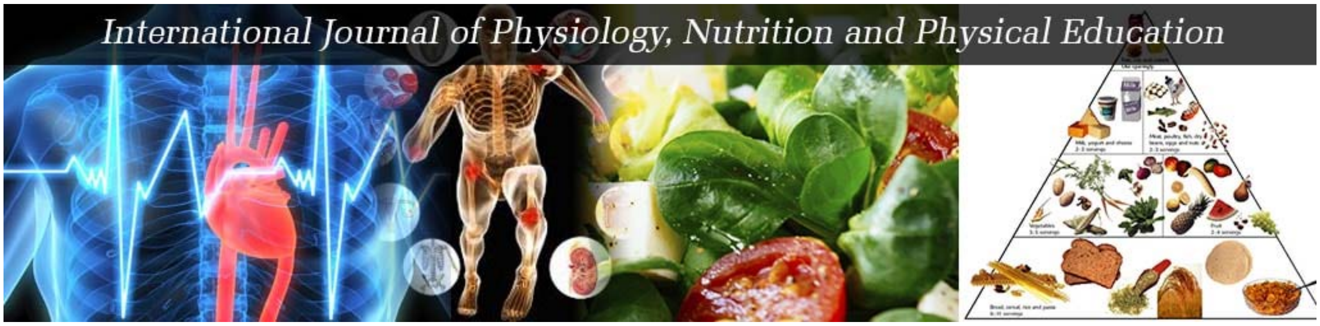

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Review on: Real and simulated altitude training on the performance of athletes

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Abstract
Differences in performance are typically less than 0.5% at the Olympic level. This indicates why many contemporary elite endurance athletes in summer and winter sport incorporate some form of altitude training plan, believing that it will provide the "competitive edge" to succeed at the Olympic level. The main objective of this paper is to explain the practical application of altitude/hypoxic/ training as utilized by elite athletes. Within the general framework of the paper, both the subjective and scientific evidence will be presented relative to the usefulness of several existing altitude/hypoxic training models and devices currently used by Olympic-level athletes for the purpose of legally enhancing performance. These comprise the three primary altitude/hypoxic training models: 1) live high + train high (LH + TH), 2) live high + train low (LH + TL), and 3) live low + train high (LL + TH). The models will be examined in detail and include various modifications: natural/terrestrial altitude, simulated altitude via nitrogen dilution or oxygen filtration. Exposure to high altitude could theoretically improve an athlete's capacity to exercise. It has also an adverse effect, for example the increase in red blood cells comes at a cost - having too many blood cells makes the blood thicker and can make blood flow sluggish. At very high altitudes (>5000m), weight loss is unavoidable because your body actually consumes your muscles in order to provide energy. Additionally, the body cannot exercise as intensely at altitude.

Keywords: Altitude Training, Hypoxia, Intermittent hypoxic training, Live high train low, Live High – train High, Live low - train High

1. Introduction
Altitude training is practiced by top athletes. Even though the efficiency of altitude/hypoxic training in terms to sea level performance is still unclear from research view point, athletes use it for preparation & competition purposes. There are numerous altitude training models which would be explained in our review.

A large number of people (80%) in the world live at low altitude (< 500 m) which has most favorable atmospheric pressure and oxygen presence for human being body functioning.

Meanwhile, if athletes ascend to high altitude they could theoretically improve their ability to do exercise. High altitude experience causes extensive physiological responses. Small oxygen pressure at high altitude can strain the oxygen transport systems of even the well- fitted athletes. The reduced amount of inspired air (P_IO_2) would lead to decrement of oxygen in the arterial blood (P_aO_2).

The extraction of oxygen for our muscles' function depends on the presence of oxygen circulating in arterial blood. Low oxygen uptake is a main problem for elite athletes at high altitude and this leads to decline in maximal oxygen uptake (V O_2 max) and performance at high altitude.

Experiment about altitude and physiological effects on human, for the first time conducted by Angelo Mosso in 1880's. Mosso's study about pulmonary ventilation improvement after participating in altitude training enabled him as a leader to this kind of research. In 1880's and 1900's other scientists also continued in studying medical aspects of high altitude training.

A group of scientists went to different mountaineers regions and tried to gather data with this particular physiological effects of high altitude. These areas were the 1911 Anglo-American Pikes Peak journey, the 1921-1922 International High Altitude to Cerro de Pasco, Peru, the 1935 International High Altitude to Chile, and the 1960-1961 Himalayan Scientific and Mountaineering Expedition (Silver Hut). As stated by, The 1968 Olympic Games in

Mexico City (~2,300 m) provoked a great deal of interest in the use of altitude training in preparation for competition. Whlie the results showed that athletes those who came from sea-level countries were affected by the low oxygen concentration at Mexico City. Likewise, performance times of sea-level middle and long distance runners' were highly decreased at Mexico City compared with their result times at sea-level the same year. Most middle and long distance track events medals were taken by athletes from high altitude-based countries. For example, Kenyan and Ethiopian athletes won 9(50%) medals out of 18 medals from the 800m through to the marathon. Since the Mexico City Olympic Games different researches have conducted in altitude training. In highly trained athletes, four weeks of training at an altitude of 1740 m produced no change in mass of hemoglobin in the blood and only a small increase in *maximum oxygen consumption* (Gore *et al*, 1997) [4]. *Altho*ugh this study did not include a train-low component, we conclude that higher altitudes are needed to stimulate red cell production in athletes living high and training low. The best duration of stay at altitude is uncertain, but there are strong clues from changes in the concentration of erythropoietin in blood during altitude exposure. The concentration rises in the first day at an altitude of 2500 m. After two weeks it is still high, but declining. After four weeks it is back to baseline (Chapman *et al*., 1998) [1].

The focus of this research was to answer important questions, what are the standard heights, ideal duration of stay at altitude and its subsequent effects on the physiology of the human body.

Moreover, in response to Levine and Stray-Gundersen (2005) [10], Gore and Hopkins maintained that the improvements in sub maximal oxygen efficiency, or even cardiovascular adaptation, rather than the hematological changes alone should be considered when assessing the mechanisms responsible for the improved sea level performance after altitude training (Gore CJ, & Hopkins WG.2005) [6]. Argue continues There is controversial issue over the mechanisms involved in performance improvement after altitude training. some studies have reported increases in hemoglobin mass (or red cell mass) after classical altitude training at altitudes of 1900m or above, others have reported no such change after training at such altitudes, or at slightly lower altitudes 1740-1800m (Gore CJ, 1997 *et al*.) [4]

Recent research has indicated that performance can actually improve as a result of altitude training in the absence of any significant increase in hemoglobin mass (Saunders P, *et al* 2004) [14]. Thus, what other mechanisms might explain the improvement in performance at sea level after altitude training. Gore and colleagues argue that altitude training improves exercise economy (Gore CJ, *et al* 2007) [5], through an increased ability to metabolize carbohydrate during oxidative phosphorylation, a decreased cost of ventilation, or by an increased ability of the muscle contractile machinery to produce work more efficiently (Green H, *et al*. 2000) [7].

An increase in buffering capacity of the muscle or blood would allow a greater build-up of acidity during exercise. Because a limiting factor to exercise is an increase in acidity, such a change would allow the athlete to exercise for longer before fatiguing. Exposure to real altitude produces a drop in P_IO_2, P_aO_2 and then arterial oxyhaemoglobin saturation (S_aO_2) resulting in a decrement in kidney oxygenation.

Levine and Stray-Gundersen (2005) [10] argued that the primary mechanism responsible for improved sea-level endurance performance following prolonged exposures to altitude is an enhanced erythropoietic response, which results in an elevated red blood cell volume and a resultant enhanced rate of oxygen transport. Recently, research at a genetic level has started to uncover some more clues as to what may be happening during altitude training (Zhu H, Bunn HF, 1999) [16].

It has been indicated that a transcription factor called hypoxia inducible factor-1 (HIF-1), which is present in every cell of the body, is the universal regulator of oxygen homeostasis and plays a vital role in the body's responses to hypoxia. During periods of normoxia the level of HIF-1 are very low, with the HIF-1 sub-units being quickly degraded, however, under hypoxic conditions the sub-units are not degraded as quickly and HIF-1 levels increase in the cells allowing it to transcribe specific genes. A summary of the genes HIF-1 activates gives us some idea of the excess ways in which altitude training may enhance performance.

Possibly one of the biggest problems athletes face when going to altitude is the drop in training velocity (pace) at training intensities comparable to those at sea level which can potentially result in detraining of the athlete. Because of the altitude-associated decrements in oxygen concentration which result in a reduction of the VO_2max and P_aO_2 which ultimately reduces oxygen to the muscles it is difficult for athletes (particularly endurance athletes) to maintain their normal sea level training intensity.

HIF-1 activates EPO, and involved in iron metabolism and erythropoiesis. HIF-1 also stimulates angiogenesis and glycolytic enzyme activity, cell glucose transporters, muscle lactate metabolism, carbonic anhydrase for enzymes that regulate pH and others that produce vasodilators such as nitric oxide (Clerici C, & Matthay MA, 2000) [2].

Because hypoxia causes a multitude of responses in the human body including but not limited to changes in red cell mass, angiogenesis, glucose transport, glycolysis, pH regulation, and changes in the efficiency of energy production at the mitochondrial level which could all potentially have a positive impact on exercise performance, potentially all of these mechanisms either solely or combined could be the cause of enhanced sea-level performance after altitude training. Further research is required to further reveal the mechanisms involved.

For each of the topics discussed in this paper, relevant searches were performed using Google Scholar, Pub articles and Med. Priority was given to more recent studies and those that used more rigorous study design.

Live high-train high model:

The Live High-Train High (LHTH) model is the conventional and commonly practiced form of altitude training. Thus, athletes live at altitude for a period of time and perform all their training and "living" in one location.

Speculated optimal altitude height for such model training is 2000-2500 m and duration for 3-4 weeks. But it is not scientifically proved. Going to very high altitude is unproductive. For example the increase in red blood cells comes at a cost - having too many blood cells makes the blood thicker and can make blood flow sluggish. This makes it harder for your heart to pump round the body, and can actually decrease the amount of oxygen getting to where it is needed.

At very high altitudes (>5000m), weight loss is unavoidable because your body actually consumes your muscles in order to provide energy. There is even a risk that the body's immune system will become weakened, leading to an increased risk of infections, and there may be adverse changes in the chemical make-up of the muscles. Additionally, the body cannot exercise as intensely at altitude.

Altitude classification

Death Zone	> 7500m
Extreme Altitude	5000-7500
High Altitude	3000- 5000m
Moderate Altitude	2000- 3000m
Low Altitude	1000- 2000m
Sea Level	< 1000m

[i] - Data adapted from Pollard and Murdoch 1998.

Taking some of the information about altitude training into consideration, various techniques have been devised in order to expose the athlete to the beneficial effects of high altitude whilst not reducing their ability to train effectively. These have been labelled 'Live High – Train High, 'Live Low – Train High' and 'Live High – Train Low'. The typical altitudes used are around 2000-2500m, which in itself reduces the risk of some of the unhelpful effects of altitude exposure. The 'low' altitudes may not actually be at sea level, but could be 1250m, for example. However, the difference between the two altitudes is significant enough to have an effect on training. But no one can agree with the above saying, because there is no specific standard or bench mark for this type of training. Examples of some of the world's altitude training bases are presented below:

Altitude Training Site	Country	Elevation (m/ft)
Albuquerque, New Mexico	USA	1525/5000
Nairobi	Kenya	1840/6035
Addis Ababa	Ethiopia	2400/7872
Bogota	Colombia	2500/8200
La Paz	Bolivia	3100/10168 etc.

Adapted from Wilber (2004)

Live high-train low model

For years, many endurance athletes have believed that exercising in thin mountain air is the best way to improve performance at sea level. But recently, a team of doctors gave a new spin to the high-altitude hypothesis and discovered that living a more sedentary life in the mountain air while training at a lower level gives athletes the greatest gains. Benjamin Levine and James Stray-Gunderson investigated the effects of living at altitude but training much closer to sea level. In their study they compared 3 groups of runners; one group lived low and trained low (San Diego, California, 150 m), another lived high (Deer Valley, Utah, 2500 m) and trained low (Salt Lake City, Utah, 1250 m), while the last group lived high and trained high (Deer Valley, Utah). Upon initial return to sea level runners in the Live High-Train Low group improved their 5-km time trial performance by 1.3% as a result of the altitude training, the Live High-Train High runners showed a small detrimental change (-0.3%), whereas the Live Low-Train Low runners got much worse (-2.7%) After 4 weeks back at sea level all groups improved but the Live High-Train Low and Live High-Train High groups remained significantly faster than the Live Low-Train Low group.

Even though this study was the first to indicate the Live High-Train Low model as the most appropriate to enhance subsequent sea-level performance a number of problems within this study do not make the results clear cut (Levine *et al.*, 1992; Levine BD and Stray J. -Gundersen, 1997) [8, 9].

High- high low model

This is a kind of modification on the Live High-Train Low model. In this case athletes live at high altitude and perform low to moderate-intensity training at high altitude but travel down to low altitude to perform high intensity training sessions. The model was developed to overcome the difficulties of performing high intensity training in a hypoxic environment.

Altitude simulation

The Finns have pioneered use of dwellings that can be flushed with air diluted with nitrogen (Rusko, 1996) [12]. Altitudes of around 2500 m can be simulated by reducing the oxygen content from the normal 21% to around 15%. A nitrogen house can be sited almost anywhere as a fixed or mobile facility and is probably the most cost-effective way to deal with teams of athletes. But athletes still have to suffer a dormitory lifestyle away from home. In most cases these apartments are designed for comfortable living by the athletes for periods between 12 to 18 hours per day. However these apartments are expensive to build and run and are not always convenient for athletes.

Altitude tents

A mini version of a nitrogen house, in the form of a tent, has recently appeared on the market. It simulates altitudes of up to 2700 m (9000 ft) and can be modified to simulate up to 4000 m (14,000 ft). The tent is set up on a bed or on the floor. The advantages are substantial: it is truly portable; it can be used with little or no disruption of family life, study, or work; and it is easily the best way to establish the altitude and program of exposure that suits the individual. This allows athletes to sleep in the hypoxic environment. But the units are moderately expensive. Examples of this type of equipment include the GO2 Altitude® Tent from Biomedtech, Melbourne, Australia, and the Altitude Tent systems from Hypoxico, New York, USA. A number of issues exist with this technology. The hypoxic environment inside the tent can be variable due to leaks and subject movement, and in some cases the inside of the tent can become warm and humid which can affect sleep quality. Because of the small size of the tent the build-up of carbon dioxide is even more dangerous in altitude tents and needs to be monitored carefully.

Intermittent Hypoxic Exposure (IHE)

As it has been stated Serebrovskaya TV. (2002) [15], intermittent hypoxic exposure (IHE) is exposure to short periods of hypoxic air at rest (9-15% oxygen, equivalent to approximately 6600-2700 m) alternated with normoxic air (21% oxygen). Athletes typically use a hypobaric chamber or a hypoxicator (machines that extract oxygen from the ambient air) to generate the hypoxic air. A typical protocol for this type of training is to breathe 5 minutes of hypoxic air followed by 5 minutes of normoxic air for a period of between 60 and 120 minutes per day for 2-3 weeks.

The drop in the inspired oxygen concentration of the air being breathed results in a drop of P_aO_2 and subsequently arterial oxyhaemoglobin saturation (S_aO_2) which stimulates the body to adapt. However, it is thought by some researchers that such a short altitude stimulus is not sufficient to cause significant haematological benefits for athletes and is therefore unlikely to produce performance change

Intermittent Hypoxic Training (IHT

As mentioned by Serebrovskaya TV. (2002) [15], IHT consists of breathing hypoxic air intermittently with normoxic air, however unlike IHE the athlete exercises while breathing the hypoxic air.

This is similar to living at sea level and conducting training sessions at altitude (LLTH). The extra stress of training under hypoxic conditions is suggested to cause increased adaptations resulting in improved performance. The effectiveness of IHT for the enhancement of sea level performance, however remain controversial. Aerobic performance change with altitude training Research into the effects of altitude training on subsequent sea level endurance performance is unclear, (Levine BD, & Stray Gundersen J. 1997) [9], with some researchers reporting significant improvements (Martino M, *et al*,1995) [11], while others report decrements in performance or in some cases no substantial change. A recent meta-analysis on the effect of various models of altitude training was published in 2009 and gives a good indication of what performance changes might be expected from the various methods.

Naturalaltitude models			**Artificial altitude models**			
	LHTH	**LHTL**	**LHTL prolonged continuous**	**LHTL short continuous**	**LHTL intermittent (IHE)**	**LLTH (IHT)**
Mean Power Output						
Elite	↔	↑	↔		↔	
Sub-elite	↔	↑	↑	↔	↑	↔
VO_2max						
Elite	↓	↔	↔	↔		
Sub-elite	↑	↔		↔		↑

The above table Data are very likely improvement in mean power output or VO_2max (↑), very likely decrement (↓) and either trivial or unclear (↔) changes in variables. LHTH, Live High-Train High; LHTL, Live High-Train Low; LLTH, Live Low-Train High; LHTL prolonged continuous, spending between 8-18 hours per day in hypoxia uninterrupted; LHTL short continuous, spending between 1.5-5 hours per day in hypoxia uninterrupted; IHE, intermittent hypoxic exposure, which was typically less than 1.5 hours per day; IHT, intermittent hypoxic training, which was typically 0.5-2 hours per day. Missing data indicates insufficient research studies to calculate an effect.

Clearly Live High-Train Low is beneficial for elite athletes. This model of altitude training typically produces a 4.0 ± 3.7% (mean ± 90% confidence level) improvement in performance at sea level. This indicates that the effect of this type of altitude training in more or less all elite athletes may be as small as 0.3% and as large as 7.7% improvement. It is clear that such an improvement in performance is not always associated with an increase in VO_2max indicating that other physiological measures may be causing the improved performance in elite athletes. Performance change in elite athletes as a result of other models of altitude training are either trivial or unclear or have not been tested to date (LHTL short continuous and IHT).

For sub-elite athletes the Live High-Train Low method is again advantageous in terms of improving performance (4.2 ± 2.9%) along with the Live High-Train Low prolonged continuous (1.4 ± 2.0%) and the Live High-Train Low intermittent methods (2.6 ± 1.2%). There are obvious gaps in the research which require further investigation such as the effect of IHT on elite performance.

Conclusion

Generally, from the reviewed literatures we found that there is no common agreement on the benefit of altitude training. But, from different perspectives there is sufficient evidence to suggest that all methods of altitude training can benefit athletic performance in some way, more over to gain improvement in sea-level performance for the top elite athletes, a Live High-Train Low method is recommended. Nevertheless, performance enhancement for athletes as a result of altitude training is not guaranteed.

Infect, some athletes may be unable to handle the extra stress that accompanies hypoxia, especially when they may be already working close to their physical limits. Thus, mal-adaptation and detraining may occur and the athlete's performance may decrease rather than increase.

Endurance performance at altitude may sometimes be improved with continued stay at altitude due to the acclimatization process. For the highly trained athlete, the training intensity required for maintenance of peak performance cannot be achieved at altitude. Also I can say that, the best duration of stay at altitude is uncertain, but there are strong clues from changes in the concentration of erythropoietin in blood during altitude exposure.

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