Short communication

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Training for performance at extreme altitude

Abstract

Elite athletes frequently utilize both the classical altitude training method of live high, train high (LHTH) and the newer model of live high, train low (LHTL) in order to optimize performance at sea level. However, if competitions are held at altitude, athletes adopt altitude-specific training strategies. When ascending to extremely high altitudes (>5000 m), alternative strategies may be necessary. Successful adaptation to extreme altitude depends on several factors, including maximal oxygen consumption (VO2max) or its percentage utilization, hypoxic ventilatory response (HVR), respiratory muscle endurance, myoglobin concentration, and muscular strength. All of these characteristics are trainable.

Keywords: altitude training, sea level performance, extreme altitude, hypoxic ventilatory response

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Introduction

As altitude increases, the partial pressure of oxygen decreases. Combined with increased UV radiation, appetite suppression, and temperature variations, individuals may experience various health and work-capacity issues. The most common problems include acute mountain sickness, increased oxidative stress, a higher risk of infection, and a reduction in body weight and tissue mass.[1–6] While athletes develop various altitude training strategies to enhance performance both at altitude and at sea level, mountaineers must develop alternative strategies to ascend and descend safely from extreme altitudes.

Altitude training approaches for performance at sea level

Today, elite athletes frequently incorporate altitude training into their annual training plans to enhance performance at sea level. The classical approach, LHTH, has been used for many years. Although some athletes have benefited from this method, many scientific studies have questioned its effectiveness in improving sea-level performance.[7,8] However, when the LHTH approach is carefully planned, it has been shown that top-level athletes can achieve performance improvements at sea level.[8] Conversely, the LHTL method, which gained popularity in the 1990s, has demonstrated a positive impact on performance at sea level through studies conducted on both humans[9–12] and rodents.[13]

The LHTL strategy has been shown to cause non-haematological (respiratory, cardiorespiratory neurophysiology, skeletal muscle and lactate metabolism) and haematological (haemoglobin and EPO) adaptations.[14]

This approach eliminates the risk of detraining or overtraining while providing metabolic and physiological advantages associated with altitude, such as increases in red blood cells, hemoglobin, muscle buffering capacity, and capillary density. Additionally, training quality is not compromised, making this model superior.

However, if competitions are to be held at altitude, the live low, train high (LLTH) strategy is more effective.[15] Hypoxic air simulations using masks at low altitudes have also introduced two distinct methods: (1) Intermittent Hypoxic Exposure (IHE), which mimics altitudes of 4000–6000 m for 1–3 hours in 1–10 minute intervals; and (2) Intermittent Hypoxic Training (IHT), which involves exercise while breathing hypoxic air equivalent to 2500–3000 m. Although IHE has shown hematological changes, its impact on performance is debated.[16] In contrast, IHT has shown promising results in enhancing exercise performance.[17,18]

Training for extreme altitude

For those aiming to ascend or stay at extremely high altitudes (≥5000 m), different training approaches are required. Success at extreme altitude depends on several key factors: VO_2max, percentage of VO_2max utilization, hypoxic HVR, respiratory muscle endurance, myoglobin concentration, and muscular strength. All of these traits are trainable. In addition, equipment, technique, and psychological traits also play significant roles in altitude success.

Elite mountaineers often exhibit VO_2max levels comparable to amateur marathon runners. One study showed that climbers with high VO_2max levels were able to reach an 8200 m summit without breaks or frostbite.[19] However, Cymerman et al.[20] found no correlation between high VO_2max and successful ascents between 6100–8848 m, suggesting that VO_2max alone is not the key determinant of success at altitude.

Nevertheless, a strong HVR is positively associated with mountaineering success. Higher HVR improves alveolar and arterial oxygenation, enhancing both altitude performance and ascent capability. Mountaineers with high HVR are also less likely to suffer from acute mountain sickness and pulmonary edema. Those with high HVR at sea level tend to achieve greater heights.[21,22] Two strategies have been identified to improve HVR: (1) training at altitude (4500m)[22] and (2) the LHTL method at 2500–600 m.[23]

However, endurance training at low altitude may reduce HVR, although a two-week break has been shown to restore it.[22]

Individuals with high myoglobin levels also benefit from increased oxygen availability during altitude training and competition. Marine mammals such as seals and whales, whose muscle mass contains up to 8% myoglobin, illustrate this adaptation. Likewise, high-altitude natives possess elevated myoglobin levels. No training approach at sea level has succeeded in increasing human myoglobin levels, although such increases have been observed in rats. However, high-intensity training conducted at altitudes of 2300–3850 m, for 4–6 weeks, 3–4 days per week, 30 minutes per day, has been shown to increase myoglobin levels in humans.[24,25]

Respiratory muscle fatigue is another factor limiting endurance performance at altitude. Staying at altitudes above 8000 m for extended periods can induce respiratory muscle fatigue. For mountaineers, the endurance of these muscles directly affects performance. At altitude, both respiratory force and ventilation increase compared to sea level.[26] It has been shown that respiratory muscle endurance can be improved within 4–5 weeks through hyperpnea training, performed 4–5 times per week for 30 minutes until fatigue sets in.[27]

Altitude-induced adaptations in skeletal muscle primarily support aerobic metabolic functions.[28,29] However, altitude has a negative effect on muscle strength. Following the second Everest expedition, reductions of 25% were observed in both type I and type II muscle fibers[28,29] and mountaineers who stayed above 5000 m for 8 weeks experienced a 20% decrease in muscle cross-sectional area.[30]

These findings indicate diminished muscle strength due to impaired force production. While muscle strength can be improved via neural adaptations and hypertrophy, muscle atrophy remains a serious issue at extreme altitudes. Thus, preventing muscle atrophy becomes particularly important. In a study by Çolak et al.[31] the application of heat stress was found to prevent protein degradation in rats exposed to 6000 m conditions for 15 days, suggesting a potential method for preventing muscle atrophy at extreme altitude.

Conclusion

Although altitude training is widely used by athletes to enhance performance at both sea level and altitude, it is essential to mitigate the negative metabolic effects of altitude on the human body. These effects become especially critical at extreme altitudes due to the risk of muscle atrophy. To reduce or eliminate altitude-induced disadvantages, athletes and mountaineers must implement various strategies. Enhancing respiratory muscle strength and endurance, increasing myoglobin content, improving HVR, and preventing muscle atrophy are among the top priorities. Most of these adaptations can be achieved through specific training regimens, while additional strategies (e.g., heat stress applications) may be necessary for preventing muscle loss. Such practices are crucial for safe and effective performance at high altitude.

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Conflicts of interest

The author declares that he has no financial or personal conflicts of interest that could have influenced the present work.

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