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Athletic altitude training protocols and their application in preparation for mountainous operations

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Abstract

In recent years, small scale counter-insurgency and expeditionary operations have frequently taken place in mountainous, high-altitude areas. Preparation of soldiers for these environments has typically focussed on extended stays at altitude to ensure physiological acclimatisation. However, with the likelihood that future UK deployments may be unpredictable and thus with little time for preparation, is there a means by which the same acclimatisation may be achieved? The field of athletics has been researching such adaptations since the rise of the elite North African long-distance runners in the 1960s. These athletes all lived high above sea level and had become accustomed to performing in the relatively hypoxic environment found at high altitudes. The research has focussed on eliciting physiological acclimatisation in as short a time as possible, while maintaining the ability to train at the correct intensity. In the following review of altitude training we highlight areas for future investigation and assess whether protocols developed for athletes can be applied to military personnel.

Introduction

In 2002, 23 of the 27 ongoing armed conflicts were occurring in mountainous environments (1). More recently, Operation HERRICK in Afghanistan has seen ISAF troops working at altitudes in excess of 2,000m (2). The difficulties associated with moving troops and supplies in these environments, together with the tactical benefits of occupying an elevated position, have been shown throughout history (3). As UK Armed Forces further transition to a posture prepared for smaller scale, expeditionary and counter-insurgency operations, high-altitude mountainous areas of operations may be encountered more frequently. As with all aspects of warfare, preparation for battle is essential, and encompasses physiological preparation for the environment to be encountered.

Training for high altitude has become of increasing interest to various military forces. The Indian and Pakistani armies, who have been fighting in the mountains of Kashmir since the 1960s, continue to use 6-7 week altitude acclimatisation periods before troops deploy (4). Such significant training burden would benefit from more rapid adaptation that does not require extended periods at high altitude. The US Army is currently exploring the use of Intermittent Hypoxic Training (IHT) to rapidly prepare troops for operations in hypoxic environments after their experiences during the early battles in the Afghan mountains (5).

Sports medicine has been challenged by this problem since the 1968 Olympic Games, held in Mexico City at an altitude of 2,280m above sea level (6). The performance of several endurance athletes was impaired due to increased physiological demands of competing at altitude. However, during these games many African runners, born and raised high above sea level, emerged to dominate long-distance running (7). This paradigm stimulated research into the benefits of altitude acclimatisation for elite endurance athletes. Currently, altitude training camps are routine, but is there a means by which we can employ similar techniques to improve the preparation of troops for operations?

Physiological effects of altitude

Altitude can be classified as high altitude (1,500-3,500m), very high altitude (3,500-5,500m) and extremely high altitude (>5,500m) (8).

Figure 1 demonstrates that increasing altitude causes a constant decline in the atmospheric density resulting in an exponential decline in the partial pressure of oxygen (PO2). For example, at sea level there is an average air pressure of 760 mmHg, while at the summit of Mount Everest (8,848m) this decreases to 253 mmHg. From Dalton’s Law, since O2 constitutes approximately 21% of atmospheric pressure, the partial pressure of O2 at sea level is 160 mmHg, but less than 50 mmHg at the summit of Mount Everest. Reduced
atmospheric O₂ availability results in a decrease in the inspired PO₂ and disturbance in the pressure gradients required for oxygenation of tissues.

Figure 1. Changes in PO₂ with altitude for global locations

As the PO₂ of inhaled air decreases, the driving pressure of diffusion of O₂ across the alveolar-capillary boundary falls, causing a reduction in the arterial partial pressure of oxygen (PaO₂) and O₂ saturation (SaO₂). The effect of altitude on the oxyhaemoglobin dissociation curve is illustrated in Figure 2. The subsequent decline in the PO₂ of the blood entering the tissue’s capillaries leads to an overall decrease in tissue oxygenation (DO₂). A decrease in DO₂ to muscle during athletic training or competition will impair performance (9).

In the short term, at high altitudes, a decrease in tissue oxygenation may be compensated by increasing heart rate. However, prolonged exposure prompts a physiological response (acclimatisation) to enable survival (7).

Additional mechanisms related to altitude acclimatisation include muscular mitochondrial efficiency, which may also improve aerobic performance (12).

Altitude acclimatisation

Haemoglobin (Hb) is the iron-containing O₂-transporting metalloprotein in erythrocytes. It is composed of four polypeptide chains (two α and two β) each attached to a non-protein haem group. A molecule of O₂ may bind to each of the four haem binding sites of an Hb molecule.

Increasing the Hb concentration of the blood increases O₂-carrying capacity, which is the adaptation sought by athletes from training at altitude. This occurs by increasing production of the hormone erythropoietin (Epo) by the kidneys, which may occur as soon as one hour after exposure to hypoxic stimulus. However, maximum circulating concentration is reached ~48 hours after exposure (10). Epo has a number of functions, but the most relevant is the stimulation of the red bone marrow to synthesise and release more erythrocytes (Figure 3) (7). Increased erythropoiesis raises the haematocrit, the red cell volume (RCV), the red cell mass and the Hb mass. VO₂ Max is a reflection of aerobic fitness and is defined as the volume of O₂ consumed while exercising at maximum capacity, expressed as ml/kg/min. The overall effect of increased O₂-carrying capacity of the blood results in increased tissue oxygenation and elevated VO₂ Max for the acclimatised individual (11).

Other medical factors

There are a number of other medical factors of relevance when training at altitude. Acute mountain sickness (AMS) presents with headache, fatigue, nausea, loss of appetite, weakness and sleep deprivation, and typically occurs at altitudes of 2,400m, although there are no known predictors of risk (13). While not life-threatening in itself, for professional athletes the symptoms of AMS may cause problems with training and should be avoided.
Life-threatening conditions such as high altitude pulmonary oedema (HAPE) and high altitude cerebral oedema (HACE) may develop in susceptible individuals. Unfortunately, it is currently not always possible to identify those at risk or the speed of ascent that is dangerous, which is relevant if ascent is too rapid for a given individual or the altitude is above 2,500m (13). To avoid these conditions the maximum altitude used for training purposes rarely exceeds 3,000m. Interestingly, attenuation of immune responses has been reported, making those training at altitude more susceptible to developing infections, and increasing their recovery time from injury (14).

These factors must be considered in relation to the amount of time athletes spend at altitude, and therefore training programmes must be specially tailored to best take advantage of the physiological effects of altitude camps, without detriment to their training.

Altitude training protocols
Several different training protocols emerged following the introduction of high altitude training among athletes familiar with training at sea level. Over time, research has identified those that are most effective, and numerous protocols have emerged (15). Whilst many studies have examined these methods, no double-blind, placebo-controlled trials have been conducted. For this reason, we will attempt to highlight the advantages and disadvantages associated with each protocol as evidence of current best practice.

Live High, Train High (LHTH)
LHTH was the original high altitude training adopted by many athletes after the 1968 Olympics. It was the simplest of all the training protocols and involved athletes moving to both live and train at altitudes, usually in excess of 2,000m.

Early research using a six-week build up and then four-week altitude phase showed improvement in both 3,000m running performance and participants’ VO2 Max (16). Other studies showed an improvement in two-mile running time only (14). However, Vallier et al found no improvement in erythropoiesis or VO2 Max in tri-athletes after spending three weeks at 4,000m (17). A decrease in running velocity was noted by Bailey et al, who also showed a 50% increase in gastrointestinal infections for the altitude group after returning to sea level (14).

A meta-analysis of LHTH studies concluded that using an enhanced protocol (optimal height and duration) results in a positive performance outcome for the LHTH method for both elite and sub-elite athletes (18). Currently, LHTH is used predominantly by athletes living at altitude due to geographical origin, such as those from Kenya or Ethiopia.

This protocol is the basis for most mountaineering expeditions, which involve long base camp stays to ensure adaptation. As mentioned earlier, this would not be suitable for units tasked with rapid deployment, due to the time required for extended stays at altitude. For this reason it is unsuitable for operational purposes.

Live Low, Train High (LLTH)
The LLTH protocol emerged as more athletes embraced high-altitude training, seeking to take advantage of the benefits of higher altitude whilst still living in lower-lying areas. While there have been few studies assessing this protocol, it has been established that it is ineffective in conferring the benefits of altitude sought by athletes. Truijens et al challenged a cohort of high-level swimmers to a five-week training programme involving sessions in a hypoxic flume to mimic either an altitude of 2,500m or a normoxic control (19). The conditions failed to demonstrate any difference in VO2 Max or performance between the hypoxic training and the control groups. The lack of ongoing research into this training protocol means it will be discounted from future training programmes, particularly those looking at rapidly acclimatising troops for operations.

Intermittent Hypoxic Training (IHT)
As previously mentioned, peak levels of circulating Epo occur approximately 48hrs post-exposure, with initial increases in Epo demonstrable as early as one hour. Much effort has focussed on taking advantage of such a rapid response with Intermittent Hypoxic Training (IHT). IHT consists of brief exposure to a severe artificial (hypobaric chamber or hypoxic tent) or natural hypoxic environment to stimulate Epo production. IHT protocols involve periods as short as 30 seconds but may last up to 90 minutes, conducted during exercise or at rest.

This protocol has been the subject of intense research over the last few years. This may be due to the increased marketing of these training methods to sub-elite and amateur athletes in gymnasiums and sports clubs (20).

Dufour et al showed a 5% VO2 Max increase after a twice-weekly hypoxic exposure of between 24–40 minutes: however, there was no corresponding haematological change to support these findings (21). Gore et al also showed no change in RCV or Hb mass in their four-week study, but did note an increase in participant’s Epo levels after exposures lasting three hours at an altitude equivalent to 4,000-5,500m (12).

Julian et al exposed 14 national level runners to alternating five-minute periods of hypoxia with normal O2 levels for 70 minutes (22). This was repeated once daily over five days per week for a total of five weeks but was not able to demonstrate a change in VO2 Max, Epo or 3,000m running performance. Explanations for these results have centred on exposure times, which are too short, as 12-18 hours per day are thought necessary to elicit a response. Though
there is very little evidence to support any performance enhancement or physiological change from this type of training, the potential benefits suggest that studies will continue. If a protocol is developed which can harness this effect reliably it would be an ideal training tool for preparing troops rapidly for operations at high altitude.

**Live High, Train Low (LHTL)**

LHTL has now established itself as the preferred high altitude training protocol. Athletes live at high altitude (physically or artificially) for the majority of the day, while training at a lower altitude. It is believed to meet the optimal balance between the advantages of Epo-stimulating hypoxic exposure and the ability to train at full capacity at low altitudes.

Levine and Stray-Gundersen compared LHTL with LHTH and a Live Low Train Low (LHTL) control group (23). The test subjects spent a two-week phase establishing a base level before being randomly assigned to one of three groups for the four-week study. The results showed a VO2 Max increase for both the LITH and LHTL groups, with no change in the control group who remained at 150m throughout. However, only the LHTL group showed significant improvement in performance (assessed by a 5,000m run). Bruginaux et al also observed an increase in VO2 Max of −5% although no significant increase in RCV or Epo levels (24). This research established the recommendations which have subsequently been used in other studies for acclimatisation to avoid AMS and attenuation of immune responses. Exposure should be for over 12 hours a day for longer than 18 days with an altitude not exceeding 3,000m.

**Hypoxic tents and houses**

In order to minimise disruption to sea-level training, other means of exploiting the benefits of high altitude, low oxygen (hypoxic) training, have been developed. These include the design of hypoxic houses and tents which enable athletes to simulate living in hypoxic environments while remaining in their chosen training location. The method of achieving hypoxia in these protocols is either by use of a hypobaric hypoxic chamber or a normobaric hypoxic tent. The hypoxic tents achieve a lower PO2 by replacing the O2 with nitrogen that reduces the percentage of O2 from approximately 21% to as low as 10%.

The number of studies assessing these protocols is increasing but results to date are controversial. A meta-analysis by Hahn et al of six studies (2,650-3,000m for 11-23 nights) showed an overall increase in VO2 Max of 1% (25). Such a lack of improvement was also shown by Neya et al who observed no improvement in VO2 Max in their elite runners after spending 29 nights at 3,000m (26). Limitations with both of these studies have been noted and neither conformed to the protocols proposed by Bruginaux et al, which may have caused the poor responses observed (24).

The evidence for altitude training as a tool for performance improvement is not conclusive: however, the widespread use of LHTL protocols and continued support in the community will likely ensure its continued practice (27). It would seem that a LHTL protocol using hypoxic tents would be the best means of preparing troops, as it would cause the least disturbance to the training programme of a unit preparing to deploy. The benefits appear to exceed the potential difficulties, and a large-scale controlled study is required for future research.

**Conclusions**

Although research is still in progress, we conclude that a physiological adaption benefit may be gained through acclimatisation using some of the aforementioned protocols, and in particular the Live High, Train Low approach. The optimal mechanism for achieving this benefit among troops during pre-deployment training is yet to be determined, and this will likely continue to be a research area of great interest to the military community, warranting further investigation.

**References**


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