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PHYSIOLOGICAL RESPONSES OF ALTITUDE TRAINING FOR SPORTS PERSONS

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Abstract: *The term altitude acclimatization broadly describes adaptive response in physiology and metabolism that improve tolerance to altitude hypoxia. For the purpose of sports competition and high quality of physical fitness it's required for each and every sports person those participating in high level of game & sports to do altitude training. Each adjustment to a higher elevation proceeds progressively, and full acclimatization required an appropriate time period. Successfully adjustment to medium altitude affords only partial adjustment to a higher elevation. Residents of moderate altitude, however, show less decrement in physiologic capacity and exercise performance than lowlanders when both groups travel to a higher altitude. It improves such physiological system; pulmonary acid-base, cardiovascular, hematological and local system that compensatory response to altitude occur almost immediately, while other adaptations take week or even month. The rapidity of the body's responses remains largely altitude dependent, yet considerable athletes variability exists for both the rate and success of acclimatization. A sports person or athletes can retain many of the beneficial submaximal exercise response with 16 days of acclimatization at 4300 m despite intermittent 8-days sojourns to sea level. This suggests that certain aspects of acclimatization regress more slowly than their acquisition.*
Keywords: *Altitude, acclimatization, energy, exercise, cardiovascular, hematology.*

Introduction: Acclimatization to altitude has become an important part of the preparation process for athlete competing above 1500m (4921ft). Conditions above this level make physical activity more difficult and limited performance (2). But what is the most effective method for acclimation and can training at altitude improve performance at sea level? This article focuses on the immediate physiological responses to a hypobaric (low atmospheric pressure) environment and the longer-term adaptations that take place in the body. Although conditions at altitude have been known for many years, in 1968 the Olympic Games in Mexico City drew considerable attention to their specific effect on athletic performance.

High Altitude Environment: Air at altitude is commonly mistaken for being lower in oxygen but this is incorrect. Air, at any level, contains 20.93% oxygen, 0.03% carbon dioxide and 79.04% nitrogen. Instead, as elevation increases, oxygen has a progressively lower partial pressure [1]. At any point on earth, the more air that is above that point, the greater the barometric pressure will be. This is the same principle as being under water. The deeper a diver is the more water there is above her and the greater the pressure. At sea level, air exerts a pressure of approximately 760mmHg. At the summit of Mount Everest, 8848m (29,028ft) above sea level, air only exerts a pressure of about 231mmHg [2].

Recall that after we inhale, oxygen in the alveoli (tiny air sacs in the lungs) passes to the blood to be transported to the tissues. This gas exchange between the alveoli and blood takes place due to a pressure difference called a pressure gradient. The pressure oxygen exerts in the alveoli is greater than the pressure of oxygen in the blood surrounding the lungs. This drives oxygen from the lungs into the blood [1, 2]. It makes sense then that any reduction in the pressure of oxygen entering the lungs will reduce the pressure difference or gradient. The result is less oxygen being driven from the lungs into the blood. At altitude that is exactly what happens.

The weight of air and the barometric pressure it exerts has an effect on the partial pressure of oxygen. At sea level, oxygen has a partial pressure of 159mmHg. In Mexico City it is approximately 125mmHg. At the top of Everest, it drops to 48mmHg, which is nearly equal to the blood surrounding the lungs [2]. With very little pressure difference at this level oxygen exchange is severely hampered and it's not surprising that supplemental oxygen becomes essential for most. While there are other changes at altitude such as a drop in temperature, decreased humidity and increased solar radiation, the reduction in the partial pressure of oxygen (and so oxygen transport to the tissues) is thought to be the major cause of reduced exercise performance [2].

Acute Response to Altitude: From VO_2 max point of view the body ability to supply and utilize oxygen is a limiting factor in performance. Up to 1500m (4921ft), altitude has little effect on the body. Above this level, studies on men show the cardiovascular, respiratory and metabolic systems are affected. Unfortunately, there are few studies on women and children at altitude and their responses may differ slightly.

Respiratory System Response to Altitude

Breathing Rate Increases at Rest and During Exercise: A smaller number of oxygen molecules per given amount of air means that increased ventilation is required to consume the same amount of oxygen as at sea level [2].

Oxygen Diffusion Decreases: At sea level oxygen exchange from the lungs to the blood is unhindered and the oxygen-carrying component of blood, haemoglobin, is about 98% saturated with oxygen. As altitude increases and the partial pressure of oxygen in the air drops, so does the pressure gradient between oxygen in the lungs and blood. This decreases the saturation of haemoglobin to about 90-92% at 2439m (8000ft). In effect, less oxygen passes (diffuses) from the lungs to the blood [2].

The Diffusion Gradient at the Active Tissues Decreases: As mentioned above, oxygen passes from the lungs to the blood due to a pressure gradient. The same process occurs when oxygen-rich arterial blood reaches the active tissues. The partial pressure of oxygen in arterial blood is about 100mmHg at sea level. In body tissue, it is a steady 40mmHg a difference or pressure gradient of 60mmHg. At an altitude of 2439m (8000ft), arterial oxygen pressure decreases to 60mmHg so the difference or pressure gradient drops to just 20mmHg - a 70% reduction. In effect, less oxygen passes (diffuses) from the blood to the tissues [2].

Volume of Oxygen (VO_2) max Decreases: Maximal oxygen uptake begins to decrease significantly above an altitude of 1600m (5249ft). For every 1000m (3281ft) above that VO_2 max drops by approximately 8-11%. At the summit of Everest, an average sea level VO_2 max of 62ml/kg/min can drop to 15ml/kgmin [3]. For individuals with a sea level VO_2 max less than 50 ml/kg/min would be unable to move as their VO_2 max would drop to 5 ml/kg/min enough only to support resting oxygen requirements [4].

Cardiovascular System Response to Altitude

Blood Volume Decreases: Plasma volume decreases by up to 25% within the first few hours of exposure to altitude and doesn't plateau until after a few weeks. This is partially a deliberate response by the body as reducing plasma (the watery part of blood) in effect increases the density of red blood cells. While no extra red blood cells have been produced in this acute phase, the amount of haemoglobin per unit of blood (called hematocrit) is now increased resulting in greater oxygen transport for a given cardiac output [1].

Cardiac Output Increases during Rest Sub-maximal Exercise: During the first few hours at altitude stoke volume decreases during sub maximal exercise, a result of the reduction in plasma volume. Heart rate increases enough to compensate for this and to actually slightly raise cardiac output. After a few days however, oxygen extraction becomes more efficient reducing the need to increase cardiac output. In fact after 10 days acclimatization to altitude results in a lower cardiac output at any given, sub maximal exercise intensity compared to sea level [5].

Maximal Cardiac Output Decreases: During exhaustive exercise at maximum levels both maximal stroke volume and maximal heart rate decrease with altitude [2]. This obviously combines to have a significant effect on maximal cardiac output. In conjunction with the reduced diffusion gradient to drive oxygen from the blood to working tissues, it is easy to see why VO_2 max and endurance performance is hindered.

Metabolic Responses to Altitude: Lack of oxygen availability and utilization at altitude places a greater demand on anaerobic metabolism to produce energy. This result in an increase in the concentration of lactic acid at any given sub-maximal exercise intensity compared to sea level. In contrast, lactate concentration is lower during maximal effort [6, 7].

Athletic Performance Altitude: As would be expected the acute responses mentioned above have a detrimental effect on exercise performance in particular the endurance events. VO_2 max decreases significantly as altitude increases. Running at 12km/h for example will equate to a higher percentage of VO_2 max when completed at altitude compared to sea level. Conversely, anaerobic events lasting under a minute such as sprinting, throwing and jumping activities are not impaired at moderate altitude. In fact, they can actually be improved due to the thinner air and less aerodynamic resistance [2].

Acclimatization to Altitude: It takes approximately two weeks to adapt to the changes associated with the hypobaric conditions at 2268m (7500ft), roughly that of Mexico City. Every 610m (2000ft) increase requires an additional week of acclimatization to altitude (1). But no matter how long an individual lives at altitude, they never fully compensate for the lack of oxygen and never regain the level of aerobic power or endurance performance they could at sea level. Below are the major adaptations occurring with acclimatization to altitude:

Red Blood Cell Count Increases: Lack of oxygen stimulates the release of erythropoietin, the hormone responsible for red blood cell production, within 3 hours and reaches a peak after 24 to 48 hours [8]. The concentration of red blood cells within a given volume of blood is called hematocrit. In sea level residents, hematocrit is about 45-48%. With 6 weeks exposure to an altitude of 4540m (14895ft) these levels can increase to 59% [2]. Initial exposure to altitude decreases plasma volume. However, this begins to increase slightly with long-term acclimatization to altitude.

Pulmonary Ventilation Stabilizes: But it remains increased during rest and exercise compared to sea level [1].

Sub Maximal Cardiac Output Decreases: While sub maximal cardiac output increases in the acute stage, following acclimatization to altitude it decreases to below sea level values. This is primarily due to a further reduction in stroke volume, which presumably occurs as changes in the oxygen-carrying capacity of the blood take the burden off the heart [1].

Muscle Cross Sectional Area Decreases: Muscle biopsy studies following 4 to 6 weeks at altitude show that slow-twitch and fast-twitch fiber area decreases by as much as 20-25%. This decreases muscle area by 11-13% [2]. It may be that muscle wasting of this nature is due to loss of appetite that often accompanies living at altitude.

The table below covers the major acute response and chronic changes associated with acclimatization to altitude:

	Acute and Chronic Response to Altitude	
	Acute Response	**Chronic Response**
Respiratory	✓ Increased breathing rate ✓ Decreased pulmonary diffusion ✓ Decreased saturation of haemoglobin ✓ Decreased in blood-tissue diffusion gradient	✓ Increased ventilation remains increased but stabilizes ✓ Pulmonary diffusion remain decreased ✓ Saturation of haemoglobin remains decreased ✓ Blood-tissue diffusion gradient remains decreased
Cardiovascular	✓ Some or slightly decreased sub maximal stroke volume ✓ Increased sub maximal heart rat ✓ Increased sub maximal cardiac output ✓ Decreased maximal stroke volume ✓ Decreased maximal heart rat ✓ Same or slightly lower maximal cardiac output	✓ Sub maximal stroke volume decreases ✓ Sub maximal heart rate remaining elevated ✓ Decreased sub maximal cardiac output to below sea level values ✓ Maximal heart rate remaining decreased ✓ Decreased maximal cardiac output
Hematologic	✓ Decreased plasma volume ✓ Increased hematocrit ✓ Increased viscosity	✓ Plasma volume increases from acute stage but remains decreased ✓ Increased red cell production keeps hematocrit elevated ✓ No change or may be less viscous than acute stage
Metabolic	✓ Increased lactate concentration at a give sub maximal workload ✓ Decreased lactate concentration at maximal workload	✓ Decreased sub maximal lactate concentration compared to acute stage ✓ Decreased maximal lactate concentration compared to acute stage
Local Tissue		✓ Increased capillary density in local ✓ Increased number of mitochondria ✓ Increased aerobic enzymes
Performance	✓ Decreased VO_2 max	✓ Decreased VO_2 max although may improve in group compared to

Preparing for Competition at Altitude: How can athletes who live at sea level prepare for a competition at altitude? One approach is to compete within 24 hours of arrival at altitude. Not much acclimatization will have taken place but most of the classical symptoms of altitude sickness will not have had time to manifest. After the initial 24 hours, dehydration and sleep disturbances become more prominent. An alternative option is to train at a higher altitude for at least 2 weeks prior to competition. Although full acclimatization to altitude takes 4 to 6 weeks, many of the physiological adaptations occur in the first 2 weeks and the more severe disturbances should have settled. It is important to remember that during the initial days at altitude work capacity is reduced, so athletes should train at 60-70% of sea level VO_2 max and build up gradually over 10-14 days.

A third approach is to devote a greater percentage of training time at sea level to endurance training several weeks prior to competition. This is a strategy often adopted within many team sports, helping to raise players' VO_2 max to a peak so that they can perform at a lower relative intensity without significant loss in performance.

Sleeping in altitude tents and hypobaric chambers may be able to adequately simulate the effects of altitude but these tend to be very expensive. Unfortunately, there is no evidence to suggest that spending 1-2 hours per day breathing hypobaric gases at sea level results in the same adaptations as living at altitude.

Conclusions: Altitude training is all about optimising the body's usage of oxygen. Make the body into an efficient O_2 transporter. The body needs oxygen for everything - breathing, digestion and even recovering from injuries. The progressive reduction in ambient PO_2 with increasing altitude produces inadequate haemoglobin oxygenation in arterial blood. Arterial de-saturation impairs aerobics physical activities at altitudes of 2000 m and above. Acclimatization entails physiologic and metabolic adjustments that improve tolerance to altitude hypoxia. The main adjustments involve; reestablishment of acid-base balance of the bodily fluids, increased synthesis of haemoglobin and red blood cells, and improved local circulation and cellular metabolism. The rate of altitude acclimatization depends on the terrestrial elevation. Noticeable improvements occur within several days. The major adjustments require about 2 week, but acclimatization to high altitude requires 4 to 6 week. Training at altitude provides no greater benefits to sea-level exercise performance then equivalent training at sea level. Athletes benefit from periodically returning from altitude to sea level from intense training to offset any "detraining" from lower levels of exercise during a prolonged altitude stay.

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