HOW MUCH OXYGEN DESATURATION OCCURS IN HEALTHY PEOPLE HIKING AT SIMULATED ALTITUDE?

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

Timothy T. Bushman

College of Exercise and Sport Science
Clinical Exercise Physiology

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HOW MUCH OXYGEN DESATURATION OCCURS IN HEALTHY PEOPLE HIKING AT SIMULATED ALTITUDE?

By Timothy T. Bushman

We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Clinical Exercise Physiology.

The candidate has completed the oral defense of the thesis.

Carl Foster, Ph. D.  
Thesis Committee Chairperson  
5/3/10

Glenn Wright, Ph. D.  
Thesis Committee Member  
5-3-10

Glenn Brice, Ph. D.  
Thesis Committee Member  
5-3-10

Thesis accepted

Vijendra K. Agarwal, Ph.D.  
Associate Vice Chancellor for Academic Affairs  
5/19/10
ABSTRACT

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Arterial desaturation often occurs during heavy exercise at altitude. This may be of concern in cardiac patients who desire to perform recreational activity (e.g., hiking) at altitude as it may provoke exertional ischemia. The purpose was to determine whether exercise intensity is appropriately regulated during hiking. Healthy physically-active young adults performed three exercise bouts of 21 min duration including a warm-up and a 'hiking' period: 1) a sea level (SL) hike at an intensity approximating the ventilatory threshold, 2) a high altitude F1O2=16.5% (~6,000 feet) hike at the same absolute intensity, and 3) a high altitude hike with the freedom to reduce or increase ambulatory speed during the 'hike.' At SL, Altitude Fixed Speed and Altitude Variable Speed, the HR was 164.2, 169.2 and 166.6 bpm, RPE was 5.2, 5.8 and 4.5, % saturation by pulse oximetry was 94.8, 87.4 and 87.8% and final speed was 4.0, 4.0 and 3.88 mph, respectively. Despite experiencing significant desaturation at simulated altitude, subjects did not display a tendency to regulate exercise intensity to protect from arterial desaturation. The results suggest that cardiac patients may need education or counseling in order to adequately protect themselves if they plan to hike at altitude.
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I would like to extend my sincere gratitude and appreciate to my family who has been the greatest influence in my life. They have been my backbone since day one and I would like to dedicate this thesis to them. Thank you for having such a positive and profound impact on the person I am today.

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INTRODUCTION

Exercise has long been known to provide health benefits. Hiking is a form of recreational exercise that often involves an individual ascending to higher altitudes where they can take-in views of unspoiled wilderness and enjoy nature in its purest form. Despite the breathtaking scenery, ascent to altitude can impose increased physiological stress. As altitude increases, the partial pressure of oxygen becomes diminished. Altitude exposure essentially limits pulmonary oxygen uptake (VO₂) due to decreased oxygen saturation in the arterial blood. This phenomenon is known as hypoxemia; or an SaO₂ of less than 88% (1).

A cross-sectional study conducted by Perez-Padilla and colleagues (1) identified several risk factors for hypoxemia including age, obesity, altitude, and smoking. Individuals greater than 75 years of age, body mass index (BMI) above 30 kg/m², high-altitude residents, and chronic obstructive pulmonary disease patients (COPD) had a significant predisposition to hypoxemia. In addition, SaO₂ decreased with the magnitude of altitude exposure.

Ample evidence exists to support the conclusion that exercise-induced arterial hypoxemia (EIAH) at sea level occurs in a vast number of healthy, fit individuals independent of gender and age. Dempsey and Wagner (2) performed a meta-analysis on the underlying causes and effects of EIAH. They defined mild EIAH as an SaO₂ of 93-95% (3-4% < rest), moderate EIAH of 88-93%, and severe EIAH as < 88%. They define
SaO\textsubscript{2} as a factor of arterial oxygen content, which is also affected by hemoglobin concentration. Generally, hemoglobin increases slightly from rest to heavy exercise which increases arterial oxygen content. EIAH tends to begin at moderate intensity workloads and usually peaks at the point of maximal exercise intensity. However, the tendency toward developing EIAH during submaximal exercise has not been adequately studied.

Hypoxia, or low ambient oxygen content, can also induce hypoxemia. Coupled with exercise-induced hypoxemia, this could create a double-whammy effect. As evidenced by numerous studies, hypoxia causes decrements in performance. Hypoxic conditions have been shown to alter human physiology during both acute and prolonged exposures. Acute exposure to hypoxia has been shown to decrease power output and reduce VO\textsubscript{2} max (3, 4, 5, 6). Prolonged exposure to hypoxia has been shown to increase hemoglobin mass and elevate plasma levels of erythropoietin (EPO) (7, 8, 9). Thus, it is the thought that chronic exposure to hypoxia may directly enhance VO\textsubscript{2} max via increased EPO and hemoglobin mass which would allow more oxygen transport to the working tissues to generate ATP through aerobic mechanisms and lead to performance benefits (10, 11).

Previous literature has shown decrements in various physiological parameters as a consequence of exposure to altitude. Such studies have raised the question of whether hypoxic altitude exposure is safe. Steinacker et al. (12) found that the risk for acute cardiac events in individuals with stable cardiovascular disease was small up to 2500 meters above sea-level. An important secondary finding was that both young and healthy populations, compared to elderly patients with some form of cardiovascular disease, seem
to employ the same mechanisms to acclimatize and adapt to hypoxic exposure at altitude. Therefore, it appears hypoxic exposure is relatively safe for most individuals regardless of underlying cardiovascular disease processes.

The majority of available research regarding hypoxia has studied highly-trained athletes and their response to hypoxia at maximal exercise (13, 3, 7, 14, 4, 10, 8, 15, 16, 17, 18, 9). A plethora of research has also compared hypoxic exposure and exercise in elite athletes versus sedentary individuals (19, 5, 6, 20). However, it is not known what happens to healthy, recreationally-active individuals at altitude exercising at submaximal intensity. Does this population experience hypoxemia much like the athletic population does? If hypoxemia is induced, does it affect performance parameters such as power output? Are people consciously aware of fluctuating $\text{SaO}_2$ levels? Would they detect the onset of hypoxemia and self-regulate power output based on changes in $\text{SaO}_2$? The purposes of this study are to determine how much oxygen desaturation occurs in healthy people hiking (submaximal intensity) at simulated altitude, and to determine if people spontaneously self-regulate their power output based on fluctuating $\text{SaO}_2$. It is hypothesized that $\text{SaO}_2$ in healthy people hiking at simulated altitude will drop below 85% and cause reductions in performance. Also, it is hypothesized that individuals will spontaneously self-regulate power output based on fluctuating $\text{SaO}_2$ levels by increasing speed at higher $\text{SaO}_2$ and decreasing speed at lower $\text{SaO}_2$.

**METHODS**

The subjects were 12 (six male and six female) recreationally-active college students (mean age = 21.9 years; range = 19-25 years; mean weight = 164.3 pounds or
74.3 kilograms; mean height = 68.2 inches; mean VO₂ = 51.1 ml/kg/min; mean ventilatory threshold or VT = 35.0 ml/kg/min). All subjects provided written informed consent and completed a health history questionnaire (American Heart Association/American College of Sports Medicine). Only subjects who met current ACSM physical activity recommendations were considered (30 minutes/day, 5 days/week moderate intensity or 20 minutes/day, 3 days/week vigorous intensity). Subjects had no evidence of cardiovascular disease and were free of signs and symptoms of cardiovascular disease. Intensity of exercise and inspiration of low-oxygen air required that this population be healthy and active, also lowering risk of potential complications. Subjects were asked to keep their weekly training/exercise volume constant during their participation. In addition, subjects were told not to engage in any exercise the day of a trial or vigorous exercise 24 hours prior. The Institutional Review Board for the Protection of Human Subjects at the University of Wisconsin-La Crosse approved the protocol. Several pilot tests were conducted to establish an experimental protocol. The hypoxic mixture subjects breathed were similar to hiking in Colorado Springs, CO (16.5% ḞO₂, ~ 6,000 feet or 1,829 meters above sea level).

The protocol involved four treadmill tests. The first was an incremental test at normal room air (ḞO₂ = 0.2093) to determine exercise capacity. Variables measured included heart rate, rating of perceived exertion, ventilatory threshold and peak oxygen consumption. From this test, the three remaining protocols were derived from the intensity at the subjects' ventilatory threshold (VT). The VT is described as the point at which ventilatory rate begins to increase in a non-linear fashion with exercise intensity or duration. Intensity was based from this marker so subjects would be challenged in their
efforts, but not over-worked to mimic a recreational, submaximal pace. During these tests (randomized order), all subjects walked at 3.5 mph, 0% grade for the first three minutes for a warm-up. After the warm-up, all subjects walked at 4.0 mph with increasing grade of +2% during each two-minute stage and progressed up to the speed and grade where their individual VT occurred. Subjects then performed a ten-minute “hike” at that workload. One test was performed at normal room air (F\textsubscript{1}O\textsubscript{2} = 0.2093) at constant speed. The other two tests were performed in hypoxic conditions (F\textsubscript{1}O\textsubscript{2} = 0.1650); one at a constant speed and one where the individual was free to self-regulate speed during their ten-minute “hike.” All tests involved a three-minute warm-up at 3.5 mph, 0% grade, and two-minute stages were used for the remainder of the tests with increasing workloads of +2% grade. All tests lasted 21 minutes. Arterial oxygen saturation was measured using pulse oximetry. A radiotelemetric heart rate monitor was worn to record heart rate. Specialized head gear was worn with a mouthpiece to administer inspired air and analyze expired air. A gas tank containing the hypoxic mixture fed three large bags which served as the reservoir for the subject to inspire hypoxic air from. Subjects were not blinded to fraction of inspired oxygen they were breathing.

**STATISTICS**

Data are presented as means ± SD. Repeated measures ANOVA was used to test the hypotheses that exercise while breathing hypoxic gas mixture would significantly reduce \( \text{SaO}_2 \) and increase the perceived effort of hiking. Also, it was hypothesized that individuals would spontaneously self-regulate power output based on \( \text{SaO}_2 \). Level of significance was \( p < 0.05 \).
RESULTS

Compared to the normoxia and hypoxia-constant (Hypo-Con) protocols, the hypoxia-variable (Hypo-Var) protocol yielded a slightly lower, non-significant speed change (3.88 mph ± 0.43) from the 4.0 mph of the constant speed trials (Figure 1). The heart rate response and peak heart rate did not differ significantly between trials (Figure 2). The peak heart rate (at minute-21) was lowest in the normoxia (164.2 bpm ± 14.5), slightly higher in the hypoxia-variable (166.6 bpm ± 11.5), and highest in the hypoxia-constant (169.2 bpm ± 15.6); no significant difference. The Rating of Perceived Exertion (RPE) (at minute-21) was highest in the hypoxia-constant (5.8 ± 1.8), slightly lower in the normoxia (5.2 ± 1.7), and lowest in the hypoxia-variable (4.5 ± 0.9); no significant difference (Figure 3). Significant differences were found between trials for SaO₂ (Figure 4). SaO₂ was highest (at minute-21) in normoxia (94.8% ± 1.4), and decreased in the hypoxia-constant (87.4% ± 3.3) and hypoxia-variable (87.8% ± 3.5). Significance was achieved between both hypoxia-constant and normoxia and hypoxia-variable and normoxia. No significant difference noted between hypoxia-constant and hypoxia-variable. Individual SaO₂ responses across time during hypoxia-variable are shown (Figure 5).
Figure 1. Mean speed trends per protocol. Both Normoxia (diamond) and Hypoxia-Constant (square) followed fixed protocols (4.0 mph) while Hypoxia-Variable (triangle) allowed individuals to self-select speeds during ten-minute hike.
Figure 2. Mean heart rate trends per protocol. No significant difference was seen across protocols.
Normoxia = F$_1$O$_2$ (0.2093), Hypoxia-Constant = F$_1$O$_2$ (0.1650) and walked at constant 4.0 mph. Hypoxia-Variable = F$_1$O$_2$ (0.1650) and walked at self-selected pace for last ten minutes.
Figure 3. Mean rating of perceived exertion trends per protocol. No significant difference was seen across protocols.
Figure 4. Mean oxygen saturation level trends per protocol. Statistical significance was found between Hypoxia-Constant and Normoxia and Hypoxia-Variable and Normoxia. No significant difference between Hypoxia-Constant and Hypoxia-Variable.
Figure 5. Individual SaO2 trends across time during Hypoxia-Variable trial. The six subjects that chose to maintain or increase speed during the ten-minute hike had an average SaO2 = 90% (Min. 11) (solid black line). The six subjects that chose to decrease speed during the ten-minute hike had an average SaO2 = 90.8% (Min. 11) (solid blue line).
Figure 6. Individual speed trends across time during Hypoxia-Variable trial. Six of the 12 subjects either maintained (4.0 mph) or increased speed during the ten-minute hike.
DISCUSSION

The results indicate that healthy, college-aged individuals experience significant arterial oxygen desaturation in response to hypoxic conditions similar to those at 6,000 feet above sea level. During the Normoxia trial, subjects never fell below the normal 95-100% SaO₂ level. During both hypoxic trials, subjects were close to the critical value of 85% (Hypoxia-Constant = 87.4%; Hypoxia-Variable = 87.8%) SaO₂ at which ACSM recommends termination of exercise bout due to inaccuracy of pulse oximetry (21). Terrados et al. (5) conducted a study on one group of eight well-trained athletes (mean VO₂ max = 71.8 ml/kg/min) and one group of eight sedentary individuals (mean VO₂ max = 48.7 ml/kg/min) that randomly performed maximal exercise tests on a cycle ergometer in a hypobaric chamber to acute exposures of differing barometric pressures. The trained group registered significantly lower SaO₂ values than untrained at submaximal and maximal (absolute) intensities at altitudes of 900 and 1500 meters. These findings suggested that trained subjects may be even more susceptible to decreases in SaO₂ at altitude than untrained due to greater arterial oxygen desaturation during maximal exercise. One plausible explanation for this finding is that trained subjects possess and employ a greater muscle mass during dynamic, multi-muscle activities which means an even greater amount of oxygen that is needed to supply the working tissues. Also, trained subjects are capable of generating high cardiac outputs. Although this is a positive training benefit, red blood cell transit times are very fast in the pulmonary capillaries. This can actually lead to a reduced oxygen diffusion between the alveoli and blood, which leads to less oxygen entering the arterial system (22).
In a follow-up study, Woorens and colleagues (20) investigated whether threshold altitude or exercise intensity induces a lower \( \text{SaO}_2 \) in trained versus untrained men. Each of the 14 subjects, seven trained and seven untrained, performed six incremental maximal exercise tests on a cycle ergometer. Subjects performed at concentrations of 0.209, 0.187, 0.173, 0.154, 0.13, and 0.117 to simulate altitudes of 1000, 1500, 2500, 3500, and 4500 meters, respectively. The main finding was that trained men showed a greater arterial desaturation at moderate exercise below VT (84%) than untrained (88%) in hypoxia but not in normoxia. The differences were evident from a \( \text{FiO}_2 = 0.154 \) or approximately 2500 meters. From this point, the differences in \( \text{SaO}_2 \) increased in magnitude and became evident at lower intensities in the trained men as the severity of hypoxia increased. Apart from maximal exercise, this was the first study to show this phenomenon at submaximal workloads. Burtscher (13) reported a decrease in \( \text{SaO}_2 \) from 98% at 700 meters to 83% at 2600 meters when one well-trained male mountaineer performed four separate ascents. Hence, a decrease in \( \text{SaO}_2 \) can occur in any individual, regardless of fitness or training status, while possibly affecting highly-trained individuals the most (13).

In addition, \( \text{SaO}_2 \) has been found to decrease proportionally to muscle mass involved during maximal exercise. Rasmussen and colleagues (15) recruited ten moderately-trained individuals to randomly perform cranking, running, and rowing exercise. Results showed that \( \text{SaO}_2 \) (analyzed by blood analysis) was unchanged after arm cranking, but decreased after running and rowing exercise. Similarly, hematocrit was found to increase after running and rowing. The finding that \( \text{SaO}_2 \) decreased after maximal exercise in proportion to the muscle mass involved supports the belief that
highly-trained athletes will desaturate faster than their sedentary counterparts in events that require large muscle groups. Again, the finding that trained athletes desaturate to a greater extent than non-athletes could be the result of increased muscle mass and/or decreased red blood cell transit time in the pulmonary capillaries. Szmedra et al. (17) found similar results when testing alpine skiers; individuals with larger thigh cross sectional areas had greater changes in oxygen desaturation. Altogether, it has been shown that both trained and untrained individuals experience significant oxyhemoglobin desaturation at maximal intensities under hypoxic conditions, while possibly affecting trained individuals the most. In our study, we found that healthy, recreationally-active individuals also experience significant oxygen desaturation at submaximal intensities under hypoxic conditions.

Contrary to the experimental hypotheses, a significant reduction in performance was not evident as individuals maintained similar speeds throughout the hypoxic conditions. Notably, six of the 12 subjects either maintained 4.0 mph or increased speed during the hypoxia-variable trial (Figure 6). Heart rate and RPE did not differ significantly between protocols, indicating heart rate was not significantly greater during hypoxia and subjects did not subjectively perceive their effort as significantly more difficult during the hypoxic trials than normoxia. A possible explanation for this finding is that oxygen requirements to meet the metabolic needs during submaximal intensities may be adequately met by the difference in arterial and venous oxygen content (a-v O₂ difference) without the need to significantly increase cardiac output. Thus, as long as a-v O₂ difference is able to supply the working tissues with sufficient oxygen, cardiac output does not need to increase as high and submaximal economies (speed regulation) may not
be affected. In regards to the Fick Equation, the VO₂ demand at a certain intensity at sea level would require the same VO₂ of equal intensity at altitude. Acute exposure to altitude causes desaturation of the arterial blood due to low PO₂ at altitude. Also, low PO₂ decreases arterial oxygen content, therefore lowering a-v O₂ difference (22). This causes a reduction in oxygen being carried to the working tissues. If a-v O₂ decreases, then cardiac output must compensate by increasing either heart rate or stroke volume. Stroke volume plateaus at about 40% of VO₂ max (22). Our subjects hiked at VT (mean VT = 35.0 ml/kg/min), which occurred well after 40% of VO₂ peak (mean VO₂ peak = 51.1 ml/kg/min). Thus, stroke volume likely reached a plateau, leaving heart rate as the only factor remaining that could increase to offset the down-shifted a-v O₂ difference and maintain the same VO₂. Although slight increases in heart rate were seen with the hypoxic trials, they were not significant. Therefore, it is possible that an adequate oxygen supply was still available in the arterial blood to perfuse the working tissues and maintain VO₂ without the need to increase heart rate. This could help explain the non-significant RPE response during the hypoxic trials and also explain why individuals felt no real need to decrease workload in response to significant oxygen desaturation. Although oxygen desaturation was significant, the arterial oxygen content may still have been sufficient to successfully perform during submaximal conditions.

The finding that half the subjects either maintained or increased speed during the hypoxia-variable trial with disregard for decreasing arterial oxygen saturation may indicate that SaO₂ is not a direct signaling mechanism for power output (Figure 5). This finding concurs with Henslin and colleagues who showed timing of inspired hypoxic air had no impact on power output and pacing strategy. Henslin et al. (14) concluded that
SaO₂ is not a direct signaling mechanism of power output. Their study utilized of eight well-trained cyclists who randomly performed three 3-km time trials, one at normal room air (F₁O₂ = 0.209) and two with hypoxic gas (F₁O₂ = 0.15). However, the subjects breathed the control or hypoxic air prior to exercise to determine if pacing strategy was affected from the beginning of effort. One experimental group began breathing the low F₁O₂ air at three minutes prior to exercise while the other began breathing at 30 seconds prior. Oxygen desaturation was greater in the experimental group breathing low F₁O₂ air three minutes before exercise (94.5%) compared to 30 seconds prior (96.5%). Results indicated that early power output was the same at the start of the time trial regardless of the F₁O₂ of inspired air prior to the trial, suggesting that SaO₂ is not a direct controller of power output.

Amann and colleagues (23) showed that power output is decreased following acute hypoxic exposure. They studied eight trained males that performed four 5-km cycling time trials when breathing gas over a range of oxygen levels (F₁O₂ = 0.15-1.0). Being that the tests were all time trials, subjects were free to self-regulate power output throughout the tests. Results indicated that power output significantly decreased across time and increased time-to-completion (483 ± 8 seconds) during the hypoxic trial. During the hyperoxic trial, power output significantly increased across time and decreased time-to-completion (439 ± 7 seconds). Mean time-to-completion during normoxic trial was 458 ± 7 seconds. Results suggested an increased arterial oxygen content (hyperoxic inspiration) resulted in parallel increases in central neural output (measured via EMG) (43%) and power output (30%) during cycling and improved time-to-completion.
Similarly, Johnson et al. (4) conducted a study with ten well-trained cyclists that randomly performed two 5-km time trials, one at normal room air \((F_{1O2} = 0.209)\) and one with hypoxic air \((F_{1O2} = 0.15)\). The time required to complete the trial was significantly greater in the experimental group, and the decrement in performance occurred during the period when subjects were breathing low \(F_{1O2}\) air. At the point subjects began to breathe low \(F_{1O2}\) air, there was a significant drop in \(SaO2\) accompanied by a simultaneous decrease in power output, both occurring within 30 seconds. When subjects began to re-breathe normal \(F_{1O2}\) air, both \(SaO2\) and power output returned to control values. Interestingly, only three out of the ten subjects could correctly identify which trial was the experimental (hypoxic) trial. These findings suggested that \(SaO2\) is at least one important signaling mechanism that can regulate power output almost instantaneously, and may not be detectable to the conscious mind.

More importantly, no coinciding alterations in speed during the hypoxia-variable trial were noted in conjunction with fluctuating \(SaO2\) levels. Hence, it appears subjects did not display a conscious awareness of \(SaO2\) levels. This raises the question of whether such individuals should be counseled prior to exercise at altitude. In addition, if healthy, college-aged individuals experienced \(SaO2\) levels nearing the critical value of 85% \(SaO2\), what happens to an older, less-fit population at altitude? Perhaps an older population would experience even greater arterial oxygen desaturation which may become a catalyst to cardiovascular complications. Possible reasons why an older population would have increased arterial oxygen desaturation include congestive heart failure or pump problems which would lead to blood backing up into the left atrium and subsequently pulmonary capillaries. Fluid build-up in the pulmonary capillary beds would disallow oxygen from
diffusing properly into the blood. Inhalation of chronic environmental air pollution or history of smoking may also destroy lung tissue and permanently reduce surface area vital for diffusion.

Several limitations regarding this study are noted. First, subjects may not have been walking at a high enough intensity to elicit a significant increase in cardiac output and cause them to slow down during the Hypoxia-Variable protocol. Second, subjects were not blinded to the type of air they were breathing. During the hypoxia trials, the large Douglas bags were placed adjacent to the treadmill. During the Normoxia trial, the bags were not present. Thus, subjects likely were aware as to whether they were breathing normoxic or hypoxic gas. This may have indirectly affected RPE and heart rate response due to increased anxiety/nervousness about the hypoxic trials. However, no significant differences between protocols were noted for either heart rate or RPE, indicating no effect on these variables. Lastly, any exercise the day of a trial or vigorous exercise 24 hours prior was not directly controlled.

**CONCLUSION**

Hypoxic conditions have been shown to alter physiological responses to exercise during acute and prolonged exposures. Acute exposure to hypoxia decreases power output and reduces VO$_2$ max (3, 4, 5, 6). This suggests that both power output and maximal oxygen consumption may be influenced by the SaO$_2$. In relation to SaO$_2$, it has been shown that both trained and untrained individuals experience significant oxyhemoglobin desaturation at both maximal and submaximal intensities under hypoxic conditions, while possibly affecting trained individuals the most. In our study, we found
that healthy, recreationally-active individuals also experience significant oxygen desaturation at submaximal intensities under hypoxic conditions.

Our data provide evidence of healthy, college-aged individuals not adjusting power output in response to decreasing \(\text{SaO}_2\) levels during submaximal exercise intensity. Also, such individuals experienced desaturation near the ACSM critical threshold of 85% \(\text{SaO}_2\). Disregard for significant decreases in \(\text{SaO}_2\) suggests individuals cannot consciously sense fluctuating \(\text{SaO}_2\) levels which may predispose them to exceeding a safe intensity of exercise at altitude. Consequently, individuals partaking in exercise endeavors at altitude may need to be educated on the dangers of falling below a safe \(\text{SaO}_2\) level in the blood, which could lead to adverse health events. This raises the question of what would happen to individuals with significant, undiagnosed coronary artery disease at altitude. If the atherosclerotic process had already manifested itself quite progressively in the coronary arteries and flow-limiting plaques had formed, would the introduction of hypoxic air during a leisurely hike elicit significant hypoxemia and provoke dangerous ischemia? More research is needed to learn how an older, less-fit population responds to recreational exercise under hypoxic conditions regarding \(\text{SaO}_2\) and regulation of power output.
REFERENCES


Informed Consent

Protocol Title: How Much Oxygen Desaturation Occurs in Healthy People Hiking at Simulated Altitude?

Principal Investigator: Timothy T. Bushman
2426 Hengel Court Apt. 213
La Crosse, WI 54601
(920)562-1820
bushman.timo@students.uwlax.edu

Emergency Contact: Timothy T. Bushman
(920)562-1820
Dr. Carl Foster
(608)785-8687

Purposes and Procedures:

- The purpose of this study is to determine how much oxygen desaturation occurs in healthy people hiking at simulated altitude.
- I will complete a written questionnaire to determine if I am healthy enough to participate.
- My participation will involve four separate treadmill tests, all of which may be fatiguing.
  
  - 1st test: a baseline exercise test breathing normal room air (20.93% oxygen) to determine my exercise capacity. Variables to be measured include heart rate, rating of perceived exertion, percent oxygen saturation, and peak oxygen consumption. Baseline testing will help determine a comfortable walking pace for each subject. The baseline test will also help with laboratory and protocol familiarization.
  
  - 2nd test: interval exercise test to measure above-mentioned variables while breathing normal room air (20.93% oxygen) from a bag at constant speed.
  
  - 3rd test: interval exercise test to measure above-mentioned variables while breathing hypoxic air (16.5% oxygen; equivalent of 6000 feet above sea-level) from a bag at constant speed.
  
  - 4th test: interval exercise test to measure above-mentioned variables while breathing 16.5% oxygen from a bag while self-selecting walking speed.

- The latter three hiking tests will involve a five-minute warm-up followed by a progressive increase in intensity until individualized protocol has been met. Then, a 10-minute segment of breathing either normal or hypoxic "altitude" air, followed by a five-minute cool-down for a total of approximately 20 minutes or until fatigue causes termination of that segment of the test.

- Total time requirement will be about three hours over a two to three week period.
During all tests, I will wear head gear and a mouthpiece to analyzing my breathing, heart rate monitor (strapped around chest) with watch, nose clip, and finger clip to measure oxygen saturation.
- I will indicate rating of perceived exertion (how tired I feel) after each minute.
- All testing will take place in room 225 Mitchell Hall, UW-L (Human Performance Laboratory).

Potential Risks
- I may experience respiratory and muscular fatigue during and muscle soreness after the test.
- The risk of serious or life-threatening complications for healthy persons like me is extremely low.
- Individuals trained in CPR, Advanced Cardiac Life Support and First Aid will be in the laboratory, and the test will be terminated if complications arise.
- The laboratory has a standard emergency plan, and an AED is available.

Rights and Confidentiality
- My participation is voluntary.
- I am free to withdraw from this study at any time without question or penalty.
- All data directly linked to my identity will be kept confidential.
- The results of this study may be published in scientific literature or presented at professional meetings using grouped data (no names).

Possible Benefits
- I may help explain how much physiological stress that recreationally-active persons encounter when hiking at altitude. These findings could potentially enhance safety and enjoyment of hiking at such altitudes and lead to a better overall experience.

Questions
- Any questions regarding study procedures may be directed to Timothy T. Bushman (920-562-1820), the principle investigator, or his faculty supervisor Dr. Carl Foster (608-785-8687), Department of Exercise and Sport Science, UW-L. Questions regarding the protection of human subjects may be addressed at the UW-L Institutional Review Board for the Protection of Human Subjects (608-785-8124) or at (irb@uwlax.edu).

Participant: ________________________________
Date:_____________________________

Researcher: ________________________________
Date:_____________________________
APPENDIX B

REVIEW OF LITERATURE
REVIEW OF THE LITERATURE

The purpose of this paper is to review the literature concerning the physiological responses to acute and prolonged hypoxic exposure; specifically, what performance variables are affected and in what manner? In addition, how does arterial oxygen saturation (SaO$_2$) respond to hypoxic exposure in people of various fitness levels?

Exercise has long been known to provide numerous health benefits to those who choose to engage in it. Hiking is a form of recreational exercise that often involves an individual ascending to higher altitudes where they can take-in majestic views of unspoiled wilderness and enjoy nature in its purest form. Despite the breathtaking scenery, such altitude can impose undue physiological stress. At these heights, partial pressure of oxygen becomes diminished. Altitude exposure essentially limits the amount of oxygen we can consume (VO$_2$ max) due to a decreased arterial oxygen content. The greater the altitude exposure the more the arterial hemoglobin saturation (SaO$_2$) declines and the less efficient our bodies are at keeping bodily tissues adequately oxygenated. This phenomenon is known as hypoxemia; or a SaO$_2$ of less than 88% (13).

A cross-sectional study conducted by Perez-Padilla and colleagues identified several risk factors for hypoxia including age, obesity, altitude, and smoking. Individuals greater than 75 years of age, body mass index (BMI) above 30 kg/m$^2$, high-altitude residents, and chronic obstructive pulmonary disease patients (COPD) had a significant predisposition to hypoxia. In addition, SaO$_2$ decreased with age and magnitude of altitude exposure (13). Szemedra et al. (17) also found that SaO$_2$ decreased with age in
older skiers. Burtscher (3) reported a decrease in SaO₂ from 98% at 700 meters to 83% at 2600 meters when one well-trained male mountaineer performed four separate ascents.

Ample evidence exists to support the conclusion that exercise-induced arterial hypoxemia (EIAH) at sea level occurs in a vast number of healthy, fit individuals independent of gender and age. Dempsey and Wagner (5) performed a meta-analysis on the underlying causes and effects of EIAH. They defined mild EIAH as an SaO₂ of 93-95% (3-4% < rest), moderate EIAH of 88-93%, and severe EIAH as < 88%. They define SaO₂ as a factor determining the arterial oxygen content, which is also affected by hemoglobin saturation. Generally, hemoglobin increases slightly from rest to heavy exercise which increases arterial oxygen content. EIAH tends to begin at moderate intensity workloads and usually peaks at the point of maximal exercise intensity. However, the tendency toward developing EIAH during submaximal exercise has not been adequately studied (5).

As evidenced by many studies, hypoxia also induces decrements in performance. Hypoxic conditions alter human physiology during acute and prolonged exposures. Acute exposure to hypoxia decreases power output and reduces VO₂ max (4, 9, 18, 21). In one study, ten well-trained cyclists randomly performed two 5-km time trials, one at normal room air (F₁O₂=0.209) and one at experimental air (F₁O₂=0.15). Time required to complete the trial was significantly greater in the experimental group, and the decrement in performance occurred during the period when subjects were breathing low F₁O₂ air. At the point subjects began to breath low F₁O₂ air, a significant drop in SaO₂ accompanied by a simultaneous decrease in power output occurred within thirty seconds. When subjects began to re-breathe normal F₁O₂ air, both of these markers returned to control
values. Interestingly, only three out of the ten subjects could correctly identify which trial was the experimental (hypoxic) trial. These findings suggested that SaO₂ is at least one important signaling mechanism that can regulate power output almost instantaneously (9).

Conversely, Henslin and colleagues (8) found that SaO₂ is not a direct signaling mechanism of power output. Their study consisted of eight well-trained cyclists that randomly performed three 3-km time trials, one at normal room air (F̄O₂=0.209) and two at experimental air (F̄O₂=0.15). However, athletes breathed the control or experimental air prior to exercise to determine if pacing strategy was affected from the beginning of effort. One experimental group began breathing the low F̄O₂ air at three minutes prior to exercise while the other began breathing at thirty seconds prior. Oxygen desaturation was greater in the experimental group at three minutes before exercise (94.5%) compared to thirty seconds prior (96.5%). Results indicated that early power output was the same at the start of the time trial regardless of the F̄O₂ of inspired air prior to the trial, suggesting that SaO₂ is not a direct controller of power output (8).

Amann et al. (1) also showed that power output is decreased following acute hypoxic exposure. They studied eight trained males that performed four 5-km cycling time trials when breathing gas over a range of oxygen levels (0.15-1.0). Being that the tests were all time trials, subjects were free to self-regulate power output throughout the tests. Results indicated that power output significantly decreased across time and increased time-to-completion (483 ± 8 seconds) during the hypoxic trial. During the hyperoxic trial, power output significantly increased across time and decreased time-to-completion (439 ± 7 seconds). Mean time-to-completion during normoxic trial was 458
± 7 seconds. Results suggested an increased arterial oxygen content resulted in parallel increases in central neural output (43%) and power output (30%) during cycling and improved time-to-completion.

VO₂ max, or the maximal rate an individual can consume oxygen during incremental exercise, has also been shown to decrease during hypoxic conditions. One study by Chapman and colleagues (4) on nineteen endurance-trained college-aged males showed a significant reduction in VO₂ max during acute exposure to mild hypoxia. The experimental group used air at F₁O₂=0.187 which simulated an altitude of about 1000 meters. They found that athletes who experience arterial oxygen desaturation during maximal exercise in normoxia are more prone to declines in VO₂ max in mild hypoxia compared to normoxic athletes.

In accordance, Woorens et al. (21) reported decreases in VO₂ max with hypoxia in fourteen sedentary sea-level native women at altitudes as low as 1000 meters. Again, this decrease in VO₂ max was thought to be attributable at least in part to increased arterial desaturation; reducing the amount of oxygen delivery to the exercising tissues.

Similarly, Terrados and colleagues (18) showed that VO₂ max is decreased following acute hypoxic exposure. One group of eight well-trained athletes and one group of eight sedentary individuals randomly performed maximal exercise tests on a cycle ergometer in a hypobaric chamber to acute exposures of differing barometric pressures. The main findings were that only the trained group saw a decline in absolute VO₂ max at an altitude of 900 meters, whereas both groups were affected at 1200 and 1500 meters, with the trained group experiencing a significant and greater decline in
absolute VO₂. In addition, the trained group registered significantly lower SaO₂ values than untrained at submaximal and maximal intensities at 900 and 1500 meters. These findings suggested that trained subjects may be even more susceptible to altitude than untrained resulting from larger desaturation during maximal exercise.

In a follow-up study, Woorens and colleagues (22) investigated whether threshold altitude or exercise intensity induces a lower SaO₂ in trained versus untrained men. Each of the fourteen subjects, seven trained and seven untrained, performed six incremental maximal exercise tests on a cycle ergometer. Subjects performed at a F₁O₂=0.209, 0.187, 0.173, 0.154, 0.13, and 0.117 to simulate altitudes of 1000, 1500, 2500, 3500, and 4500 meters, respectively. The main finding was that trained men desaturated to a lower SaO₂ (84%) than untrained (88%) in hypoxia but not in normoxia. The differences were evident from a F₁O₂=0.154 or approximately 2500 meters. From this point, the differences in SaO₂ increased in magnitude and became evident at lower intensities as the severity of hypoxia increased. Apart from maximal exercise, this was the first study to show this phenomenon at submaximal workloads. Hence, a reduction in SaO₂ can occur in any individual, regardless of fitness or training status while possibly affecting highly-trained individuals the most.

In addition, SaO₂ has been found to decrease in proportion to the muscle mass involved during maximal exercise. Rasmussen and colleagues (14) recruited ten moderately-trained individuals to randomly perform cranking, running, and rowing exercise. Results showed that SaO₂ (analyzed by blood analysis) was unchanged after arm cranking, but decreased after running and rowing. Similarly, hematocrit was found to increase after running and rowing. The finding that SaO₂ decreased in proportion to
the muscle mass involved perhaps indicates that highly-trained athletes, possessing and employing more muscle mass during exercise, will desaturate faster than their sedentary counterparts in events that require large muscle groups. Szmedra et al. (17) found similar results when testing alpine skiers; individuals with larger thigh cross-sectional areas had greater changes in oxygen desaturation.

Hypoxic conditions have also been shown to alter human physiology during prolonged exposures. One study conducted by Heinicke and colleagues (7) found that prolonged intermittent hypoxic exposure resulted in increased hemoglobin mass and elevated erythropoietin (EPO) plasma levels. Forty-three male subjects were divided into four subgroups according to duration of hypoxic exposure. The groups consisted of sea-level residents, altitude residents, intermittent exposure to hypoxia for six months, and intermittent exposure to hypoxia for twenty-two years. Intermittent and altitude subjects resided at 3550-4500 meters. Their main finding was that acclimatization to long-term intermittent hypoxia resulted in similarly elevated hemoglobin mass and red blood cell volume as altitude residents. This means that prolonged exposure to high altitude may increase the oxygen-carrying capacity of our blood and therefore enhance oxygen transport to the working bodily tissues (7).

Mounier et al. (12) studied blood marker responses to hypoxic testing involving an acute exposure of three hours at simulated altitude of 3000 meters. Thirty high-level endurance athletes partook in this simulated experiment before actual training. One key finding was that after three hours at simulated altitude of 3000 meters, mean serum EPO concentration increased by an astounding 21%. Twenty-four of the athletes increased EPO levels whereas the remaining six either did not respond to the hypoxic conditions or
saw a decrease in EPO. The authors surmised that similar individuals may respond to hypoxic conditions in different ways; those that positively respond and increase EPO and those that negatively respond or have no physiological response at all (12).

Similar results were discovered by Wehrlin and colleagues (20) when investigating the effects of living at an altitude of 2500 meters and training at lower altitude for twenty-four days on EPO in elite endurance athletes by using direct measurement of hemoglobin mass. They recruited ten athletes to complete a “live high-train low” approach which emphasizes living at altitude while training at sea-level to potentially enhance physiological parameters vital to athletic success. Their main finding was that after twenty-four days of living at 2456 meters and training at 1000-1800 meters, hemoglobin mass and red blood cell volume increased by 5% compared to no change in these two variables with the control group living and training at altitudes between 500 and 1600 meters for twenty-four days.

This same “live high-train low” approach was implemented into a study conducted by Levine and Stray-Gundersen (10). They recruited forty-one collegiate distance runners who were sea-level residents. All athletes completed baseline sea-level training to nullify any differences in training ability and familiarization. Subjects were divided into three groups; living at moderate altitude (2500 meters) and training at low altitude (1200-1400 meters), living at moderate altitude and training at moderate altitude, and living at sea-level (150 meters) and training at sea-level. Results showed that living at moderate altitude while training at low altitude resulted in greater improvements in running performance over 5000 meters. This improvement was not seen in the other experimental group that also trained at moderate altitude. The authors concluded that
there is an apparent altitude-acclimatization effect which increases blood oxygen-carrying capacity and subsequently VO2 max. Several studies have supported the potential for performance gains when this “live high-train low” approach is implemented by athletes (11, 12, 20).

However, Rodriguez et al. (15) reported that intermittent hypoxic exposure of three hours per day, five days per week for four weeks did not improve running or swimming performance. Twenty-eight athletes, seasoned runners and swimmers, participated in the study. The purpose of the study was to investigate if intermittent hypoxic exposure combined with sea-level training affected performance in trained athletes. Performance was measured during time trials of 100/400 meter swims or three-kilometer runs. Interestingly, no improvement was found in either swimming or running performance after the hypoxic intervention in both sexes. The data also indicated no improvement on submaximal economy or acceleration of EPO. It was concluded that this amount of hypoxic exposure is insufficient to have a positive effect on performance.

Truijens et al. (19) reported similar findings. A study of 28 athletes of both sexes exposed to intermittent hypoxia did not improve submaximal economy in time trials of running or swimming. Athletes were exposed to hypobaric hypoxia for three hours per day, five days per week, for four weeks; identical to the protocol used by Rodriguez et al. (15). Economy was measured as oxygen uptake (liters/minute) at a certain speed and as the slope of the linear regression between oxygen uptake and speed according to a sport-specific protocol. Both studies support the conclusion that this amount of hypoxic exposure has no positive effect on time to complete time trials. A possible explanation for this finding is that submaximal intensities are affected more so by the difference in
arterial and venous oxygen content (a-v O₂ difference) than by SaO₂ or hemoglobin concentration. Thus, as long as there is enough oxygen in the arterial blood to meet the needs for a-v O₂ difference, submaximal economies may not be affected.

Prolonged exposures from living at moderate altitude may also lead to oxidative stress independent of physical exertion in trained individuals. Heinicke and colleagues (6) investigated whether prolonged periods of exercise at moderate altitude led to increases in oxidative stress. Five endurance-trained biathletes and five sedentary control subjects were investigated during a six-week training camp. Increased levels of oxidative markers were found at altitude in both groups. The main finding was that living at moderate altitude for an extended period of time is accompanied by a long-term increase in oxidative stress independent of strenuous physical exertion in trained subjects. Hence, individuals may experience the same degree of physiological stressors regardless of exercise intensity.

Previous literature has shown decrements in various physiological parameters in response to altitude exposure. Such studies have raised the question of whether hypoxic altitude exposure is safe. Steinacker et al. (16) found that the risk for acute cardiac events for individuals with stable cardiovascular disease was small up to 2500 meters above sea-level. An important secondary finding was that both young and healthy populations compared to elderly patients with some form of cardiovascular disease seem to employ the same mechanisms to acclimatize and adapt to hypoxic exposure at altitude. Therefore, it appears hypoxic exposure is relatively safe for most individuals regardless of underlying cardiovascular disease processes.
Arterial hemoglobin desaturation occurs as the result of altitude exposure, or lower partial pressures of oxygen in the ambient air. This environmental stressor can induce hypoxemia, or a $\text{SaO}_2$ less than 88%. Although acute hypoxic exposure may be detrimental to performance endeavors, research indicates that prolonged exposure may actually enhance performance potential through proper training. The majority of available research regarding hypoxia has studied highly-trained athletes and their response to hypoxia and exercise (3, 4, 7, 8, 9, 10, 12, 14, 15, 17, 19, 20). A plethora of research has also compared hypoxia exposure and exercise in elite athletes versus sedentary individuals (6, 18, 21, 22). However, it is not known what happens to healthy, recreationally-active individuals at altitude. Does this population experience hypoxemia much like the athletic population does? If hypoxemia is induced, does it affect performance parameters such as power output? Are people consciously aware of fluctuating $\text{SaO}_2$ levels? Can they detect the onset of hypoxemia and self-regulate power output based on this mental awareness? The purposes of this study are to determine how much oxygen desaturation occurs among healthy people hiking at simulated altitude, and to determine if people spontaneously self-regulate their workload based on fluctuating changes in $\text{SaO}_2$. It is hypothesized that $\text{SaO}_2$ in healthy people hiking at simulated altitude will drop below 85% and cause reductions in performance. Also, it is hypothesized that individuals will spontaneously self-regulate workload based on fluctuating $\text{SaO}_2$ levels by increasing workload (speed) at higher $\text{SaO}_2$ and decreasing workload at lower $\text{SaO}_2$. 
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