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Anaerobic and Performance Adaptations to a “Live High–Train Low” Approach Using Simulated Altitude Exposure

By

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Abstract

The purpose of this study was to determine if a seven-day live high–train low (LHTL) simulated altitude exposure could improve (a) anaerobic and/or aerobic capacity (VO_{2peak}) in trained cyclists (n = 10) and (b) VO_{2peak} and/or 400m swimming performance in collegiate swimmers (n=8).

In procedures approved by the EMU Human Subjects Review Board, cyclists performed seven cycle ergometer trials to measure maximal mean power output ($MMPO_{4min}$), maximal accumulated oxygen deficit (MAOD), and VO_{2peak}, whereas swimmers completed five incremental arm ergometer trials (VO_{2peak}) and 400m swimming performance trials before and after LHTL. No significant changes were observed in any measured parameter. Therefore, the conclusion of this study is that a 7-day simulated altitude exposure of 2,500m for 8.5 hours each night is insufficient to result in changes in MAOD, VO_{2peak}, or performance among highly trained cyclists and swimmers.

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Chapter I: Introduction

Athletes around the world train to perform optimally during competition. Some, however, may have an edge over the competition due to where they live. Athletes who live at high altitudes are exposed to a decreased barometric pressure in the atmosphere. This decreased pressure makes the transfer of oxygen from the alveoli to the blood stream more difficult, in return requiring the individual's physiologic system to adapt and become more efficient (Wilber, 2001). The physiologic adaptations of altitude exposure feature enhanced erythropoiesis (increased oxygen carrying capacity), increased red blood cell volume (RCV), and increased oxygen carrying capacity (VO_{2max}; Bailey & Davies, 1997; Levine & Stray-Gundersen, 1997), as well as improved muscle buffer capacity and maximal accumulated oxygen deficit (MAOD; Gore, Clark, & Saunders, 2007; Gore, Hahn, Aughey, Martin, Ashenden, Clark, Garnham, Roberts, Slater, & McKenna, 2001; Mizuno, Juel, Bro-Rasmussen, Mygrind, Schibye, Rasmussen, & Saltin, 1990; Roberts, Clark, Townsend, Anderson, Gore, & Hahn, 2003).

Although these adaptations can arise through altitude exposure, training at altitude may result in a significant decrease in training intensity and thus athletic performance (Gore, Little, Hahn, Rice, Bourdon, Lawrence, Walsh, Stanef, Barnes, Parisotto, Martin, & Pyne, 1997; Squires & Buskirk, 1982). Therefore, debate about the tradeoff between the "benefits" of altitude exposure and the limitations of a decreased training intensity exist. In a benchmark study performed by Levine and Stray-Gunderson (1997), a "live high–train low" (LHTL) approach was implemented over the classic "live high–train high" (LHTH) approach also developed by Levine and Stray-Gunderson (1992). The results of this study demonstrated a greater improvement in the LHTL group when compared to the LHTH group, therefore suggesting that the LHTL approach elicits greater adaptations to altitude exposure.

Due to the limited locations that would allow an individual to conveniently live at altitude and train at sea level, the utilization of altitude tent systems have become more prevalent in recent years (Baker & Hopkins, 1998). Altitude tents simulate a natural altitude environment by adding nitrogen into the air, thus lowering the oxygen concentration. This allows individuals to follow the LHTL approach in a convenient manner.

Several studies have demonstrated proposed performance or physiologic improvements after exposure to a simulated altitude; however, the mechanism behind the adaptation is unclear (Wilber, 2001). Many studies (Chapman, Stray-Gundersen, & Levine, 1998; Levine & Stray-Gundersen, 1997; Nummela & Rusko, 2000) have shown that performance improvements after simulated altitude exposures are due to increases in VO_{2max} and therefore adaptations in aerobic metabolism. However, other studies have revealed that adaptations to the simulated altitude exposure occur in the anaerobic energy systems, with increased muscle buffer capacity and MAOD being reported after altitude exposure (Mizuno et al., 1990; Roberts et al., 2003; Saltin, Kim, Terrados, Larsen, Svedenhag, & Rolf, 1995). There is also uncertainty regarding the necessary level of exposure (elevation and duration) to achieve optimal adaptation. Previous research has suggested the duration of exposures to be upwards of 28 days (Gore et al., 1997; Levine & Stray-Gundersen, 1997), which may seem impractical for some individuals. The results indicated above, specifically the dramatic improvements in MAOD after a short term altitude exposure found by Roberts et al. (2003), and the limited research regarding the potential anaerobic adaptations to short term altitude exposure have motivated this study.

Statement of the Purpose

The purpose of this research was to determine if a short-term, seven-day simulated LHTL altitude exposure could increase (a) anaerobic capacity, as assessed by MAOD, and/or aerobic capacity in trained cyclists; and (b) aerobic capacity and/or 400-meter swimming performance in highly trained swimmers.

Significance

Technology has continued to play a role in the development of sport performance through the creation of simulated altitude training systems. This theory is founded on the discoveries, led mostly by Levine and Stray-Gunderson (Reviewed in Wilber, 2001), that highlight the effects of altitude exposure. The major manufacturers of these systems are Hypoxico Altitude Training Systems (Hypoxico Inc., NY) and Colorado Altitude Training Systems (Colorado Altitude Training, CO). The literature has focused primarily on the aerobic adaptations associated with altitude exposure. However, other research suggests that there may be a substantial anaerobic effect as a result of the simulated altitude exposure.

Research Questions

1. Can significant physiologic anaerobic improvements, specifically MAOD, and/or aerobic capacity improvements occur in trained cyclists after a seven-day simulated altitude exposure?
2. Does a short-term, seven-day simulated altitude exposure significantly improve aerobic capacity and race performance in 400-meter swimming trials among highly trained collegiate swimmers?

Assumptions

1. All participants will occupy the tent alone under simulated altitude conditions eight to twelve hours per day for the duration of seven days.
2. All participants will appropriately and thoroughly document daily training in a logbook that will be turned in to the researcher at the end of the study.
3. The altitude tent will accurately and consistently maintain the level of oxygen that would be equivalent to a desired altitude of 2,500m.
4. The participants will follow all specific guidelines and recommendations given by the researcher.

Limitations

1. There are a limited number of altitude tents available for use in this study, therefore limiting the number of subjects tested.

2. Due to the inability of all subjects to undergo the altitude exposure at the same time, participants' fitness levels may vary based on the point of season that the simulated altitude exposure is completed.
3. Due to a limit of altitude tent systems, a single/double blind control group cannot be part of this study's protocol.

Delimitations

1. Participants will sleep in the altitude tent for a seven-day period.
2. Participants must reside in the tent for eight to twelve hours per day.
3. Participants will be members of the Eastern Michigan University Swim Team and the local cycling community, ranging in age from 18 to 45 years.
4. Participants who have been exposed to an altitude greater than 2,000m for longer than 14 days in the past three months may be excluded from the study.

Definition of Terms

1. Simulated Altitude – Altitude tents, like those designed by *Hypoxico Altitude Training Systems* and *Colorado Altitude Training,* allow individuals to sleep at a simulated elevation and gain the benefits associated with altitude exposure. The tent fits over an individual's bed and is reasonably air tight, but allows room air to enter as a safety precaution. An oxygen concentrator is used to pump lower percentage oxygen air into the tent simulating a given altitude (2,500m in this case).

2. Live High–Train Low (LHTL) – Individuals who spend a substantial portion (e.g. 8 hrs/day) at moderate elevations but train at lower elevations, preferably near sea-level.
3. Live High–Train High (LHTH) – Individuals who live and train at moderate elevations (2,000-3,000m).
4. Live Low–Train Low (LLTL) – Individuals who live and train at elevations near sea-level.
5. Intermittent Altitude Exposure (IAE) – Generally speaking, individuals participating in an IAE protocol will be exposed to altitude periodically and for relatively shorter durations compared to constant exposure.
6. Hypoxia – an oxygen deficiency caused by a reduction in the partial pressure of oxygen in ambient air because of a decrease in either the ambient barometric pressures or the oxygen concentration of the inspired gas (Mazzeo & Fulco, 2006).
7. Erythropoiesis – The stimulation of erythrocytes, which allow for an increased ability to transport and utilize oxygen within the body (Mack, 2006). Erythrocytes transport the oxygen-carrying molecule hemoglobin from the lungs to the tissues. Exercise and hypoxic conditions can increase the levels of erythrocytes in one's body.
8. Maximal Oxygen Uptake (VO_{2max}) – Maximum amount of oxygen utilized during whole body dynamic exercise.
9. Peak Oxygen Uptake (VO_{2peak}) – The greatest amount of oxygen uptake used by small muscle mass (e.g. upper vs. lower body).
10. Maximal Accumulated Oxygen Deficit (MAOD) – Oxygen deficit is represented as the area between the curve of the oxygen demand and the curve of the actual oxygen

uptake and is representative of the anaerobic capacity (Medbo, Mohn, Tabata, Bahr, Vaage, & Sejersted, 1988).

11. Na+ -K+ -ATPase – Maintains Na^+ and K^+ concentration gradients as well as membrane excitability (Clausen, 2003; Fowles, Green, Tupling, O'Brien & Roy, 2002; Fraser, Li, Carey, Wang, Sangkabutra, Sostaric, Selig, Kjeldsen & McKenna, 2002), therefore maintaining the muscle membrane potential necessary for muscular contraction.
12. Erythropoietin – a hormone that stimulates red blood cell production.
13. Hematocrit – component of blood that is composed of cells, mostly red blood cells.
14. Hemoglobin – a protein in red blood cells that is responsible for transporting oxygen to tissues.
15. Red Blood Cells – contain hemoglobin for the transport of oxygen to the tissues.
16. Reticulocytes – immature cells that do not have all the characteristics of red blood cells.

Chapter II: Review of Literature

Introduction

For nearly half a century, scientists have known that altitude can have both a detrimental and positive impact on sports performance (Levine, Stray-Gundersen, Gore, & Hopkins, 2005). In an effort to achieve the potential performance adaptations, altitude training has become a prominent component to seasonal training designs (Wilber, 2001) in some athletes. However, research has been unable to provide a clear understanding as to the mechanisms involved in adaptations to altitude exposure and the optimal training design to result in the greatest benefits. This ambiguity has continued the progression in simulated altitude research and has inspired scientists to attempt to uncover the mystery.

Approaches to Altitude Exposure

Increases in natural altitude coincide with a decreased barometric pressure. This leads to progressive decreases in the partial pressure of inspired oxygen and, at some point, the partial pressure of oxygen in arterial blood. According to Boyle's Law, the reduction in barometric pressure associated with increases in altitude results in an increase in the volume of atmospheric gases, specifically nitrogen, oxygen, and carbon dioxide (Mazzeo & Fulco, 2006). This makes the delivery of oxygen to the tissues more difficult, resulting in either a necessary reduction in exercise intensity and/or physiologic adaptations to account for this environmental change.

There are many methods to achieve an artificial altitude exposure without actually traveling to a natural altitude environment. Some artificial methods simulate the actual change in barometric pressure through the utilization of an airtight environment (e.g.

barometric pressure chambers). Alternatively, individuals can attain a similar response by lowering the oxygen concentration of the inspired gas (e.g. altitude tent or house). Regardless of the approach taken, the results are very similar. The focus of research is now centered on determining the exposure approach that achieves the greatest adaptation.

Intermittent Altitude Exposure (IAE).

According to Levine (2002), intermittent altitude exposure is a method in which individuals discontinuously expose themselves to hypoxic conditions attempting to receive similar adaptations to that of natural altitude exposure, in effort to improve athletic performance. The thought behind this approach is that a more severe exposure will allow for adaptations to an altitude environment; however, the shorter durations will not result in a detrimental decrease in performance. However, individuals who exercise at altitude typically experience confounding results compared to individuals who follow a LHTL approach or IAE approach without exercise.

In an attempt to better understand this approach, researchers asked six males and females living at sea level to complete a cycle time trial both before and after a three-week period of IAE (Beidleman, Muza, Fulco, Cymerman, Ditzler, Stulz, Staab, Robinson, Skrinar, Lewis, & Sawka, 2003). The IAE consisted of four hours per day, five days per week, over a three-week period, at an elevation of 4,300m. The protocol had participants cycle for 45-60 minutes at an intensity of 60-70 percent VO_{2max} during each IAE session, followed by resting for the remainder of the exposure. The IAE training approach improved time trial performance by 21 percent, adductor pollicis endurance by 63 percent, and resting arterial O_2 saturation at altitude by 10 percent.

Based on the results, these researchers argue that IAE training can yield similar benefits and adaptations as chronic altitude residence.

Morton and Cable (2005) investigated whether IAE would enhance performance to a greater degree than would equivalent sea level training. Sixteen moderately trained males were split into treatment and control groups. Throughout a four-week period, the participants performed 30 minutes of cycling exercises three times per week. The treatment group completed the exercise at a simulated altitude of 2,750m, while the control group completed the workouts at sea level. Researchers measured changes in VO_{2max}, blood lactate, anaerobic performance (e.g. power output), and hemoglobin and hematocrit, but found no significant differences between groups. Therefore, it was concluded that this IAE routine had no impact on aerobic or anaerobic performance, possibly due to the fact that the treatment group exercised at altitude.

Researchers followed a Chilean Army's long-term exposure to intermittent hypoxia demonstrated by relocating from sea level to 3,550m every three and a half days over a 22-year period of time (Heinicke, Prommer, Cajigal, Viola, Behn, & Schmidt, 2003). The soldiers' hematological response to this change in altitude was analyzed and resulted in an 11 percent increase in total hemoglobin mass and similar increases in red cell volume and hematocrit. Based on these results, it was determined that acclimatization to long-term IAE results in similarly elevated hemoglobin and red cell volume responses to that of chronic hypoxic exposures.

Live High–Train Low Approach.

In 1997, Levine and Stray-Gundersen performed one of the most notable altitude studies that changed previous notions in regards to what was deemed the best way to approach altitude exposures. Previously, researchers believed that individuals received peak adaptation by following a LHTH approach (Levine & Stray-Gundersen, 1992). However, the results from this groundbreaking research demonstrated more robust adaptations. Therefore, Levine and Stray-Gunderson (1997, 2006) suggested living high, which stimulates erythropoiesis and maximizes the oxygen transport adaptations associated with altitude, and training low, which avoids a detraining effect with the necessary decrease in intensity at altitude as well as any detrimental effects of altitude (e.g. altitude sickness).

Therefore, Levine and Stray-Gundersen (1997) set out to uncover the mystery about the physiologic differences to a variety of altitude exposure approaches. Participants were divided into one of three natural altitude groups: (a) LHTL - live at 2,500m and train at 1,200-1,400m, (b) LHTH - live at 2,500m and train at 2,500m, or (c) LLTL - live at sea level (150m) and train at sea level (150m). All three groups were exposed to similar training regimens to control for training adaptations, and all groups were exposed to an environment with similar terrain. After the four-week exposure to this approach, the group that demonstrated the most robust improvement was the LHTL group, who had an increase in VO_{2max} as well as race performance.

Another study sought to compare the difference between a LHTL and LLTL regimen among participants (Schmitt, Millet, Robach, Nicolet, Brugniaux, Fouillot, & Richalet, 2006). The LHTL participants were exposed to simulated altitudes of 2,500m, 3,000m, and 3,500m and completed training sessions at 1,200m. Alternatively, LLTL participants remained at a constant elevation of 1,200m throughout the study's duration. Results demonstrated an increase in VO_{2max} in both the LHTL and LLTL groups, although the groups were not significantly different. However, peak power tended to increase more in the LHTL group than the LLTL group (4.1 percent vs. 1.9 percent, respectively, $p=0.06$). Based on these results, researchers agreed that the best approach to altitude exposure is by following the LHTL approach.

A similar LHTL approach exposed participants to simulated altitudes of 2,500m, 3,000m, and 3,500m for 11 hours per day and trained at an altitude of 1,200m. Results from this LHTL approach found a variety of blood parameters demonstrating significant improvements up to the elevation of 3,000m when compared to the pre-test values (Robach, Schmitt, Brugniaux, Nicolet, Duvallet, Fouillot, Montereau, Lasne, Pialoux, Olsen, & Richalet, 2006a). Despite these adaptations in the participant's blood composition, VO_{2max} and time to exhaustion resulted in no improvement from pre- to post-test for the two groups.

The same researchers (Robach, Schmitt, Brugniaux, Roels, Millet, Hellard, Nicolet, Duvallet, Fouillot, Montereau, Lasne, Pialoux, Olsen, & Richalet, 2006b) also followed a LHTL approach almost identical to that just mentioned by Robach et al. (2006a). Red blood cell volume increased only in the LHTL group, and their VO_{2max} tended to increase to a greater amount than in controls. Therefore, authors concluded that improvements in blood parameters do not always lead to improvements in VO_{2max} and performance.

The literature indicates that the best approach to altitude training is to follow a LHTL technique (Baker & Hopkins, 1998; Levine, 2002; Levine & Stray-Gundersen, 1997, 2006). This enables the individual to gain the benefits from altitude exposure and yet train at elevations that facilitate intensities necessary to improve or maintain fitness and thus performance. Intermittent hypoxic exposures occur for shorter durations, which may be convenient; however, this is likely outweighed by the severe levels of hypoxia that may result in negative reactions (e.g. altitude sickness) by participants.

Optimal Exposure of Altitude

Research over the past decade has provided supporting evidence that a LHTL approach results in the most robust performance enhancements. However, still debated by researchers are the levels of altitude and duration of exposures that result in the greatest adaptations (Hahn, Gore, Martin, Ashenden, Roberts, & Logan, 2001; Rusko, 1996). An altitude too great may result in detrimental effects (e.g. detraining and/or altitude sickness), whereas one too low may not allow for adaptations to occur (Levine & Stray-Gundersen, 1992, 1997). A variety of elevations have been found to result in adaptations: 2,200m (Nummela & Rusko, 2000), 2,500m (Levine & Stray-Gundersen, 1997; Ri-Li, Witkowski, Zhang, Alfrey, Sivieri, Karlsen, Resaland, Harber, Stray-Gundersen, & Levine, 2002), and 3,000m (Brugniaux, Schmitt, Robach, Jeanvoine, Zimmermann, Nicolet, Duvallet, Fouillot, & Richalet, 2006; Gore et al., 2001; Robach et al., 2006a). In addition to the optimal elevation, researchers must also determine the appropriate duration of exposure to result in adequate adaptations. Research has indicated improvement in 5 to 7 days (Ashenden, Gore, Dobson, Boston, Parisotto, Emslie, Trout, & Hahn, 2000; Koistinen, Rusko, Irjala, Rajamaki, Penttinen, Sarparanta, Karpakka, & Leppaluoto, 2000; Roberts, Clark, Townsend, Anderson, Gore, & Hahn, 2003), 14 days (Levine & Stray-Gundersen, 1997; Mizuno et al., 1990), or more than 27 days (Gore et al., 1997; Stray-Gundersen, Chapman, & Levine, 2001).

Elevation of Simulated Altitude.

Levine and Stray-Gundersen (1997) created a longitudinal research design to study the effect of LHTL on performance. Recruited were 27 male and 12 female competitive distance runners, aged 18 to 31 years. Participants performed a six-week "lead-in" phase near sea level where the training was supervised, and familiarization trials took place to assess baseline fitness. Participants were then divided into one of three natural altitude groups: (a) LTHL [live at 2,500m and train at 1,200-1,400m], (b) LHTH [live at 2,500m and train at 2,500m], or (c) LLTL [live at sea level (150m) and train at sea level (150m)]. After a four-week period, the LHTH group experienced similar adaptations in red blood cell volume and VO_{2max} while living and training at 2,500m as did the LHTL group while living at 2,500m and training at 1,250m. The difference between the two was an improvement in 5,000m time trial only seen in the LHTL group. Therefore, it was concluded that exposure to a moderate altitude (e.g. 2,500m), combined with training at low altitude, is adequate to elicit 5,000m running performance improvements.

Ten Swiss national team orienteers were paired with a control group and followed a LHTL routine by living at 2,500m for 18 hours per day and training at 1,800m and 1,000m above sea level for 24 days (Wehrlin, Zuest, Hallen, & Marti, 2006). The hypoxic group showed increases in hemoglobin mass (5.3 percent, $p<0.01$) and red cell volume (5 percent, $p<0.01$) compared to the control group, which showed no change. These changes coincided with improvements in VO_{2max} (4.1 percent, $p< 0.05$), time to exhaustion (41 seconds, $p<0.05$), and 5,000m running times (18 seconds, $p<0.05$). Therefore, the researchers concluded that significant improvements, particularly hemoglobin mass and red cell volume, were made by living at 2,500m and training between 1,000 and 1,800m.

Ri-Li and colleagues (2002) investigated the impact of a variety of altitudes on the stimulation of erythropoietin release. Over a four-week duration, participants were exposed to altitudes of 1,780m, 2,085m, 2,454m, and 2,800m for a period of 24 hours. Researchers measured erythropoietin levels at sea-level and after 6 and 24 hours at each altitude. It was reported that erythropoietin increased significantly by 24-30 percent ($p<0.05$) after 6 hours of exposure at all altitudes. However, erythropoietin experienced increases of approximately 77-92 percent at the altitudes of 2,454m and 2,800m, which continued to increase after 24 hours. These results allowed researchers to conclude that the threshold altitude for stimulating sustained erythropoietin release is 2,100-2,500m. Below this altitude, the erythropoietic response is minimal and not sustained for long periods of time.

The rate of erythropoiesis, arguably a primary mechanism for performance improvement (Levine & Stray-Gundersen, 1997), is dependent upon the severity of altitude (Ri-Li et al., 2002). This would suggest that the greater the altitude, the greater the adaptation in erythropoiesis. However, some researchers believe that altitudes above 3,500m would result in detrimental effects, such as altitude sickness (Montgomery, Luce, Michael & Mills, 1989). Therefore, a group of researchers designed a LHTL study to evaluate the effects of varying altitude on a group of swimmers, cross-country skiers, and runners (Brugniaux, Schmitt, Robach, Jeanvoine, Zimmermann, Nicolet, Duvallet, Fouillot, & Richalet, 2006). Cross-country skiers were exposed to 2,500, 3,000, and 3,500m for 11 hours per night and six nights at each altitude. Swimmers spent approximately 16 hours per day at altitude, with five nights at 2,500m and eight nights at 3,000m. Runners were exposed to altitude 14 hours per day, with six nights at 2,500m and twelve nights at 3,000m. Athletes exposed to 3,500m demonstrated no performance improvement, no improvement in VO_{2max}, and declines in overnight oxygen saturation. Alternatively, participants below 3,500m experienced improvements in these measures. Therefore, it was concluded that a LHTL exposure should not exceed 3,000m for a period of 18 days, with at least 12 hours per day exposure.

As discussed in the opening section regarding LHTL (Robach et al., 2006a), adaptations ceased beyond exposure of 3,000m. Participants were exposed to 2,500m, 3,000m, and 3,500m for 11 hours per day, for six days at each altitude, while training at 1,200m. A variety of blood parameters demonstrated significant improvements up to 3,000m but either declined or stayed the same after the exposure was increased to 3,500m.

Furthermore, Robach et al. (2006b - discussed in the LHTL section) exposed swimmers to a 13-day LHTL protocol. Participants spent 16 hours per day at 2,500m for five days and at 3,000m for eight days while performing their training at 1,200m. This exposure failed to result in performance improvements; however, blood parameters were affected.

Participants trained at 1,200m while living at simulated altitudes of 2,500m for five to eight days and then between 3,000m and 3,500m for eight to twelve days, as was presented in the LHTL section (Schmitt et al., 2006). Results determined no significant increase in VO_{2max} between the LHTL and LLTL groups, whereas peak power tended to increase more in the LHTL group than the LLTL group (4.1 vs. 1.9 percent, respectively, $p=0.06$).

Duration at Simulated Altitude.

Contrary to a generalized belief that 14 days is the minimum duration needed at simulated altitude to elicit adaptations (Levine & Stray-Gundersen, 1997, 2006), others have discovered improvements after much shorter durations (Ashenden et al., 2000; Koistinen et al., 2000; Roberts et al., 2003). Subjects followed a seven-day continuous (24 hours per day) or intermittent (12 hours per day) simulated altitude exposure protocol at 2,500m (Koistinen et al., 2000). Both the continuous and intermittent groups resulted in 78 and 71 percent increases ($p<0.05$) in serum EPO levels, respectively. Due to the similarities in results, it was concluded that exposures beyond 12 hours per day may have no added impact on erythropoietin levels.

Likewise, six well-trained middle-distance runners spent 8-11 hours per night for five nights in a simulated altitude tent at 2,650m (Ashenden et al., 2000). Five squad members undertook the same training as a control group, which was conducted near sea level (600m). For both groups, this five-night protocol occurred on three different occasions, with a three-night interim between successive exposures. Venous blood samples were measured for serum erythropoietin. The well-trained runners experienced significant improvements in serum erythropoietin (57 percent, $p < 0.01$) levels above baseline values compared with the control group, whose erythropoietin levels did not change. However, the increase in serum erythropoietin was insufficient to stimulate reticulocyte production. It was concluded that when daily training loads are controlled, the increases in serum erythropoietin known to occur following brief (e.g. 5-day) exposure to a simulated altitude of 2,650m are insufficient to stimulate reticulocyte production.

In an effort to determine if short-term simulated altitude was enough to elicit performance adaptations, specifically those achieved through anaerobic sources, researchers (Roberts et al., 2003) had participants undergo LHTL exposures of 5, 10, or 15 days. A total of 19 participants underwent testing on a cycle ergometer to measure MAOD (as described by Medbo et al., 1988). Participants were assigned to a LHTL simulated altitude exposure of 5, 10, or 15 nights at 2,650m for eight to ten hours each night. Adaptations were discovered in their study, both aerobic and anaerobic in nature. It was concluded, based on the results, that there was no difference in adaptation between the 5, 10, or 15 day exposure.

Stray-Gundersen, Chapman, and Levine (2001) completed a study using 22 individuals who followed a LHTL protocol by living at 2,500m while performing high intensity training at 1,250m for 27 days. This resulted in significant increases in erythropoietin of nearly 100 percent (8.5 ± 0.05 to 16.2 ± 1.0 IU/ml), VO_{2max} by 3 percent, and 3,000m running performance times of 1.1 percent. Based on these findings, and in accordance with their previous findings, researchers concluded that 27 days of living high and maintaining high intensity training at lower altitudes is effective to achieve physiologic adaptations that can improve performance.

Based on a review of previously published research (Wilber, Stray-Gundersen, & Levine, 2007), it was concluded that the optimal exposure of altitude must consist of 2,000-2,500m (1,780m may not be high enough to stimulate erythropoiesis; alternatively, 2,800m produced no additional stimulus in erythropoiesis and potentially resulted in a decreased performance) for a minimum of 12 hours per day, for 21 to 28 days.

Performance Evaluation

Many researchers (Reviewed in Wilber, 2001) agree that exposure to altitude results in adaptations that lead to performance improvements. This has been demonstrated in numerous scientific studies that expose participants to a variety of previously described exposure parameters. What is not agreed upon is the mechanism responsible for these adaptations. Some researchers feel the adaptation is aerobic (Levine & Stray-Gundersen, 1997; Schmitt et al., 2006), anaerobic (Gore et al., 2001; Mizuno et al., 1990; Roberts, 2003), or even the result of a placebo effect (Baker & Hopkins, 1998; Clark, Hopkins, Hawley, & Burke, 2000). Therefore, further research is needed to better understand the physiologic changes that occur as a result of altitude.

Aerobic.

The physiologic adaptations to altitude exposure have been shown to be similar to those of athletic training alone (Hoppeler & Vogt, 2001). Levine and Stray-Gundersen (1992, 1997, 2006) are highly convinced that the main mechanism for performance improvements after altitude exposure is the result of stimulation of erythropoiesis, which has the potential to lead to increased production of red blood cells in the bone marrow, and can, with time, improve an individual's aerobic capacity and thus performance potential. Increases in erythropoietin and red cell mass have been observed with several hours of sleep exposure to altitude (Gore, Rodreguez, Truijens, Townsend, Stray-Gundersen, & Levine, 2006; Hoppeler & Vogt, 2001). Therefore, the utilization of altitude exposure in an athlete's training scheme may prove to be beneficial to performance.

In 1997, Levine and Stray-Gundersen found that LHTH and LHTL subjects demonstrated increased erythropoietin secretion, increased red blood cell volume by 9 percent ($p<0.01$), and VO_{2max} improvements of 5 percent ($p<0.05$). However, 5,000m time trial improvements of 1.3 percent ($p<0.05$) were seen only in the LHTL group. These increases were found despite equivalent training between all groups, which supports the conclusion that the altitude exposure was the reason for adaptation. Therefore, it was concluded that a LHTL protocol is capable of eliciting more significant 5,000m running performance improvements.

One year later, Chapman, Stray-Gundersen & Levine (1998) retrospectively studied the results to better understand potential individual variability in response to altitude exposure. Based on the runners' 5,000m running performance pre- and post-altitude, researchers divided the group into responders and non-responders. The main stimulus for adaptation appeared to be demonstrated by altitude responders (52 percent) who had a greater release of erythropoietin 30 hours after altitude exposure than did the non-responders (34 percent), and this trend continued for the duration of the 28-day period. The participants who experienced this greater increase of erythropoietin also demonstrated greater increases in the other measures. For example, responders resulted in a 6 percent ($p<0.05$) improvement in VO2max, compared to non-responders who experienced no change. Finally, 5,000m run performance times in the responders significantly improved by 37 seconds ($p<0.05$), whereas the non-responder's performance time was 14 seconds slower.

As previously mentioned, Brugniaux et al. (2006) examined the optimal exposure of altitude to elicit the best adaptation. Participants were exposed to varying altitudes of 2,500m, 3,000m, and 3,500m, for 11 to 16 hours per night, and for 5 to 12 nights at each altitude. The athletes demonstrated a lack of improvement in performance beyond 3,500m as well as poor acclimatization. Mean nocturnal oxygen saturation (SaO_2) declined to as low as 90 percent at 3,500m and showed no improvement with acclimatization. Conversely, the lower elevations experienced an initial decrease in SaO_2 but later demonstrated normalization with acclimatization. The swimmers and runners who did not go above altitudes of 3,000m experienced a VO_{2max} increase of 8.1 percent ($p=0.09$) and 7.1 percent ($p<0.05$), respectively. Conversely, the cross-country skiers demonstrated no change in VO_{2max}. Therefore, it was concluded that a LHTL exposure should not exceed 3,000m for a period of 18 days, with at least 12 hours per day exposure.

Mentioned previously were two similar studies to determine the optimal adaptation after exposure to two different altitudes (Robach et al., 2006a; Robach, et al., 2006b). In both studies, participants were exposed to altitudes of 2,500m, 3,000m, and 3,500m for varying lengths of time while training occurred at 1,200m in all instances.

The Nordic skiers experienced significant improvements in hematocrit (2.3 percent, $p<0.05$), hemoglobin (0.3 percent, $p<0.05$), red blood cell count (.2 percent, $p<0.05$), and serum EPO (2.2 percent, $p<0.05$) up to 3,000m, but either declined or stayed the same after the exposure was increased to 3,500m (Robach et al., 2006a). The LHTL swimmers significantly improved red blood cell volume (8.5 percent, $p=0.03$); and VO_{2max} tended to increase (8.1 percent, $p=0.09$) to a greater amount than in controls (2.5 percent, $p=0.21$; Robach et al., 2006b). Swimming performance trials of 2,000m were unchanged with LHTL. The results demonstrate that altitudes greater than 3,000m serve no extra benefit to individuals participating in a LHTL protocol and that an improvement in blood parameters, specifically erythropoietin, does not always coincide with an improvement in VO_{2max} and performance.

Anaerobic.

As previously stated, Levine and Stray-Gundersen (2005) have suggested the main mechanism for increases in sea-level performance after an altitude exposure are the result of improved aerobic metabolism. However, the same authors (1997) stated that the correlation between changes in VO_{2max} versus the change in red blood cell volume yielded a modest $r^2 = 0.137$. According to Gore, Clark, and Saunders (2007), 86 percent of the variance in VO_{2max} could be derived from sources other than red blood cell volume. This demonstrates that more than VO_{2max} alone determines performance ability (di Prampero, 1986).

Adenosine triphosphate (ATP) is the body's main source of energy to perform work (Medbo et al., 1988). ATP can be created aerobically and anaerobically, depending on the energy demands of the body. An individual's anaerobic capacity can be determined through a method of properly identifying maximal accumulated oxygen deficit (MAOD; Medbo et al., 1988). Oxygen deficit is represented as the area between the curve of the oxygen demand and the curve of the actual oxygen uptake and represents the maximal amount of ATP formed by anaerobic processes during exercise. Therefore, proper quantification of MAOD allows for researchers to understand any physiologic changes occurring in anaerobic capacity.

As mentioned previously, Roberts et al. (2003) exposed participants to LHTL exposures of 5, 10, or 15 days to assess changes in anaerobic capacity. No significant difference in Maximal Mean Power Output in four minutes ($MMPO_{4min}$), VO_{2max}, or MAOD were found when comparing the 5, 10, or 15 day exposures separately. However, when the exposure durations were pooled together, significant improvements in the following parameters were demonstrated. The LHTL athletes demonstrated a 3.7 percent ($p<0.05$) increase in $MMPO_{4min}$ and a 9.6 percent ($p<0.05$) increase in MAOD from pre- to post-test. Both the LHTL and control group demonstrated small yet significant improvements in VO_{2max} after exposure, but were not significantly different between groups. These authors concluded that a short-term exposure to simulated altitude, such as 5, 10, or 15 days, was enough to stimulate significant improvements in individual's anaerobic capacity.

In addition, some athletes have improved their efficiency after altitude exposure (Hahn et al., 2001). Therefore, performance benefits are possibly the result of increased anaerobic capacity or a greater efficiency of aerobic metabolism. These participants demonstrated significant increases in erythropoietin of 80 percent ($p<0.05$) after one to five nights at a moderate altitude exposure. However, this increase in erythropoietin was not enough to stimulate erythrocyte production over the participants' 11 to 23 night exposure to 2,650-3,000m, likely because erythropoietin values were no longer significant at the end of the exposure. Thus, there is a demonstration of an anaerobic improvement because VO_{2max} tended to decrease ($p=0.07$) in the LHTL group but not in controls; however, a four-minute supramaximal performance showed slight, non-significant improvements (1 ± 0.4 percent) after the exposure.

Nearly all systems of the body have mechanisms in place to regulate physiological functions in order to maintain homeostasis. During exercise, lactate levels have been known to increase in association with increases of hydrogen ions (H+) in the cell, thus impacting the pH of the cell (Clark, Aughey, Gore, Hahn, Townsend, Kinsman, Chow, McKenna, & Hawley, 2004). Regarding muscle pH, the Na+/H+ exchanger is responsible for this maintenance of homeostasis at rest (Juel, Grunnet, Holse, Kenworthy, Sommer & Wulff, 2001). As exercise intensity increases, monocarboxylate transporters MCT1 and MCT4 are responsible for the transport of lactate in the muscle by coupling this with the transport of H+ in a 1:1 ratio (Juel & Halestrap, 1999; Juel, 1996). MCT4 transporters are primarily located in glycolytic fibers and are believed to have a major role in lactate removal (Juel & Halestrap, 1999). Therefore, improvements in the appearance of MCT1 and MCT4 may have the ability to maintain appropriate levels of pH and lactate within the body.

To better understand the anaerobic adaptations after altitude exposure, researchers investigated monocarboxylate transporters MCT1 and MCT4, lactate kinetics, and muscle buffering capacity (Clark et al., 2004). Therefore, 29 participants were exposed to 20 nights of continuous, intermittent (four 5 night blocks of exposure), or control treatments. The simulated altitude was equivalent to 2,650m, and individuals were exposed to 9-10 hours of this treatment nightly. After this exposure, all participants including controls exhibited improvement in VO_{2peak} as well as peak power output ($p<0.05$). Lactate kinetics were significantly altered ($p<0.05$) after the continuous LHTL exposure, which was demonstrated by decreased plasma lactate concentration at 85 percent VO_{2max} as well as an increase in workload at 4 mmol/L lactate. However, there were no differences among the groups in regard to muscle buffer capacity or MCT1 and MCT4 abundance. Therefore, researchers concluded that this particular 20-night exposure was successful at delaying blood lactate accumulation but did not alter lactate metabolism or pH regulation. The explanation for this was left to further investigation.

High intensity exercise may result in pH decreases from about 7.1 to 6.5. This can negatively impact muscle performance due to low pH inhibiting functions within the muscle cell. Muscle buffer capacity, or the ratio of lactate accumulation and observed change in muscle H^+, may improve with training, potentially attributed to an individual's increased ability to slow lactate accumulation by improving lactate removal from the muscle tissue as a result of increased level of monocarboxylate transporters MCT1 and MCT4 (Aagaard & Bangsbo, 2006; Gore, Clark, & Saunders, 2007). This improvement has also been demonstrated after a LHTL-simulated altitude exposure (Gore et al., 2001). The LHTL group spent 23 nights at a simulated altitude of 3,000m, for 9.5 hours each night. The control group experienced the location's natural altitude of 600m for the entire study. Participants demonstrated a significant 7 percent reduction in VO_{2peak} after LHTL, whereas the control group experienced no change. This occurred without any significant change in the work performed throughout the cycle ergometer testing, which may allude to an increased efficiency. Furthermore, muscle buffer capacity increased significantly in the LHTL group (17.7 ± 4.9 percent) but was unchanged in the control. Finally, blood lactate levels did not increase significantly due to the LHTL exposure; however, values were significantly different between the LHTL and control groups pre- and post-exposure (15.4 ± 3.3 mmol/L vs. 17.4 ± 1.2 mmol/L pre- vs. 17.3 ± 2.6 mmol/L vs. 22.4 ± 1.7 mmol/L post-exposure, respectively). Therefore, these researchers concluded that the increase in muscle buffer capacity may be indicative of an improved mechanical efficiency.

Ten cross-country skiers were studied during a 14-day exposure to altitude where participants stayed at 2,100m and trained at 2,700m (Mizuno et al., 1990). After this treatment, researchers noticed no improvement in VO_{2max}, whereas increases were seen in oxygen deficit (MAOD; 29%, $p<0.05$) as well as short-term running performance (17%, $p<0.05$). Muscle biopsies of the gastrocnemius and triceps brachii demonstrated a 6 percent improvement in muscle buffer capacity ($p<0.05$). These researchers found the improvement in muscle buffering capacity of interest because both muscle groups demonstrated similar changes, regardless of the differences in use specific to cross-country skiing. Therefore, this study supports the results for anaerobic adaptations from altitude exposure over the previously emphasized aerobic improvements.

Nummela and Rusko (2000) explored anaerobic adaptations occurring after a 10-day simulated altitude exposure of 2,200m for 16 to 17 hours per day on male and female 400m sprinters. After the simulated altitude exposure, researchers found a one percent ($p<0.05$) improvement in 400m times. These athletes also performed a maximal anaerobic run test, which consisted of a variable number of 20-second runs with 100 seconds of recovery until volitional exhaustion occurred. Participants were able to run significantly faster at given lactate concentrations, which demonstrated an improvement in anaerobic capacity (Nummela, Alberts, Rijntjes, Luhtanen, & Rusko, 1996; Nummela, Mero, Stray-Gundersen, & Rusko, 1996). The researchers speculated that this adaptation may have been the result of an improvement in muscle buffering capacity. This can be supported by a significantly higher resting blood pH ($p<0.05$) in the altitude exposed athletes than in the control group.

Retrospective analysis of 2,147 college-aged cadets was performed throughout their time attending the U.S. Air Force Academy (USAFA) at an altitude of 2,210m (Brothers, Wilber & Byrnes, 2007). All participants were sea-level residents prior to their move to the USAFA complex. The cadets completed several tests to assess fitness, the most noteworthy being an aerobic 1.5 mile run test and a series of testing stations to identify anaerobic physical fitness. After two years of residence at 2,210m, the aerobic 1.5 run test improved significantly by 8.6 percent ($p<0.002$) over a sea-level control group. Additionally, the levels of anaerobic physical fitness significantly improved in the altitude exposed group by 6.8 percent ($p<0.01$). Brothers et al. (2007) concluded that moderate altitude can result in significant hematological adaptations; however, this may take up to seven months. Additionally, both aerobic and anaerobic adaptations may occur as a result of this exposure.

The enzyme Na^+ -K^+ -ATPase is primarily located in the sarcolemma and plays an important role in maintaining Na^+ and K^+ concentration gradients as well as membrane excitability (Clausen, 2003; Fowles, Green, Tupling, O'Brien & Roy, 2002; Fraser, Li, Carey, Wang, Sangkabutra, Sostaric, Selig, Kjeldsen & McKenna, 2002). The primary importance of Na^+ -K^+ -ATPase is that it maintains the muscle membrane potential necessary for muscular contraction. It has been previously demonstrated that exposures to altitude often result in Na^+ -K^+ -ATPase downregulation, as expressed by the near 14 percent reduction in Na^+ -K^+ -ATPase experienced by six mountain climbers who took a 21-day expedition to the top of Mount McKinley (6,194m; Green, Roy, Grant, Burnett, Tupling, Otto, Pipe & McKenzie, 2000).

In order to better understand the Na^+ -K^+ -ATPase response to altitude, participants were exposed to a simulated altitude of 3,000m for approximately 9.5 hours each night for 23 nights while their training occurred at a natural altitude of 600m (Aughey, Gore, Hahn, Garnham, Clark, Peterson, Roberts & McKenna, 2005). Muscle biopsies were performed in order to realize changes in Na^+ -K^+ -ATPase enzyme activity. After this exposure, LHTL participants resulted in a 7.2 ± 4.1 percent ($p<0.05$) reduction in VO_{2max} with no change in the control group. This reduction in VO_{2max}, however, did not result in any difference in total work between groups. There was also a small but significant 2.9 percent ($p<0.05$) reduction in muscle maximal Na^+ -K^+ -ATPase activity, but there was no corresponding decrease in this measure's content, performance, or plasma K^+ regulation. This is important because it suggests that the LHTL altitude exposure prevented the expected suppression of Na^+ -K^+ -ATPase due to altitude. Therefore, they concluded that exposures such as this one might allow athletes to minimize or completely avoid detrimental impacts on Na^+ -K^+ -ATPase, yet still benefit from other potential physiologic adaptations from altitude exposure.

The research provided above demonstrates that there are numerous physiologic adaptations that can occur as a result of altitude exposure. These adaptations include changes in EPO, VO_{2max}, muscle buffer capacity, MAOD, performance, and more. However, it is extremely difficult, and in many cases impractical, to measure all of these parameters in one study. Therefore, researchers are presented with a great challenge to identify the complete mechanism behind the adaptation.

Chapter III: Methods

Introduction

Inclusion Criteria and Sample Recruitment

Eastern Michigan University's College of Health and Human Services Human Subjects Review Board approved this study prior to implementation. All participants were required to provide medical clearance for maximal exercise and simulated altitude exposure of 2,500m either by presenting a doctor's note or through the EMU Athletics Department mandatory physical assessment of athletes. Participants were recruited by word of mouth and flyers posted throughout the cycling and swimming community.

Participants randomly served in both altitude and control conditions in order to account for potential training adaptations. The study followed a cross-over design; therefore, participants changed treatments after completion of the first assigned treatment. If the altitude treatment was performed first, there was a three-week pause in data collection before completing any testing as a control to allow any adaptation to "washout."

The following tests were performed to analyze any potential adaptations resulting from the study design. All participants completed the tests to the best of their ability and followed the instructions of the researchers. Researchers required that any workouts completed the day before testing sessions remain easy and that participants consume a consistent diet prior to all testing sessions. Also, in effort to maintain proper circadian rhythm (Riley & Down, 1992), testing sessions were scheduled at similar times of day for individual participants.

Due to the swimmers' training and competition schedule, data collection was divided into two components (swimmers and cyclists) to allow for timely measurement of the parameters involved. This design eliminated the confounding factors of competition preparation (e.g. tapers, shaving, etc) and enabled researchers to structure workouts to accommodate laboratory testing.

Part I: Maximal Accumulated Oxygen Deficit Adaptations

Description of Sample

Eight trained male cyclists ranging in age from 19 to 42 years participated in this study. The average age was 29 ± 7.5 years, height 181 ± 2.9 cm, mass 75.3 ± 4.7 kg, and training volume of 10.2 ± 1.4 hours per week.

Procedure

On seven separate occasions, participants came to the Exercise Physiology Laboratory at Eastern Michigan University. Participants began the study by completing a familiarization Maximal Mean Power Output in four minutes ($MMPO_{4min}$) test on a Velotron (Racermate, WA) electronically braked cycle ergometer (Figure 1). The purpose of the familiarization trial was to reduce the possibility for learning improvements. A second $MMPO_{4min}$ test was performed to confirm the results from the familiarization trial. The values from these tests were used to determine appropriate workloads in subsequent tests. This is relevant because a four-minute performance trial would rely largely on aerobic metabolism; however, it is expected there is a significant anaerobic contribution that needs to be considered (Medbo et al., 1988). Additionally, this time frame is a common duration in international competitions for swimming, track, and cycling (Craig, Norton, Bourdon, Wollford, Stanef, Squires, Olds, Conyers & Walsh, 1993; Spencer & Gastin, 2001) and is sufficient to exhaust anaerobic metabolism.

Testing for Maximal Accumulated Oxygen Deficit (MAOD) occurred immediately prior to the start of the simulated altitude exposure. Participants slept alone in a Hypoxico Altitude Tent System (Hypoxico Inc., NY) that simulated an altitude of 2,500m. The concentration of oxygen was measured using a Handi (Maxtec, UT) handheld oxygen sensor. Participants were instructed to occupy the tent for eight to twelve hours each day for a seven-day period. Immediately concluding the simulated altitude exposure, participants performed a final MAOD test to realize any adaptations. Throughout the duration of the study, participants documented training sessions in a logbook provided to them.

Testing Measures

Maximal Mean Power Output in four Minutes (MMPO$_{4min}$).

The first two tests completed were MMPO$_{4min}$ tests as recommended by Roberts and colleagues (2003). Participants used a Velotron cycle ergometer to complete this test. The ergometer was sized according to each individual's preference, and these settings were recorded. Before beginning the MMPO$_{4min}$ test, a ten-minute warm-up at a maximal limit of 200 Watts (W) was performed. The participant then performed a four-minute all-out effort to determine maximal mean power output and maximal oxygen uptake (VO$_{2peak}$). Participants' VO$_{2peak}$ was determined as the greatest 30-second average of oxygen consumption at any point during the test. Participants were required to pedal between the cadences of 90 to 110 revolutions per minute. The data from this test were then used to calculate workloads for future MAOD testing sessions. Blood lactates were analyzed immediately before and after the $MMPO_{4min}$ test using LactatePro (Arkray, Japan) handheld lactate analyzers.

Figure 1. Velotron Cycle Ergometer

Maximal Accumulated Oxygen Deficit (MAOD).

The remaining testing sessions were identical and measured participants' anaerobic capacity. This was achieved by following a MAOD protocol (Roberts et al., 2003) on a Velotron cycle ergometer. Participants began the test by completing a four-minute warm up at 25 percent of $MMPO_{4min}$. This was followed by an incremental test with three intervals lasting six minutes each at 50, 62.5, and 75 percent of $MMPO_{4min}$. After each six-minute interval there was a four-minute rest, consisting of two minutes active rest at 25 percent of $MMPO_{4min}$ followed by two minutes seated passive rest. After the final four-minute resting period, an $MMPO_{4min}$ was administered. Blood lactates were analyzed immediately before and after the MAOD test using LactatePro handheld lactate analyzers.

The determination of MAOD was calculated utilizing an Excel spreadsheet (Microsoft, WA). First, the actual oxygen consumption during the $MMPO_{4min}$ test was determined for each 15-second segment throughout the 4-minute trial. This value was compared to the calculated oxygen consumption based on extrapolation of the relationship of oxygen consumption between the three submaximal stages, and the difference was reported. This 15-second calculated difference was then added throughout the 4-minute effort, unless there was a segment that did not incur an oxygen deficit, in which case that segment was not added to the total. This determination of MAOD was compared to an alternative global method where any positive oxygen deficits were not excluded from the overall result and no significant differences were found (results not shown).

Table 1

Cyclist's study design

	Familiarization	**Trial 1**	**Trial 2**	**Trial 3**
MMPO$_{4min}$	x	x		
MAOD			x	x
Lactate	x	x	x	x
Altitude Tent In			x	
Altitude Tent Out				x

Part II: Aerobic and Swimming Performance Adaptations

Description of Sample

Ten highly trained male swimmers from Eastern Michigan University's Swim Team, ranging in age from 19-21 years, participated in this study. The average age was 20 ± 0.6 years, height 185 ± 5.0 cm, and mass 80.8 ± 3.9 kg.

Procedure

On nine separate occasions, participants came to the campus of Eastern Michigan University. Swimming trials occurred in the Jones Natatorium, and laboratory testing occurred in a laboratory. The laboratory testing sessions consisted of VO_{2peak} tests on a SciFit Arm Ergometer (SciFit, OK; Figure 2), completing a ramp protocol to volitional exhaustion. Bar-Or and Zwiren (1975) found that the arm ergometer had excellent reproducibility and validity. The first test served as a familiarization trial to reduce the possibility for learning improvements as well as to ensure valid determination of the participant's peak power output (PPO) and VO_{2peak}. The participants performed a 400-meter time trial swim performance one day before completing the baseline VO_{2peak} test. Participants then slept alone in a Hypoxico Altitude Tent System that simulated an altitude of 2,500m. As the same for the cyclists, the concentration of oxygen was analyzed each night using a Handi oxygen sensor. Participants were instructed to occupy the tent for eight to twelve hours each day for a seven-day period. After six nights in the simulated altitude tent, a 400-meter swim trial was performed. After seven nights, VO_{2peak} was re-evaluated to test for adaptations. Blood lactates were analyzed immediately before and after the VO_{2peak} test and swim trial using LactatePro handheld lactate analyzers.

Testing Measures

Peak oxygen consumption (VO_{2peak}).

The first test was a VO_{2peak} test and was completed on a SciFit Arm Ergometer. The test began with a four-minute warm-up at 15 W. Next, the participant performed a ramp protocol starting at 50 W for two minutes; followed by 10 W increases in workload every two minutes until volitional exhaustion occurred. This test resulted in VO_{2peak} and Peak Power Output (PPO) values. The PPO was determined to be the lowest workload completed to establish VO_2 plateau.

Figure 2. SciFit Pro II Arm Ergometer

Swimming Trials.

Race performances were assessed once each week at the Jones Natatorium with a timed 400 long-course meter swim. A standardized warm-up was developed for all swimmers to complete before the swim trial, which consisted of an 800-meter choice, 600-meter kick/drill/swim alternating every 50 meters, and a 400-meter drill/build by 50 meters. Participants were started three to four minutes apart with no more than two swimmers per lane to eliminate racing strategies and other uncontrollable factors. Blood lactates were analyzed before warm-up and immediately after the race performance, using a LactatePro hand held lactate analyzer.

Table 2

Swimmer's study design

	Familiarization	**Trial 2**	**Trial 3**
VO2peak	x	x	x
400-meter Performance		x	x
Lactate	x	x	x
Altitude Tent In		x	
Altitude Tent Out			x

Common Procedures for Testing Cyclists and Swimmers

VO_{2peak} Measurement

A Jaeger Oxycon Mobile Metabolic Cart (Cardinal Health, CA; Figure 3) was used to collect expired gases. This consisted of a facemask attached to a small unit worn by the participant during exercise. This device measured the oxygen and carbon dioxide inhaled and expired, respectively. As mentioned previously, VO_{2peak} was defined as the greatest 30-second average of oxygen consumption at any point during the test. Heart rates were monitored with a Polar (Polar Electro, Finland) heart rate monitor.

Figure 3. Jaeger Oxycon Mobile Metabolic Cart

Blood Lactate Analysis

Each participant’s blood lactate concentration was measured in duplicate form before and after each test throughout the study. This involved a small finger prick to allow for the blood sample. This was achieved by using LactatePro (Arkray, Japan) handheld analyzers.

Simulated Altitude

Hypoxico Altitude Tent Specifications: The HYP100 Hypoxic Generator (Figure 4) can produce airflow up to 5400 L/h and can simulate 0 – 6,400m. The tent’s (Figure 5) dimensions were 55cm H x 27cm W x 58cm D and the generator weighed 25 kg (Hypoxico Inc., NY). The simulated altitude exposure occurred in the participant’s home and was supervised by an adult whom they deemed responsible to monitor their safety and well-being. The tent was either set up by the principal investigator or its assembly was explained in detail. The Hypoxico generator’s flow volume was set to approximately 90 percent to achieve an oxygen percentage of approximately 15.42 percent, which simulated the appropriate altitude of 2,500m (according to manufacturer’s instructions).

Figure 4. HYP100 Hypoxic Generator

Image 5. Hypoxic Altitude Tent

Logbook

Participants maintained a detailed workout logbook throughout the duration of the study. It included daily recordings of workout distance or duration, perceived difficulty, modality of training, and maximal heart rate (HR). Also included was information about the simulated altitude exposure, such as hours of sleep, quality of sleep, resting HR, and verification of the O_2 percentage inside the tent. Any additional comments the participant felt pertinent and necessary were encouraged to be included in the logbook. The questions regarding perceived workout difficulty and quality of sleep were ranked on a 1-10 scale. For example, workout difficulty was defined as 1 being the lightest workout possible and 10 being the most vigorous. Sleep quality was defined as 1 being the worst sleep quality and 10 being the best.

Data Analysis

All values are reported as mean ± standard deviation. Results were analyzed using SPSS software version 15.0 (SPSS Inc, IL). A Multivariate Analysis of Variance (MANOVA) was used to analyze differences by time and treatment in cyclists for: VO_{2peak}, MAOD, resting lactate, post lactate, and power output. The MANOVA was used in swimmers for race time, VO_{2peak}, power output, resting lactate, post lactate, and time to exhaustion. Significance values were set at Alpha = 0.05.

Chapter IV: Results

As stipulated in the Methods, there were two groups of athletes participating in this study, and the results will be presented separately in this section.

Cyclists

Subject Characteristics

Eight trained male cyclists were included in the present study (Table 3). All participants were required to be competitive cyclists for at least 2 years, train a minimum of 8 hours per week, and be between the ages of 18 and 45.

Table 3

Cyclist characteristics

Subjects

Parameter	Value
Age (yrs)	29.3
	7.55
Height (cm)	181.4
	2.92
Weight (kg)	75.3
	4.77
VO2peak (ml/kg/min)	57.5
	5.2
Power (Watts)	356
	35

Mean values represented in first row with the standard deviation below.

Attrition

Due to a malfunction in the metabolic analysis, one participant’s altitude trial had to be removed from the data analysis. During the $MMPO_{4min}$ portion of the post-treatment MAOD test, the metabolic cart’s sample line became occluded and was not able to collect accurate measures of VO_2.

Table 4

Physiologic results during cycle ergometer tests

Cyclists

Parameter	Trial 2	Trial 3
VO_{2peak} (ml/min)	4588.38	4639.13 *
	517.68	464.20
VO_{2peak} (ml/min)	4287.86	4295.57 *
	311.29	369.85
MAOD (ml/min)	3992.75	4190.88
	1486.38	919.23
MAOD (ml/min)	3735.29	4223.86
	930.49	1094.87
Resting Lactate (mmol/L)	2.13	1.26
	1.42	0.39
Resting Lactate (mmol/L)	1.37	1.45
	0.36	0.40
Post Lactate (mmol/L)	13.99	13.40
	1.87	2.10
Post Lactate (mmol/L)	13.81	13.98
	1.80	2.10
Power (Watts)	353.88	354.63
	30.55	34.62
Power (Watts)	351.29	359.86
	42.89	34.6

Control treatment in white; altitude treatment in gray. Mean values represented in first row with the standard deviation below. * = treatment effect ≤ 0.05.

Peak Oxygen Consumption

There were no significant differences found between trials; however, there was a significant difference ($p \leq 0.05$) between groups where the control group expressed higher VO_{2peak} values (Table 4). It is also visible that the $MMPO_{4min}$ trial resulted in a non-significantly lower VO_{2peak} in both groups.

Maximal Accumulated Oxygen Deficit

There were no significant differences demonstrated in MAOD between groups; however, the difference in MAOD between Trial 2 and 3 was non-significantly greater in the altitude group (3735 ± 930.5 vs. 4224 ± 1094.8 ml, respectively) than the control group (3992 ± 1486.3 vs. 4190 ± 919.8 ml, respectively; Figure 6).

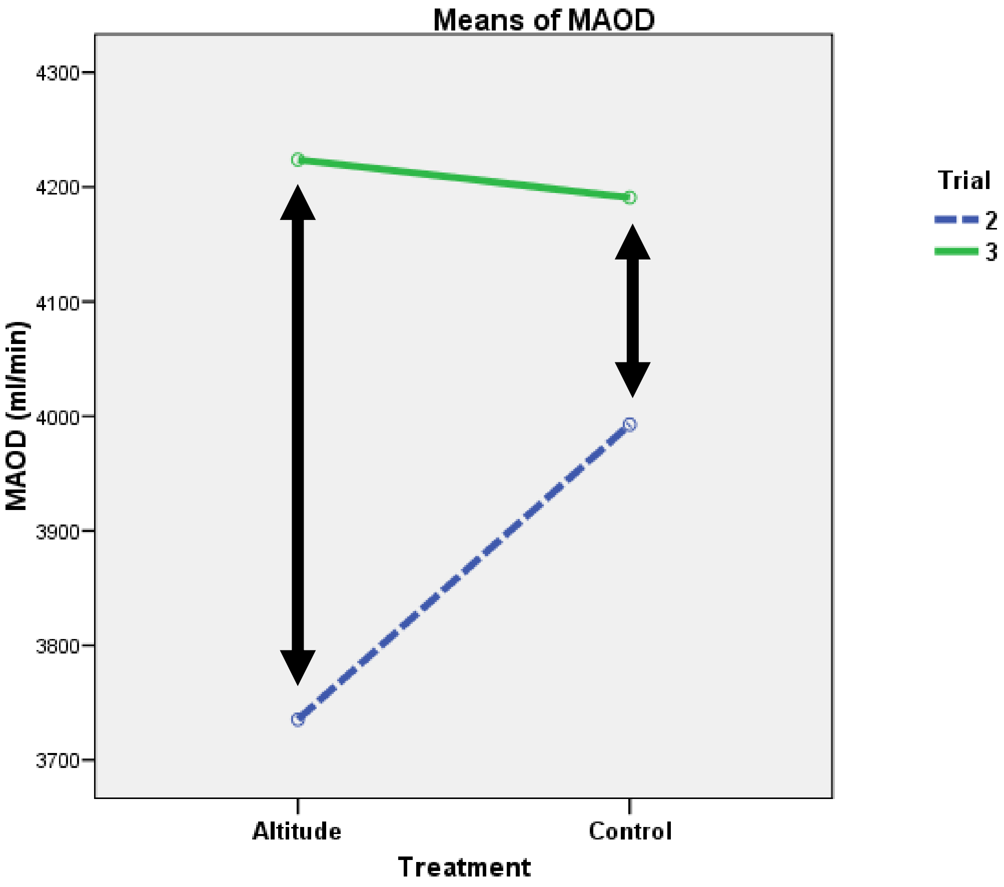

Figure 6. MAOD differences between groups and trials

Research Question 1:

Can significant physiologic anaerobic improvements, specifically MAOD, and/or aerobic capacity improvements occur in trained cyclists after a seven-day simulated altitude exposure?

Using a MANOVA to compare the dependent variables MAOD and VO_{2peak} through a treatment by trial analysis, the results demonstrated no significant improvement in either parameter among the trained cyclists in the present study (p=0.730 and p=0.892, respectively).

Lactate

There appeared to be a trend (p=0.12) for a treatment by trial interaction in resting lactate values. Resting lactate concentrations in the control group decreased to a greater extent from Trial 2 to 3 (2.13 ± 1.4 vs. 1.26 ± 0.39 mmol/L, respectively) than in the altitude group (1.37 ± 0.36 vs. 1.45 ± 0.41 mmol/L, respectively).

Post lactate concentrations were not significantly different in either the altitude or control group.

Power

There were no significant differences in power output between treatment groups. However, the altitude group resulted in a greater, non-significant, improvement in power output between Trials 2 and 3 (351 ± 42.89 vs. 359 ± 34.60 W, respectively). This is compared to the control group's power output that was unchanged between Trials 2 and 3 (353 ± 30.55 vs. 354 ± 34.62 W, respectively).

Logbooks

There were no significant differences in any of the parameters identified by the workout logbooks (difficulty, duration, and maximal heart rate) between the altitude and control group (Table 5).

Table 5

Cyclist's workout logbooks

Daily Workouts	
Parameter	**Value**
Difficulty	6.05 2.03
Difficulty	5.88 1.86
Duration (mins)	91.34 60.40
Duration (mins)	86.45 54.17
Max HR	162 20.58
Max HR	165 18.49

Control treatment in white; altitude treatment in gray. Mean values represented in first row with the standard deviation below.

Simulated Altitude Exposure

The altitude group's sleep patterns were the only ones analyzed, and the groups demonstrated a daily trend (p=0.086) in improved quality of sleep as the altitude exposure progressed over the 7-day period. No other parameters expressed differences between them by day.

Table 6

Cyclist's simulated altitude exposure

Altitude Exposure	
Parameter	**Value**
O_2% In	16.06
	0.51
O_2% Out	15.54
	0.50
HR In	56
	5.92
HR Out	52
	6.54
Hours Exposure	8.54
	1.11
Hours Sleep	7.80
	1.12
Sleep Quality	6.40
	1.83

Mean values represented in first row with the standard deviation below.

Swimmers

Subject Characteristics

Ten highly trained male swimmers from Eastern Michigan University's Swim Team ranging in age from 19-21 years participated in this study (Table 7).

Table 7

Swimmer characteristics

Subjects	
Parameter	**Value**
Age (yrs)	20.30
	0.67
Height (cm)	185.6
	5.03
Weight (kg)	80.8
	3.97
VO2peak (ml/min)	42.6
	4.90
Power (Watts)	139
	25.13
400-meter Time (m:ss.ms)	4:47.67
	00:10.50

Mean values represented in first row with the standard deviation below.

Attrition

There was one instance where a participant was unable to finish the testing for the control trials due to unforeseen and unavoidable circumstances. Therefore, this participant's control trials were not included in the data analysis.

Table 8

Physiologic results during arm ergometer tests

Arm Ergometer Tests

Parameter	Trial 1	Trial 2	Trial 3
VO_{2peak} (ml/min)	3379.00	3301.67	3417.67
	563.21	379.16	490.14
VO_{2peak} (ml/min)	3671.80	3471.80	3541.50
	363.79	383.22	371.93
Resting Lactate (mmol/L)	1.76	1.75	1.73
	0.65	0.42	0.42
Resting Lactate (mmol/L)	1.92	1.74	1.60
	0.14	0.79	0.35
Post Lactate (mmol/L)	9.66	8.03	9.53
	1.37	1.23	2.20
Post Lactate (mmol/L)	10.53	9.42	9.10
	4.07	2.02	1.64
Power (Watts)	112.00	141.00	138.00
	38.62	24.21	23.15
Power (Watts)	152.00	138.00	147.00
	23.87	23.47	20.57
TTE (minutes)	19.85	24.59	24.50
	8.23	5.12	4.52
TTE (minutes)	26.65	23.90	25.90
	4.63	4.70	4.16

Control treatment in white; altitude treatment in gray. Means represented in first row with the standard deviation below. Trial 1 = Familiarization, Trial 2 = Pre; Trial 3 = Post.

Table 9

Performance results from the 400-meter swim trials

Performance Tests

Parameter	Trial 1	Trial 2
Time (m:ss.ms)	4:51.45	4:46.33
	0:13.29	0:08.90
Time (m:ss.ms)	4:48.08	4:45.07
	0:10.03	0:09.86
Resting Lactate (mmol/L)	1.72	1.82
	0.56	0.49
Resting Lactate (mmol/L)	2.00	1.99
	0.81	0.77
Post Lactate (mmol/L)	10.46	10.82
	1.66	1.15
Post Lactate (mmol/L)	11.21	11.05
	1.70	1.76

Control treatment in white; altitude treatment in gray. Means represented in first row with the standard deviation below. Trial 1 = Pre; Trial 2 = Post.

Peak Oxygen Consumption

No significant differences in VO_{2peak} were found between altitude and control groups (Table 8). However, it appears that the altitude group experienced a trend in treatment effect (p=0.139) with elevated VO_{2peak} when compared to the control group. Additionally, the control group resulted in a non-significantly greater improvement from Trial 2 to 3 (3301.67 ± 379.16 vs. 3417.67 ± 490.14 ml/min, respectively) than the altitude group (3471.80 ± 383.22 vs. 3541.50 ± 371.93 ml/min, respectively).

Swim Performance Time

The results conclude that there was no significant difference in 400-meter performance time between treatment groups (Table 9). The altitude group reported faster overall times than the control group; however, the control group non-significantly improved more from Trial 1 to 2 (4:51.45 ± 00:13.29 vs. 4:46.33 ± 00:08.90 minutes, respectively) than did the altitude group (4:48.08 ± 00:10.03 to 4:45.07 ± 00:09.86 minutes, respectively; Figure 7). There was individual variation in 400-meter performance time between trials in both the control and altitude group (Figure 8 & 9, respectively).

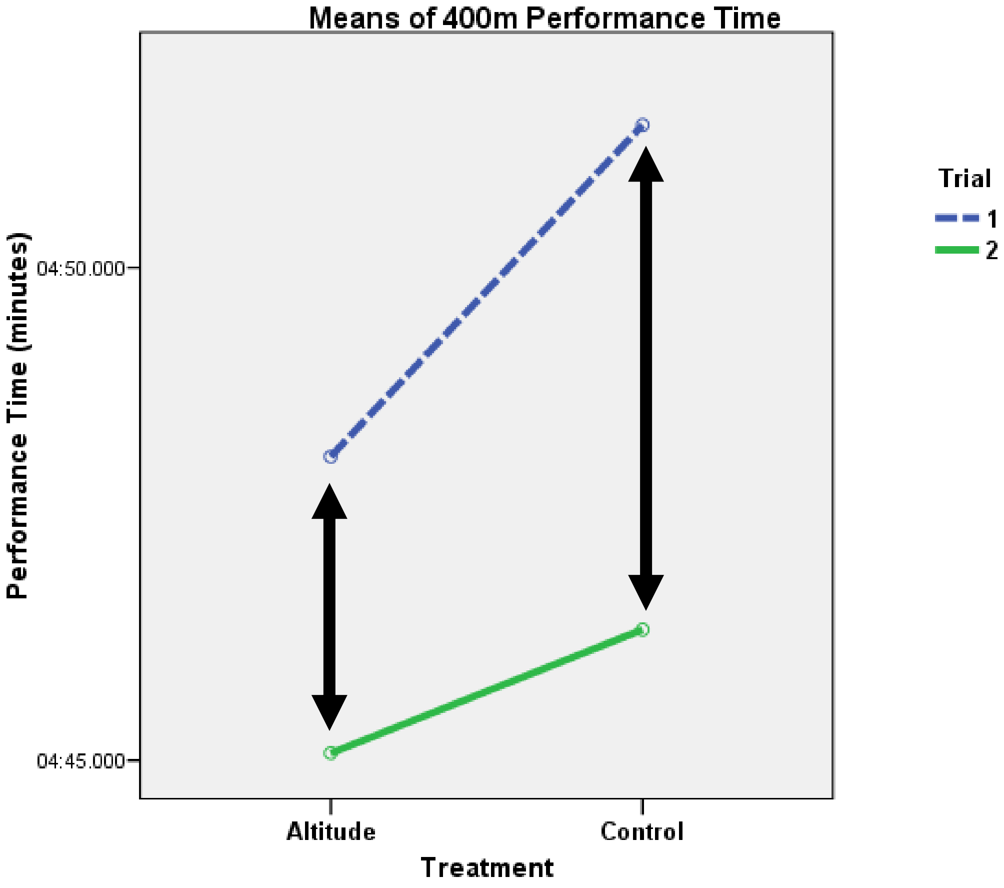

Figure 7. 400-meter performance time differences between groups and trials

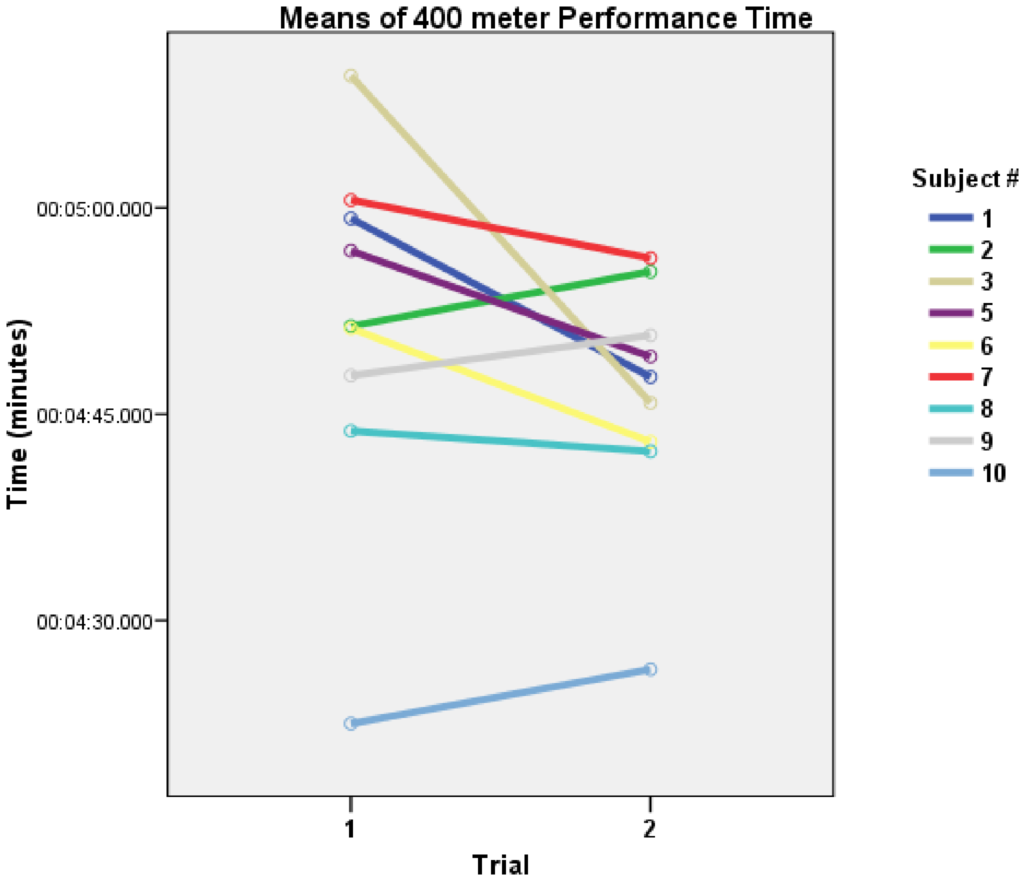

Figure 8. Control performance results between trials as individuals

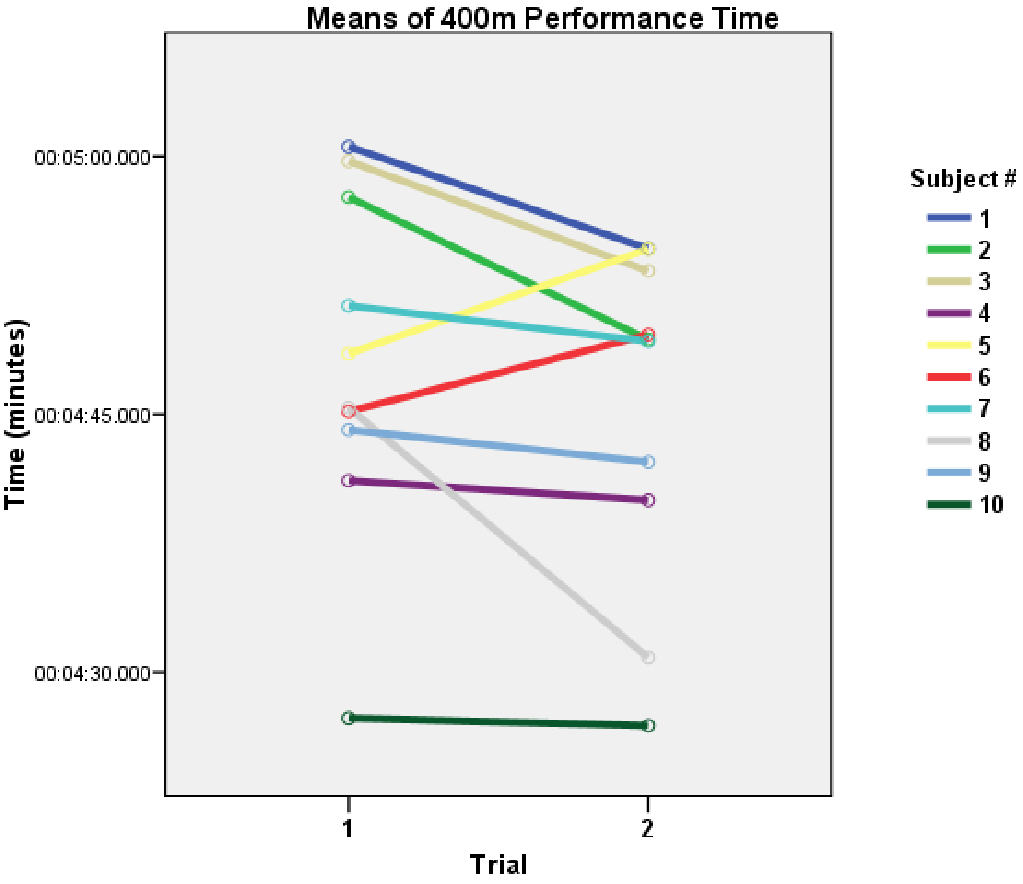

Figure 9. Altitude performance results between trials as individuals

Research Question 2:

Does a short-term seven-day simulated altitude exposure significantly improve aerobic capacity and race performance in 400-meter swimming trials among highly trained collegiate swimmers?

Using a MANOVA to compare the dependent variables VO_{2peak} and 400-meter swimming performance through a treatment by trial analysis, the statistical analysis resulted in no significant improvement in either parameter among the swimmers in the present study (p=0.883 and p=0.761, respectively).

Lactate

There were no significant differences in resting lactate values between groups when completing the laboratory ergometer sessions. However, the altitude group demonstrated a slight non-significant reduction in resting lactate between Trials 1, 2, and 3 (1.92 ± .14 vs. 1.74 ± .79 vs. 1.60 ± .35 mmol/L, respectively), whereas the control group's resting lactate concentration stayed essentially the same (1.73 ± .65 vs. 1.75 ± .42 vs. 1.73 ± .42 mmol/L, respectively). Post-lactate concentrations after the laboratory ergometer sessions were not significantly different in either the altitude or control group.

The 400-meter swimming performance trials resulted in no significant difference in resting or post-lactate concentration between groups (Table 9). However, the control group experienced a slight non-significant increase in resting lactate concentration from Trial 1 to 2 (1.72 ± 0.56 vs. 1.82 ± 0.49 mmol/L, respectively), whereas the altitude group demonstrated no change in resting lactate concentration from Trial 1 to 2 (2.00 ± 0.81 vs. 1.99 ± 0.77 mmol/L, respectively). Likewise, post lactate concentrations experienced no significant changes between trials. The altitude group experienced a slight reduction in post-lactate concentration from Trial 1 to 2 (11.21 ± 1.70 vs. 11.05 ± 1.76 mmol/L, respectively); conversely, the control group experienced slight increases in post-lactate concentration from Trial 1 to 2 (10.46 ± 1.66 vs. 10.82 ± 1.15 mmol/L, respectively).

Power

Demonstration of a greater power output capability by the altitude group over the control group resulted in a trend (p=0.058; Table 8). Furthermore, a trend in treatment by trial interaction (p=0.112; Table 8) was shown through the altitude group's ability to produce a greater amount of power from Trial 2 to 3 (138 ± 23.47 vs. 147 ± 20.57 W, respectively) when compared to the control group (141 ± 24.21 vs. 138 ± 23.15 W, respectively).

Time to Exhaustion

Results indicate a moderate trend in treatment by trial interaction (p=0.193; Table 8), allowing the altitude group to have a greater time to exhaustion between Trials 2 and 3 (23.90 ± 4.70 vs. 25.90 ± 4.16 minutes, respectively) compared to the control group (24.59 ± 5.12 vs. 24.50 ± 4.52 minutes, respectively). There was also a treatment effect (p=0.114; Table 8) experienced by the altitude group who had a greater overall time to exhaustion (25.25 ± 4.44 minutes) than their control counterparts (23.69 ± 5.56 minutes).

Logbooks

Based on the perceived difficulty of practices by the swimmers, there was no significant difference between groups. Likewise, there were no significant differences in maximal heart rate between groups during any of the workout days. However, differences were found within workout distance between the altitude and control groups. A significant treatment effect (p=0.043; Table 10) was shown where the control group swam a greater distance during workouts than the altitude group. Also, a trend was visible for a treatment by day interaction (p=0.132) for workout distance.

Table 10

Swimmer's workout logbooks

Daily Workouts	
Parameter	**Value**
Difficulty	6.91
	1.41
Difficulty	6.38
	1.56
Distance (meters)	4486.36 *
	1259.74
Distance (meters)	3714.29 *
	1042.73
Max HR (bpm)	175
	11.02
Max HR (bpm)	172
	14.96

Control treatment in white; altitude treatment in gray. Mean values represented in first row with the standard deviation below. * = treatment effect ≤ 0.05.

Simulated Altitude Exposure

Similar to the cyclists' altitude exposure, only the altitude group's sleep patterns were analyzed and demonstrated no significance between days for any parameters. However, when the cyclists' (Table 6) and swimmer's (Table 11) altitude exposure was analyzed together, an effect for day (p=0.083) was noticed where the quality of sleep progressively improved each day throughout the exposure (Figure 10).

Table 11

Swimmer's simulated altitude exposure

Altitude Exposure

Parameter	Value
O_2% In	17.54
	2.20
O_2% Out	15.36
	0.33
HR In	61
	11.17
HR Out	59
	11.53
Hours Exposure	9.25
	1.10
Hours Sleep	8.66
	1.32
Sleep Quality	7.58
	1.78

Mean values represented in first row with the standard deviation below.

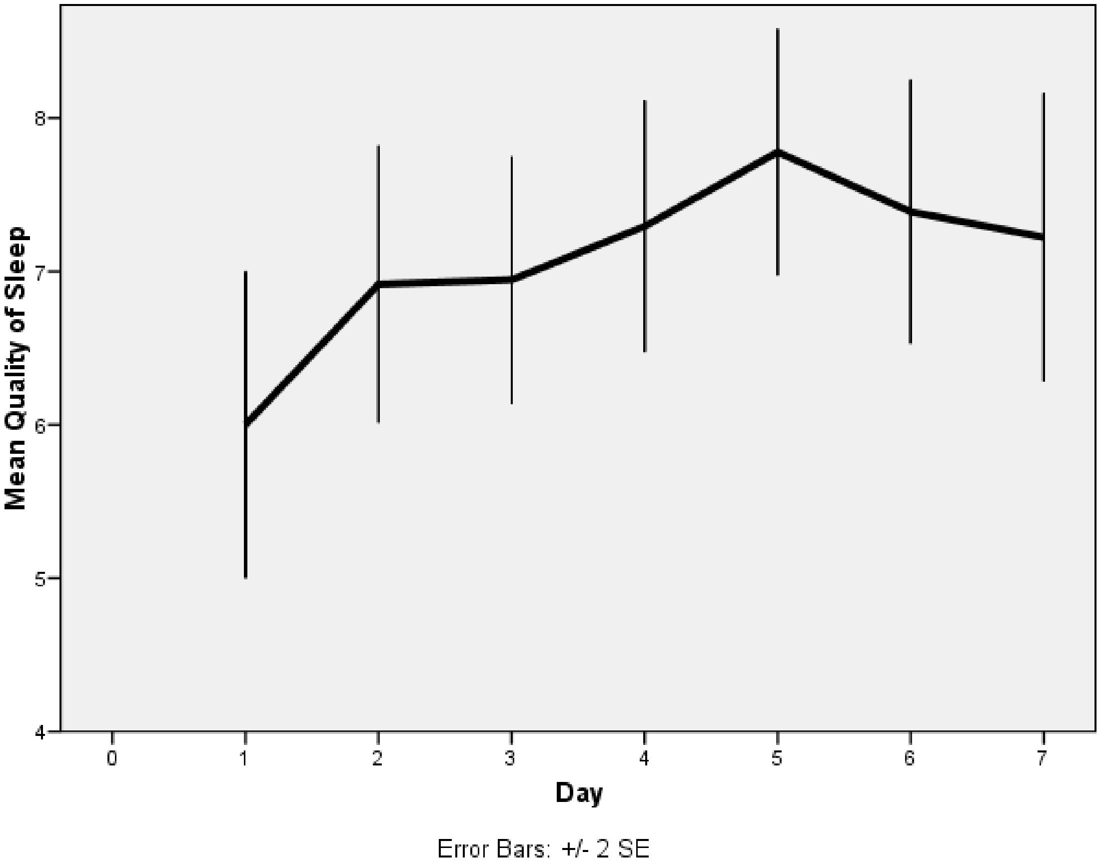

Figure 10. Altitude exposure sleep quality for cyclists and swimmers. The quality of sleep was rated on a 1-10 scale, 1 being the worst sleep quality and 10 being the best.

Chapter V: Discussion

The study design utilized two groups of athletes in order to allow for both the assessment of MAOD in trained subjects and, in particular, performance in swimmers. Because of the constraints of the competitive season, it was not possible to do both using collegiate swimmers. The design was intended to ultimately integrate the two groups at the completion of the study to analyze the overall effect of the simulated altitude exposure. Therefore, the discussion section is structured in a way that will highlight the individual aspects of each study as well as unite the overall findings of the simulated altitude exposure.

Prior to this study, two research questions were formulated to better understand the potential relationship between simulated altitude exposure and performance.

1. Can significant physiologic anaerobic improvements, specifically MAOD, and/or aerobic capacity improvements occur in trained cyclists after a seven day simulated altitude exposure?
2. Can a short-term, seven-day simulated altitude exposure significantly improve aerobic capacity and/or race performance in 400-meter swimming trials among highly trained collegiate swimmers?

The overall findings of the present study demonstrate that there were no significant adaptations in any parameter measured throughout the seven-day simulated altitude exposure to 2,500m among trained male cyclists and swimmers. Particular individuals did demonstrate changes pre- and post-treatment; however, these variables were not statistically significant, which led the investigators to conclude that there was no overall effect of the treatment with regard to either of the research questions.

Performance Results

Cyclists: In the present study there was no significant difference in $MMPO_{4min}$ between the two groups. However, there was a greater yet non-significant improvement in power output from Trial 2 to 3 in the altitude compared to the control group.

Swimmers: There were no significant differences between the altitude and control group regarding the 400-meter swim performance time. Even though the fastest times occurred during the altitude treatment, the control group non-significantly improved their performance time from Trial 1 to Trial 2 (Figure 7). It is difficult to state with confidence what occurred as a result of the altitude exposure regarding swim performances. Seeing that the control group improved to a greater extent from Trial 1 to Trial 2 eliminates the explanation of a treatment effect. This also contradicts previous arguments for a placebo effect (Baker & Hopkins, 1998; Clark, Hopkins, Hawley & Burke, 2000). Although the control group experienced a greater volume of training ($p=0.043$) than the altitude group, the swimmers swam as a team with their coach in the “spring season” to avoid any confounding factors in their schedule (e.g. competitions, tapers, etc.). This difference in training volume was a coincidence of the cross-over design. Since the swimmers were intercollegiate varsity athletes, the level of fitness is consistently high and therefore is less likely to have been affected by the difference in training volume (Bailey, Davies, & Baker, 2001; Levine & Stray-Gundersen, 1997).

Robach and colleagues (2006b) found no significant improvements in swimming performance after a 13-day LHTL exposure. Results did indicate improvements in red cell volume and VO_{2max}; however, these did not translate to performance. The exposure parameters by Robach et al. (2006b) exposed the swimmers to 13 days of LHTL at 2,500m, 3,000m, and 3,500m for 11 hours a day, which was a greater degree of exposure than in the present study. Based on previous conclusions regarding the optimal approach to altitude exposure, the approach of Robach et al. (2006b) should have been more likely to result in performance improvements.

Then again, a variety of researchers have discovered performance improvements of 1 to 4 percent for events lasting 1 to 15+ minutes after LHTL exposures (Reviewed in Roberts et al., 2003). According to Hopkins (1999), a 1 percent improvement in performance time increases the chance of winning an international 1500m running race by 10 to 20 percent. The time frames to complete the test event are similar between Hopkins' and the present study (3:30 vs. 4:30 minutes). Therefore, this level of change could have a similar impact in the results for the 400-meter in swimming.

Peak Oxygen Consumption (VO_{2peak})

Cyclists: The results show that the control group's VO_{2peak} was significantly higher ($p \leq 0.05$) compared to the altitude group. Training was recorded but not controlled, and consideration for the time of the season was not accounted for when initiating the testing for this research. Therefore, these factors could have coincidentally contributed to a greater level of fitness when the participants completed control testing compared to altitude testing.

Trial 1 resulted in a lower VO_{2peak} in both the altitude and control groups when compared to Trials 2 and 3, although non-significant. This difference in VO_{2peak} could have been a result of the differences in protocol. The warm-up associated with Trials 2 and 3 arguably allowed for a greater ability to initiate aerobic metabolism prior to the start of the test.

Swimmers: The results indicate that there was not a treatment by trial interaction regarding VO_{2peak} among the swimmers. However, the altitude group tended ($p=0.139$; Table 8) to have a mean VO_{2peak} greater than that of the control group. Conversely, the control group resulted in a non-significantly greater improvement in VO_{2peak} from Trial 2 to 3 than the altitude group. As previously stated in the discussion of 400-meter performance trials, regardless of the control group's greater training volume over the altitude group, the nature of the team's consistent conditioning should limit any impact on fitness improvements.

Several studies have resulted in VO_{2max} improvements (Wehrlin, Zuest, Hallen, & Marti, 2006; Stray-Gundersen, Chapman, & Levine, 2001). However, each study has a slightly different protocol design, which could result in significant implications on the results. Levine and Stray-Gundersen (1997) discovered improvements of 5 percent ($p<0.05$) in VO_{2max}. However, this was demonstrated in both the altitude and control group. Therefore, this adaptation cannot be concluded to be a result of the altitude treatment. Brugniaux et al. (2006) found VO_{2max} improvements in swimmers and runners of 8.1 percent ($p<0.09$) and 7.1 percent ($p<0.05$), respectively. Opposing this common view, Gore et al. (1997) discovered no change in VO_{2max} in high-caliber cyclists after a 31 day exposure at 2,650m. This supports the more recently developed thought that adaptations in the aerobic energy systems may not be as prominent or important as once believed, leaving other mechanisms as possible contributors.

Although this was not the result of the present study, many researchers have discovered a decrease in VO_{2max} after exposure to altitude (Gore et al., 2001; Hahn et al., 2001). Gore et al. (2001) discovered a 7 percent reduction in VO_{2max} after 23 nights of LHTL and concluded that there was likely an increase in mechanical efficiency. The explanation for a reduction in VO_{2max} is not fully understood, but the most common thought is that the body's mechanical efficiency is improved or the individual is experiencing a detraining effect due to constraints and/or alterations in their training routine (Gore et al., 2001). Furthermore, Hahn et al. (2001) contends that the systemic delivery of oxygen is redistributed, allowing only a portion of the increased oxygen carrying capacity to be fully utilized by the exercising muscles.

Much of the previous research involving altitude research has included blood analysis. Several blood components, such as erythropoietin, red blood cell number and volume, iron levels, hematocrit, and hemoglobin, are analyzed to evaluate the effect of altitude. These analyses allow for identification of the underlying mechanisms that ultimately promote metabolic and performance improvements. However, the resources for these measurements were unavailable in the present study; therefore, reliance on previous research was made to provide possible implications of blood adaptations on the results of this study.

Although there was no overall adaptation found in the present study, the simulated altitude exposure may have stimulated other physiological parameters that were not analyzed. Increases in erythropoietin are often believed to be a major contributor, and often times the first adaptation necessary, to allow for other physiologic adaptations (Levine & Stray-Gundersen, 1992, 1997, 2006). Ri-Li et al. (2002) discovered that erythropoietin increased significantly (24-30 percent, $p<0.05$) after 6 hours exposure and further increased by approximately 77-92 percent ($p<0.05$) after 24 hours. Koistinen et al. (2000) measured the erythropoietic effects to a seven-day altitude exposure to 2,500m. Results demonstrated serum erythropoietin increases of 78 and 71 percent ($p<0.05$) in both the 24-hour-per-day and 12-hour-per-day groups, respectively. Similarly, Hahn et al. (2001) discovered significant increases in erythropoietin of 80 percent ($p<0.05$) after five nights at a moderate altitude exposure. However, this increase in erythropoietin was not enough to stimulate erythrocyte production. In agreement, Ashenden et al. (2000) found significant ($p<0.01$) increases in erythropoietin levels in the altitude exposed group but not in the control group. Regardless of this increase, reticulocyte production was not affected at any point. This exemplifies that an increase in erythropoiesis does not always result in improvements in red cell volume, VO_{2max}, or performance. These findings relate well to the present study due to the similarities in exposure parameters. Therefore, one could postulate that the participants in the present study may have adapted in a similar fashion; however, blood analysis was not performed in order to realize these adaptations. Regardless, the participants in the present study did not demonstrate improvements in the measured parameters, thereby suggesting that any improvements in EPO after a seven-day altitude exposure are not capable of eliciting aerobic and/or anaerobic capacity improvements.

Maximal Accumulated Oxygen Deficit

Cyclists: In the present study, no significant difference was found in MAOD between the altitude and control groups. However, pre- to post-treatment results demonstrated a greater yet non-significant increase in MAOD among the altitude group than the control group (Figure 6).

The postulation of anaerobic improvements as a result of altitude exposure is a fairly new topic of research. Roberts and colleagues (2003) used very similar altitude exposure parameters in their study design and found significant adaptations in $MMPO_{4min}$ (3.7 percent, $p<0.05$), MAOD (9.6 percent, $p<0.05$), and VO_{2max} ($p<0.05$). In fact, the present study was designed in some regards after Roberts et al. (2003) in order to investigate potential anaerobic and performance adaptations to a short-term altitude exposure. The results obtained in the present study, which presented no significant values in MAOD or VO_{2peak}, conflict with the results found by the Roberts team. Roberts et al. (2003) looked at changes in MAOD after altitude exposure of 5, 10, and 15 days. There was no difference in the MAOD adaptation between the varying lengths of exposure. However, when the exposure durations were analyzed as a group, significant improvement in MAOD was observed. Further, in the group analysis, there was no significant difference between the individual exposure durations. The lack of significant MAOD improvement ($p=0.730$) in the present study's 7-day exposure conflicts with Roberts and colleague's (2003) finding of significant MAOD ($p<0.05$) adaptation after 5 days of exposure. Therefore, it is speculated that the combination of all three exposure groups may have strengthened the overall power by improving a potentially weak power in the 5-day exposure.

Mizuno et al. (1990) found a 29 percent ($p<0.05$) improvement in MAOD as well as short-term running performance ($p<0.05$) among runners after altitude exposure. This performance improvement occurred even though VO_{2max} was unchanged. Furthermore, muscle biopsies of the gastrocnemius and triceps brachii demonstrated a 6 percent improvement in muscle buffer capacity ($p<0.05$). Seeing as there was no improvement in VO_{2max}, the improvement in performance likely resulted from a greater anaerobic capacity as a result of the LHTL exposure. In another study, Hahn et al. (2001) found that athletes were able to produce more work per liter of oxygen consumed after altitude exposure, possibly concluding that performance benefits are likely the result of increased anaerobic capacity or a greater efficiency of aerobic metabolism. There were no significant changes in cyclist's VO_{2peak} or power output in the present study. However, the altitude group demonstrated a non-significantly greater improvement in power output from Trial 2 to 3 than the control group. Gore et al. (2001) discovered a decrease in VO_{2peak} after LHTL exposure but no significant change in the work performed throughout the cycle ergometer testing. Furthermore, muscle buffer capacity increased significantly in the LHTL group ($p<0.05$) but was unchanged in the control. Therefore, had the subject number been higher in the present study, similar adaptations may have demonstrated a greater level of significance.

Contrary to the previous research, Levine and Stray-Gundersen (2006), who have completed several altitude related research studies (Levine, 2002; Levine & Stray-Gundersen, 1992; Levine & Stray-Gundersen, 1997), adamantly state that they have never seen an improvement in MAOD, buffer capacity, or running economy. Similar techniques to realize these measures were used over the course of 10 years with more than 100 athletes. The primary focus for these researchers surrounds aerobic adaptations; therefore, little discussion occurred regarding this discrepancy.

Blood Lactate Concentration

Cyclists: In the present study there were no significant changes in blood lactate concentration under resting or post exercise conditions, although there was a trend for treatment by trial interaction ($p=0.12$) in the control group, whose resting lactate concentration decreased from Trial 2 to 3 to a greater extent than the altitude group.

Swimmers: There were no significant differences found between resting or post-lactate concentrations in either group while performing the laboratory tests. However, the altitude group demonstrated a non-significant gradual decline in resting lactate values over the course of the three trials.

There were no significant differences during the 400-meter performance trials in resting or post-lactate concentrations between the altitude and control groups.

Nummela and Rusko (2000) analyzed sprinters and discovered a significant improvement in 400-meter running performance time (.8 percent, $p<0.01$), as well as running speed at given lactate concentrations after a 10-day exposure to 2,200m. Therefore, it was concluded that the adaptation was an improvement in anaerobic capacity. Additionally, Clark et al. (2004) performed a simulated altitude exposure protocol very similar to the present study; however, the length of exposure was 20 days. Lactate kinetics were significantly altered ($p<0.05$) after the continuous LHTL exposure, which was demonstrated by decreased plasma lactate concentrations at 85 percent VO_{2max} as well as an increase in workload at 4 mmol/L lactate. However, there was no difference between any group in regard to muscle buffer capacity or MCT1 and MCT4 abundance. This is possibly due to the belief that the lactate/H^+ transport system is more active during activity compared to rest, so altitude exposure during resting conditions may not be appropriate to elicit alterations (Juel, Lundby, Sander, Calbert & Hall, 2003). Therefore, this could have contributed to the lack of significant difference in lactate values throughout the simulated altitude exposure.

Participants in a LHTL exposure by Gore et al. (2001) demonstrated a significant 7 percent reduction in VO_{2peak}, whereas the control group experienced no change. This occurred without any significant change in the work performed throughout the cycle ergometer testing. Furthermore, muscle buffer capacity increased significantly in the LHTL group but was unchanged in the control. Finally, blood lactate levels did not increase significantly due to the LHTL exposure, although values were significantly different between the LHTL and control groups pre- and post-exposure. However, the present study's lack of significant increase in post-lactate concentration and performance improvement after maximal exercise and LHTL exposure likely indicate no improvement in muscle buffer capacity.

Power Output

Swimmers: The altitude group was able to produce a greater amount of power ($p=0.058$) than the control group. Furthermore, a trend for a treatment by trial interaction ($p=0.112$) is visible with regard to the improvement in power production from Trial 2 to 3 by the altitude group when compared to the same parameters in the control group.

Time to Exhaustion

Swimmers: The altitude group completed the arm ergometer test protocols longer, therefore resulting in a trend for a treatment by trial interaction (p=0.193) and treatment effect (p=0.114).

Without a significant increase in VO_{2peak} or lactate values, it is difficult to speculate why these trends occurred.

Responders VS. Non-responders

As athletes and coaches continue to incorporate altitude training into their seasonal plan, many want to know if any adaptation to the exposure is likely to occur. Some have postulated that one's ability to adapt to altitude is dependent on appropriate iron levels (Levine, 2002; Baker & Hopkins, 1998). According to Baker and Hopkins (1998), adequate iron levels allow for red blood cell improvement, which may ultimately promote an improvement in performance. Chapman, Levine, and Stray-Gundersen (1998) categorized participants as either responders or non-responders based on some participants' inability to demonstrate an adaptation to the altitude exposure, whereas others demonstrated significant adaptations (as introduced in the Literature Review section). Therefore, Chapman et al. (1998) classified participants based on their ability to express a series of acclimatization response increases in erythropoietin, red cell volume, VO_{2max}, and ultimately performance time.

At this point, it is difficult to predict an individual's response to altitude exposure. There are numerous combinations to the exposure, training, and physiological parameters that ultimately contribute to the classification of "responder" or "non-responder." Even still, the magnitude of response is no guarantee. Therefore, Wilber, Stray-Gundersen, and Levine (2007) conclude that there is an inability to identify exactly why individualized responses to altitude exposure exist.

Limitations

The modalities used to complete the laboratory testing sessions were performed on sport-specific equipment. The Velotron was appropriately fit for each cyclist in order to replicate the geometry of their personal bicycle. This ensured that participants were comfortable and able to produce optimal results during the testing sessions. However, many of the swimmers using the arm ergometer suffered from forearm and hand fatigue during the tests. Subjects were encouraged to change hand positions throughout the test, although all grips ultimately required the musculature of the forearms to a greater extent than many were accustomed to. However, due to the lack of significant difference in power output between Trials 1, 2, and 3, this was not a factor in the present study. A recommendation for future investigators using an arm ergometer is to develop a strap system for the hands so the participant’s arms can be safely and effectively fixed to the ergometer without requiring the subject to constantly grip the handles of the ergometer. This may more effectively allow the participant to exhaust the cardiorespiratory system instead of the forearm musculature affecting the test.

Due to the altitude exposure timeline being strictly set at seven days, all testing surrounding this timeline was extremely sensitive. In order to maintain optimal accuracy, reproducibility, and reliability of the laboratory tests, the test schedule was to be replicated for each participant. As mentioned in the results section, there were a few unavoidable circumstances that necessitated altering of this schedule. One subject became ill with an upper respiratory tract infection, requiring the final trial of the control round to be delayed by four days. It is possible that this deviation in protocol could have impacted the participant's performance. Another individual was physically assaulted before he could complete his control round testing, and therefore that participant's control data were discarded. This study incurred tight time constraints, which exacerbated many of these issues. Individuals interested in embarking on a similar study should create a timeline that allows for equipment malfunctions and/or participants' unexpected inability to test on a scheduled day.

The participants in this study reported that they had an overall positive experience while using the altitude tents. A common comment by many researchers is that participants experience altitude sickness (Roeggla, Roeggla, Podolsky, Wagner, & Laggner, 1996). This was not the case for any participants in this study, indicating that 2,500m was an appropriate level of simulated altitude. Alternatively, the stimulus may have been insufficient because no participants resulted in significant performance improvements or altitude sickness. Some made comments that they felt more energized during workouts and laboratory sessions, and recovered more quickly after workouts. However, several participants complained about the quality of sleep during their simulated altitude exposure, largely a result of the hot and stuffy environment inside the tent. Additionally, four participants stated they had unusual nightmares on more than one occasion while in the altitude tent. Figure 10 demonstrated a significant daily improvement ($p=0.05$) in sleep quality as the seven-day exposure progressed. Due to the fact that the control group did not record quality of sleep it is difficult to speculate, but it is possible that the poor quality of sleep in the first few nights could have negatively impacted the participant's ability to perform on subsequent testing days. As athletes prepare for competition, sleep is regarded as an important component in that preparation (Samuels, 2008). Therefore, if a participant's sleep quality in the present study was jeopardized, that could provide a rational explanation, at least in part, for an inability to improve performance.

Direction of Future Research

Future research should further investigate the potential physiologic adaptations to both (a) short term altitude exposures and (b) anaerobic capacity improvements. Roberts et al. (2003) were able to identify significant improvements in MAOD using an altitude exposure for as little as 5 days. The potential for anaerobic capacity improvements elicited from altitude exposure could revolutionize sport; however, it may take a longer exposure to result in the necessary adaptations. The present study was not able to analyze changes in blood parameters to the seven-day exposure; however, future studies could investigate the potential impact on performance. The main focus should be to discover the exposure parameters necessary to result in optimal anaerobic and aerobic performance improvements, understanding that these two likely require a different exposure structure.

Conclusion

It has been demonstrated in much of the previous research that exposure to altitude can result in physiologic and performance adaptations (Gore et al., 2001; Levine

& Stray-Gundersen, 1997, 2001; Roberts et al., 2003; Wilber, 2001). There are many likely explanations for the lack of significant adaptations in our participants. First of all, one of the novel aspects to our approach was the short term (7-day) exposure. To reiterate, much of the literature strongly states a minimum of 14 days is needed to allow for adaptations. Therefore, it is possible that participants were not given adequate time to initiate the necessary adaptations that would be visible in our laboratory measures. Secondly, the length of daily exposure may have also been too short. Again, previous studies suggest 12-16 hours of exposure per day, whereas our participants were instructed to occupy the tent for 8-12 hours per day. Saying this, the average daily exposure by our participants was actually 8.5 hours per day. Therefore, the participants in this study may have needed to occupy the altitude tent for a greater duration each day.

The overall findings of this research conclude that there were no significant adaptations in MAOD, VO_{2peak}, or performance among highly trained cyclists and swimmers after a 7-day simulated altitude exposure. There were, however, interesting trends that call for further investigation. Previous research has demonstrated that altitude exposure has the potential to result in physiologic adaptations; however, appropriate levels of elevation and duration to the altitude exposure must be achieved to elicit these improvements. Therefore, it is the conclusion of this study that a 7-day simulated altitude exposure to 2,500m for 8.5 hours each night is insufficient of resulting in MAOD, VO_{2peak}, or performance improvements among highly trained cyclists and swimmers.

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APPENDIX A

Cyclists Informed Consent

Eastern Michigan University
Applied Physiology Laboratory
Informed Consent for Research Involving Human Subjects

Title of Project:
Adaptations in Maximal Accumulated Oxygen Deficit (MAOD) after a "Living High-Training Low" approach using simulated altitude exposure

Principal Investigator: Ian Ratz

Co-Principal Investigator: Stephen J. McGregor, Ph.D.
318 Porter Building
(734) 487-7120 ext. 2726

Methods: You have been invited to participate in a study examining the effects of simulated altitude exposure on anaerobic performance adaptations. You must be a recreationally trained individual (minimum of 8 hours/week) and range in age from 18 to 45 years. All participants will be required to provide medical clearance for maximal exercise and simulated altitude exposure. If you have been exposed to an altitude greater than 2000m for longer than 14 days in the past 3 months, you may be excluded from the study.

On seven separate occasions, you will be asked to come to the Exercise Physiology Laboratory at Eastern Michigan University. Your first two testing sessions will consist of a Maximal Mean Power Output in 4 minutes ($MMPO_{4min}$) test, where your power output and maximal oxygen uptake (VO_{2max}) will be measured over a 4 minute all out effort on a Velotron cycle ergometer. These are accepted measures of an individual's aerobic capacity and will be used to determine workloads for subsequent tests. Blood lactates will be analyzed immediately after the $MMPO_{4min}$ test. This will consist of either an earlobe or finger prick to draw a small blood sample.

The remaining testing sessions are identical and will measure your anaerobic capacity. This will be achieved by following a Maximal Accumulated Oxygen Deficit (MAOD) protocol on a Velotron cycle ergometer. You will first complete a 4-minute warm up at 50 W. This will be followed by an incremental test with three intervals lasting 6 minutes each at 50%, 62.5%, and 75% of $MMPO_{4min}$. After each 6-minute interval a 4-minute rest will take place, consisting of 2 minutes active rest at 50 W followed by 2 minutes seated passive rest. After the final 4-minute resting period, the same $MMPO_{4min}$ test will be administered. Blood lactates will be analyzed immediately after the MAOD test. This will consist of either an earlobe or finger prick to draw a small blood sample.

During these sessions a Jaeger Oxycon Metabolic Cart will be utilized to collect expired gases. This consists of a facemask attached to a very small unit worn on your body during exercise. This device measures the oxygen and carbon dioxide gases that you inhale and exhale to give the physiologists the data we need to determine aerobic capacity and other important information that will be shared with you at the end of the study. Your heart rate will be monitored with a Polar heart rate monitor.

You will be asked to adhere to several restrictions prior to performing each of the laboratory testing sessions. Your workouts the day before testing should be light and easy. You will need to reside in the altitude tent by yourself (sleeping or awake) for 8-12 hours/day for a period of 7 days. The principle investigator will setup the tent at your home and will explain its operation before use. You will need a responsible adult in your home to supervise your well being during the simulated altitude exposures. You will be asked to keep a logbook including daily recordings of workout distance, intensity/pace, modality of training, and max heart rate (HR). It should also include information about the tent such as hours spent in tent each night, hours of sleep, quality of sleep, resting HR, and verification of the O_2 percentage inside the tent. Any additional comments you feel necessary should be written in the logbook. Finally, you are requested to refrain from the consumption of alcohol 24 hours before a testing session and caffeine consumption the day of a testing session. Also, do not eat anything 2 hours prior to testing.

Benefits: There is no monetary compensation for participating in this study. You will benefit by learning your aerobic fitness level ($MMPO_{4min}$), anaerobic work capacity (MAOD test), and your response to simulated altitude exposure. Your performance could potentially improve due to the simulated altitude exposure. The simulated altitude exposure could potentially negatively impact performance if the recommended guidelines are not followed (ie: oxygen concentration too low).

Potential Risks: Individuals may experience symptoms of altitude sickness, which may include: headache, lack of appetite, nausea, vomiting, fatigue, weakness, dizziness, light-headedness, and insomnia. The manufacturer of the tent, *Hypoxico,* has determined the tent to be “just as safe as flying in a commercial plane”. Participants will be exposed to an altitude that is between Denver, CO (1609 m) and Breckenridge, CO (2926 m).

Equipment Responsibility: It is expected that you will take care of the Simulated Altitude Training System while it is in your posession. The principle investigator will set up the system in your home and give thorough instruction of its use. Adherence to these instructions should prevent damage to the system. If, however, the Simulated Altitude Training System is damaged during your possession that is not attributed to a “normal malfunction”, you are to be held responsible for this damage. This damage includes, but is not limited to: carelessness, neglecting the operating instructions given by the Principle Investigator, overheating of the generator due to improper location of the generator, ripping/tearing of the tent material, damage to the oxygen sensors, etc.

Therefore, please lock your doors and make sure you are the only person using the Simulated Altitude Training System. If at any point while the tent is your possession and malfunction or damage to the system is to occur, you are to call the principle investigator directly at (952) 210-3003.

It is important for you to understand that at any time, you may withdraw from the study without prejudice or effect on your relationship to Eastern Michigan University.
All of the results from this study will be kept confidential. If publication occurs, only numbers will be used, not names. Throughout the study, some of the data obtained from your participation will be made available to you. At the conclusion of the study, any additional data obtained from your participation will be made available to you. Any concerns with regard to approval or research procedures should be directed to the Eastern Michigan University College of Health and Human Services Human Subjects Review Committee. The Chairperson of the committee may be contacted at (734) 487-1238.

I,________________________________, hereby give my consent to participate in the research study entitled *"*Anaerobic and performance adaptations to a "Living High-Training Low" approach using simulated altitude exposure.*"* The details of which have been provided to me, including anticipated benefits, risks, and potential complications. I also understand the operation of the Simulated Altitude Training System and agree to take responsibility for any unnecessary damage to the system.

I fully understand that I may withdraw from this research project at any time without prejudice or effect on my standing with Eastern Michigan University. I also understand that I am free to ask questions about any techniques to be used or procedures to be undertaken.

I understand that in the unlikely event of a physical injury resulting from research procedures that medical treatment will be arranged but the costs of the treatment will be my responsibility since Eastern Michigan University will not provide financial compensation.

Finally, I understand that the information about me that is obtained during the course of this study will be kept confidential unless I consent to its release.

____________________________________ ________________

Participant's signature *Date*

I hereby certify that I have given an explanation to the above individual of the contemplated study and its risks and potential complications.

____________________________________ _________________

Principal Investigator *Date*

APPENDIX B

Swimmers Informed Consent

Eastern Michigan University
Applied Physiology Laboratory
Informed Consent for Research Involving Human Subjects

Title of Project:
Aerobic and performance adaptations to a "Living High-Training Low"
approach using simulated altitude exposure

Principal Investigator:	Ian Ratz
Co-Principal Investigator:	Stephen J. McGregor, Ph.D. 318 Porter Building (734) 487-7120 ext. 2726

Methods: You have been invited to participate in a study examining the effects of simulated altitude exposure on aerobic capacity as well as performance adaptations. You must be a trained swimmer from Eastern Michigan University's Swim Team, University of Michigan's Swim Team, Club Wolverine, or part of the local masters team and range in age from 18 to 45 years. If you have been exposed to an altitude greater than 2,000m for longer than 14 days in the past 3 months, you may be excluded from the study.

On five separate occasions, you will be asked to come to the campus of Eastern Michigan University. Swimming trials will occur in the Jones Natatorium and laboratory testing will occur in Warner 109. University of Michigan testing will occur at Canham Natatorium. You will perform five tests that will elicit peak oxygen consumption (VO_{2peak}) on a SciFit arm ergometer. This will require you to perform an incremental protocol starting at 50 Watts and ending with volitional exhaustion. This test will result in your VO_{2peak} and Peak Power Output (PPO), which are accepted measures of an individual's aerobic capacity. During a portion of the study, you will serve as the treatment group when you will undergo a seven-day period of simulated altitude exposure at 2,500m. Blood lactates will be analyzed pre- and post-test. This will consist of either an earlobe or finger prick to draw a small blood sample.

During these sessions a Jaeger Oxycon Metabolic Cart will be utilized to collect expired gases. This consists of a facemask attached to a very small unit worn on your body during exercise. This device measures the oxygen and carbon dioxide gases that you inhale and exhale to give the physiologists the data we need to determine aerobic capacity and other important information that will be shared with you at the end of the study. Your heart rate will be monitored with a Polar heart rate monitor.

You will complete a swimming trial one time each week throughout the study. This will require you to swim a timed 400 meter freestyle swim at your maximal ability as part of your training sessions. Blood lactate concentrations will be analyzed pre- and post-test in the same manner described previously.

You will be asked to adhere to several restrictions prior to performing each of the laboratory testing sessions. Your workouts the day before testing should be light and easy. Your coach is aware of this restriction. You will need to reside in the altitude tent by yourself (sleeping or awake) for 8-12 hours/day for a period of 7 days. The principle investigator will setup the tent at your home and will explain its operation before use. You will need a responsible adult in your home to supervise your well being during the simulated altitude exposures. You will be asked to keep a logbook including daily recordings of workout distance, intensity/pace, modality of training, and max heart rate (HR). It should also include information about the tent, such as hours spent in tent each night, hours of sleep, quality of sleep, resting HR, and verification of the O2 percentage inside the tent. Any additional comments you feel necessary should be written in the logbook. Finally, you are requested to refrain from the consumption of alcohol 24 hours before a testing session and caffeine consumption the day of a testing session. Also, do not eat anything 2 hours prior to testing.

Benefits: There is no monetary compensation for participating in this study. You will benefit by learning your aerobic fitness level (VO_{2peak}) and your response to simulated altitude exposure. Your swimming performance could potentially improve due to the simulated altitude exposure. The simulated altitude exposure could potentially negatively impact performance if the recommended guidelines are not followed (ie: oxygen concentration too low).

Potential Risks: Individuals may experience symptoms of altitude sickness, which may include: headache, lack of appetite, nausea, vomiting, fatigue, weakness, dizziness, light-headedness, and insomnia. The manufacturer of the tent, *Hypoxico,* has determined the tent to be "just as safe as flying in a commercial plane". Participants will be exposed to an altitude that is between Denver, CO (1609 m) and Breckenridge, CO (2926 m).

Equipment Responsibility: It is expected that you will take care of the Simulated Altitude Training System while it is in your posession. The principle investigator will set up the system in your home and give thorough instruction of its use. Adherence to these instructions should prevent damage to the system. If, however, the Simulated Altitude Training System is damaged during your possession that is not attributed to a "normal malfunction", you are to be held responsible for this damage. This damage includes, but is not limited to: carelessness, neglecting the operating instructions given by the Principle Investigator, overheating of the generator due to improper placement of the generator, ripping/tearing of the tent material, damage to the oxygen sensors, etc.

Therefore, please lock your doors and make sure you are the only person using the Simulated Altitude Training System. If at any point while the tent is your possession and malfunction or damage to the system is to occur, you are to call the principle investigator directly at (952) 210-3003.

It is important for you to understand that at any time, you may withdraw from the study without prejudice or effect on your relationship to Eastern Michigan University.

All of the results from this study will be kept confidential. If publication occurs, only numbers will be used, not names. Throughout the study, some of the data obtained from your participation will be made available to you. At the conclusion of the study, any additional data obtained from your participation will be made available to you. Any concerns with regard to approval or research procedures should be directed to the Eastern Michigan University College of Health and Human Services Human Subjects Review Committee. The Chairperson of the committee may be contacted at (734) 487-1238.

I,_______________________________, hereby give my consent to participate in the research study entitled "Aerobic and performance adaptations to a "Living High-Training Low" approach using simulated altitude exposure." The details of which have been provided to me, including anticipated benefits, risks, and potential complications. I also understand the operation of the Simulated Altitude Training System and agree to take responsibility for any unnecessary damage to the system.

I fully understand that I may withdraw from this research project at any time without prejudice or effect on my standing with Eastern Michigan University. I also understand that I am free to ask questions about any techniques to be used or procedures to be undertaken.

I understand that in the unlikely event of a physical injury resulting from research procedures that medical treatment will be arranged but the costs of the treatment will be my responsibility since Eastern Michigan University will not provide financial compensation.

Finally, I understand that the information about me that is obtained during the course of this study will be kept confidential unless I consent to its release.

________________________________ _______________

Participant's signature *Date*

I hereby certify that I have given an explanation to the above individual of the contemplated study and its risks and potential complications.

________________________________ ________________

Principal Investigator *Date*

APPENDIX C

Altitude Tent Exposure Supervisor Informed Consent

Eastern Michigan University
Applied Physiology Laboratory
Informed Consent for Research Involving Human Subjects

Title of Project:
Aerobic and performance adaptations to a "Living High-Training Low" approach using simulated altitude exposure

Principal Investigator: Ian Ratz

Co-Principal Investigator: Stephen J. McGregor, Ph.D.
318 Porter Building
(734) 487-7120 ext. 2726

As a safety precaution during the "Aerobic and performance adaptations to a "Living High-Training Low" approach using simulated altitude exposure" study, it is requested that you provide supervision to the participant. This requires that you will be in the same residence as the participant throughout the 7-day duration of the simulated altitude exposure.

I understand that my responsibilities include, but are not limited to:

1) Verifying that the oxygen concentration is at the recommended setting before the participant enters the simulated altitude tent.
2) Checking on the participant periodically to ensure their safety.
3) Checking for signs of altitude sickness:
    a. Headache (generally in combination with one or more of the below symptoms)
    b. Lack of appetite, nausea, or vomiting
    c. Fatigue or weakness
    d. Dizziness or light-headedness
    e. Insomnia
4) Calling the Principle Investigator if there are any equipment malfunctions.
5) Calling 911 in the event of an emergency.

I also understand that it is the participant's decision to participate in this study and I am volunteering as an extra safety precaution. The participant is aware of the protocol and of any potential risks and benefits.

I,________________________________, hereby agree to provide responsible adult supervision for _____________________________ while he is residing in the Hypoxico Altitude Tent provided for the purposes of the "Aerobic and performance adaptations to a "Living High-Training Low" approach using simulated altitude exposure" study. I will be in the same residence as the participant throughout the 7-day duration of the simulated altitude exposure. I am aware of my responsibilities during the participant's exposure.

I fully understand that I may withdraw from this research project at any time without prejudice or effect on my standing with Eastern Michigan University. I also understand that I am free to ask questions about any techniques to be used or procedures to be undertaken.

_________________________________ ________________

Supervisor's signature *Date*

I hereby certify that I have given an explanation to the above individual of the contemplated study and its risks and potential complications.

_________________________________ ________________

Principal Investigator *Date*

APPENDIX D

Cyclists Logbook

Altitude Exposure Logbook

Name:

Please complete this logbook everyday and provide as much detail as possible. This will allow the researcher to better analyze the results and understand your individual experience in the simulated altitude tent.

Definitions of Terms:

AM & PM Workout

Type: type of workout? (e.g. group ride, endurance, intervals, sprints, strength, etc.)
Difficulty: 1 is considered the "easiest" workout, 5 is an "average" workout, 10 is considered the "hardest" workout.
Distance: total miles in that workout session.
Duration: length of workout session (in hours).
Power: If available, record average power and kilojoules for each workout session.
Max HR: maximum heart rate during your workout session for that day
Notes: please provide any additional notes you deem necessary, appropriate, or helpful.

Entering Tent

Time on: the time that you turned the generator's power on.
Time in: the time that you entered the tent.
O2%: the oxygen concentration value inside the tent upon entering.
Resting HR: your heart rate while resting and relaxed.
Alcohol?: Did you consume alcohol today? If so, what type, in what quantity, and when did you finish drinking?

Exiting Tent

O2%: the oxygen concentration value inside the tent upon exiting.
Resting HR: your heart rate while resting and relaxed.
Time out: the time that you exit the tent.
Hours of sleep: the number of hours you slept while inside the tent.
Sleep quality: 1 would be the "worst" nights sleep, 5 would be an "average" nights sleep, 10 would be the "best" nights sleep. *Please explain …*

Daily Notes: please provide any additional notes you deem necessary, appropriate, or helpful. This could include things such as extra alertness, increased fatigue, headache, more stamina, better endurance, shortness of breath, feelings of discomfort, irritability, anxiousness, extra energy, increased mood, etc.

DAY #1	**Date:**
AM Workout	
Type:	
Difficulty (1-10):	
Distance:	
Duration:	
Power:	
Max HR:	
Notes:	
PM Workout	
Type:	
Difficulty (1-10):	
Distance:	
Duration:	
Power:	
Max HR:	
Notes:	
Entering Tent	
Time on:	
Time in:	
O2 %:	
Resting HR:	
Alcohol?	
Exiting Tent	
O2 %:	
Resting HR:	
Time out:	
Hours of sleep:	
Sleep Quality (1-10):	
Daily Notes:	

APPENDIX E

Swimmers Logbook

Altitude Exposure Logbook
Name:

Please complete this logbook everyday and provide as much detail as possible. This will allow the researcher to better analyze the results and understand your individual experience in the simulated altitude tent.

Definitions of Terms:

AM & PM Practices/Workouts

Type: what type of practice was it? (e.g. sprint, distance, kicking, pulling, stroke, etc)
Difficulty: 1 is considered the "easiest" practice, 5 is an "average" practice, 10 is considered the "hardest" practice.
Distance: total meters swam during that day's practice session.
Duration: length of time that practice lasted.
Max HR: maximum heart rate during your practice session for that day
Notes: please provide any additional notes you deem necessary, appropriate, or helpful.

Entering Tent

Time on: the time that you turned the generator's power on.
Time in: the time that you entered the tent.
O2%: the oxygen concentration value inside the tent upon entering.
Resting HR: your heart rate while resting and relaxed.
Alcohol?: Did you consume alcohol today? If so, what type, in what quantity, and when did you finish drinking?

Exiting Tent

O2%: the oxygen concentration value inside the tent upon exiting.
Resting HR: your heart rate while resting and relaxed.
Time out: the time that you exit the tent.
Hours of sleep: the number of hours you slept while inside the tent.
Sleep quality: 1 would be the "worst" nights sleep, 5 would be an "average" nights sleep, 10 would be the "best" nights sleep. *Please explain …*

Daily Notes: please provide any additional notes you deem necessary, appropriate, or helpful. This could include things such as extra alertness, increased fatigue, headache, more stamina, better endurance, shortness of breath, feelings of discomfort, irritability, anxiousness, extra energy, increased mood, etc.

DAY #1	**Date:**
AM Practice	
Type:	
Difficulty (1-10):	
Distance:	
Duration:	
Max HR:	
Notes:	
PM Practice	
Type:	
Difficulty (1-10):	
Distance:	
Duration:	
Max HR:	
Notes:	
Entering Tent	
Time on:	
Time in:	
O2 %:	
Resting HR:	
Alcohol?	
Exiting Tent	
O2 %:	
Resting HR:	
Time out:	
Hours of sleep:	
Sleep Quality (1-10):	
Daily Notes:	

APPENDIX F

Human Subject Approval Form

EASTERN MICHIGAN UNIVERSITY

April 12, 2007

Ian Ratz
c/o Stephen J. McGregor, PhD
School of Health Promotion and Human Performance
Eastern Michigan University
Ypsilanti, MI 48197

Dear Mr. Ratz,

The CHHS Human Subject Review Committee has reviewed your request entitled "Anaerobic and performance adaptations to a "Living High – Training Low" approach using simulated altitude exposure " and has found that it meets the Minimal Risk Standards and is approved for initiation with the following provisions:

- There was considerable concern by the committee that the sleep experiences were unsupervised and in the event of machine failure may cause harm to the subjects. We strongly suggest that there be "responsible adult supervision" during the time of the simulated altitude exposure.
- The informed consent document should be modified to better explain the tim frequency and risk related to the simulated altitude exposure.

The Committee may request further approval if secondary analysis of the data is conducted.

Sincerely,

Stephen A. Sonstein, PhD
Chair, CHHS Human Subjects Review Committee

APPENDIX G

Manufacturer's Oxygen Equivalents

Enter genuine altitude in feet in red square, and sea-level pressure in green square. Go down yellow column to observed oxygen content (calibrate at 20.9 outside hypoxic environment), read off effective oxygen content and effective altitudes, and also partial pressure of oxygen. Units for the Partial pressure column is the SAME as you use for the pressure in the green box.

Enter Location Height in feet	**850**	**Enter Sea level pressure**	**760**

Location Height in Meters	259
pressure factor compared with sea level	0.970

Monitor reading	effective Oxygen %	Effective H in Feet	Effective H in meters	Partial pressure Oxygen	Monitor reading	effective Oxygen %	Effective H in Feet	Effective H in meters	Partial pressure Oxygen
20.9	20.26	850	260	154.0	13.7	13.28	12,010	3,660	101.0
20.7	20.07	1,110	340	152.5	13.5	13.09	12,380	3,770	99.5
20.5	19.88	1,380	420	151.1	13.3	12.90	12,760	3,890	98.0
20.3	19.68	1,650	500	149.6	13.1	12.70	13,140	4,010	96.5
20.1	19.49	1,920	580	148.1	12.9	12.51	13,530	4,120	95.1
19.9	19.29	2,190	670	146.6	12.7	12.31	13,920	4,240	93.6
19.7	19.10	2,470	750	145.2	12.5	12.12	14,310	4,360	92.1
19.5	18.91	2,740	840	143.7	12.3	11.93	14,720	4,490	90.6
19.3	18.71	3,020	920	142.2	12.1	11.73	15,120	4,610	89.2
19.1	18.52	3,300	1,010	140.7	11.9	11.54	15,540	4,740	87.7
18.9	18.32	3,590	1,090	139.3	11.7	11.34	15,950	4,860	86.2
18.7	18.13	3,880	1,180	137.8	11.5	11.15	16,380	4,990	84.7
18.5	17.94	4,160	1,270	136.3	11.3	10.96	16,810	5,120	83.3
18.3	17.74	4,460	1,360	134.8	11.1	10.76	17,240	5,260	81.8
18.1	17.55	4,750	1,450	133.4	10.9	10.57	17,690	5,390	80.3
17.9	17.36	5,050	1,540	131.9	10.7	10.37	18,130	5,530	78.8
17.7	17.16	5,350	1,630	130.4	10.5	10.18	18,590	5,670	77.4
17.5	16.97	5,650	1,720	129.0	10.3	9.99	19,050	5,810	75.9
17.3	16.77	5,950	1,810	127.5	10.1	9.79	19,520	5,950	74.4
17.1	16.58	6,260	1,910	126.0	9.9	9.60	20,000	6,100	72.9
16.9	16.39	6,570	2,000	124.5	9.7	9.40	20,490	6,240	71.5
16.7	16.19	6,890	2,100	123.1	9.5	9.21	20,980	6,400	70.0
16.5	16.00	7,210	2,200	121.6	9.3	9.02	21,480	6,550	68.5
16.3	15.80	7,530	2,290	120.1	9.1	8.82	22,000	6,700	67.1
16.1	15.61	7,850	2,390	118.6	8.9	8.63	22,520	6,860	65.6
15.9	15.42	8,180	2,490	117.2	8.7	8.44	23,050	7,020	64.1
15.7	15.22	8,510	2,590	115.7	8.5	8.24	23,590	7,190	62.6
15.5	15.03	8,840	2,690	114.2	8.3	8.05	24,140	7,360	61.2
15.3	14.83	9,180	2,800	112.7	8.1	7.85	24,700	7,530	59.7
15.1	14.64	9,520	2,900	111.3	7.9	7.66	25,270	7,700	58.2
14.9	14.45	9,860	3,010	109.8	7.7	7.47	25,860	7,880	56.7
14.7	14.25	10,210	3,110	108.3	7.5	7.27	26,450	8,060	55.3
14.5	14.06	10,560	3,220	106.8	7.3	7.08	27,060	8,250	53.8
14.3	13.86	10,920	3,330	105.4	7.1	6.88	27,690	8,440	52.3
14.1	13.67	11,280	3,440	103.9	6.9	6.69	28,320	8,630	50.8
13.9	13.48	11,640	3,550	102.4	6.7	6.50	28,980	8,830	49.4