Altitude Training and its Effects on the Human Body

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CHAPTER 1

INTRODUCTION

The effect of altitude on the human body, especially in relation to training, is gaining more popularity than ever. The many physiological effects of altitude on the body are being investigated much more thoroughly than previous research, especially in athletes who train and compete at altitude (7.8,11,13,14,21,22,31).

Along with the physiological changes that are happening in the body in response to altitude, there have also been a lot of studies done on different types of altitude training (8,13,14,23). Altitude training has become popular in the last few decades, and it does not seem to be losing any momentum. Various programs have been developed to determine the most effective altitude training for athletes (7,13,15). However, if altitude training is not done effectively, it may cause unwanted complications such as acute mountain sickness. For example, acute mountain sickness is when the body does not react to altitude in a favorable way (26). If not treated quickly, acute mountain sickness can turn from acute to severe in a matter of a few hours.

In this paper, the body's response to altitude will be addressed, along with various training programs and altitude related illnesses that may arise.

Purpose

The purpose of this paper is to examine the current available literature in order to provide insight on altitude's effect on the human body in both untrained and trained individuals.

Delimitations

1. Sports Discus and PubMed databases were used as search engines.

2. Only field studies were included.

Definitions

1. Acclimatization: The physiological changes the body uses to compensate for decreased oxygen (10)
2. Acute Mountain Sickness: an illness that can affect mountain climbers, hikers, skiers, or travelers at high altitudes, usually above 2,400 meters (26)
3. Altitude: Any elevation above sea level (10)
4. Altitude Training: Training at an elevation above 1,500 meters in order to obtain the benefits of hypoxic exposure (16)
5. Erythropoiesis: the production of red blood cells
6. High Altitude Cerebral Edema: A severe form of altitude sickness caused by the lack of oxygen distribution (10)
7. High Altitude Pulmonary Edema: A severe form of altitude sickness caused by lack of oxygen distribution and has the highest related altitude death rate (10)
8. Hematocrit: blood test that measures the percentage of the volume of whole blood that is made up of red blood cells (25)
9. Hypobaric: Conditions with low pressure (10)
10. Hypocapnia: Reduced carbon dioxide in the blood (11)
11. Hypoglycemia: Low blood sugar (9)
12. Hypoxia: when oxygen concentrations fall below the oxygen content at rest (34)
13. Sickle Cell Anemia: Sickle cell anemia is a disease in which your body produces abnormally shaped red blood cells which look sickled (2)

14. Sleep Apnea: a common disorder that causes your breathing to stop or get very shallow. (24)
15. Transthoracic Echocardiography: A medical test that creates a picture of the heart using sound waves to make a clear image (2)

CHAPTER 2

LITERATURE REVIEW

CLASSIFICATIONS OF ALTITUDE

The body reacts in differing ways at varying levels of altitude. This will be extremely important to know when traveling to altitude and exercising at altitude. There are different classifications of high altitude, and each has its own effects on the human body.

High Altitude

High altitude is classified as 1,500m-3,500m. At this altitude, there is an onset of physiologic changes in response to the decreased inspiratory oxygen pressure, which include a decreased exercise performance and an increased ventilation response. At this altitude, there are also minor impairments that reduce the oxygen transport to the organs of the body (11). Also, if a person would ascend too rapidly, there is a high correlation between rapid ascent and high altitude sickness. Their oxygen saturation immediately drops which causes a headache that can progress quickly if no action is taken (2). A city located within these parameters would be Denver, Colorado.

Very High Altitude

Very high altitude is classified as anywhere from 3,500m-5,500m. A city located within these parameters would be La Paz, Bolivia. Extreme hypoxemia, with oxygen saturations falling below 90%, may occur during exercise, sleep, and in the presence of a preexisting acute lung condition, such as high-altitude pulmonary edema (11). Severe altitude sickness could occur at this specific altitude as well.

Extreme Altitude

Extreme altitude is at 5500m or greater. The peak of Mt. Everest reaches 8,848 meters. Hypoxemia, hypocapnia, and alkalosis are likely to occur at this altitude level (11). There is progressive impairment of physiologic function due to the physiological changes at this level, which eventually could lead to death (11). Because of the extreme stress to the body's physiologic systems, there is no permanent human habitation at this altitude.

IMMEDIATE PHYSIOLOGICAL CHANGES AT HIGH ALTITUDE

With increasing altitude, the drop in barometric pressure causes a drop in the partial pressure of oxygen, which causes a hypobaric hypoxic effect (10). With the drop in barometric pressure, the body works to protect itself in order to make sure its systems keep working. This protection system is better known as acclimatization. Acclimatization is the physiological changes the body uses to compensate for decreased oxygen when exposed to high altitude.

One change experienced in the respiratory system while exercise at high altitude is an increased ventilation rate. Increased ventilation rate is a short-term change the body uses to compensate for the difference in oxygen when at altitude.

It lasts anywhere from 10-14 days due to the increasing sensitivity in the peripheral chemoreceptors. Increased ventilation rate can cause respiratory alkalosis, which can be fully reversed in one day by an increase in the renal bicarbonate excretion, which decreases the buffering capacity of plasma (2). The importance of this mechanism is to maintain the acid base balance in the body. It is important to know ventilation rate and increased arterial saturation only increase over approximately the first two weeks after one arrives at altitude. The last major change the respiratory system makes is decreased oxygen saturation during exercise. This is primarily because of a diffusion limitation, caused by the lower alveolar pressure of oxygen, and an increased pulmonary blood flow with exercise (2). This drop in oxygen saturation can be more severe in endurance-trained athletes. Many people may not think athletes are affected as much as non-athletes, but the decrease in oxygen saturation is larger in endurance-trained athletes because they have a higher overall cardiac output.

Some physiological changes that occur in the blood are an increase in hemoglobin concentration, a decrease in plasma volume, and a significant increase in red blood cells. The plasma volume will drop because of dehydration, which causes the hemoglobin concentration to increase. Dehydration occurs because of the increased respiratory response. With an increased respiratory response the body loses water through expiration. Hemoglobin concentration also increases because of the delayed effect of increased erythropoiesis (2). Another change occurring in the blood during the first three weeks is an increase in the red blood cell mass. The importance of the increased red blood cell mass is associated with the increase in hemoglobin concentration, which in turn has been shown to improve an athlete's performance.

The cardiovascular system experiences changes at altitude. There is an increase in the sympathetic activity over time, and the maximum heart rate decreases with increasing altitude. This is due to the increase in vagal tone, and may be from the down-regulation of beta-receptors (2). These effects can occur anywhere from four to eight hours after arriving at altitude. Cardiac output increases in order to compensate for the reduced pressure of oxygen and tissue hypoxia. Cardiac output is also affected by the increased heart rate (34). The increase in heart rate immediately upon arriving at altitude can be attributed to an increase in the peripheral resistance, which causes stroke volume to decrease. Therefore, the heart rate increases in order to maintain cardiac output (19). An increased catecholamine response can also further increase heart rate and blood pressure (34).

Other cardiovascular changes that occur are an increase in the pulmonary artery pressure and systemic blood pressure. The increase in pulmonary artery pressure, which can increase by approximately 60 %, can be attributed to hypoxic vasoconstriction (2). Systemic blood pressure increases over the first 20 days because of the increase in sympathetic activity (2). This change in systemic blood pressure does not occur in people at altitudes less than or equal to 2,000m.

Skeletal muscle adaptations can also occur during extended periods at high altitude. Hypoxia is the predominant force when discussing changes in skeletal muscle. One of the most prominent changes in muscles are the transport of bicarbonate, hydrogen ions, and lactate and are up regulated when exposed to hypoxic situations. The adaptations made will intensify the capacity of all of those ions and help improve the body's ability to maintain the acid-base balance (2). Another adaptation is the down regulation of the sodium-potassium pump; however, the significance of this particular change has not been tested. Hypoxia stimulates glycolysis and can increase the availability of pyruvate. The increased availability of pyruvate can either be used for further oxidation in the mitochondria or increased lactate production. As a result of hypoxia, there is a greater lactate response for a given workload. The muscles energy source gains more energy from carbohydrates than fatty acids (2). The main cause of these muscular changes can be attributed to the lack of oxygen.

Sleep patterns are also disturbed when a person travels to altitude. When a person arrives at altitude, the reduced oxygen content in the blood produces breathing instability with periods of deep and rapid breathing (27). This can affect sleep by causing periods of apnea. Apnea is a cessation of the movement of the respiration muscles, which causes the lung volume to remain unchanged. Sleep apnea can also be a risk factor to heart disease, which is why apneas are not ideal. Apneas are a cessation of breathing while a person is sleeping, and they can last anywhere from a couple seconds to minutes (27). Sleep apneas cause frequent sleep disturbances and the feeling of oxygen deprivation. With a lack of sleep, this can cause depressive mood, anger and fatigue (27). Central sleep apneas occur more frequently at high altitude and are considered short-term problems because, as a person becomes acclimatized, their sleep quality improves.

Each person’s body reacts differently to altitude. In some cases, their bodies have slow acclimatization and they may become ill. This would be the onset of altitude sickness. Altitude sickness is commonly associated with the onset of headaches and nausea, and can be treated by returning to sea level or, in extreme cases, medication.

LONG-TERM ADAPTATIONS IN ALTITUDE

When a person moves to altitude, their body goes through a series of physiological changes known as acclimatization. As discussed earlier, the body makes various changes in order to adapt to altitude. However, after some time, the body will lose the short-term changes (i.e. an increased ventilation rate) and inherit long-term changes instead. Examples of long-term changes are discussed later in this paper. With people who normally live at altitude, their bodies induce physiological changes in compensatory mechanisms that include the respiratory, hematologic, cardiovascular, and muscular systems (12).

In high altitude, natives undergoing full acclimatization develop higher levels of gas exchange than those living at sea level. This can be attributed to these people constantly being in a state of hypoxia. Pulmonary blood pressure and vascular density will also increase when a person is acclimatized to high altitude. This occurs to allow for improved pulmonary perfusion (34). As ventilation continues to be increased, people become dehydrated quicker at altitude because of their loss of body fluid (6). With increased ventilation rate, people are losing water through exhalation which can cause dehydration. With these changes in the pulmonary system, it is important to take the proper precautions while training (34). Some of these precautions include taking in more water to prevent dehydration and not using heart rate as a reference point to how difficult the exercise regimen is.

Another change in the body's physiology for those who live at altitude is the composition of the blood. After a period of time at altitude, the hemoglobin concentration increases dramatically, and as the altitude continues to increase, the hemoglobin concentration increases accordingly (2). Another change is the plasma volume in the blood will increase over time as the body becomes more acclimatized (2).

When a person arrives at altitude, there is an increase in their sympathetic activity, which increases their ventilation and heart rates. However, as time goes by, their maximum heart rate decreases as the altitude increases (2). The mechanism currently thought to causing this is an increased vagal tone and the down regulation of beta-receptors. Another cardiovascular change is that stroke volume is decreased, which leads to a lower cardiac output. Mean arterial pressure also increases due to systemic vascular resistance, increased catecholamine secretion at specific workloads, and the increased blood viscosity that results from increased hematocrit (25, 34). Blood pressure has not been demonstrated to change at altitude (25).

The skeletal muscle also adapts when a person lives at high altitude. Muscle mechanical efficiency had previously been thought to change at high altitude, but after a comparison of studies done by Lundby et al., it has been determined there is no change in muscle mechanical efficiency (22). Living in constant hypoxia is believed to be the reason for some of the muscular changes. In skeletal muscle, there is increased capillary density within the muscle cells (16). The proteins involved in the transport of bicarbonate, hydrogen ions, and lactate are up regulated when exposed to altitude for a long period of time (2). Also, the sodium potassium pump may be down regulated when in hypoxia for a sustained period of time. Hypoxia can stimulate glycolysis and also increase the availability of pyruvate through elevated epinephrine levels in the blood (2). With the knowledge of these changes, it becomes important to further study other adaptations made in response to altitude.

ALTITUDE SICKNESS

Altitude sickness is directly related to the altitude attained, and is inversely related to the degree of acclimatization a person has (26, 33). Altitude sickness is divided into three different levels. There is acute mountain sickness (AMS), high altitude cerebral edema (HACE), and high altitude pulmonary edema (HAPE). These different classifications of altitude sickness have increasing levels of severity respectively. If not treated, the least serious case of high altitude sickness can progress to the worst. It is imperative to be cautious when dealing with high altitude sickness.

Acute Mountain Sickness

AMS is most likely after the first night spent at any given altitude. AMS can either resolve spontaneously after one to three days, or get worse if a person continues to ascend (28). Several factors contribute to AMS, such as ascent rate, elevation obtained, intensity of physical exertion, hydration level, and individual variability. Risk factors for developing high altitude sickness are rapid ascent, strenuous physical exertion, young age, living at a low altitude, and history of altitude sickness. There is limited evidence that suggests that obesity may be a risk factor for AMS as well (9). Rapid ascent is a risk factor because of the stress put on the body. The body needs time to acclimatize, and with a rapid ascent, the body does not have enough time to make the required physiological changes. Living at a low altitude is a risk factor because people are not used to the thin air at altitude, and their bodies are not acclimatized to the high altitude like the people who live at high altitude. Fitness level is not an indicator for the amount of acclimatization or likelihood of getting AMS. Even elite athletes can have trouble with acclimatization.

Risk stratification is a method for identifying the level of risk a person has to developing altitude sickness. A low risk person would have no prior history of high altitude sickness, and would be at an altitude less than 2,800m. Also, if a person is taking longer than two days to arrive at their desired altitude of 2,500-3,000m, along with sleeping at an elevation of 500m or greater, they would be considered low risk. A moderate risk person would have a history of AMS and is ascending to 2,500-2,800m, or a person with no history of AMS and is ascending to an altitude greater than 3,000m in one day. Lastly, a high risk person would have a history of AMS and be ascending to greater than 2,900m in one day, a prior history of HACE or HAPE, no prior history and ascending to 3,500m in one day, or very rapid ascents (9). With these different risk categories, one can decide how likely it is they will develop any type of AMS.

AMS is the least severe of the high altitude sicknesses. People with AMS have a headache and at least one other symptom, which could include: loss of appetite, nausea, vomiting, weakness, difficulty sleeping, and/or dizziness (5). Approximately 25% of tourists each year are affected to some degree from AMS (14). These symptoms may develop within 6-12 hours upon arrival at altitude (5, 28). The reason why AMS occurs is because of hypoxemia.

The symptoms will first begin with a headache then with one of the other symptoms. Not enough oxygen is traveling through the blood stream and getting to the vital organs of the body. The high altitude headache is reported to be the precursor to AMS and one of the most unpleasant symptoms of AMS. The headache is pounding and usually is not relieved with any type of medication (5). In the study done by Smith et al., it was found that cerebral blood flow was a factor in developing AMS. The resting cerebral blood flow was lower in the subjects who developed AMS than those who did not develop AMS (29).

The first line of defense to treat AMS is to descend immediately. However, if descent is absolutely impossible, medication can help. If a person is unprepared for altitude, dexamethasone can be taken to help AMS. Dexamethasone should be taken as follows: 2mg every 6 hours or 4 mg every 12 hours (9). However, if a person knows they are at risk to develop AMS, they should use the preventive medication known as acetazolamide.

Acetazolamide is to be taken at 250mg/day, that should start one day prior to ascent, and continue taking this two days after arriving at altitude. Acetazolamide is effective because it can significantly increase the minute ventilation rate by 50%. With increasing the minute ventilation, it can improve arterial oxygenation and the oxyhemoglobin saturation (20). Although this can combat altitude sickness, there are some side effects of acetazolamide, including paresthesia (sensation of tingling), diuresis (increased urine excretion), and an aversion to caffeine (9). Acetazolamide is the preferred defense to combat AMS and HACE; dexamethasone may be effective as well.

High Altitude Cerebral Edema

HACE is also known as high altitude cerebral edema. HACE occurs in less than 1% of people who travel to high altitude, and only at extreme altitudes. Generally HACE is present several days after arriving at altitude (10). Some symptoms of HACE include headache and one of the following: anorexia, nausea or vomiting, dizziness, lightheadedness, insomnia, or fatigue/weakness. If a person has a headache, one or more of the symptoms previously listed, and ataxia (an altered mental status), they are most likely to experience HACE and need to seek medical attention (9). HACE can progress quickly, usually from mild ataxia to a coma, with death occurring within hours. If remained untreated, HACE can cause brain herniation from unchecked cerebral edema. Along with acetazolamide and dexamethasone, HACE can be treated with supplemental oxygen. Full recovery may take several weeks after the onset, and may leave permanent brain damage or impairment (10). If any symptoms are present, medical attention needs to be sought out immediately and one needs to descend from high altitude if possible.

High Altitude Pulmonary Edema

HAPE is the last high altitude sickness and is less common than AMS. Approximately less than 1% of people will develop HAPE. However, HAPE causes the most deaths related to high altitude (10). Some symptoms of HAPE include dyspnea at rest, cough, weakness or decreased exercise performance, chest tightness or congestion, crackles or wheezing, central cyanosis, tachypnea, and tachycardia (9). One way to confirm the diagnosis of HAPE is by using pulse oximetry to measure oxygen saturation levels. Anything less than 90% would be a reason to suspect HAPE. Another way to tell if HAPE is present is a chest radiograph. This will show asymmetric patch infiltrates (9). Symptoms develop two to four days at altitude and can occur with or without the presence of AMS (5).

One of the reasons HAPE occurs is because of a low hypoventilatory response (HVR). The low hypoventilatory response causes HAPE because it is the body's way of trying to save energy (5). Exercise and the colder temperatures at high altitude elevate pulmonary hypertension. Increased stress on the capillaries from pulmonary hypertension can cause a mechanical stress on the fragile endothelium, leading to fluid extravasation into the interstitial and alveolar space (5). Therefore, sodium and water transport are shown to be impaired in HAPE. When HAPE is present, it is extremely important to avoid any type of physical exertion.

The treatment for HAPE is Nifedipine 20-30 mg sustained-release capsule every 12 hours. Some other drugs that can be used to treat HAPE are Salmeterol, Tadalafil, Sildenafil, and Dexamethasone. Immediate descent is the most important treatment. If descent does not take place, the person may not respond to treatments. Supplemental oxygen can also help improve the symptoms of HAPE as well. Another possible treatment for HAPE is a hyperbaric chamber or a continuous positive airway pressure device (9). With an early recognition and appropriate treatment, the recovery can be fairly rapid, but return to exertion should be gradual (10).

When traveling to high altitude, there are preventative measures that can be taken in order to try and avoid the development of any of the high altitude sicknesses. One way is a slow ascent. With a slow ascent, the body is able to acclimatize to each level of altitude. Another method is through pre-acclimatization. Pre-acclimatization can be achieved by living at 900m or above for at least 4 weeks (10). Other ways to prevent high altitude sickness are to avoid moderate exercise within the first two days at altitude, drinking plenty of water, eating an adequate amount, and obtain sufficient sleep. The avoidance of alcohol and nicotine can also prevent high altitude sickness (5). With these strategies, one may be able to prevent or reduce their chances of developing high altitude sickness.

OTHER CONDITIONS OCCURING AT HIGH ALTITUDE

Along with altitude sickness, some people with varying metabolic diseases will be affected in one way or another at a high altitude. The table below discusses various problems associated with altitude. This table gives examples, causes, and remedies as well. See Table 1 below for more information.

Table 1

Type of Problem	Example	Cause	Remedy
Sleeping Patterns	Sleep Apnea	Lack of oxygen (9)	Zolpidem (Sleep Aid)
Dehydration	Dehydration	-Increased metabolic and respiratory demands -Sweat Evaporation (6,9)	Drinking plenty of fluids
Cold Injuries	Frostbite, hypothermia	-As altitude increases the temperature drops (9)	-Warm clothing, and lots of layers
Skin Injuries	Sunburn, eye injuries	-With higher altitude one is closer to the sun -Increase in ultraviolet light (9)	-Protective eyewear, sunscreen
Thrombotic events	Pulmonary embolism	-Combination of dehydration, cold, polycythemia, and peripheral edema (9)	-Descend immediately
Cough	Cough	-Dry air (9)	-Scarf, facemask, throat lozenges, benzonatate, low dose narcotics

CHAPTER 3

FINDINGS OF THE STUDY

In the study conducted by Roth et al., the sleep of high altitude natives was compared to sea level natives. The study took two elite soccer teams, one from Australia and one from Bolivia, and compared their cumulative sleep time, sleep onset, total sleep time, and subjective sleep quality (24). The study took place in La Paz, where a training camp was attended to prepare for the 2012 Asian Soccer Confederation under 16 championships. During the camp, the two teams played five games, two at sea level and three at high altitude where the players slept at an altitude of 3,600m each night. The players' sleep behavior was monitored by self-report sleep diaries and activity monitors that were placed in the hotel rooms which monitored the motion of the players. The results demonstrated that the Bolivians slept better than the Australians, who were not as well acclimatized to the high altitude. Also, the Bolivians slept less, but felt more rested than the Australians at altitude (24). These results indicate there are definite differences in those who live at altitude and those who live at sea level.

Another study investigated cardiovascular adaptations in people who live at high altitude (2). In this study done by Stembridge et al., the researchers wanted to learn if the ventricular structure, function, and mechanics of the heart at high altitude were chronically remodeled in Sherpa people compared to that of people who live at sea level, and adapt in a short amount of time. Sherpa people are a group who have lived in the Himalayan Mountains for over 25,000 years and are well adapted to life at high altitude. This study took 11 men from the Sherpa clan and 11 men who resided at sea level and compared transthoracic echocardiography between the two groups. To begin the study, the sea level men had a 10-day ascent to altitude. This study compared the ventricular structure, which included left ventricular thickness and the internal diameter, function, which included the measurement of stroke volume, cardiac output, and heart rate. Another factor looked at was systolic and diastolic function (30). The results revealed that the Sherpa have a smaller relative left ventricular size compared to the sea level men. However, there was no difference in the area ratio of the right ventricle to the left ventricle. The Sherpa people also have a higher maximal heart rate than the sea level men. Another finding was that the Sherpa showed a slower diastolic relaxation. In sea level men, the short-term high altitude exposure caused an increased in pulmonary artery systolic pressure, reduced right ventricular strain and stroke volume, and a difference between right and left ventricular filling. With these findings, it was determined that in order to generate the required cardiac output with a smaller left ventricle, the Sherpa people have developed a higher maximal heart rate than sea level men at high altitude. This could indicate one method in which the heart has remodeled itself in order to adapt to the high altitude conditions (30).

In a study done by Tannhemier et al., they investigated if a pre-acclimatized group of people improved performance at altitude. This study took participants of the German Army Mountain Guide Course as subjects for this study (32). Pre-acclimatization was obtained by them participating in two previous Army Mountain Guide Courses. The first test was conducted as soon as the subjects arrived at the Turin Hut, which was at 3,371 meters. The test was to run up a 90-meter staircase as fast as possible then slowly descend and repeat. The test was timed and their oxygen saturation was tested, along with tracking any apparent altitude sickness symptoms 32). At day 9, the subjects performed this test again. The results from this study showed that even in well-acclimatized individuals, the tests improved with further acclimatization (32). The stair climb was completed in less time and the oxygen saturation improved. With this knowledge, it is important to realize that pre-acclimatization may help athletes who are subjected to AMS symptoms. If they slowly reach altitude, rather than ascending quickly, AMS may be prevented.

ALTITUDE TRAINING

Altitude training is a fairly new type of training that involves athletes training at higher altitudes in hopes of developing key physiological adaptations from the hypoxic exposure and the results of acclimatization (16). Altitude training is popular with middle and long distance runners, along with other endurance athletes. Typically, aerobic athletes tend to perform worse at altitude, with the exception of athletes that participate in short, anaerobic sports such as cycling and speed skating. The reduced density of air provides these athletes with better performance (7). Some of the body's adaptations at altitude include increased ventilation, increased heart rate, and reduced plasma blood flow (13). These adaptations occur initially in order to compensate for the lack of oxygen at altitude. After a few days to a few weeks, the body starts to acclimate to the decreased oxygen at high altitude. A few of the physiological changes that occur are an increase in hemoglobin brought on by the increase in red blood cells. The increase in the red blood cells and hemoglobin help to increase an athlete's VO_2max (13, 15). There are various different theories behind altitude training. These theories include "live high-train high," "live high-train low," and intermittent hypoxic training (13, 23).

Live High-Train High

The first type of altitude training is “live high-train high,” also known as classical altitude training. Live high-train high is the original form of altitude training, and is described as athletes living, sleeping, and training at a high altitude location for approximately two to four weeks (13). According to Lundby et al., in the 1968 Olympic Games, the East African athletes were known to live and train at a moderate altitude, which was quickly adopted by other athletes. This training was believed to induce altitude acclimatization, thus, increasing the red blood cell volume and also superimpose an additional training stimulus due to tissue hypoxia (17, 21). This type of training provides a continuous state of hypoxia for athletes. However, with this type of altitude training, the training quality and intensity can decrease if the altitude they are working at is too high. The ideal altitude for this type of training ranges from 1800m-2500m above sea level (13). The constant state of hypoxia associated with this type of training is attributed to the gains in performance the athlete develops. The training adaptations that are made are an increase in hemoglobin brought on by the increase of red blood cells. This is believed to help increase the VO_2max (13).

In a study performed by McLean et al., live high-train high theory was tested. This study took a group of Australian Football players and split them into two groups, an altitude-training group and a control group. The altitude group lived and trained at high altitude for 19 days of an 8-week training block, while the control group lived and trained at sea level. This particular study measured running performance using a 2000-meter running time trial and measured training load, training duration, and rate of perceived exertion (23). The rate of perceived exertion is how each particular athlete felt the difficulty of the training program was, and how they rated their level of fatigue. The results from the study showed three things: training load was almost certainly higher in the altitude group. Training duration was higher in the altitude group than in the control, and the mean rate of perceived exertion was higher in the altitude group. The 2000-meter time trial determined that, in the first posttest, the altitude group was possibly faster than the control group; but in the second posttest, the altitude group had performed better than the control group (23). These results have demonstrated that this type of altitude training is helpful to increase the level of performance.

Live High-Train Low

The next type of altitude training is “live high-train low.” Live high-train low is performed by living at a high altitude and training at a lower altitude. This, however, can be difficult to follow because of the amount of travel time needed in order to spend time at both of these altitudes. The location would have to be picked out very carefully to help decrease the amount of travel time required. However, there are altitude houses and tents, which can simulate a high altitude environment. With the development of these altitude houses and tents, it has become easier to bring the “mountains to the sea” (13). The athletes train at a normal altitude and then will live in altitude houses in order to carry out this training method. However, one has to remember when doing this type of training is that enough hours need to be spent in hypoxia in order to receive the benefits from this training program. Approximately 14 hours a day is recommended for an athlete to stay in the altitude houses in order to receive any sort of benefit from altitude training (13).

In a study done by Garviacan-Lewis et al., they examined various periods of altitude exposures on water polo players' hemoglobin mass and aerobic fitness. These measures were assessed through carbon monoxide rebreathing and the multistage shuttle swim test. Over six months, the athletes went through a total of 3 simulated live high train low exposures (14). The first block was 11 days long at 3,000 meters of altitude. Blocks two and three were both 9 days long at 2,500 meters of altitude, followed by 11 days at home, and then 10 days at 2,800 meters. The results indicated that after block one, the player's hemoglobin mass increased, and after blocks two and three, hemoglobin mass also increased (14). There was also a large correlation between hemoglobin mass and the multistage swim shuttle test scores. With these results, the investigators concluded that extra hemoglobin mass was achieved during this study, proving this to be an effective training strategy. However, this does not show whether an increase in hemoglobin mass can effectively increase aerobic power (14).

Intermittent Hypoxic Training

Another form of altitude training is "intermittent hypoxic training," which is also known as "live low-train high." This type of altitude training is popular especially with elite team sports. They complete this training by spending a few days in hypoxia then coming back to sea level (13). There is little data on whether intermittent hypoxic training has any true effect on performance, because exposure times are usually too short to induce any of the adaptations that are associated with altitude training (13).

With altitude training, timing is imperative. In order to see any gains from altitude training, the athlete has to spend enough time at altitude. Garvican et al. believe this to be at least 11 days for elite athletes, while other researchers believe it to be at least three to four weeks (8, 15). There are some discrepancies as to how long the gains last. According to the study by Garvican et al., after three days there was already a decline in the hemoglobin mass in their study (15). Chapman et al. discusses how the timing of the return from altitude is imperative in order to perform at a high level. In this study, it is believed that the athletes need to live at an altitude for a minimum of 28 days in order to maximize the changes provided through the hypoxic environment in altitude (8). It was also determined that for optimal performance, an athlete should return three to seven days before competition; however, this is not from a physiological standpoint (8). The investigators discuss that there still needs to be more research done in order to absolutely determine when is the best time to return from altitude for a competition (8).

Altitude training will continually have to be studied in order to determine all of the beneficial effects that can be achieved from this type of training. Even though research has identified the gains that can be made, there will always be more to know in regards to altitude training. However, it is believed that athletes will benefit from altitude training once or twice a year, especially if the athlete is utilizing the “live high-train high” or “live high-train low” programs (3). However, the coaches need to be very responsive if an athlete is not feeling well. This could mean the athlete is developing altitude sickness. Altitude sickness will hurt the athlete’s performance, especially if the athlete continues to ascend rather than come down from high altitude.

CHAPTER 4

RECOMMENDATIONS

Recommendations

Based on the research reviewed in this article, “live high-train low” is the best method of altitude training in order to have the best performance possible. More research needs to be done on this program in order to ensure the athletes can receive the greatest benefits. Another recommendation would be to study the duration of the effects of altitude. The “live high-train low” method needs approximately three to four weeks in order to achieve all of the benefits.

Summary

The body responds to different stimulus in different ways. In this paper, the body’s changes to altitude were discussed, along with different types of altitude training. As an athlete, it is important to know how your body will react to different types of training in order to determine which type is best for each individual. With new types of training developing everyday, it is important to know the effects of each one. In the future, it will continually be important to keep investigating the body’s response to altitude to find new ways to improve athlete’s performance, along with preparing their body’s for the changes when competing at altitude. Altitude training will continue to grow in popularity and it is important to keep researching different areas of this. A specific focus for future research is determining the best time for an athlete to return from altitude to compete in a competition in order to obtain all the benefits that altitude can bring.

In order to achieve the results desired from altitude training, it is also suggested that the person have a slow ascent up to altitude. This will decrease their chances of succumbing to altitude sickness. This will also allow the body time to fully acclimatize to the change in conditions and undergo the necessary physiological changes discussed in this paper.

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