

## **Altitude, hypoxic and hyperoxic Training: research evidence vs. practical applications**

- by Dr. Trent Stellingwerff, PhD -

I recently attended the 53<sup>rd</sup> annual American College of Sports Medicine (ACSM) Conference in Denver, Colorado from May 31<sup>st</sup> to June 3<sup>rd</sup>, 2006. While there, I attended a two-hour symposium on altitude and hypoxic training featuring five world leading experts in the area, namely Drs. Ben Levine (*Presbyterian Hospital of Dallas*), Chris Gore (*Australian Institute of Sport*), Games Stray-Gundersen (*University of Utah*), Randall Wilber (*US Olympic Committee*), and Stephen Muza (*US Army Research Institute*)(see symposium outline- Appendix 1). Between them, they have over 60<sup>+</sup> scientific publications on the effects of altitude, training at altitude and the Live High- Train Low protocol (LHTL). What each of these presenters did during the symposium was provide a clear and concise overview on approximately a decade of research, which I hope to adequately reiterate below. But instead of citing every individual study throughout the review, I have provided a reference list for the enthusiastic reader at the end that comprises some of the more pertinent references (see: 1-65). I also hope to provide some future ideas and questions that I have formulated and discussed with colleagues. It should also be pointed out that there is ample evidence to show that living and training at altitude does increase endurance performance in competitions *at* altitude. However, to date, there is still no clear and consistent evidence showing the same increases in performances in competitions at sea level (where the vast majority of competitions are located). This lack of a clear effect of altitude training on sea-level performance likely has to do with a myriad of potential issues such as, training load, iron status, protocols and individual responses and variability. This review will attempt to unravel some of these misconceptions and shed light on a complicated area of sport performance.

### ***The Basics- definitions and ideas***

For readers already familiar with this field, the following may be redundant. But for those that are not, the following definitions will make sure that everyone is on the same understanding when it comes to enhancing performance through adaptations from training and living in situations of altered O<sub>2</sub> provisions.

*Adaptation* - Adjustment to environmental conditions or a new stimulus (such as training) as:

a) Adjustment of an organ of tissue to the intensity or quality of stimulation b) modification of an organism or its parts that make it more fit for existence under the conditions of its environment.

*Normoxia* - The normal oxygen content reaching tissues and organs at sea level (with 21% O<sub>2</sub> in the air, with a sea-level atmospheric pressure (or driving pressure) of 760 mmHg).

*Hyperoxia* - A condition characterized by a greater oxygen content of the tissues and organs than normally exists at sea level (ie. having someone breath air that contains greater than 21% O<sub>2</sub> contents).

*Hypoxia* - A deficiency of oxygen that normally reaches the tissues of the body, such as at altitude (generally considered less than 21% O<sub>2</sub> contents or at a reduced atmospheric pressure such as at altitude).

It should be made clear that there are three very different altered O<sub>2</sub> conditions that result in different acute and chronic adaptations that could increase performance:

1) *Hypoxic Living* - The chronic adaptations and acclimation that occur when spending the majority of ones time in hypoxic conditions (either consistently living at altitude or spending a significant amount of time in a simulated altitude environment such as a tent)

2) *Hypoxic Training* - The acute adaptations that occur when training in a hypoxic environment.

3) *Hyperoxic Training* - The acute adaptations that occur when training in a hyperoxic environment.

From these three conditions, several training and altered O<sub>2</sub> adaptation protocols have been hypothesized to maximize performance (for the sake of consistency, I will define altitude as anything greater than 2000m (~6500 feet):

*Live High- Train High (LHTH)* - Situation where one primarily lives *and* trains under hypoxic conditions, such as those found at altitude (for example, Kenyan runners that live and train in the Rift Valley which is at 2000<sup>+</sup>m above sea level).

*Intermittent Hypoxic Training (IHT)* - Situation where one lives at sea level but undertakes intermittent, or periodic, hypoxic training (such as driving up to altitude to do training sessions, or using a commercially available system to decrease O<sub>2</sub> provision during training such as see: <http://www.go2altitude.com/> and <http://www.altipower.com/>).

*Live High- Train Low (LHTL)* - Situation where one primarily lives in a hypoxic state, but trains in normoxic conditions (for example, someone who lives at altitude but drives down the mountain to lower altitudes to do training or someone who sleeps in a tent to simulated hypoxia, but does all training at sea level).

*Live High- Train Low with supplemental O<sub>2</sub> (LHTLO<sub>2</sub>)* - Situation where one primarily lives in a hypoxic state, but does some/all hard training in hyperoxic conditions (for example, someone who lives at altitude or sleeps in a tent, but undertakes some training while breathing supplemental oxygen (greater than 21% O<sub>2</sub>)).

And when undertaking these training and O<sub>2</sub> adaptation protocols, ideally they result in:

*Cardiovascular Adaptations* - Any stimulus that results in an increased ability for your body's cardiovascular system (hearts, lungs, blood) to pump oxygen and nutrient rich blood to the tissues of your body.

*Peripheral Adaptations* - Any stimulus that causes adaptation in any organ or tissue that is away from the central or core region of the body (ie. training increasing mitochondria in the leg muscles).

*Central Adaptations* - Primarily refers to the central nervous system and a training situation or stimulus that allows for increased drive and/or motivation, or increased subconscious neural-muscular firing that results in increased performance.

### ***Why does it work- mixed mechanisms and evidence?***

As already outlined in the definitions section, there are three main potential methods utilizing altered O<sub>2</sub> provision that could provide beneficial adaptations leading to increased performance for an athlete. It should be made clear that each of these three situations provides the body with different acute and chronic stimuli for cardiovascular, peripheral and central adaptations. Thus, a myriad of potential

mechanisms exist that justify why each of these three approaches possibly work, of which I will just highlight the main arguments.

1) Hypoxic Living (effects of chronic hypoxic acclimation and adaptation):

Recently there has been disagreement among the leading experts in the field over what is the primary mechanism to explain the increases in performance caused by LHTL (or the chronic adaptation effects of being at altitude)(17). Several researchers claim that the *only* effect of living at altitude is an increase in the kidney-derived hormone erythropoietin (EPO- which can also be made synthetically to treat anemia or illegally increase performance). Increased EPO then stimulates red blood cell (RBC) mass production in the bone marrow, resulting in increased RBC volume (or increasing hemtocrit). This in turn allows the blood to both transport more oxygen to working muscles and clear more carbon dioxide away, resulting in increases in  $VO_{2max}$  and performance. Or, in other words, primarily just cardiovascular adaptations. Other researchers have argued that the chronic effects of being at altitude can also be mediated through alternative mechanism(s) of either peripheral or central adaptations, such as increases in running economy/efficiency or increased blood lactate buffering capacity (15, 48). Most likely there is a myriad of mechanisms contributing to the increased performance generally (but not always) found after athletes have spent time at altitude, utilizing the LHTL protocol or LHTH protocol.

2) Hypoxic Training (acute hypoxic training stimulus LHTH):

Many researchers suggests that the primary mechanism of hypoxic training seems to be mediated through acute peripheral adaptations in the skeletal muscles (along with the chronic effects of cardiovascular adaptation from just living at altitude). Although more complex than this, in general the current thinking is that hypoxia stimulates a protein HIF-1 (hypoxia inducible factor-1), which in turn causes a myriad of adaptive processes to occur in the body. During hypoxic training, many of the adaptations take place within the skeletal muscle such as increased capillarization, vasodilation of blood vessels and increases in glycolytic and oxidative enzymes (anaerobic and aerobic metabolism). This allows a better production of oxidative (aerobic) energy, and less reliance on substrate level phosphorylation (anaerobic energy production, which also results in lactate production and associated acidosis). Of course the considerable negative consequence of training at altitude is a drastic reduction in training intensity and compromised training pace, resulting in a decreased mechanical and neuromuscular stimulus. Indeed, reduced electromyogram (EMG) activity has been recorded during exercise in hypoxia as compared to normoxia.

3) Hyperoxic Training (LHTL or LH-TLO<sub>2</sub>):

The whole concept of LHTL is that it ideally puts the athlete in the best situation for chronic adaptations caused from living at altitude (or sleeping in the tent), without compromising training load and training intensity or pace. In other words, it is vital that athletes live at a high enough altitude for a long enough period (see below for protocols) to achieve a large acute increase in EPO that is sufficient to increase the total red blood cell volume and  $VO_{2max}$ . And, at the same time, train at a low enough altitude to maintain interval training velocity and  $O_2$  flux near sea-level values. By training at sea-level, the athlete can still maintain a high training speed at lower lactate levels, which also allows for better neural (central nervous system) adaptations and better recovery from hard sessions.

There has been recent renewed interest in the idea that training with supplemental  $O_2$  may also cause additional acute stimulus in each training bout, which over time will lead to greater training adaptations for an endurance athlete. There has been a long history of utilizing extra  $O_2$  in augmenting performance. In fact, Sir Roger Bannister (of sub-4 minute mile fame) did some work on the effects, adding oxygen to the inspired air on performance, already in 1954 during some research while he was in medical school (6). But these studies just examined the acute effects of adding addition  $O_2$  to performance, which of course cannot be applied to a real competition setting (since athletes would have to run with  $O_2$  canisters on their backs). Recently, there have been several studies looking at the chronic

effects if training with supplemental O<sub>2</sub>, which requires subjects to come into the lab and cycle or run on a treadmill while breathing greater than 21% O<sub>2</sub> (usually 60 to 100% O<sub>2</sub>) through a breathing hose (44, 61, 62). These studies seem to show that when athletes train with supplemental O<sub>2</sub>, they are able to better maintain high power outputs without as much lactate production at the same heart rate as during normoxic training. Much of my PhD examined the acute metabolic effects of subjects breathing hyperoxic air (60% O<sub>2</sub>) during cycling exercise. In general, hyperoxia decreases the use of stored muscle glycogen, resulting in less lactate production. As well, hyperoxia attenuates epinephrine (adrenaline) release and heart rate that is normally seen during intense exercise- so there is a neural effect as well (49, 50). However, whether this translates directly to a substantial enough increase in training load during each workout to result in an increased performance, as compared to just normal training, remains to be fully proven. As well, there may be an ideal time and place to try and utilize hyperoxic training that “fits” with a certain athlete’s periodization of training (see below for more ideas). Nevertheless, as with all of these protocols utilizing altered O<sub>2</sub> provisions, measuring minute, but still worthwhile, increases in performance can sometimes be beyond the sensitivity of most laboratory tests.

### *Measuring performance in the lab*

Discussing elite level endurance performance in the scientific literature can be entirely different as compared to whether something “works” in a practical competition setting. For a scientist to publish and believe whether a certain method or intervention indeed increases performance, a statistical analysis showing significance is needed (ie. a p-value of less than 0.05). Due to variability among individual subjects, some studies need to show a 5% improvement in performance (sometimes even more) in the intervention group as compared to the control group of data to show a statistically significant difference. With elite level athletes, a 5% increase in performance is massive, and does not even approach what is practically needed to make a protocol or intervention worthwhile to undertake. For example, at the Olympic level, many times the difference between the gold medal and placing 10<sup>th</sup> in the final can be less than a 1% time difference! Obviously, it is impossible for a laboratory to have sensitive enough performance measures and equipment to try and pick up a 1% difference, let alone the 0.1% difference than often separates the medalists. So, from a practical stand-point, as both a scientist and also a coach, I tend to take a more liberal view of the scientific literature regarding sport performance.

I believe, if a certain protocol or intervention *claimed* to increase performance has: 1) is not on WADA’s banned substance list (see discussion below); 2) physiological and metabolic efficacy; 3) does not cause undue discomfort or extreme situations that compromises an athlete’s short and long-term health; 4) does not cause undue and long-term training decrements; and 5) shows no negative performance outcomes in the literature, then I tend to recommend that athletes, with monitoring from their coaches, should go ahead and individually experiment with the intervention or protocol (even if there is a *lack* of statistically positive performance increase in the scientific literature). The placebo effect is a real phenomenon, and if the athlete *thinks* he or she is going to increase their performance with a certain intervention, then in many instances the intervention has already “worked”.

### ***What “works”- do athletes actually use scientifically sound protocols?***

Anecdotally, during many conversations with athletes, coaches and scientists, one of the principal concerns with this whole area of performance enhancement, and the reason for the performance discrepancies seen in the scientific literature, is that most athletes are *not* using the most scientifically sound and supported protocols. In other words, many athletes are not using their altitude tents properly *or* are over-doing or under-doing altitude (hypoxic) training *or* not getting enough recovery while at altitude, resulting in overtraining and performance decrements. I will try and outline the most up-to-date protocols below, but it should be made clear that each athlete is different and therefore responds differently. Some athletes are responders and non-responders. As well, studies looking at the practical application of science into the optimal periodization of using altered O<sub>2</sub> to enhance performance are lacking.

### Initial blood screening

When going to altitude, or simulated altitude such as an altitude tent, ideally the chronic response that the athlete hopes to achieve is an increase in red blood cell (RBC) mass. This increase in RBC will result in the ability to carry more oxygen in the athlete's blood to the working muscle, resulting in increased endurance performance. All RBC's contain iron, and to produce new RBC's the athlete needs to have ample iron stores, or iron deficiency anemia will occur, resulting in a drastic *reduction* in endurance performance. Iron deficiency anemia is much more prevalent than most people realize. It is estimated that 20% of women, 50% of pregnant women and 5% of men are iron deficient. Therefore, since iron stores are so vital to healthy and viable RBC's, and ultimately to an athlete's performance, I would recommend at least a yearly blood iron analysis. And, if an athlete plans to go to altitude, or into an altitude tent, than an initial blood screening should be considered mandatory to rule out borderline iron deficiency anemia *before* going to altitude where it could result in a performance decrement. The following are the normal ranges and the parameters that should be assessed for male and female runners:

Table: Common iron blood parameters

Parameter	Females	Males
hematocrit	36.1 to 44.3%	40.7 to 50.3%
hemoglobin	12.1 to 15.1 g/dl	13.8 to 18.2 g/dl
serum ferritin	12 to 150 ng/ml	12 to 300 ng/ml
serum iron	iron: 60 to 170 mcg/dl TIBC: 240-450 mcg/dl transferrin saturation: 20-50%	

(note: for ferritin units ng/ml = ug/L)

Again, I would recommend that all athletes (regardless of whether altitude training is planned or not) get their blood checked for these parameters at least yearly (females should be checked several times per year and especially if already at risk). It should also be noted that there is a range that is considered "normal," but elite level endurance athletes are anything but normal humans, due to the daily strain of training and racing placed on their entire body. So if your blood values are on the low-end of the normal range, it would probably NOT be wise to undertake any altitude training or hypoxic stimulus, since this will place you at a greater risk for iron deficiency anemia. I would only start any altitude stimulus when your iron ranges are *well within* the normal ranges. To be safe, for elite female endurance athletes, I would supplement with iron and not undertake any altitude training if serum ferritin is below 20 ng/ml (despite the low range being 12). For men, a safe cut off is also around 20 ng/dl.

Many studies also supplement subjects with iron when undertaking altitude training to prevent potential anemia from occurring. Unless experienced, or at the high-end of the normal iron range parameters outlined above, I would also recommend that *all* athletes supplement with iron when going to altitude or into a tent. In fact, some studies have supplemented up to 100mg daily of supplemental iron to prevent anemia (see below).

### Iron supplementation

With iron, absorption is the key. Calcium and tannin (present in tea and coffee) prevent iron absorption; therefore never take an iron supplement with milk, tea or coffee. Also antacids, vitamin E and the antibiotic tetracycline (used with acne) prevent absorption. Also higher intensity workouts and foot contacts during running, slightly decrease iron absorption. Therefore, if you are really low in serum ferritin, doing non-impact and lower-intensity work for several weeks helps make the return to normal quicker. Vitamin C assists in iron absorption, therefore taking iron on an empty stomach with orange juice (that is not fortified with calcium) is probably the most ideal way to supplement.

If you are indeed diagnosed as anemic or borderline anemic (serum ferritin of less than about 12 or 15 for men and less than 20 for women), one should be looking to try and get a total of 75-100 mg of elemental iron per day (this is much more than you normally need per day, which is around 15-20mg daily, and is probably 3 to 4 pills worth (most pills)). Ferrous gluconate, which is the pill form, tends to be a little easier on most individuals stomach. Also you can get iron in liquid form, which some people handle better in terms of stomach discomforts and can easily be mixed in with orange juice to help mask the taste and also help with absorption. A common type of iron in the liquid form is called “Palafer Suspension” and is ferrous fumarate. Supplementation can, and probably will, cause some GI discomfort and some pretty abnormal looking feces (very dark and almost black sometimes). Have blood work done in about 4-6 weeks to see where your ferritin and other iron parameters have progressed.

Research has shown that natural iron sources actually offer a higher bioavailability of iron than compared to synthetic supplementation- so a combination may be best if really low in iron stores. Also, the body is better at absorbing heme iron (from animal sources) than non-heme iron (from plant sources). Natural sources of iron include: lean red meat, dark-meat poultry, dried beans, whole grains, enriched grain products, leafy green vegetables like spinach. Beef liver has the most concentrated source of iron. Fortified cereals with iron are a great source as well.

*Altitude tents*

One of the major messages that I would like to emphasize is that there needs to be a balance between the increased hypoxic stimulus resulting in adaptations versus increased recovery and regeneration. Rest and recovery is vital, as the hardest workouts and increased hypoxic stimulus will result in nothing if the athlete is not able to recover and become stronger.

One of the main reasons for the discrepancies in the scientific literature regarding whether LHTL leads to sea-level performance increases is due to so many studies using different types of subjects and differing protocols resulting in some studies showing performance benefits, while other studies do not. The studies that do show a performance benefit from LHTL all share the following features:

- How hypoxic? – ~2200 to 3200m of altitude (~7,200 to ~11,000 feet)
- How long for each exposure? – 14 to 24 hours per day, 7 days per week
- How many weeks? - >3<sup>+</sup> weeks

Therefore, to get a performance increase you need athletes under this level of hypoxic conditions (either at altitude or in the tent) for greater than 50% of the day for at least 3 weeks. The name of the game is consistency! But, unfortunately, most scientific publications do not accomplish this level and length of hypoxic stimulus, thus resulting in large variations in performance measure outcomes. Below is a table taken from the Australian Institute of Sport and their protocol of altitude adaptation that they have used with elite level runners:

*Table: LHTL simulated altitude protocol*

<b>Week</b>	<b>Mon</b>	<b>Tues</b>	<b>Wed</b>	<b>Thur</b>	<b>Fri</b>	<b>Sat</b>	<b>Sun</b>
<b>1</b>	0	2000	2000	2200	2500	0	0
<b>2</b>	2500	2500	2500	2500	2700	0	0
<b>3</b>	2500	2700	2800	2800	3000	0	0
<b>4</b>	2700	2900	3000	3000	3100	0	0

*Numbers are in meters.*

I would note that the above table is a conservative approach to increasing an athlete’s adaptation to altitude, and for some athletes a more aggressive increase could be warranted (as long as sleep is not overly hampered). Some individuals may not need any nights out of the tent during training phases, but again as long as consistent sleep is still occurring. In conversations with athletes that have used a tent, and from previous personal experience, I would also note the following regarding using altitude tents:

- 1) Sleep will generally be hindered when in the tent, or when initially acclimatizing to altitude. Therefore, trying to get extra nighttime sleep and/or a nap during the day will help attenuate the effects of building fatigue.
- 2) Get a pre- and post-blood draw so that analysis can be made as to whether or not you are a responder or non-responder in terms of RBC mass, hematocrit and possibly natural EPO (but this test is more expensive and it is better to have hematocrit and RBC mass anyway).
- 3) It is vital to hit 2500 to 3200m consistently for at least 50% of the athletes day and for at least 3 weeks to maximize the effects of altitude on natural EPO and RBC mass. Going higher than 3200m can result in a decrease in quality sleep.
- 4) If feeling over fatigued, take 1 or 2 days out of the tent per week. If not feeling fatigued and getting consistent sleep, without any upcoming competitions, it is better to just stay in the tent for an increased hypoxic stimulus.
- 5) Try and place the tent in a cool room (or air conditioned room), as it tends to get very warm inside while sleeping (a small fan inside the tent works great as well).
- 6) For small, lower-key competitions, it is suggested to sleep at sea-level the night before the competition to optimize sleep.
- 7) Generally, for major competitions/championships, it is best to sleep at normal sea-level for at least 1 week before the major race.
- 8) After at least a 4-8 week hypoxic stimulus, resulting in increased RBC mass, an athlete will benefit from this increased RBC mass and potential performance for at least 2 weeks and possibly up to 3 weeks for some athletes.

### *Living and training at altitude*

The original or traditional method of living *and* training at altitude is a totally different physiological stimulus than the LHTL protocol (see mechanisms section above). In general, training and recovering at altitude is physiologically much more difficult on an athlete's body. But it is argued that it is this extreme stimulus that can possibly push an already well-trained elite athlete up to that next level. In this vein, I would only recommend altitude training for very elite level endurance athletes, as university or club level runners would probably benefit more from just an increased training stimulus while still at sea-level, where recovery and critical training velocity are not hampered.

Although also important at sea-level, it is even more imperative at altitude, for the coach and the athlete to individually monitor training workload and intensity leading to fatigue factors. Each individual athlete can respond different to altitude: some athletes may experience altitude sickness within a day or two at 3000m and never be able to undertake altitude training, while others may not experience any side effects and only minutely experience the normal training pace decrease that occurs at altitude. Some other negative side effects of living *and training* at altitude include: increased overtraining symptoms, increased sympathetic nervous system responses (increase epinephrine/adrenaline release) which leads to an increased use of stored muscle glycogen, increased resting serum cortisol (possible marker for overtraining), decreased serum testosterone concentrations, decreased immunoreactivity, and a 50-100% increase in the frequency of upper respiratory tract and gastrointestinal tract infections when at altitude. However, if athletes are monitored closely, the increased training stimulus can overcome these negative consequences. Some of these recommendations may help in this regard:

- 1) Blood analysis should be done to assess iron status before going to altitude.
- 2) There is also some anecdotal evidence suggesting that it may be warranted to use a LHTL protocol in an altitude tent for at least a month prior to going to altitude to train to augment RBC levels and attenuate the normal training velocity decrease that is normally experienced by athletes initially going to altitude.
- 3) Higher altitude is not always better! When training at altitude, most suggest ~2000m to 2500m for 3 to 4 weeks for the optimal dose and duration. Once you get too far above 2500m, training

pace drops significantly, recovery time increases and the possibility for sickness increases. For example, St. Moritz in Switzerland, a popular altitude training location among elite endurance athletes, is located at an ideal 2500m.

- 4) A high carbohydrate diet (~60-70% of total intake) may help reduce the risk for mountain sickness and increase acclimation. Avoid alcohol, because this also increases the risk for mountain sickness and dehydration.
- 5) Mountain air is cool and dry, therefore drink even more fluids than normal (try and maintain urine color as clear, not dark yellow)
- 6) Initially, workout intensity will need to be lower until some adaptation can occur. Pushing your workouts too hard when just getting to altitude may increase your risk of overtraining or injury. Additionally, some people just do not adapt as well as others. There is not one workout program that is appropriate for everyone -- just like at sea level. Undertake a period of easier runs with some threshold training (under lactate or ventilatory threshold) at sea-level heart rate targets (ie. you will be running slower at altitude) for at least a week or two before undertaking harder  $VO_{2max}$  and/or interval based track sessions.
- 7) Keep a log where you rate fatigue during workout and at rest, morning resting heart rate, body weight, and mood changes. Correlate these parameters with the intensity of your workouts and durations of recoveries and this will help you and your coach develop a plan that is right for you.
- 8) Many coaches and athletes believe that the peak time for performance post-altitude training is approximately two weeks after descending to sea level. However, RBC's lifespan is 2 to 3 months in athletes, and therefore there is a possibility of having increased performance at least several months after altitude training (although this has never been rigorously tested).
- 9) Whether altitude training increases sea-level performance is still equivocal and highly individual, but it is clear that the chronic effects of living at altitude (increase in RBC mass) will most certainly increase sea-level performance.

### *Responders vs. non-responders*

All scientists working in this area have identified two subsets of endurance athletes who seem to be either “responders” or “non-responders”, in terms of an individual ability to first get an increase in natural EPO, leading to an increase in RBC mass and  $VO_{2max}$ . Unfortunately, there does not seem to be any readily identifiable specific characteristic that will pre-identify (before going to altitude) an individual to being either a responder or non-responder. The only measurable parameter is that once at altitude responders will show measurable increases in natural EPO within 30 hours, but non-responders show no such increase. There does not seem to be any identifiable mechanism or reason for this. (Note- Unfortunately, a blood EPO test is expensive!). Some have suggested that being a responder or non-responder may have to do with 1) genetics 2) initial iron storage status 3) training level 4) initial hematocrit and 5) fatigue level (over-training status). Either way, most experts would agree that an athlete will most certainly be a non-responder if: 1) they go to altitude already in a tired and over-reaching and/or over-trained state 2) they over-train once at altitude and 3) they already have initially low iron stores. Therefore, individual experience and close monitoring of blood iron status and training load are vital when attempting any hypoxic stimulus.

### ***Does altitude training increase sea-level performance? = Recovery is key!***

Although I have reiterated this already in several previous sections, from looking at the literature it seems that regardless of the stimulus, if recovery is not taking place, adaptation leading to performance increases will also not take place. When examining the scientific literature on LHTH effects on sea-level performance, the results are equivocal. Some studies have shown a positive effect, while other studies have not. The disparity in the results may have to do with subject variability, differing exercise protocols and performance tests as well as the negative consequences of training at altitude (mainly decreased



training velocities), over-riding the positive effects of training at altitude (mainly skeletal muscle adaptation and increased RBC volume). This is why the studies utilizing the LHTL method have found a more consistently produced increase in sea-level performance, since during LHTL it is possible to attain the benefits of both chronic altitude acclimatization and normoxic training stimulus. However, the LHTH protocol, coupled with proper recovery, may have a proper time and place in the intergraded yearly training periodization for an elite level endurance athlete.

### ***Hypoxic versus hyperoxic training- when, why and how much?***

Although probably impossible to test in a well-controlled study, many of these protocols when considering the physiological pros and cons, should be periodized according to the individual athlete's short-term and long-term training and competition goals. I will attempt to provide some ideas and current theories regarding hypoxic and hyperoxic training. It should be made clear that many of these ideas have not been critically tested in the scientific field, but instead are more practical recommendations and current ideas and hypothesis that will need more research to better elucidate.

#### *Intermittent hypoxic training*

I have already covered the more extensively researched LHTH above. But recently, there have been a couple of companies that have furthered the idea of hypoxic training through the development of intermittent hypoxic training (IHT) commercial systems (see definitions above for websites). Currently, there are only a couple of well-controlled scientific studies examining these hypoxic inducing systems with divergent results. As well, athletes and coaches should always be weary of websites and companies that exclusive claim their product "works," when the research has not been done by an unbiased outside source. If it sounds too good to be true, in most cases it is. Anecdotally, while talking to some researchers and athletes, there are some that believe these systems work in terms of some kind of central or peripheral adaptation leading to a decreased rating of perceived exertion and possibly better running economy. This has yet to be consistently shown in the scientific literature. As well, with IHT there is not enough chronic hypoxic stimuli to increased red blood cell mass, so obviously any adaptations must be either central or peripheral. Clearly, more well-controlled studies are needed to better elucidate the performance increasing mechanisms and potential of these IHT systems.

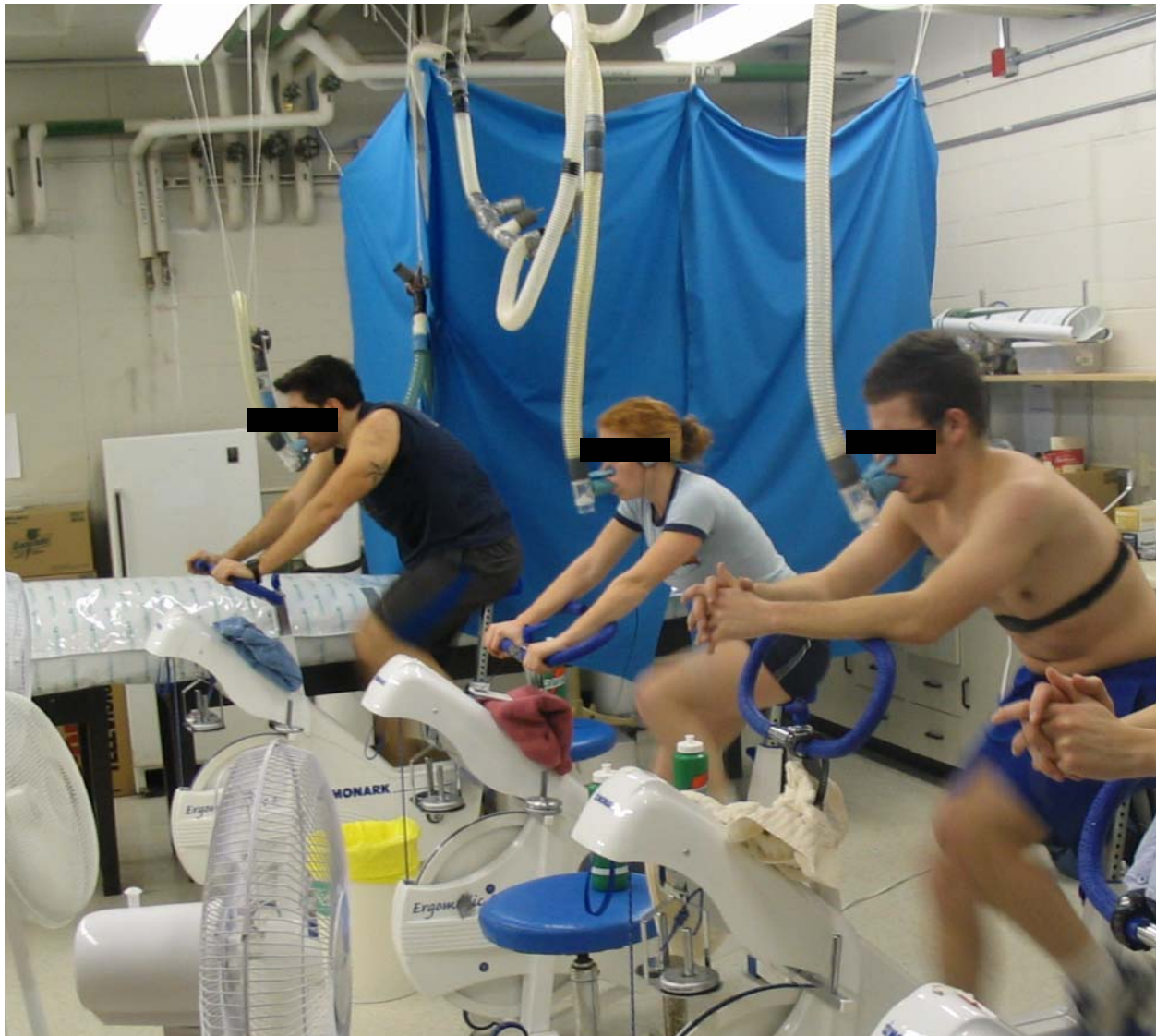
#### *Chronic hypoxic training*

Many coaches and athletes believe that the peak time for performance post-altitude training (LHTH) is approximately two weeks after descending to sea level. However, RBC's lifespan is 2 to 3 months in athletes, and therefore, in scientific theory, there is a possibility of having increased performance at least several months after altitude training (although this has never been rigorously tested). In conversation with several coaches and athletes, some have suggested positive performance outcomes in coming to sea-level after 3 or 4 weeks of altitude training, to perform several weeks of high-end speed work. This sea-level interval training allows the re-establishment of any neural adaptations and firing that might have been compromised during the altitude training due to decreased running speeds before major competitions.

#### *Intermittent hyperoxic training*

As I already mentioned, during my PhD we did several studies looking at the effects of subjects exercise while breathing hyperoxic air (60% O<sub>2</sub>). As well, Dr. Wilber, who works with USA Speed Skating, also showed some data outlining how periodically the Olympic Speed Skaters also undertook hyperoxic training, where they actually wore O<sub>2</sub> canisters on their backs and breathed in hyperoxic air while skating (61, 62). From our data (49, 50), and in conversation with others, it seems that major benefit of hyperoxic training seems to be mediated through increased power outputs or velocity at a given training intensity (ie. heart rate). So, for example, instead of doing a workout of 8 x 800m in 2:12 with 2 min recovery, under hyperoxic conditions the athlete might average 2:08. Other data also shows that there

may be a more efficient neural firing pattern (or increased central nervous system drive), as evidence from an increased EMG measurements. However, of all of the different types of altered O<sub>2</sub> training protocols implementing hyperoxic training is probably the most difficult to undertake for athletes, due to the technicalities of having athletes breathing 60 to 100% O<sub>2</sub> while training. Generally a laboratory or hospital setting is needed where athletes then periodically train either on a treadmill or cycle ergometer while breathing through a tube (see Fig. 1 below).



**Fig. 1.** Hyperoxic training set-up for 3 cyclists. Hyperoxic air (in this case 60% O<sub>2</sub>) is collected in the large bag (background), and transferred to each subject via the hoses, while subjects breathe the hyperoxic air through 2-way mouthpieces. (photo courtesy of Chris Perry, University of Guelph).

#### *Periodization of hypoxic and hyperoxic training for optimal performance gains*

As with all types of training, there is an optimal time, place, duration and intensity. In this regard, it seems pretty clear that living at altitude (or sleeping in a tent) will help increase both training and racing performance through augmented RBC volume. However, training at altitude, due to the associated decreases in training intensity and speeds, may be better served to do during base season or during training where the majority of the work is done at or below lactate or ventilatory threshold. Some of the recent hypoxic training studies (12, 45, 65) showed a performance benefit utilizing a longer duration exercise protocol (ie. 20-40 min of ventilatory threshold work) instead of higher end interval type training. Conversely, the hyperoxic training helps increase normal training speeds and neural firing and therefore

may be better used during more peaking speed workouts, approaching championship season. Keeping all of these issues in mind, along with some of the more readily accepted training principles, I will roughly outline two examples of the different ideas and trends involving hypoxic and hyperoxic training that a coach and athlete could *possibly* incorporate for optimal performance gains into two charts below. For simplicity, I have assumed that the athlete is on 7-day training mesocycles, that includes: 3 hard workouts per week (ie. anaerobic threshold runs,  $VO_{2max}$  sessions, interval sessions, speed sessions etc.), a long run and the remainder of the days (or double days) consists of easier/moderate recovery based mileage. I have purposely kept the charts more *general* in nature, due to the fact that no two athletes are alike and therefore, at the elite level, training should be highly monitored and continually altered and individualized.

**SCENERIO I: Elite longer-distance athlete prepping for the long-course IAAF World Cross-Country (XC) Championship race at the end of March and also competing in some of the European based XC season.**

Parameter	<b>General Prep</b> Sept. to December	<b>Specific Prep</b> Jan. to mid- Feb.	<b>Pre-Comp Phase</b> Feb to mid-March	<b>Comp Phase</b> end of March
Training Volume	BUILDING TOWARDS HIGH VOLUMES	MAINTAINING HIGH VOLUME	SLIGHTLY LOWERED VOLUME	LOW
Training Intensity / Speed	LOWER	BUILDING	HIGH	HIGH
Potential Use of Hypoxic Conditions	LHTH for all runs and 2 above AT threshold WO's / week	LHTH for all easy runs and long run and 1 AT WO/week	SLEEP AT ALTITUDE only  (LHTL)	NO USE OF HYPOXIC STIMULUS (sleep&train at sealevel)
Potential Use of Hyperoxic Conditions	at sea-level: 1 harder $VO_{2max}$ or interval WO/week	at sea-level: 2 harder WOs/week	at sea-level: all runs and 2 WO's/week  1 hyperoxic WO/week	at sea-level: all runs and 1-2 WO's/week 1-2 hyperoxic WO/week
Number of Races and Importance of Races	LOW	FEW RACES OF LOWER IMPORTANCE	MORE RACES OF BUILDING IMPORTANCE	WORLD XC CHAMPs ULTIMATE IMPORTANCE

SCENERIO II: Elite middle-distance athlete preparing for the 1500m at the IAAF World Track and Field Championships in late summer and also competing in some of the European based track season.

Parameter	General Prep Jan to end of April	Specific Prep May to June	Pre-Comp Phase July to mid-Aug	Comp Phase end of August
Training Volume	BUILDING TOWARDS HIGH VOLUMES	MAINTAINING HIGH VOLUME	SLIGHTLY LOWERED VOLUME	LOW
Training Intensity / Speed	LOWER	BUILDING	HIGH	HIGH
Potential Use of Hypoxic Conditions	LHTH for all runs and 1 to 2 above AT threshold WO's / week	LHTH for all easy runs and long run	SLEEP AT ALTITUDE only (LHTL)	NO USE OF HYPOXIC STIMULUS (sleep&train at sealevel)
Potential Use of Hyperoxic Conditions	at sea-level: 1 to 2 harder VO2max or interval WO's/week	at sea-level: 2 WO's/week 1 hyperoxic WO/week	at sea-level: all runs and 1-2 WO's/week 1-2 hyperoxic WO/week	at sea-level: all runs and 1-2 WO's/week 1-2 hyperoxic WO/week
Number of Races and Importance of Races	LOW	FEW RACES OF LOWER IMPORTANCE	MORE RACES OF BUILDING IMPORTANCE	WORLD TnF CHAMPs ULTIMATE IMPORTANCE

WO= hard workout

AT= anaerobic or lactate threshold tempo run

Although there are a fair amount of assumptions and speculation in the outlined charts, after reading well-controlled studies and talking to coaches and athletes that have experimented and used altered O<sub>2</sub> (either hypoxic or hyperoxic) conditions, there does seem to be ever-strengthening support for the ideas and trends that I have laid out above. Of course, designing a study to examine all of these variables would be impossible and also being an athlete with the options to undertake many of these protocols is very difficult. But for the very elite level athlete that is looking for every single *legal* edge they can find to be the best athlete that they can be, then maybe some of these ideas and protocols might work for you.

***To Ban or Not to Ban: WADA’s current stance on simulated altitude systems.***

I should digress a little into the World Anti-Doping Association’s (WADA) rationale for putting substances on their banned list, as I think not enough athletes and coaches have a strong grasp on this. One of WADA’s primary mandates is to try and level the playing field for all athletes. In other words, eradicate all dopers and illegal practices (<http://www.wada-ama.org/en/>). The WADA “Code” is a 44-page document that outlines every aspect of doping rationale, testing, education and prevention ([http://www.wada-ama.org/rtecontent/document/code\\_v3.pdf](http://www.wada-ama.org/rtecontent/document/code_v3.pdf)). Over the past few years, there has been some serious discussion on whether or not simulated altitude systems (tents, chambers, houses, re-breathers etc.) should be banned as an illegal performance enhancer. This discussion was alive and well at the past ACSM meeting, as several of WADA’s primary scientific advisors were also attending the conference. Supposedly, a final decision regarding the use of tents will be made this September and a new list will be published this October and taking effect on January 1<sup>st</sup> of next year (2007).

These are the 3 main criteria that WADA considers when evaluating the criteria as to whether a substances or practice should be banned (taken from the “Code” above):

**4.3.1** A substance or method shall be considered for inclusion on the *Prohibited List* if WADA determines that the substance or method meets any two of the following three criteria:

- 4.3.1.1** Medical or other scientific evidence, pharmacological effect or experience that the substance or method has the potential to enhance or enhances sport performance;
- 4.3.1.2** Medical or scientific evidence, pharmacological effect or experience that the *Use* of the substance or method represents an actual or potential health risk to the *Athlete*.
- 4.3.1.3** WADA's determination that the *Use* of the substance or method violates the spirit of the sport described in the Introduction to the *Code*.

Most (not all) experts agree that simulated altitude systems meet criteria 4.3.1.1, in so much that if used properly they will lead to performance increases in certain sports and events. But I should also point out that things such as training or a proper diet also meet criteria 4.3.1.1! And it is also pretty well agreed upon that simulated altitude systems do not meet criteria 4.3.1.2 (other than the possibility of a few headaches and less consistent sleep). So the interpretation of 4.3.1.3, or what WADA considers a violation of the spirit of sport, is going to dictate whether or not WADA decides to ban simulated altitude systems. The spirit of sport is loosely defined as comprising many of the following values: ethics, fair play, honesty, health, excellence, dedication, respect for rules and laws...to name a few. In personal communication with a few of the presenters at the conference, the point that WADA is concerned about, is that altitude tents allow for enhanced sport performance via "passive" mechanisms (ie. the athlete just needs to lay around in the tent and he/she will get better). And it is this perception of "passive" improvement that, according to WADA, *possibly* violates the spirit of the sport (they aren't sure yet). Of course, several scientists at the conference made the point to WADA that hard training actually puts an athlete's body in a catabolic state, and it is only during "passive" recovery, when the body is more anabolic, that the positive effects of training are mediated through increased skeletal muscle mass, proteins, mitochondria, enzymes etc.

So in my opinion, I believe that altitude tents actually help level the playing field between athletes who happen to live and train at sea-level, as compared to athletes in countries at altitude. Hopefully, WADA will eventually see it the same way.

### ***Future Directions***

Obviously, providing future ideas and directions are going to be dependant upon the upcoming WADA ruling. Despite the fact that the last decade or so of research has answered many questions, there are still many inquiries that remain that have already been outlined, such as: mechanism of improvement, responders vs. non-responders, screening of over-training symptoms while at altitude, stress vs. recovery ratios etc. The recent development of IHT, and the commercially available systems that can provide this stimulus, has provided another area ripe for future research. Probably, the most important question and mechanism that coaches and athletes are interested in is the ideal, or optimal, practical applications of all these stimuli into an integrated and periodized approach for each athlete in each unique situation. Of course as with many potential ergogenic phenomena, many times what is consistently occurring in the field and anecdotally "works", tends to precede the results in the laboratory. As well, it should be pointed out that with performance testing what many scientists tend to dismiss as a small positive trend without statistical significance, most times may be the slight edge that an elite athlete needs to win.

## **Appendix 1: Symposium Outline**

Session Title: **Altitude/Hypoxic Training: Research Based Evidence and Practical Application**  
Thursday, Jun 01, 2006, 8:00 AM -10:00 AM

Chair: Randall L Wilber, United States Olympic Committee, Colorado Springs, CO

Presentations:

8:00 a.m. - 8:05 a.m.--Introduction and Overview--Randall L. Wilber, FACSM. United States Olympic Committee, Colorado Springs, CO.

8:05 a.m. - 8:25 a.m.--**Physiological Responses and Underlying Mechanisms of Hypoxic Exposure**--Benjamin D. Levine, FACSM. Presbyterian Hospital of Dallas, Dallas, TX.

8:25 a.m. - 8:45 a.m.--**Non-Haematological Markers of Hypoxic Acclimatization**--Christopher J. Gore, FACSM. Australian Institute of Sport, Brooklyn Park SA, Australia.

8:45 a.m. - 9:05 a.m.--**Simulated Altitude: Titration of the Hypoxic Dose**--James Stray-Gundersen, FACSM. University of Utah, Salt Lake City, UT.

9:05 a.m. - 9:25 a.m.--**Practical Application of Altitude Training for Elite Athletes**--Randall L. Wilber, FACSM. United States Olympic Committee, Colorado Springs, CO.

9:25 a.m. - 9:45 a.m.--**Military Applications of Hypoxic Training**--Stephen R. Muza. U.S. Army Research Inst.of Environmental Medicine, Natick, MA.

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