level performance", "hypoxia" and "athletes". Citations were omitted if they excluded control groups. **Results**: Physiological adaptations were found in most subjects following return to normoxia, however, these adaptations did not always equate into performance benefits. This included elevated erythropoietin levels without corresponding increases in reticulocyte formation. Such benefits as increases in VO_2max (7%), red cell mass (9%), Hbconc., maximal power output, mean power output in 4min, improved running and decreased time-trial duration were reported in subjects at sea-level following altitude sojourns. The greatest benefit on the aerobic energy at sea level was in subjects who lived at altitude (>20h.day^{-1} at 2500m) and trained in normoxia for four weeks. The greatest increase in the anaerobic system was in subjects who spent 2h.day^{-1} exercising at 60-70% heart rate reserve for 10days. **Conclusion**: Further research needs to be done before it can be scientifically proven that altitude training enhances both aerobic and anaerobic sea-level performances. It's also recommended that future studies not restrict the training program to that on a treadmill or cycle ergometer. **Key Words:** ALTITUDE, ACCLIMATISATION, HYPOXIA, NORMOXIA, SPORTS, MAXIMAL OXYGEN UPTAKE

Introduction

The use of altitude acclimatisation as a training stimulus was originally based on the information that highlanders (people born and living at high altitudes >2000m) have increased red blood cell (RBC) mass when compared to those born or living at sea-level (lowlanders) (3,10,13,25). The reduced partial pressure of oxygen significantly decreases at altitudes >2000m, stimulating increased erythropoietin (EPO) release due to tissue hypoxia (3,6). Increased serumEPO (sEPO), either from altitude acclimatisation, pharmacological interventions or blood reinfusion has been found to increase oxygen transport capacity that enhances the aerobic energy system (3,8,17,21). This increase will help lead to improved maximal oxygen uptake (VO_{2max}), and therefore improve athletic performance in sports relying on the aerobic energy system such as 10-000m – marathon run or road cycling (1). However, research into increased reticulocyte formation following hypoxic exposure with increased EPO levels has been equivocal at best, and no such evidence has been found to confirm altitude training does increase sea-level performance (4,23). Poorer still is support that nitrogen houses or tents that simulate altitude hypoxia increase sea-level performance (3). However, many athletes still train at altitude and use altitude training techniques in the hope of gaining small improvements to win races.

The purpose of this study was to review current literature into whether training at altitude, or using altitude tents does actually improve sea-level performance in athletes. It also includes a review on methods used to try and determine whether athletes will, or won't respond to altitude acclimatisation. Finally the review summarises the findings on the best way, if there is, to use altitude training.

Methods

Several electronic databases: PubMed, Web of Science and Google Scholar were searched for citations published 1992 through 2009 using search terms: "altitude training", "sea-level performance", "hypoxia" and "athletes". Additional citations were retrieved from the reference sections of citations identified from the database searches. Citations used in the review were limited to those available at The University of the Sunshine Coast, Australia library database, or were able to be viewed free of charge. Only citations retrievable in English were used in the review.

Citations excluding control groups were omitted from the study to ensure any adaptations reported were because of altitude training stimulus, and not physiological adaptations to the training load.

Results

The majority (92%) of literature revised found altitude training elicited some type of physiological adaptation in athletes that wasn't present in control subjects who only trained or lived in normoxia (Table 1). These adaptations though weren't consistent across type and method of altitude exposure, and didn't always enhance performance or oxygen carrying capacity as altitude training is believed to.

Many of the increases in aerobic performance associated with altitude training have been derived from studies that exposed athletes to either real or simulated hypoxia during rest or sleep (>8hours hypoxic exposure per day), and allowed them to train at sea-level or lower altitudes (12,13,23). This method of live high-train low (LHTL) allows athletes to maintain sea-level training intensities without complications associated with high intensity training at altitude (Table 2)(13).

The LHTL method was used in the most extensive altitude training study reviewed (12) that included 39 trained subjects (Table 1). The trial included a two week familiarisation lead in phase and four weeks of supervised training at sea-level before subjects were separated into a control group (normoxic condition; NC), or altitude training groups (hypoxic condition; HC). For four weeks, athletes under HC spent >20hours per day at an altitude of 2500m and trained at a lower altitude, while athletes under NC completed similar training whilst living and training at sea-level (12,13). The authors reported that altitude training increased sea-level run times and VO_{2max} in direct proportion to an increase in red cell mass volume in athletes under HC, and found no improvements in performance or oxygen carrying capacity in NC group who underwent similar training (12). This LHTL protocol was repeated using 22 elite athletes (mean VO_{2max} >70mL. $kg^{-1}.min^{-1}$) and found elite athletes had similar physiological adaptations and improvements when returning to sea-level as non-elite athletes (23). However, due to the exclusion of controls, this study should be interpreted with caution.

Several other studies (4,7,18,20)(Table 1) that used simulated altitude and different LHTL protocols reported hypoxic exposure elicited similar or additional benefits in athletes on return to sea-level.

Additional benefits reported include: increased muscle buffering capacity (βm)(7), reduced submaximal VO_2 indicating improved running efficiency and economy (7,20), improved mean power output in 4 minutes ($MMPO_{4min}$) and maximal accumulated oxygen deficit (MAOD) (18). However, none of these increases were reported to be due to enhanced VO_{2max} or oxygen carrying capacity as previously found (12).

Separate approaches using different LHTL protocols found no indications that LHTL elicits a positive training effect on sea-level performances (2,19,24). One study that used simulated altitude exposure of 4000-5000m 3h/day, 5days/wk for four weeks found no difference in sea-level values of athletes following altitude acclimatisation or those who completed similar training at sea-level (19,24)(Table 1). The study reported that this LHTL protocol has no benefit in enhancing submaximal HR, [La-], VE or velocity at VO_{2max}. It was concluded that this method of LHTL is not beneficial in improving sea-level submaximal economy or the oxygen transport system and would not enhance performance. A similar study found that although serum erythropoietin (sEPO) levels were significantly elevated following altitude training, they were not elevated enough to cause increases in reticulocyte production and would therefore not enhance athletic performance at sea-level (1,2)(Table 1).

An alternative altitude training regime to LHTL is the "live-low train-high" (LLTH) intermittent hypoxic training (IHT) method where athletes are only exposed to hypoxia during exercise. In LLTH, hypobaric chambers are used during exercise to simulate altitude with athletes residing and recovering in normoxia. The protocol aims at increasing training stimulus whilst avoiding any of the negative effects of prolonged altitude exposure (Table 2).

Time subjected to hypoxic conditions in LLTH varied from 30min/day to 2hr/day and were on average 10h/day less than in LHTL protocols (Table 1)(9,14).

The most significant increases found from LLTH on sea-level performance was from a cross-over study where athletes exercised between 60-70% of heart rate reserve for 2h/day for 10 consecutive days in a hypobaric chamber equal to 2500m (9,14). The authors reported that VO_{2max}, maximal power output (W_{max}) and mean power output were elevated 9days post-trial in only the HC group. W_{max} was also elevated 2days post-trial in both the NC and HC groups, however, 9days post treatment the NC group W_{max} had returned to pre-trial levels whilst the HC group W_{max} remained elevated. It was concluded that this protocol increased both the aerobic and anaerobic energy-supply systems (9,14). These findings were in disagreement by a study that trained athletes exercised for $2h.day^{-1}$ at lactate threshold for $3days.wk^{-1}$ for 3weeks at simulated altitude ~2750m (11). No changes in W_{max}, arterial O_2 content, VO_2 at lactate threshold (LT) or VO_{2max} were found in either the HC group or NC group, suggesting that LLTH doesn't benefit sea-level performance.

Three studies using shorter duration of $exercise.day^{-1}$ found conflicting evidence of whether LLTH enhances the aerobic and/or anaerobic energy-supply systems (5,6,16). The first study used $30min.day^{-1}$ continuous exercise above lactate formation for 6wks (J14) at hypoxia ~3850m (6). The only increase found in the HC group when compared to the NC group was increased muscle volume of the knee-extensors and increased muscle oxidative capacity. A second study on untrained athletes used three 10x1min bouts at 80% VO_{2max} separated by 1min recovery bouts at 50% VO_{2max}, $3days.wk^{-1}$ found no difference between the HC and NC groups. The evidence of whether LLTH is beneficial in normoxia remains controversial.

Table 2. Complications associated with altitude exposure.

Risk Factors	Ref
↓Cardiac Output	3
↓Blood flow to skeletal muscle	3
↑Pulmonary artery pressure	20
↓Immune function	3
↑Tissue damage mediated by oxidative stress	12
↑Risk of dyspnea, fatigue, and exercise intolerance	27
↓Intensity able to maintain in training	12

Discussion

This review of available evidence indicates that altitude training may be beneficial at increasing the aerobic and anaerobic energy systems at sea-level, but at best remains equivocal. The majority of original literature used in this study did indicate some benefit associated from hypoxic sojourns, such as increased performance in both laboratory and field testing due to increases in VO_{2max}, W_{max} and oxygen carrying capacity, but wasn't sufficiently supported by other similar studies. Other reviews greater than this one have also failed to find substantial evidence on the benefits of altitude training on sea-level performance and conclude that further research in the area needs to be done (3,8,21,25).

One reason literature on effects of altitude training on sea-level performance remains unequivocal after numerous reviews is due to altitude training eliciting separate responses on individuals. Subjects can be separated into two groups: responders who benefit from HC, and non-responders who show no effect from HC. Currently there remains no method of screening for whether a person will respond to altitude acclimatisation or not (4,10). However, two articles found trends between those who did and didn't respond to altitude training (4,10). It was found that responders increased EPO to a greater extent over the first 30h of acute hypoxic than non-responders. The exact cause of this greater initial elevation and maintenance of an elevated EPO level over 14days of hypoxic exposure is unknown and needs to be further studied (4). An alternative method to detect whether an athlete will respond has been to screen them for the I allele of the ACE gene. Athletes who responded typically had the I allele, which possibly exerts a response on the cardiovascular system (10).

EPO is an important hormone in the body which is responsible for the maintenance of RBC mass by stimulating reticulocyte formation when released (2). Hypoxic conditions are known to enhance EPO release, however, in the literature it was found that increased EPO release wasn't always correlated with similar increases in reticulocyte formation (2). One possible reason for this may be due to normobaric hypoxia being used in simulated altitude exposure doesn't elicit reticulyte formation to the same extent as hypobaric hypoxia (2,13). Studies that did find increased reticulocyte production had increases in EPO concentrations of over 70% (14).

The review was limited by the number of citations retrievable.

In agreement with previous reviews, whether altitude training enhances sea-level performance remains equivocal. Increases in VO2max, run times, as well as anaerobic measurements were all found following altitude sojourns, but have not always been able to be repeated. If one is to still use altitude training to elicit aerobic sea-level training effects it is recommended that they use the LHTL protocol and maintain at altitude for maximum periods of time per day. If adaptations are b

Although studies using individualised training programs designed by the athlete or coach, not the scientist might not be as statistically strong, more studies need to conducted this way. This is due to many of the laboratory training programs do not replicate training loads often undertaken by athletes who do train at altitude on their own.

References

1. Ashenden MJ, Gore CJ, Dobson GP, Hahn AG. "Live high, train low" does not change the total haemoglobin mass of male endurance athletes sleeping at a simulated altitude of 3000 m for 23 nights. *Eur J Appl Physiol*. 1999;80:479-84.
2. Ashenden MJ, Gore CJ, Dobson GP, et al. Simulated moderate altitude elevates serum erythropoietin but does not increase reticulocyte production in well-trained runners. *Eur J Appl Physiol*. 2000;81:428-35.
3. Bailey DM, Davies B. Physiological implications of altitude training for endurance performance at sea level: a review. *Br J Sports Med*. 1997;31:183-90.
4. Chapman RF, Stray-Gundersen J, Levine BD. Individual variation in response to altitude training. *J Appl Physiol*. 1998;85:1448-56.
5. Dufour SP, Ponsot E, Zoll J, et al. Exercise training in normobaric hypoxia in endurance runners. I. Improvement in aerobic performance capacity. *J Appl Physiol*. 2006;100:1238-48.
6. Geiser J, Vogt M, Billeter R, Zuleger C, Belforti F, Hoppeler H. Training high - living low: changes of aerobic performance and muscle structure with training at simulated altitude. *Int J Sports Med*. 2001;22:579-85.
7. Gore CJ, Hahn AG, Aughey J, et al. Live high:train low increases muscle buffer capacity and submaximal cycling efficiency. *Acta Physiol Scand*. 2001;173:275-86.
8. Hahn AG, Gore CJ. The effect of altitude on cycling performance - A challenge to traditional concepts. *Sports Med*. 2001;31(7):533-57.
9. Hendriksen IJM, Meeuwsen T. The effect of intermittent training in hypobaric hypoxia on sea-level exercise: a cross-over study in humans. *Eur J Appl Physiol*. 2003;88:396–403.
10. Hinckson EA, Hopkins WG. Changes in running endurance performance following intermittent altitude exposure simulated with tents. *Eur J Sport Sci*. 2005;5(1):15-24.
11. Kime R, Karlsen T, Kioka S, et al. Discrepancy between cardiorespiratory system and skeletal muscle in elite cyclists after hypoxic training. *Dyn Med*. 2003;2:5-14.
12. Levine BD, Stray-Gundersen J. "Living high-training low": effect of moderate-altitude acclimatization with low-altitude training on performance. *J Appl Phys*. 1997;83:102-12.
13. Levine BD. Intermittent Hypoxic Training: Fact and Fancy. H*igh Alt Med Biol*. 2002;3(2):177-93.
14. Meeuwsen T, Hendriksen IJM, Holewijn M. Training-induced increases in sea-level performance are enhanced by acute intermittent hypobaric hypoxia. *Eur J Appl Physiol*. 2001;84(4):283-90.
15. McArdle WD, Katch FI, Katch VL. Exercise Physiology: Energy, Nutrition and Human Performance. 6th ed. Baltimore (MD): Lippincott Williams and Wilkins; 2007. p. 617-636.
16. Morton JP, Cable NT. The effects of intermittent hypoxic training on aerobic and anaerobic performance. *Ergonomics*. 2005;48(11):1535-46.
17. Neya M, Enoki T, Kumai Y, Sugoh T, Kawahara T. The effects of nightly normobaric hypoxia and high intensity training under intermittent normobaric hypoxia on running economy and haemoglobin mass. *J Appl Physiol*. 2007;103:824-34.
18. Roberts AD, Clark SA, Townsend NE, Anderson ME, Gore CJ, Hahn AG. Changes in performance, maximal oxygen uptake and maximal accumulated oxygen deficit after 5, 10 and 15 days of live high:train low altitude exposure. *Eur J Appl Physiol*. 2003;88:390-5.

19. Rodriguez FA, Truijens MJ, Townsend NE, Stray-Gunderson J, Gore CJ, Levine BD. Performance of runners and swimmers after four weeks of intermittent hypobaric hypoxic exposure plus sea level training. *J Appl Physiol*. 2007;103:1523-35.
20. Rubin LJ. Endothelin-1 and the pulmonary vascular response to altitude: A new therapeutic target? *Circulation*. 2009;119:1703-10.
21. Rusko HK, Tikkanen HO, Peltonen JE. Altitude and endurance training. *J Sport Sci*. 2004;22:928-45.
22. Saunders PU, Telford RD, Pyne DB, et al. Improved running economy in elite runners after 20days of simulated moderate-altitude exposure. *J Appl Physiol*. 2004;96:931-7.
23. Stray-Gundersen J, Chapman RF, Levine BD. "Living high-training low" altitude training improves sea level performance in male and female elite runners. *J Appl Physiol*. 2001;91:1113-20.
24. Truijens MJ, Rodriguez FA, Townsend NE, Stray-Gunderson J, Gore CJ, Levine BD. The effect of intermittent hypobaric hypoxic exposure and sea level training on submaximal economy in well-trained swimmers and runners. *J Appl Physiol*. 2008;104:328-37.
25. Wilber RL. Current Trends in Altitude Training. *Sports Med*. 2001;31(4):249-65.