WHAT EFFECT DOES ALTITUDE TRAINING HAVE ON ATHLETIC PERFORMANCE?

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ABSTRACT

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Aim

To determine whether altitude training, and living/sleeping at altitude has any beneficial effect on physical performance in athletic sports. I also aim to identify the positive and negative consequences of living/training at altitude, and suggest possible methods of maximizing performance.

Method

I have considered the evidence in the literature about living and/or training at altitude. A qualitative research study was based solely on this literature review. Major studies conducted in this area, such as that by Stray-Gundersen, 2001, were used as the basis for my research. These studies were examined to try and culminate the information in order to provide athletes with an holistic view of the benefits of living/training at altitude.

Discussion/Conclusions

To improve sea-level performance, only the live high, train low model has been proven to enhance performance in elite athletes. A 1-3% improvement in sea level performance can be expected by using this method. Athletes need to live at an altitude of 2-3000m, and return to an altitude of less than 1250m to train, for this strategy to work effectively.
Studies are inconsistent in regards to changes in blood chemistry and v02 max from altitude. Training at altitude is unlikely to improve performance at sea level, however, acclimatization to altitude will improve performance at altitude. Future studies need to include a larger sample size, a control group performing the same training program, and an altitude high enough to produce physiological gains.

Introduction

The concept of living and/or training at altitude to improve athletic performance has a number of implications for athletes. A great deal of research has been performed in this area, to examine whether such practices are worthwhile or not. In an era where winners are decided by the smallest of margins, altitude training may be an effective method of legal performance enhancement. The writer of this study considers the literature on the concept of altitude training, to arrive at reasoned conclusions as to how it can be most effectively used by athletes to enhance performance. The study is divided into the following sections:

- Changes to the Environment at Altitude
- Physiology of Altitude Exposure
- Negative Consequences of Altitude Exposure
- Altitude and the Athlete
- Erythropoietin (EPO) Injection and Blood Doping: A Comparison to Altitude Exposure
- What Altitude and Duration is Necessary for Optimal Results?
- Common Methods of Altitude Training (Live High/Train High, Live High/Train Low)
- Alternatives to Traditional Methods
- Discussion/Conclusions
- References

Literature Review

Changes to the Environment at Altitude

At sea level, the fractional percentage of oxygen in the air is 20.93%. With altitude, the air temperature, barometric pressure, and the oxygen content of the air (partial pressure of oxygen – Po2), all decrease. At an altitude of 18000 to 19000 feet (ft), the barometric pressure is about 350mm Hg, which is approximately half that of sea level. At an altitude of 65000ft, the barometric pressure falls below the pressure of water vapour, which causes tissue fluids to 'boil' or 'vaporize'. When an individual who normally lives at sea level, spends a period of time at high altitude, a number of compensatory responses develop – a process called acclimatization. With acclimatization, an individual is able to reach high altitudes without the use of supplementary oxygen. However, if this individual is suddenly exposed to such high altitudes, a loss of consciousness will occur within minutes. These changes have a number of implications for athletes (Jardins, 1998).

Physiology of Altitude Exposure

Red Blood Cells (RBC)

RBC's, or erythrocytes, are the cells that carry oxygen around the body. Altitude exposure increases red blood cells (Cedaro, 2002). Altitude Exposure leads to a condition called polycythemia. When an individual is exposed to a low concentration of oxygen for a long period of time, the hormone erythropoietin (EPO) stimulates the bone marrow to increase Red blood cell (RBC) production. The increased haemoglobin available in polycythemia, is an adaptive mechanism that increases the oxygen carrying capacity of the blood. In high altitude natives, the oxygen carrying capacity of the blood is normal, despite chronically low Pao2 and oxygen saturation. In lowlanders that ascend to high altitudes, the RBC's increase for about 6 weeks before the production rate levels off. As the volume of RBC's increase, the plasma volume of the blood decreases (Jardins, 1998). Altitude training has been shown to significantly increase red blood cell concentration even after plasma volumes have normalized following an initial brief period of suppression (Cedaro, 1993)

Hematocrit (HCT)

HCT is an expression of red cell volume as a percentage of total blood volume. A normal adult usually has an HCT between 40-45 % (Cedaro, 2002). It is not clear whether altitude training increases hematocrit, especially in elite athletes. Some studies have shown an increase, although limitations in study design affect the validity and reliability of the results. These limitations, which are explained later, include the variation in individual response to altitude, an insufficient altitude to increase HCT, lack of control groups, and the use of moderately trained rather than elite athletes.

Haemoglobin (Hb)

Haemoglobin is the protein that binds and carries oxygen on the RBC. Altitude exposure has been shown to increase Hb (Cedaro, 2002).

VO2 Max

V02 Max refers to the maximum rate of oxygen consumption in an individual (De Castella, 1996). An increase in red cell mass is known to boost maximal oxygen uptake (Balsom et al, 1994, cited in Mcardle, 1996). A great deal of anecdotal evidence and some research supports the notion that because of this, altitude training will improve sea level performance. This is only in moderately trained or untrained individuals though. When highly trained athletes are concerned, many studies have failed to show any improvement. Athletes need a precise knowledge of how long, how high and what training needs to be done at altitude to maximise performance (Ashenden, 1998). Improved VO2 Max enhances aerobic performance. Thus, using exposure to a hypoxic environment is a legal and safe method to enhance aerobic performance (Randall, 2002).
Burtscher, et al, 1996, found a significant increase in vo2 max (10%) between day 3 and 12 of altitude training at 2315 metres (m). This was significantly higher than the sea level group. Performance improved 8%. They suggested that training at moderate altitude improved performance at sea level more than training at sea level. They used amateur runners, however. Some researchers have reported vo2 max increased 3 to 5% in athletes who spent approx 3 weeks at 2300m to 3100m. Many studies, however, have shown a reduction in v02 max and the anaerobic threshold level at altitude (Boning, 1997; Gore, 1997; Suslov, 1999). Saltin 1996, reported that exposure to hypoxia has barely any effect on maximal oxygen uptake.

This lack of consensus could be due to the altitude employed. Less than 2200m has been thought to be not sufficient stimulus to increase vo2 max. The difference in initial fitness levels between the athletes would also affect the results. Gore et al, 1997, hypothesized that highly trained athletes have little scope for improvement in vo2 max from altitude training. The differences between studies could also be due to individual biological variability and random measurement error. Evidence from studies using highly trained athletes indicates that altitude training is unlikely to improve vo2 max.

Erythropoietin (EPO)

EPO is the hormone that regulates the growth and development of RBC's and hB from the stem cells of long bones. EPO concentrations increase significantly within hours of altitude exposure, by as much as 40% and hit maximum levels within 72 hours. The higher the altitude the greater the EPO response (Cedaro, 2002).

Myoglobin

Myoglobin enhances the transfer of oxygen between the capillary blood and the peripheral cells, buffers regional Po2 differences, and provides an oxygen storage compartment for short periods of very severe oxygen deprivation (Jardins, 1998). The concentration of myoglobin is increased in high altitude natives.

Serum Ferritin

Serum ferritin is a common indicator of iron stores, which in turn are an indicator of hB production. A low ferritin can be an indicator of iron deficiency, which is not uncommon for athletes traveling to altitude for the first time. This can result in overtraining, reduction in performance and illness. Studies indicate that iron supplementation may be beneficial to athletes training at altitude, but a doctor should be consulted first (Cedaro, 2002).

Lactic Acid Buffering

During exercise, lactic acid accumulates in the muscles in accordance with the exercise intensity. This lactic is acid is buffered effectively at low intensities. At high intensities, however, the body is unable to buffer the accumulation of lactic acid, which affects the ability of the muscles to keep going, forcing the individual to slow down or stop (De Castella, 1996). A major response to altitude training is the lower lactate response to sub-maximal exercise and a shift in the anaerobic threshold to a higher intensity when returning to sea level (Hellemans, 1993).

Oxygen-diffusion capacity

High altitude natives have been shown to have an oxygen diffusion capacity that is about 20-25 % greater than those native to sea-level areas, both at rest and during exercise. This may be explained by the larger lung size seen in these people, which provides an increased alveolar surface and a larger capillary blood volume. There is no significant change in lowlanders who acclimatize to high altitude. Studies have shown that animals that develop in hypoxic (low-oxygen) environments grow larger lungs, and animals that develop in hyperoxic (excess oxygen) environments develop smaller lungs than the average population (Jardins, 1998).

Cardiac Output

When an individual is acutely exposed to an hypoxic environment, the cardiac output increases during both rest and exercise. This increases the oxygen delivery to the peripheral cells. This is not seen in high altitude natives or those that have acclimatized to altitude. In these individuals, the cardiac output is the same as at sea level. The reason for this is unclear, however it seems to be related to polycythemia (Jardins, 1998).

Mechanical Efficiency (ME) and Coordination

Mechanical efficiency, or the oxygen cost for a particular task, is an important contributor to exercise performance. When comparing two athletes, for example, the athlete with a greater Vo2 max and more effective biomechanics, among other factors, will generally have better mechanical efficiency. This athlete will use less oxygen at the same intensity as the other athlete, and produce more power for a given vo2, resulting in improved performance. Many studies have shown that altitude training can improve ME. Mountaineers, for example, exhibited a 5 % improvement in ME in sub-maximal cycling after a 21-day ascent to 6000m (Hahn, A. Gore, C. 2001). Not all studies support this, however. Hochachka and colleagues, for example, found that ME was not significantly altered after 5 weeks of sub-maximal cycling at an altitude of 5050m. This study did show a trend towards reduction though (cited in Hahn, A. Gore, C. 2001).
The major mechanism for this improved ME is usually attributed to the preferential utilization of carbohydrates and a down-regulation of ATP (Adenosine Tri-Phosphate) consuming processes within skeletal muscles and other tissues at altitude (Hahn, A. Gore, C. 2001).

Nutrition at Altitude

At altitude there is a lowered appetite due to the increase in basal metabolic rate. A high energy output combined with a lowered inclination to eat can result in micro-nutrient deficiencies and weight loss (Jardins, 1998). It seems logical, however, that an increase in metabolic rate and energy output would increase appetite. Most studies do not explain why appetite is suppressed – which is needed to develop measures. Also, since relative humidity at altitude is lower than sea level, ventilation draws extra moisture out of the body. In addition, you are also breathing harder and more deeply which results in fluid loss. This means that increased fluid intake is necessary (Cedaro, 2002; Hahn, A. Gore, C. 2001; Hellemans, 1993).

All athletes should increase their intake of protein marginally if at altitude for extended periods. At altitude, there is a shift from fat and glycogen use to blood glucose combustion (Boning, 1997; Hahn, A. Gore, C. 2001), so increasing carbohydrate intake is an advantage. Research by Rose et al, 1988, showed that long-term altitude exposure results in a significant decrease in body fat. Why this occurs is not clear, since fat utilisation decreases at altitude.

Negative Consequences of Altitude Exposure

Work Capacity

At altitude, work capacity is decreased due to the reduced oxygen. Ventilation and heart rate increases for the same rate of exertion (Scott, 1985; Suslov, 1999). The problem with this is that lowering the intensity affects motor patterns and muscular strength (Cedaro, 1993). Moderate altitude facilitates catabolism in swimmers, which affects power output. Energy supply is also affected, which consequently affects swimming skills. Since neuromuscular skills play an important role in swimming, with regard to technique and mechanical efficiency, performance can be greatly affected (Miyashita, 1996). Muscle fibre size is reduced in most individuals while at altitude (Saltin, 1996). Shrinkage may be as much as 20% within a month at extreme altitude. As capillary length is unaltered, this may enhance the oxygen delivery to muscles. Athletes requiring a great deal of strength for performance should take note of this (Saltin, 1996).

Cognitive Ability

High altitudes can cause insomnia and suppress appetite and can prevent athletes from using their muscles intensely enough to get a benefit (Holden, 1997).

Alterations in psychological mood, personality, cognitive function, and behaviour associated with altitude have been well documented. Such changes, which result from the effects of hypoxia, often include increases in euphoria, irritability, hostility and impairment of neuropsychological functions such as vision and memory. Interestingly, these changes persist for a period of time after descent. No change has been observed below 3600m, where memory for recent events becomes slightly impaired. As the person ascends, such changes become worse and more severe (Barhke, 1993). Haldane, et al, 1919 (cited in Bahrke, 1993), showed that severe degrees of acute hypoxia cause a definite impairment of mental ability. There is also some evidence indicating that at the pressure equivalent to an altitude of 2400m, learning of complex mental tasks is slower than at sea level (Denison, 1966, cited in Bahrke, 1993). Medication can also affect cognitive function at altitude.

It was found by Forwand et al, 1968 (cited in Bahrke, 1993), that Acetazolamide significantly reduced the symptoms of acute mountain sickness. Hypoxia also affects vision, in particular night vision, impairing the ability of retinal cones and rods to adapt to the dark (Gibson et al, 1981, cited in Bahrke, 1993)

These changes to cognitive function have the potential to adversely affect athletes in many ways, such as:

a) Arousal, which is an important aspect of performance. If athletes are unable to reach their optimal level of arousal, they will not be able to effectively prepare mentally for a good performance (De Castella, 1996).
b) Inability to reach a comfort zone during exercise
c) Concentration may be affected which is potentially dangerous in many sports, such as cycling.
d) Poor Social Skills, which may indirectly affect training and racing. For example, a poor relationship with family may result in depression and a lack of motivation.

Immune Function

Hypoxia is responsible for a depression in immune function and increased tissue damage from oxidative stress (Bailey, 1997). Studies have shown that moderate altitude resulted in a 50% increase in the frequency of upper respiratory tract infections and gastrointestinal tract infections during the altitude sojourns (Bailey et al, 1998)

Mountain sickness (MS)

Acute MS - This occurs usually in those new to high altitudes. It is characterized by headache, fatigue, dizziness, insomnia, nausea, and loss of appetite. Symptoms do not usually occur until 6-12 hrs after ascending to high altitudes and are generally most severe on the second or third day. Acclimatization is usually complete by the fourth or fifth day. It is thought to be caused by hypoxia, and the alkalosis that occurs at altitude. Symptoms seem to be more severe in younger people (Jardins, 1998; Grant, 2002)
Chronic MS - Also known as Monge's disease, it is sometimes seen in long-term residents of high altitude. It is characterized by reduced exercise tolerance, fatigue, loss of mental acuity, and severe hypoxemia. Blood becomes viscous due to the high levels of hematocrit, and the right ventricle of the heart often atrophies (Jardins, 1998). Symptoms such as these could severely affect athletic performance.

Pulmonary and Cerebral oedema

Pulmonary - Also due to hypoxia, symptoms include a dry cough, shortness of breath and fatigue. Physical Signs include tachycardia and crackles at the lung bases. Death may occur. It is thought to be linked to the pulmonary vasoconstriction that occurs as a result of alveolar hypoxia. Treatment consists of rapid descent and oxygen therapy, if available.
Cerebral - occurring as a result of acute mountain sickness, it is characterized by hallucinations, photophobia, coma, and possibly death. It is thought to be linked to the cerebral vasodilation and blood flow that occurs in hypoxia (Jardins, 1998).

Altitude and the Athlete

Altitude has a significant effect on athletic performance and remains a very controversial area of elite athletic training (De Castella, 1996). Altitude training involves moving to an area of high altitude to live or train, in the belief that it will improve performance. It is most commonly used by athletes from endurance sports, which are dependent on the body's ability to transport oxygen to the muscles. Red blood cells (RBC's) transport oxygen to the working muscles, therefore the more RBC's an athlete can produce and utilize, the more speed and endurance they will have. Exposure to a hypoxic environment, like that found at natural altitude, stimulates the body's natural ability to produce more RBC's, enhancing oxygen carrying efficiency and also causing skeletal muscular changes that are known to enhance performance. Exposure to a hypoxic environment (also known as altitude training) is an efficient and legal method for enhancing oxygen-carrying efficiency for athletes (Saltin, 1996; Randall, 2002).

At altitude, the atmospheric air exerts pressure on the alveoli within the lungs. Since oxygen diffusion is dependant on this pressure gradient, less oxygen is available to be delivered into the bloodstream. Within the first four hours of altitude exposure, breathing frequency is increased to counter the reduced availability of oxygen. While this increases oxygen delivery to the lungs, it also increases the amount of Carbon Dioxide (c02) excreted by the lungs. As the amount of dissolved c02 in the blood is reduced, there is a decrease in the hydrogen ion level, which causes the blood pH to increase (become less acidic). Soon after altitude exposure, the kidneys begin to increase the excretion of bicarbonate (the primary buffer of lactic acid) in an effort to restore the acid-base balance of the blood. An initial fall in plasma volume within the first 24-48 hrs is accompanied by an increase in the production of EPO, which stimulates RBC production. Depending on the height above sea level, within 2-3 weeks the total number of RBC's within the blood will have increased (Ashenden, 1998).

Many previous studies indicating an increase in RBC mass, however, were carried out at relatively high altitudes of between 4390 and 4540 m, and reported that RBC volumes were elevated by more than 80% compared with those of subjects at sea level. Most of the subjects were born at altitude though. Because the population stemmed from natives, who had lived there for generations, and from lowlanders, who have generations originating from sea level, effects on the RBC system due to genetic adaptation must be taken into consideration (Schmidt, 2002). It is, however, still not clear whether the high haemoglobin (Hb) values found in the athletic altitude groups can be seen to represent the maximum effect of adaptation that sea-level athletes could also attain during very long periods of altitude training, or whether a genetic predisposition is necessary for effective erythropoiesis (Schmidt, 2002).

It is a well-known fact that athletes born and living at moderate altitude, as e.g. Kenyan runners, are very successful in endurance competitions. As yet, only few structural and functional differences have been found between athletes living at altitude and those at sea level. In the muscle tissue of Kenyan runners, Saltin, 1996, detected higher levels of activity in some enzymes than in European athletes. They also characterized the Kenyan athletes by individually very high $\dot{V}O_2max$ values and by generally higher running efficiency, a lower blood lactate concentration, and by extremely low ammonia accumulation during exercise. Saltin contends, however, that these differences do not satisfactorily account for the physiological mechanisms responsible for the extraordinary endurance performance of these athletes.

Another important advantage of exposure to a hypoxic environment, is the ability to acclimatize to a certain altitude "There is approximately a 1 percent drop-off in performance for every 100 meters above 500 meters," says Dr. Benjamin Levine, who with Dr. Jim Stray-Gundersen published a seminal study on altitude training (p.3). The percent of drop off is greater for athletes competing at altitude without acclimatizing first. Therefore exposure to a hypoxic environment before a competition at altitude will help the athlete minimize the percent drop-off in performance (Randall, 2002).

At altitude, there is a considerable increase in maximal strength and power. There is also an improvement in fine neuromuscular co-ordination, which enables the athlete to overcome speed barriers. It has also been noted that some improvements occur in reaction to moving objects and precision of movements. These positive changes persist for some eight weeks after return to sea level (Suslov, 1999). Anaerobic events that involve throwing, kicking, jumping, and sprinting are enhanced by high altitude because of the lowered air resistance to balls and objects moving through the air. On the other hand, aerobic events can be severely compromised because of the reduced oxygen concentration (Pyne et al, 1992; De Castella, 1996; Suslov, 1999).

Erythropoietin (EPO) Injection and Blood Doping: A Comparison to Altitude Exposure

The effect of altitude is that less oxygen is bonded to the haemoglobin in the red blood cells, so the body responds by increasing the haemoglobin and red blood cell production. This increases the oxygen-carrying capacity of the blood in a way that is similar to blood doping or taking EPO (Hellemans, 1993). The problem with doping and EPO use, however, is that both are banned practices within the sporting arena. Such practices are potentially dangerous to the human body. Artificially increasing the volume of RBC's causes the blood to become more viscous. When Hematocrit (HCT) increases above 50% there is an exponential rise in blood viscosity. This makes it harder for the heart to pump blood, and can result in death due to blood clots (Randall, 2002). This led to many sporting drug agencies to cap the maximum legal level of HCT at 50%. The problem with this though, is that athletes will use these practices to reach the limit. In addition, some athletes, such as those native to altitude, may naturally have a HCT greater than 50%, which would result in a number of positive tests, albeit unfounded (Cedaro, 2002). The difference with altitude is that the increase in haemoglobin and red blood cells is always within normal physiological limits, thereby avoiding an increase in blood viscosity (Hellemans, 1993). Studies have been conducted which have compared the response of EPO to altitude exposure and blood doping. In most cases, it was demonstrated that altitude caused no significant change in EPO compared to blood doping, which caused a marked increase (Ashenden, 2001). Other studies, however, have demonstrated a significant increase in EPO to altitude, especially in the initial stages. The difference in results may have been due to the subjects not being at a high enough altitude. The findings in many studies are inconsistent, and often hard to interpret.

The classic response to altitude is an initial increase in EPO, followed by a gradual regression to pre-altitude levels, despite the hypoxic stimulus. The response is much lower than EPO administration (Hahn et al, 2001).

What Altitude and Duration is Necessary for Optimal Results?

The optimal altitude for athletes is still unclear. The main reason for this is that there is great individual variability in the response to hypoxia (Miyashita, 1996; Grant, 2002). Athletes with an initial low haemoglobin level seem to respond best (Hellemans, 1993).
Altitude training camps for athletes typically take place at altitudes between 1800m and 2500m and last for two to four weeks. They will usually finish three weeks before a major competition (Martin, 2003). Many coaches, however, continue to include altitude training in their programmes, despite there being no proven 'ideal' altitude for training and no agreed-on duration for maximum benefit (Martin, 2003).

Red blood cells have been found to increase significantly after as little as one days exposure to 2500m, yet a substantially longer period is needed to improve VO2 max and athletic performance. Since EPO concentrations peak within 48hrs and decrease over 3-4 weeks back down to normal levels, 3-4 weeks to maximise blood changes is often recommended (Cedaro, 2002; Hellemans, 1993). This research has been well supported (Myashita, 1996; Suslov, 1999). Miyashita, 1996, studied swimmers at altitude and his results concluded that 3-4 weeks at 2-2300m is necessary for effective adaptations. Intensity should be reduced in first 5-8 days to increase ventilatory capacity and Hb concentration. Over the next 8-10 days, intermittent race pace efforts with long rests should be performed to increase capillary density, mitochondrial density and aerobic enzyme activity. Swimming style needs to be carefully monitored during this time. In the last stage, volume needs to be decreased and time trials performed at up to 2/3 of race distance, 2-3 times per day.

This research concluded that there are physiological benefits to altitude training, despite recent research demonstrating that performance actually suffers during altitude training. Obviously, the altitude at the location of the race or event will determine the optimal altitude at which to train.

Stray-Gundersen et al, 2001, showed that when using the LHTL approach, living at an altitude of 2500m, and returning to an altitude of less than 1250m to train, resulted in a 1-3% improvement in performance. 2500m is generally accepted as the necessary altitude for physiological improvements. The overall effects of altitude last for 1-3 weeks when coming back down to sea level (Hellemans, 1993).

In preparation for competition due to take place at medium and high altitudes, several (20 – 35) training periods are needed during the yearly training cycle to adapt effectively (Suslov, 1999)

Common Methods of Altitude Training

Live High and Train High (LHTH)

This method involves living/sleeping and training at altitude. There have been many anecdotal reports indicating that athletes who spent two to four weeks training at altitude improved their sea level performance (Dick, 1992, cited in Martin, 2003), however, as explained later, most scientific literature does not support this practice. This is because of factors such as a reduction in v02 max and training intensity at altitude. (Hahn and Gore, 2001)

The main positive effect of altitude training for improved sea-level performance is an expected increase in V02 max due to an increase in the volume of RBC mass. A review of the literature shows that no control group has been included in most altitude training studies of athletes (Friedmann, 1997). A few of those studies have shown an increased sea-level V02 max after altitude training. Maybe the most important study in favour of altitude training was that done by Daniels and Oldridge, in 1970 (cited in Rusko, 1996). They studied six elite runners who lived and trained at an altitude of 2300 meters, for 42 days. After the altitude training period, the sea-level V02 max of the athletes had increased by 4.4%, five of the runners ran their personal best, and one runner broke a world record in the 1-mile run.

However, there are many similar studies on athletes that have shown no change in sea level V02 max despite a short or long duration at altitude or residence and training altitude. There are also some studies on athletes that include a control group at sea level. The results of those studies are also inconsistent; sometimes findings of a decrease, no change, an increase, or similar occurrences have been observed. One of the recent studies is very interesting because the subjects were elite athletes and the two groups studied had training camps away from their home countries. Nine national team-level rowers went to a training camp at 1800 meters for 21 days and another 9 rowers of the same level went to a similar training camp for 3 weeks at sea level. After training camps, sea-level V02 max and performance improved significantly by 4% and 3%, respectively, in the sea-level group and no change was observed in the altitude group. In both groups, considerable individual variation in response to training was observed (Rusko, 1996). This variation affects the validity of the results, as it cannot be determined whether the improvement in performance was due to the altitude or the training effect. Hahn and gore, 1998, found a 4% improvement in cyclists training at 2690m for 31 days, however there was no change in vo2 max or Hb mass.

All these data attest that altitude training may increase sea-level V02 max in some athletes but individual responses are so different that a significant group-level improvement cannot always be found A review of the literature shows that we have much data that show that Hb and hematocrit values of athletes are increased after acclimatization and altitude training but, because of the plasma volume changes, this cannot be regarded as clear evidence that red blood cell mass has also increased after altitude training (Rusko, 1996).

It has also been shown that acclimatization for 3 to 4 weeks increases red blood cell mass in non-athletes even without training at altitude. However, it is difficult to apply these studies to athletes because training at sea level itself increases red blood cell mass significantly and elite endurance athletes exhibit 20% to 25% greater red blood cell mass than untrained subjects even without training at altitude (Rusko, 1996)
Very few studies that show that RBC mass really has increased in athletes after training at altitude. Stray-Gundersen et al, 1993 (cited in Rusko, 1996), found a 9% increase in RBC mass in athletes who had trained 4 weeks at an altitude of 2500 meters. Rietjens, 2002, has shown that training at an altitude of 2600m for 3 weeks improves Hb and HCT concentration. Their data suggests that training at greater than 2000m is necessary to have an effect on hematological status. They also concluded that iron supplementation during periods of heavy training should be considered. There are data that show that individual red blood cell mass response is related to the availability of iron and the ability of bone marrow to produce red blood cells. Other factors may also affect individual responses in red blood cell mass levels. For instance, these factors could be high initial RBC mass, high stress from altitude and altitude training, the level of arterial hypoxemia, and increased acidity during training at altitude, which could induce a depression of erythropoiesis in the bone marrow. One reason for the increased blood lactate concentration during altitude training is the decrease in the oxygen saturation of blood. Overtraining is also a real possibility at altitude, suggesting that living and training at altitude may be so stressful that athletes may become exhausted and are unable to react positively to training stimulus at altitude (Rusko, 1996)
In contrast, Schena et al, 2002, found that cross country skiers who trained at 3100m for 6 days failed to show significant increase in hematocrit and EPO levels. The un-trained control group, however, showed a marked increase in both of these parameters. It was concluded that the athletes in the study remained at moderate altitude for too short a period to influence hematological parameters. Previous studies indicating a change in total red cell volume following altitude used subjects with only modest aerobic power. No increase in Hb mass was observed in trained athletes.

It is thought that athletes already have erythrocytic hypervolemia and have limited capability to further increase total red cell volume or Hb mass naturally (Hahn, 1997).
Training at altitude will generally involve an ‘easy’ introduction. Followed by a high volume, high intensity block, then an ‘easy’ final few days (Dick, 1992, cited in Martin, 2003). While at altitude, some coaches will adjust training zones in attempt to compensate for the elevated heart rates and lactates associated with a given power output (Burke, 1995, cited in Martin, 2003). This is not necessary, however, as it has been shown that athletes naturally compensate for power output in threshold and high intensity intervals so that heart rate and blood lactate are similar to those values obtained at sea level (Bronsan et al, 2000, cited in Martin, 2003). Scientific data suggests that in many cases the problems associated with altitude training may outweigh any potential benefits. Coaches and athletes continue to utilize this method, however, often because it has worked for them in the past, or because they feel it works if you know what you are doing (Dick, 1992, cited in Martin, 2003). Future studies of this method need to evaluate types of training programs at altitude that will most likely result in improved performances at sea level, instead of evaluating the type of altitude exposure that works best with a generic training program (Martin, 2003).

Live High and Train Low (LHTL)

This method involves sleeping and recovering at a relatively high altitude (between 2,000m and 3,500m) and then moving to a lower altitude to train. This method is limited by a lack of suitable geographic locations, the financial burden of travel to such locations, and the stress of being away from home (Randall, 2002). Research thus far has found that sleeping at an altitude of up to 3000m does not interfere with low-altitude training (Martin, 2003). Although other researchers have disputed this claim, arguing that even sleeping at moderate altitudes can affect training due to factors such as; reduced sleep quality in some individuals, impaired recovery from training, dehydration, and cost (Cedaro, 1993; Randall, 2002).
Hahn and Gore, 2001 have shown that this strategy is most effective with 400m runners, middle distance runners, rowers, and elite female road cyclists. Their studies, along with the well-publicised study by Levine and Stray-Gundersen, 1992 (cited in Hahn, A. Gore, C, 2001), used fitness-matched control athletes with no exposure to altitude. This was to ensure that the changes in performance were not merely due to training. In these studies, athletes slept at an altitude of around 2500m, and returned to an altitude of 1250m or less to train. They have proven a 1 to 3 percent improvement can be expected by using this method. Although this may not seem much, small percentages such as this often determine the difference between first and last in some Olympic sports.
Levine and Stray- Gundersen, 1992 (cited in Hahn, A. Gore, C. 2001), concluded that LHTL increases the hormone EPO, haemoglobin concentration and maximal oxygen uptake (V02 max). They also conclude that improvements in performance are related to altitude-induced increases in red blood cell mass. Australian researchers, however, have found similar improvements in athletes, without increases in red blood cell mass. They attribute the performance boost to improvements in the anaerobic energy systems and an increase in muscle buffering capacity. Critics to this method state that despite the large amount of research in this area, a properly designed placebo-control study has not yet been conducted, and they attribute the performance gains to the athlete’s belief in the system (placebo effect).
The majority of studies on LHTL have shown that acclimatization to moderate high altitude accompanied by training at low altitude improves sea level endurance performance in accomplished, but not elite, runners. A major study by Stray Gundersen et al, 2001, showed that sea level 3,000-m time trial performance was significantly improved by 1.1% in a group of elite athletes. One-third of the athletes achieved personal best times for the distance after the altitude training camp. The improvement in running performance was accompanied by a 3% improvement in maximal oxygen uptake. Circulating erythropoietin levels were near double initial sea level values 20 hours after ascent to high altitude.

Hb concentration measured at sea level increased over the course of the camp. Hematocrit was significantly elevated when measured on the 19th day at altitude and remained significantly elevated on return to sea level Plasma erythropoietin concentration doubled after one night at 2,500 m and remained at that level. They concluded that 4 weeks of acclimatization to moderate altitude, accompanied by high-intensity training at low altitude, improves sea level endurance performance even in elite runners and was not different from baseline after 19 days at the camp. The study suffers from a major limitation shared by most research conducted in elite athletes: namely, the absence of a concurrent control group performing a similar training camp at sea level. Such a control group would be optimal to ensure that the athletes did not improve merely from the result of a training camp per se, rather than living high-training low. A number of lines of evidence, however, suggest that the study design employed in their experiment was sufficient to account for most of this effect. As far as could be determined from inspection of training logs and individual meetings with each athlete over the course of the study, no one had a change in training that could explain an improved performance. Also, the athletes were reportedly equally motivated to give their best performance in pre-camp as well as post-camp tests. This was evidenced by a similar respiratory exchange ratio and heart rate (for example, maximal heart rate was 192 on the first test and 191 on the second test). They also concluded that LHTL improves sea level performance in events lasting 8-20 mins. This means that caution needs to be heeded when applying these results to events of a longer duration.

Rusko, 1996, found a significant improvement (5 %) in maximal oxygen uptake in the high-low group. The high-low group also improved their sea-level 5 km running time by 30 seconds, while no change was seen in the se level group. The high-low group also showed a significant 500-ml increase in total blood volume that was not seen in the sea level group; this suggests that acclimatization to altitude may be the most important factor for improving exercise performance at sea level. The training at lower altitude made it possible to avoid the problems related to decreased training pace usually seen at altitude. These results are also supported by Miyazaki, 2000. Other studies, however, have shown similar gains in performance, without an increase in Hb or v02 max. These gains are usually attributed to an increase in lactic acid buffering capacity (Hahn, A. Gore, C. 2001).

Improvements from using the LHTL method are largely dependant on:

a) living at a high enough altitude to achieve a large acute increase in EPO, sufficient to increase the total red cell volume and V02 max
b) Training at a low enough altitude to maintain interval training velocity and O2 flux near sea-level values.

It is possible that these findings could be applied in a manner that would serve to minimize the number of athletes who do not respond to an altitude training camp with an increase in performance. By screening the erythropoietic and training velocity response to acute altitude, either shortly after arrival at altitude or in a laboratory setting, adjustments could be made in the altitude(s) where living and interval training take place, or perhaps individual assignment of appropriate living and training altitudes could be made before an altitude training camp. A screening procedure of this type may also identify athletes who could use the classic form of altitude training (LHTH) and still experience performance gains, thereby minimizing the inconvenience of travelling to a low-altitude site several days per week, while expanding the number of available altitude training sites. Similarly, athletes who apparently will not respond adequately to altitude, regardless of an individual prescription of living and training altitudes, might also be determined. This type of athlete would likely be better served by staying at an appropriate sea-level training site, sparing the expense and inconvenience of relocating to an altitude training camp. However, more research is needed in this area (Chapman, 1998).

Alternatives to Traditional Methods

Simulated Altitude Environment (SAE)

Rapid improvements in technology over recent years has led to the development of the simulated altitude environment (SAE). A simulated altitude environment (SAE) is an enclosure in which a person spends time, which simulates a *hypoxic environment* similar to that found at natural altitude. The SAE simulates living at a moderately high altitude and allows the athlete to train at a low altitude (<1000m), thus utilising the LHTL principle. Advantages of this method include the portability of the equipment, the lack of disruption to family life, school and work, the ability to train at high intensities and the ability to adjust the system to individual needs (Randall, 2002).
Nitrogen houses/apartments, hypoxic tents/rooms and hypobaric chambers are forms of SAE's. Hypoxic tents are the most affordable and portable option for individual athletes and are the best option for athletes that travel to different training and competition sites. A nitrogen house/apartment or a hypoxic room system, however, is the best-equipped option to handle a group of more than 2 athletes (Randall, 2002). However, nitrogen houses have been proven to increase serum EPO and RBC count (Rusko, 1995, cited in Randall, 2002) Results from the first study of six cross-country skiers showed that serum EPO and reticulocyte numbers were both significantly increased during the 8-day altitude house period. Reticulocytes are red blood cells that are a few days old, and increases in reticulocytes and serum EPO suggest that red blood cell production was increased during the altitude house period. Recent studies on skiers, runners, and race-walkers have confirmed that the increase in serum EPO and in reticulocyte number is significant and continues to stay at high levels for at least 2 weeks during the altitude house exposure (Rusko, 1996).

Chambers manufactures are claim that hypoxic tents and chambers improve an athletes performance by 2-3%, similar to the LHTL method (Rucci, 2003)

Intermittent Hypoxic Training (IHT)

IHT refers to the discontinuous use of hypoxia, in an attempt to reproduce some of the key features of altitude acclimatization. It has been shown to produce similar effects to the LHTL method (Levine, 2002).
In a study of eight subjects, that were trained at a simulated altitude of 2.500 m, a significant increase of 7.0% was seen in VO 2 max. In the sea-level group, no significant changes were seen. Their results indicate that IHT can improve both the aerobic and the anaerobic energy-supply systems (Meeuwsen et al). Bailey et al, 2000, has also reported similar gains in v02 max. The small sample size, and the fact that the athletes were not elite, means that this data cannot necessarily be applied to elite athletes.
Rodriguez, 1999, showed that very short intermittent exposure to hypoxia induces acclimation and improved aerobic performance capacity in healthy subjects. The increase in maximal exercise time can be contributed to lower lactate accumulation during exercise. Hematological profile improved remarkably. A significant increase was observed in erythrocitic mass, PCV, red blood count, reticulocyte count and Hb concentration. This research was supported by Hellemans, 1993 (cited in Cedaro, 1999), who found in his pilot study on endurance athletes, that hematocrit increased on average by 4.8%. IHT was used for a period of 3 weeks. Koistenen, 2000, suggested that intermittent exposure to moderate hypoxia, 12 hours daily for 1 week induces a similar stimulation of erythropoiesis as continuous exposure.

DISCUSSION/CONCLUSIONS

What effect does altitude training have on athletic performance?

Scientific research suggests that the LHTL method of altitude training improves performance by 1-3 percent in elite athletes (Levine, 2001). EPO concentrations increase markedly in the first 48 hrs, and then level-off. RBC's, Hb and other blood parameters increase in response to altitude exposure. It is still unclear whether hematocrit and v02 max increase by using this method. LHTL also improves the ability of the body to buffer lactic acid when performing at sea level. The optimal altitude to live, without serious complications, is 2-3000m. Athletes should return to an altitude below 1250m to train. These factors have a great deal of potential for athletes. Traditional altitude training, or LHTH, has not been shown to effectively improve sea-level performance in most athletes. There is a large variation in individual response to altitude exposure. SAE's and IHT are viable alternatives to the above methods of altitude training. More research needs to be done into these alternatives, however, to ensure that the performance gains are similar to LHTL.

One area of concern is that studies have not specifically compared the different methods (LHTL, LHTH), to determine which is the best for improving sea-level performance. LHTL is assumed to be the most effective, however, from the research that has been currently performed (Martin, 2003).

From the study by Pyne, et al 1992, it is difficult to determine whether the performance improvement was due to altitude training alone. Some swimmers failed to improve, which may have been due to illness, residual fatigue from jetlag and travel, reduced training in the week prior to the race, or possibly some psychological factors.

Increases in reticulocytes (cells involved with oxygen transport), have been reported for both LHTL and LHTH athletes. The findings, however, are inconsistent and difficult to determine. The increase could have been caused by increased training load. The techniques used in counting them also lack precision in many studies, resulting in a great variation in results.

Studies on acclimatization have concentrated on physiological variables rather than performance changes. Even when included, they have differed widely in nature, inhibiting comparison. It is often impossible to determine whether improvements were a result of training, hypoxia, or a synergism between the two (Hahn and Gore, 2001; Mcardle, 1996).

Studies of LHTL have shown a 4.3 % improvement in V02 max and 25 sec improvement in a 5km run. However the studies used a small number of participants and amateur runners. Evidence suggests a small improvement for some athletes, however further research is needed. Caution needs to be heeded before extrapolating these findings, as the benefits of LHTL have not been demonstrated in events of longer duration (Hahn and Gore, 2001).

Studies conducted at altitude frequently suffer from the following methodological inadequacies such as:

a) Difficulty in obtaining large numbers of participants
b) Individual variations in fitness levels
c) Problems in monitoring controls and a lack of control groups
d) Measuring different variables from study to study
e) Non-specific testing of altitude effects (i.e. testing runners on a bicycle)
f) Wide individual response to the effects of altitude (Barhke, 1993).

It is also important to note the following:

a) All athletes benefit from any type of training camp, whether at high altitude or anywhere else. It is group dynamics. Supervised training anywhere will enhance performance.
b) Red blood cell mass will not increase without supplements of elemental iron.
c) It takes years to fully increase red cell mass while acclimating to high altitudes.
d) Hypoxic training is not as fast as training at sea level.
e) At high altitudes, training must have less volume and less intensity because of less oxygen

(Christensen, 1996)

Due to the cost of conducting an altitude training camp to measure performance improvement, it would be impractical for me to do so. However, in the future, this may become a possibility. In addition, there is limited research on the effect of living high and training low, which is now considered to be the preferred method of altitude training. This has affected the validity and reliability of my findings.

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