ABSTRACT

EFFECTS OF INTERMITTENT HYPOXIC TRAINING ON ATHLETIC PERFORMANCE

by Sarah K. Teckman

This paper reports a study testing the effects of intermittent hypoxic training (IHT) on athletic performance. IHT is a training protocol that periodically administers hypoxic air to gain the physiological affects of high altitude. This study involved 12 college aged subjects and were administered the IHT, based on their group, for 15 minutes a day/five days a week/three weeks total. Athletic performance was measured using a VO$_{2\text{max}}$ test and an interval maximal running test. Both blood draws and lactate were taken to measure the effects of IHT. The four variables were taken pre and post IHT. Results were analyzed using a series of 2x2 (Group x Time) mixed model analysis of variance with repeated measures on the second factor. VO$_{2\text{max}}$ values were non-significant, blood hemoglobin and interval maximal running times were trending towards significance, and blood lactate values were significant. This paper reports limitations, and future direction for this research.
EFFECTS OF INTERMITTENT HYPOXIC TRAINING ON ATHLETIC PERFORMANCE

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## Table of Contents

<table>
<thead>
<tr>
<th>Chapter One: Introduction</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explanation of Intermittent Hypoxic Training</td>
<td>1</td>
</tr>
<tr>
<td>The Effects of Hypoxia</td>
<td>2</td>
</tr>
<tr>
<td>The Effects of Erythropoietin</td>
<td>2</td>
</tr>
<tr>
<td>How Intermittent Hypoxic Training Affects the Blood</td>
<td>2</td>
</tr>
<tr>
<td>Respiratory Effects of Intermittent Hypoxic Training</td>
<td>3</td>
</tr>
<tr>
<td>Practical Implications of Intermittent Hypoxic Training</td>
<td>3</td>
</tr>
<tr>
<td>Intermittent Hypoxic Training and Athletes</td>
<td>4</td>
</tr>
<tr>
<td>Exercise and Intermittent Hypoxic Training</td>
<td>5</td>
</tr>
<tr>
<td>Disproof in the Literature</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Two: Method</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>7</td>
</tr>
<tr>
<td>Procedures</td>
<td>8</td>
</tr>
<tr>
<td>Data Gathering Instruments</td>
<td>10</td>
</tr>
<tr>
<td>Measures</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Three: Study Design and Statistical Analysis</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Four: Results</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive Results</td>
<td>12</td>
</tr>
<tr>
<td>Preliminary Analysis</td>
<td>12</td>
</tr>
<tr>
<td>Main Analysis</td>
<td>13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter Five: Discussion</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>
List of Tables

Table 1  Descriptive Data for Pre and Post Time Points  12
Table 2  Descriptive Data for Pre and Post Time Points: Experimental and Control Groups  12
List of Figures

Figure 1  Hemoglobin Group X Time Interaction  13
Figure 2  VO$_2$max Time Main Effect  14
Figure 3  Lactate Group X Time Interaction  15
Blood doping has recently been prevalent in the news and has been associated with endurance athletes. Most recently, the controversy surrounding Lance Armstrong and whether he was blood doping has brought even more attention to doping and the unfair advantages of those who participate in the illegal activity. The practice of blood doping originally began to increase the number of red blood cell mass in athletes via blood transfusions, which resulted in increased athletic performance. Now, blood doping has taken on a new definition of artificially increasing performance through the administration of recombinant human erythropoietin (Cazzola, 2000). Erythropoietin (Epo) is a glycoprotein that is stimulated by hypoxic conditions to increase the production of red blood cells (Jacobs et al., 1985). Although the hormone Epo and red blood cells are naturally found inside the human body, it is the synthetic increase of both red blood cells and Epo that is illegal and unfair in competition. The desire to improve human performance leads to the question: Is there a natural way to increase red blood cell mass and Epo for athletes who want an advantage over their competition? Intermittent hypoxic training (IHT) is one solution, and has become a popular and legal way to increase not only red blood cell mass and Epo production, but other mechanisms that improve performance. The purpose of this research project is to observe the physiological effects of IHT and determine if those changes improve athletic performance, specifically running performance.

**Explanation of Intermittent Hypoxic Training**

Intermittent hypoxic training (IHT) is defined as “the discontinuous use of normobaric or hypobaric hypoxia, in an attempt to reproduce some of the key features of altitude acclimatization, with the ultimate goal to improve sea-level athletic performance” (Levine, 2002). The four main adaptations that occur due to chronic exposure of altitude are decreased resting ventilation and hypoxic ventilatory response, and an increased oxygen saturation and hemoglobin concentration compared to sea level dwellers (Beall, 2000). Further more, IHT is a training technique that temporarily administers hypoxic air to breathe in order to simulate altitude and to eventually gain the advantageous physiological effects that altitude has on the body. The goal of IHT is to become acclimated to high altitude conditions in order to improve athletic performance at sea level. An athlete, or person who participates in IHT, experiences
high altitude conditions by breathing in the hypoxic air by either directly breathing it through a mouthpiece, or spending time in a chamber that simulates a high altitude environment. The hypoxic air is only breathed for short periods of time during a day, varying from minutes to hours.

**The Effects of Hypoxia**

Hypoxia is a term used to describe an inadequate amount of oxygen reaching the muscles of the body even though there are normal values of blood reaching the muscles in need (Harris, 2000). At sea level, and everywhere else within the earth’s atmosphere, there is 21 percent oxygen. On average, the normal atmospheric pressure at sea level is 760 mmHg. At this pressure, oxygen is easily able to diffuse and reach the alveoli within the lungs where oxygenation and filtration occurs. The oxygen from the alveoli is then able to bind to hemoglobin found in red blood cells. Hemoglobin is made up of four subunits, and in order to be fully saturated, there must be one oxygen molecule attached to each subunit. In a hypoxic environment, such as at high altitude, the atmospheric pressure is lower than 760 mmHg. Due to the lower pressure, oxygen is not able to diffuse and bind to hemoglobin as easily, and results in lower oxygen saturation of the blood. In order for the body to compensate for the effects that hypoxia and high altitude, an increased production of the hormone erythropoietin (Epo) occur (Hall, 2011).

**The Effects of Erythropoietin**

In order to compensate for lowered partial pressure of the atmosphere associated with hypoxic conditions or high altitudes, the kidneys stimulate production of Epo (Gore et. al., 2007). An increase of red blood cells due to Epo production increases the opportunities for oxygen to bind to more hemoglobin. Knowing that hypoxia increases Epo production and red blood cells, which then leads to the opportunity for increased oxygenation capacity; IHT has become a technique of interest for researchers and athletes who want to discover whether this type of training will produce an increase in athletic performance.

**How Intermittent Hypoxic Training Affects the Blood**

Epo is stimulated by hypoxia and increases red blood cell mass (Jacobs et al., 1985). However, Epo is not the only protein that is stimulated when exposed to hypoxia and high altitudes. Vascular endothelial growth factor (VEGF) also increases when an individual is
exposed to intermittent hypoxia (Neubaumer, 2001). VEGF is a protein that stimulates the production of new blood vessels. Under hypoxic conditions, capillary-length density increases (Vogt et al., 2001). More blood vessels and increased capillary-length density are beneficial to compensate for the increase in mass of red blood cells. Increases of VEGF benefits working muscles because the increase of blood vessels is integrated where they are needed. During IHT, the increases of Epo and VEGF production increase the oxygen carrying capacity. However, it is predominantly the increase of Epo that leads to an improvement in athletic performance, which includes $VO_{2\text{max}}$ and running performance (Levine, 2002).

**Respiratory Effects of Intermittent Hypoxic Training**

The hypoxic ventilatory response (HVR) increases when an individual is exposed to hypoxic conditions. HVR is the body’s attempt to increase oxygen uptake and increase the expiration of carbon dioxide though hyperventilation. The peripheral chemoreceptors located in the carotid artery and aortic bodies are essential for ventilatory changes due to hypoxic conditions (O’Regan & Majcherczyk, 1982). When peripheral chemoreceptors sense a decrease of partial pressure, and decreased arterial oxygen, increased respiration is stimulated. Several factors can influence HVR: the pattern and intensity of hypoxic exposure, length of time of exposure, and the components of responses (Powell et al., 1998). IHT causes an increase of ventilation, due to an increased sensitivity to hypoxia via the peripheral chemoreceptors (Bernardi et al., 2001 & Powell et al., 1998). This increased respiratory rate thus increases sensitivity and HVR.

**Practical Implications of Intermittent Hypoxic Training**

The benefits of IHT are applicable to human activities beyond improving athletic performance. For example, IHT has shown to be beneficial to participate in before being exposed to long-term high altitude conditions (Savourey et al., 1994; 1996). Receiving IHT before an expedition to summit mountains decreases the amount of time spent acclimatizing and increases the amount of time climbing (Rose et al., 1988). Another example of the benefits of IHT was demonstrated during Operation Enduring Freedom and Operation Anaconda Reveal. During these operations, 8 percent of soldier casualties were related to altitude. Tannheimer and colleagues conducted a study and applied IHT to soldiers and found that IHT before sending
soldiers to high altitude locations like Afghanistan decreased the amount of altitude related injuries and casualties (Tannheimer, 2009).

Studying IHT can be applied to other aspects of life and individuals who naturally do experience intermittent hypoxic conditions, even at sea level. Sleep apnea is characterized as intermittent hypoxia/re-oxygenation, and is an independent risk for cardiovascular disease (Silke et al., 2005). Those who suffer from sleep apnea suffer from about 20 second episodes of not breathing during sleep followed by an abrupt restoration of ventilation (Foster et al., 2007). By understanding the molecular benefits of IHT, it can then be applied to patients who are naturally hypoxic to improve their quality of life. In addition to sleep apnea, patients who suffer from Chronic Obstructive Pulmonary Disease (COPD) are naturally hypoxic as well. It has been shown that patients with mild COPD and cardiovascular abnormalities, greatly benefited from IHT at rest. These patient’s cardiovascular abnormalities returned to normal after receiving IHT (Haider et al., 2009). The above researchers believed that IHT could be a beneficial therapy for patients with early/mild COPD

IHT has the potential to improve the quality of life of many people with different diseases as well as improve the athletic performance of those who do not suffer from these debilitating diseases. By further studying what physiological effects of IH, it may prove effective as an alternative therapy for individuals who suffer from diseases such as COPD or sleep apnea. IHT has many beneficial implications that include increased red blood cells, increased Epo production, increased VEGF production, as well as stimulated the HVR response. All of these factors can lead to an improved performance, but more importantly these factors can lead to an increased quality of life in patients who suffer from respiratory diseases.

**Intermittent Hypoxic Training and Athletes**

IHT training has been more commonly known for the improvement of endurance performance in athletes (Katayama et al., 2004). When IHT is used as a part of an endurance athlete’s training, it is generally applied in one of two different protocols: IHT during exercise and IHT at rest (Levine, 2002). IHT during exercise can take the form of the live high, train low (LHTL) method. The LHTL method consists of an individual living at a higher altitude to obtain the physiological advantages, such as increased red blood cell mass and Epo production, and trains at sea level so they can train at a higher intensity compared to how they could perform at
high altitude. LHTL has been observed to be superior to standard sea-level training or a live high, train high method (Wehrlin et al., 2006). Research has shown that IHT at rest has the potential to have advantageous effects that can result in improved endurance performance, however further research is needed. (Rodriguez et al., 2007; Rusko et al., 2004; & Truijens et al., 2003).

In contrast to LHTL, IHT at rest protocols generally varies by the amount of time exposed. A short exposure is generally less than five hours and a long exposure is more than eight hours in a 24-hour period (Katayama et al., 2004). Research has shown that IHT at rest produces adaptations of the cardiovascular and respiratory system, as well as an increased production of Epo. IHT at rest has also shown to decrease VO$_2$ uptake at sub-maximal exercise, which leads to the theory that IHT increases exercise efficiency (Green et al., 2000; Katayama et al., 2004; & MacDonald et al., 2001). Although there has been extensive research done on the effects of IHT, it is worth dissecting specific protocols and determining more precisely the physiological changes and if it is an effective training method to improve performance.

**Exercise and Intermittent Hypoxic Training**

Oxygen carrying capacity increases with IHT due to an increase of red blood cell mass and blood vessels. This results in an increase of VO$_{2\text{max}}$. However, IHT decreases VO$_2$ during sub-maximal exercise (Katayama et al., 2003 & Truijens et al., 2002). The volume of inspired oxygen during a sub-maximal work rate is less after IHT, and thus an athlete has the potential to produce more work and expend more energy when they reach their maximal amount of work they can perform. A decrease of VO$_2$ during sub-maximal exercise is evidence that efficiency and economy improved due to IHT (Katayama et al., 2003).

Exercise economy has been shown to improve because of IHT (Katayama et al., 2003). The underlying mechanisms associated with an improved economy are decreased heart rate, decreased cost of ventilation, greater glycolytic metabolism, greater carbohydrate utilization, and greater excitation-contraction processes at a lower cost (Sauders et al., 2004). Furthermore, IHT decreases fat metabolism and creates a greater reliance on glucose metabolism during exercise. This greater dependence on glucose for energy is beneficial because glucose produces more ATP per molecule of oxygen (Roberts et al., 1996; Saunders et al., 2004). All of these factors contribute to improved performance due to IHT.
IHT increases athletic performance, endurance, and economy/efficiency during sub-maximal exercise. The provided evidence leads observers to believe that IHT is just as effective as the LHTL method; however, other research has shown that IHT does not produce improvements. Differences in results have been due to the amount of time that subjects participate in IHT protocol, whether IHT was given at rest or during exercise, and the type of participant.

Disproof in the Literature

The literature has conflicting results on whether IHT improves performance, with the main difference being type of participants, length of time, and whether IHT was given at rest or during exercise. This research can add to the literature by reinforcing what others have already found. It will either reinforce that IHT does improve performance, or that it does not improve performance. Studies that have not found an improvement from IHT have been done from a range of two to four weeks with either untrained or elite athletes.

Morton and Cable demonstrated that during a four-week IHT period, while inspiring hypoxic air for 30 minutes/day, there were no significant improvements when compared to a control group. There were no significant differences in VO$_{2\text{max}}$, power output, and peak power. No significant changes were seen in hematological levels between the groups that were observed (Morton & Cable, 2005). A two-week IHT study performed by Ogita and Tabata resulted in no change in VO$_{2\text{max}}$. Levine observed that IHT does not increase training stimulus, but rather decreases speed and power output the participants produced. He concluded that IHT is not an advantageous method for a well-trained athlete (Levine, 2002). In untrained individuals IHT was shown to provide no significant benefits because the effects of training predominantly overshadowed any positive effects of IHT (Emmonson et al., 1997; Levine et al., 1992; & Loepky et al., 1970). Just as untrained individuals did not benefit from IHT, elite athletes experienced a similar conclusion, however it was because the elite athletes had reached their maximum athletic potential and could not improve any further (Vallier et al., 1996). Similarly, Katayama et. al., demonstrated that IHT performed for six consecutive days during exercise did not improve HVR or athletic performance (Katayama et. al., 1999).

Why should we care about IHT and its effects, and whether or not it can be used as a successful training method? IHT is advantageous compared to the LHTL method or a hypobaric
chamber because it is less costly and because the advantages to sea level performance need further research. Levine describes IHT as “bringing the mountain to the athlete” and is less expensive than the LHTL method because IHT can be done at sea level. Athletes and coaches wouldn’t have to relocate to an area where there is a high enough altitude within close enough proximity to a lower altitude to train. If location is not a primary issue, a hypobaric chamber can create environments that simulate high altitudes, but these types of chambers are extremely costly. IHT can be performed at any altitude, and all that is required is a rebreather, which can simulate a hypoxic breathing condition.

In addition to being less expensive, IHT can improve an athlete’s performance at sea level using legal and fair methods. IHT naturally manipulates the physiology of the body so that oxygen carrying capacity increases thus improving efficiency and economy. The improvements observed in successful IHT studies were slight, but the differences between first and second place could be slight as well.

The gaps and contradictions in research regarding IHT vary in the types of participants used and the duration of IHT. There is a gap in the literature regarding how effective IHT is if the participant is at rest or if the participant is receiving treatment during exercise. The purpose of my study would be to observe the effects that IHT has on athletic performance and analyze the mechanisms that are changed by IHT. I hypothesize that IHT will improve athletic performance in active, non-elite athletes when exposed for a three week long period for 15 minutes/day, for five days a week, while walking on a treadmill at 3.7 miles per hour.

**Methods**

**Participants**

Participants consisted of 12 college aged males (6) and females (6); the average age was 21.3 (SD = 1.96); average weight (kg) was 67.33 (SD = 11.69); and average height (cm) was 167.87 (SD = 6.95). Participants were self-classified as “active” and in good health for their age and sex. Chosen participants did not suffer from any form of neurological conditions including migraines, any form of cardiovascular or respiratory diseases, and were non-smokers. The participants filled out a medical health history questionnaire (Appendix E), to rule out those who may suffer from the above diseases, or who may suffer from other health problems that the investigators felt were unsafe. Research subjects did not participate on a collegiate team, due to
the extra training received. Participants were given an informational flyer (Appendix C), and signed an informed consent (Appendix D).

The participants were recruited from undergraduate classes from the Kinesiology and Health Department during the 2013-2014 academic school year.

**Procedures**

Researchers received approval from the Institutional Review Board before beginning recruitment of participants. Participants were recruited throughout the Kinesiology and Health Department from Miami University, Oxford, Ohio. All of the exercise tests were performed in the physiology laboratories, rooms 16 and 18, and the biomechanics laboratory of Phillips Hall. Research participants were given a consent form created by the researcher to fill and return to the researcher. The primary investigator read the Research Description (Appendix C) and Informed Consent (Appendix D) with the participants to ensure the participant understood what was expected of them, ask questions, and understood that they may halt participation at any point of the study. Before data collection began, participants signed the informed consent form. After the informed consent form had been signed, participants completed a Medical Health History Questionnaire (Appendix E). The questionnaire form evaluated pre-existing diseases such as cardiovascular and respiratory disease, or musculoskeletal injuries. Participants who recognized such diseases or musculoskeletal injuries within the past two years were not permitted to participate in the study.

Participants visited the physiology laboratories and Biomechanics laboratory a total of 20 times for the treadmill pre/post tests, exposure to the protocol, and the IHT interventions. The two treadmill pre/post tests were performed in the physiology labs and consist of a VO\(_{2\text{max}}\) test and an intermittent run till exhaustion test. The tests themselves lasted about 10-15 minutes, but the total time required from the participant was about an hour. The exposure to the protocol was used to familiarize the participants to the rebreathers and took place in the Biomechanics lab, and last about an hour total. Research subjects participated in the IHT intervention five days a week for a total of three weeks, and took place in the Biomechanics lab. Each session lasted about 20 minutes.

The first exercise pre test was a VO\(_{2\text{max}}\) test performed by all participants on a treadmill. The test increased in speed and grade until the participant reached their maximal effort and could no longer continue the test. The test began with the subject walking at a very light intensity as a
warm up and progressively increased intensity levels for several minutes. Next, depending if the subject participated in regular running or jogging, their normal running pace was determined after the warm up. At the chosen pace, the incline of the treadmill was increased in two-minute stages until volitional failure was achieved. The total time of the maximal effort test lasted about 10-15 minutes. After every stage of the VO$_{2\text{max}}$ test was completed, participants were asked their rate of perceived exertion (RPE) on a scale of 1-20. The scale began with 1 being rest and 20 being maximal effort. The maximal effort run was self determined. The VO$_{2\text{max}}$ of each participant was recorded. A metabolic cart in the Kinesiology Department labs will analyze the results of the VO$_{2\text{max}}$ test.

All participants performed the second pre test, as an intermittent treadmill running test until exhaustion. Depending on each participant’s highest stage reached during the VO$_{2\text{max}}$ test, participants ran for three minutes at the last stage completed during the VO$_{2\text{max}}$ test, followed by three minutes of walking at 3.7 miles per hour. Participants continued to walk and run at the given intensity until exhaustion. The amount of time spent during each running stage was self determined. The investigators recorded the total time completed during the running stages.

Participants had a blood draw taken at the Student Health Center on Miami University’s campus. A hematological content analysis was performed for each participant’s blood sample, measuring hemoglobin content. A phlebotomist who collected approximately 3 ml of blood from a forearm vein using standard blood collection techniques performed the blood draw. The results were given to the participant, who then delivered their results to the primary investigator’s thesis advisor and was saved.

Next, participants were randomly assigned to a control or intervention group. The intervention group received the IHT treatment. The intervention group breathed in the hypoxic air for 15 minutes a day, five days a week, for a three-week long period. The hypoxic air was administered through an Altolab rebreather. Participants walked on a treadmill in the Biomechanics lab at 3.7 miles per hour while receiving the IHT treatment. A nose clip was worn to ensure no additional oxygen was inspired through the nose. Researchers observed the participants while they received the IHT treatment to ensure participant’s safety. The same protocol was administered to the control group, except their rebreather did not contain the IHT treatment. The control group walked on a treadmill at the same speed, for the same duration of time as the intervention group.
Data Gathering Instruments

A Polar Heart Rate Monitor was worn to monitor heart rate during the VO$_{2\text{max}}$ and intermittent running tests. Heart rate monitors have been shown to be a reliable computation of heart rate at varying intensities (Moore, et al., 1997; Macfarlane, et al., 1989).

During the VO$_{2\text{max}}$ and the intermittent running test, participants wore a nose clip to eliminate supplementary oxygen being inspired and a mouth piece connected to a laboratory metabolic cart used to analyze oxygen consumption and expired gases. Ventilation was measured on a breath-by-breath basis and averaged over 30 second periods. The accuracy of this computerized metabolic system using inspiratory and expiratory methods of measuring ventilation, has been investigated and shown to accurately measure metabolic variables over varying ranges of intensities (Bassett, et al. 2001).

Oxygen saturation was recorded via a pulse oximeter that the participants wore on their index finger during the IHT intervention period. Light originates from the probe inside the pulse oximeter at two wavelengths, 650nm and 805nm. The light is partly absorbed by hemoglobin (Hb), by amounts which differ depending on the oxygen saturation levels. By calculating the absorption at the two wavelengths the processor computes the proportion of Hb that is oxygenated.

The rebreather used for this study is produced by AltoLab LLC USA, located in Phoenix, Arizona. The purpose of using this rebreather is because it mimics high altitude and creates a hypoxic environment, while being cost effective. This devise is defined as an autohypoxicator, meaning it includes biological feedback (Kolchinskaya et al., 1999 & Nemerovski, 1992). This breathing circuit includes a Hypoxic Silo and AltoMixers. The AltoMixers are what create a hypoxic environment and the more AltoMixers used, the more hypoxic of a condition is created, as well as a higher altitude is simulated. The rebreather creates a “hypoxic gas mixture” by collecting carbon dioxide, while the subject rebreathes the mixture (Lopata & Serebrovskaya, 2012). The participants breathed through the mouthpiece of the rebreather to receive the IHT. Participants also wore a nose clip to ensure they were not inspiring supplementary oxygen through their nose.

After the three-week IHT period had ended, a post-test was given to all participants in the control and hypoxic groups. The post-test included a final blood draw, VO$_{2\text{max}}$ test, and interval running test based on their VO$_{2\text{max}}$ pre test results.
Measures

VO\textsubscript{2max} tests results were measured in ml/kg/min. The values were measured using a Metabolic Cart located within the Kinesiology Department laboratories. The data was saved within the metabolic cart and printed. The investigator recorded the pre and post test value of each participant’s VO\textsubscript{2max} test. The percentage of saturation levels was measured with a pulse oximeter. Researchers monitored the blood saturation during the 15 minute IHT periods to ensure the subjects stayed within the wanted saturation range (80-85%). Hematological content was measured by the Student Health Center and the pre and post values were recorded. The investigator recorded the pre and post total time completed during the interval running test.

Study Design and Statistical Analysis

The primary purpose of the current study was to assess the effects that IHT has on athletic performance and to analyze the particular mechanisms that may be changed by IHT. To investigate this issue, a 2 X 2 (Experimental Group by Time) repeated measures experimental study design was used. Study participants were randomly assigned to either an experimental group that received three weeks of IHT-based training or to a control group that did not receive IHT. It was hypothesized that the IHT group would exhibit greater improvement in run time and aerobic capacity than would the control group, due to changes in hematological content. Based on the lack of previous research in this area, no specific hypotheses were forwarded regarding any differences between the IHT and control groups in regard to lactate.

Obtained data were first examined using a series of descriptive analyses that verified the linearity and normality of the data. A preliminary one-way multivariate analysis of variance was conducted to determine if the study participants' pre-test scores differed as a function of the experimental group to which they were assigned. Main study hypotheses were assessed using a series of univariate 2 X 2 (group by time) mixed model analyses of variance with repeated measures on the second factor.

Results

The purpose of this study was to determine if participants who were exposed to intermittent hypoxic training during moderate exercise would exhibit greater improvements in athletic performance and more altered hematological content than would participants who were not exposed to such training. Based on the research to date, it was hypothesized that the IHT
group would exhibit greater improvements in athletic performance and more advantageous physiological effects of altered hematological content than would the control group who did not participate in the training. The data obtained from this study were statistically analyzed using a variety of procedures. The results are presented in the following sections.

**Descriptive Results**

Descriptive statistics (means, standard deviations, and standard error of the mean) for all study variables at pre and post time points are presented in Table 1. Results were examined for univariate normality, and all scores were normally distributed with no outliers.

**Table 1: Descriptive Data for Pre and Post Time Points**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre (Mean/SD/St error mean)</th>
<th>Post (Mean/SD/St error of mean)</th>
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<tbody>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>47.24/5.36/1.54</td>
<td>48.75/5.22/1.50</td>
</tr>
<tr>
<td>HGB (g/dl)</td>
<td>14.50/1.50/.45</td>
<td>14.65/1.67/.48</td>
</tr>
<tr>
<td>Running time (min)</td>
<td>11.01/2.02/.58</td>
<td>10.82/1.93/.55</td>
</tr>
<tr>
<td>Lactate (mmol)</td>
<td>11.05/2.64/.76</td>
<td>9.87/2.26/.65</td>
</tr>
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**Table 2: Descriptive Data for Pre and Post Time Points: Experimental and Control Groups**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Pre (Mean/SD)</th>
<th>Post (Mean/SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO2max (ml/kg/min)</td>
<td>Experimental</td>
<td>47.75/3.93</td>
<td>49.76/4.45</td>
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<tr>
<td></td>
<td>Control</td>
<td>46.73/6.88</td>
<td>47.76/6.14</td>
</tr>
<tr>
<td>Running time (min)</td>
<td>Experimental</td>
<td>10.86/2.25</td>
<td>11.01/2.03</td>
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<tr>
<td></td>
<td>Control</td>
<td>11.17/1.96</td>
<td>10.64/2.00</td>
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<tr>
<td>Hemoglobin (g/dl)</td>
<td>Experimental</td>
<td>14.68/1.31</td>
<td>14.43/1.41</td>
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<tr>
<td></td>
<td>Control</td>
<td>14.28/1.83</td>
<td>15.00/2.22</td>
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<tr>
<td>Lactate (mmol)</td>
<td>Experimental</td>
<td>10.75/2.44</td>
<td>10.88/2.21</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>11.36/3.02</td>
<td>8.88/2.01</td>
</tr>
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**Preliminary Analysis**

A one-way multivariate analysis of variance was conducted to determine whether the study groups differed in their scores at the pre test time point, (see Table 2). The independent variable for the analysis was the assigned group (experimental or control), and the dependent
variables for the analysis were VO$_{2\text{max}}$, interval running time, hemoglobin (HGB), and lactate. The results indicated no significant main effect for group ($p = .76$), indicating that the groups were statistically similar at the pre test time point.

**Main Analysis**

To examine whether the two groups (IHT and control) differed across time in their performance and hematological content, a series of 2x2 (Group x Time) mixed model analysis of variance with repeated measures on the second factor were conducted. The independent variable for the analysis was the assigned group (experimental or control), and the dependent variables for the four analyses were VO$_{2\text{max}}$, interval running time, hemoglobin (HGB), and lactate. Results for each dependent variable are presented in the following paragraphs.

For the interval run time scores, the 2x2 ANOVA results revealed a non-significant time main effect ($p = .78$), a non-significant group main effect ($p = .98$), and a non-significant Group x Time interaction effect ($p = .61$). These results, then, indicate that the groups did not differ from each other over time, and the interval run time performance scores did not change significantly over time.

For the hemoglobin values, the 2x2 (Group x Time) ANOVA results revealed a non-significant time main effect ($p = .40$), as well as a non-significant group main effect ($p = .94$). However, the Group x Time interaction effect was trending towards significance, $F(1, 9) = 3.31$, $p = .10$, $\eta^2 = .27$. Graphical illustration of this close significant interaction effect is presented in Figure 1.

![Figure 1: Hemoglobin Group x Time Interaction](image)
For the VO\textsubscript{2max} scores, the results of the 2x2 (Group x Time) ANOVA revealed a non-significant group main effect (p = .63), and a non-significant group by time effect (p = .55). The main effect for time, however was close to significant, F (1,10) = 3.78, p = .08, $\eta^2 = .27$. Graphical illustration of this close to significant time main effect is presented in Figure 2. As this graph reveals, the scores of all participants appeared to increase from the pre to post time point (although this change over time only approached significance).

![Figure 2: VO\textsubscript{2max} Time Main Effect](image)

For the lactate data, the results of the 2x2 (Group x Time) ANOVA revealed a non-significant group main effect (p = .62). However, the time main effect was significant, F (1,10) = 7.31, p = .02, $\eta^2 = .42$, indicating that the study participants as a whole showed significant changes over time in their blood lactate levels. This significant time main effect was superseded by a significant Group X Time interaction effect, F (1,10) = 8.82, p = .01, $\eta^2 = .47$. These results indicate that the experimental and control groups differed significantly in the changes that each experienced over time. A graphical illustration of this significant interaction effect is presented in Figure 3.
Follow-up paired comparison t-tests were conducted to determine how the two groups changed over time. The results of these analyses indicated that the experimental group exhibited no significant changes from pre to post time point in their lactate scores, t (5) = -.29, p = .79. However, the control group showed a significant decrease from pre to post time point in their lactate scores, t (5) = 3.20, p < .03.

Discussion

The experimental group showed no significance in increased interval running time, as displayed in Table 2. This is consistent with the results found by Julian et. al. (2004) and Truijens et. al. (2003). This was an important finding since the experimental group displayed a downward slope of hemoglobin concentration after the IHT (Figure 1). The experimental group’s hemoglobin concentrations did not show a significant improvement, and this may be one explanation for why the interval running times did not improve.

The study performed by Julian et. al. not only found that IHT did not improve athletic performance in the form of a time trial, but they also found Epo levels decreased for the experimental group. In addition to lower Epo, they found hemoglobin levels were not significantly different from baseline measurements. A decrease of Epo production could be one explanation why neither the experimental, nor the control groups experienced a significant change of hemoglobin levels over time. A decrease of Epo production could negatively affect the production of red blood cells, which would then decrease oxygen’s ability to bind to hemoglobin. This is consistent with the findings from the current study, as well as the findings from Morton.
The current study found there was no increase in hemoglobin levels, displayed in Figure 1, and may be explained by insufficient exposure time to the hypoxic condition. Gore and Hopkins (2005) found an exposure of 8-10 hours/day for 10-21 days at a simulated altitude of about 8,000-10,000 feet was not enough to elicit an increase of hemoglobin. Furthermore, Julian et. al. (2004) found an exposure of five minutes to hypoxia (as low as 82% oxygen saturation), with five minutes breathing normal room air for 70 minutes, 5 days/week, four weeks total was not enough exposure time to improve 3,000 m time trial, VO$_{2max}$, or change Epo levels. These findings may indicate the current study did not expose the experimental subjects to the treatment for a long enough time, and why there was no increase of hemoglobin levels. A mechanism that may explain why Epo and hemoglobin are unchanged is due to the gene Hypoxia-Induceable Factor 1 (HIF-1) and it’s ability to thrive in a hypoxic condition. When HIF-1 is exposed to a hypoxic environment, it produces more Epo and VEGF; and when HIF-1 is exposed to normoxia, Epo production is decreased, iron and bone marrow turnover is decreased, and red blood cell survival is decreased (Julian et. al. 2004). Intermittently exposing the subjects to a hypoxic condition, followed by spending the rest of the day in a normoxic condition may have caused HIF-1 to become unstable and why the experimental group had a decrease of hemoglobin levels.

Although results for the VO$_{2max}$ showed there was no significant time main effect, the results were close to trending, and both groups displayed an upward slope, which suggests an improved VO$_{2max}$ performance. This is consistent with other studies performed by Dufour et. al. (2006) and Morton and Cable. Previous studies performed by Casas et. al. (2000), Oelz et. al. (1986), and Ferretti et. al. (1990) found that IHT did not change VO$_{2max}$ during incremental exercise. However, they found a higher VO$_{2max}$ was not a critical physiological parameter for successful elite climbers, because, different VO$_{2max}$ levels at varying success were not significantly different. This supports that an unchanging VO$_{2max}$ during running performance is not the most important physiological component to observe to determine if athletic performance has improved.

This study found there was a significant group and time interaction for lactate that was taken after the interval running max test. The results also found the lactate levels significantly decreased for the control group after IHT and had no significant change for the experimental group. The decrease of lactate could explain why the control group also experienced an observed
increase in VO_{2\text{max}} performance. Although the experimental group’s lactate levels did not significantly change over time, with more subjects, there is a possibility that they could have followed the same trend as the control group. A study performed by Vallier, Chateau, and Guezennec (1996) found blood lactate during peak exercise tended to be lower in a hypoxic condition compared to a normoxic condition, but the findings were also not significant.

Lastly, a reason why this study was performed was to examine the length of time IHT was given; the intensity with which the subjects received the treatment, the type of subjects, and whether that supported or refuted previous findings. This study did not find any improvements in hemoglobin when subjects were exposed to a hypoxic environment for 75 minutes a week, for three weeks total. In a previous study Julian et. al. reported that when there is an exposure of up to 90 minutes a week, for three weeks, red blood cell count and hemoglobin increased progressively over time. Other studies have found that at least 120 minutes of continuous exposure to hypoxic conditions or 240 minutes of intermittent exposure to hypoxia at a simulated altitude of 4,000-5,000 m is needed to increase Epo production (Julian et. al., 2004 and Casas et. al., 2000).

The intensity that the subjects received IHT was at a moderate walking pace of 3.7 mph on a treadmill for 15 minutes. Previous studies found that IHT at vigorous intensities for 24-40 minutes was enough to improve VO_{2\text{max}} in already trained athletes. Although the present study did not demonstrate a significant increase in performance, it did not show a trend toward an increase in performance. It is possible that a greater number of subjects was needed to establish significance in our study. This suggests that IHT given at a moderate intensity is enough to improve VO_{2\text{max}} in non-trained subjects, but would not be enough to improve performance in trained athletes because the subjects of the current study were defined as active, but were not specifically training for an athletic event.

In conclusion, this study supported that IHT at a moderate intensity, at a simulated altitude of 15,000 ft, for 15 minutes a day/5 days a week/3 weeks total does not improve athletic performance due to hematological changes. This study did not elicit the advantageous effects that hypoxia has on Epo production and hemoglobin concentration due to IHT, but it did find that IHT at a moderate intensity in untrained individuals can improve performance, in the form of VO_{2\text{max}}, and can potentially see these changes with more subjects to observe lactate changes.
Reference


Appendix C

Research Description for Participants

Title of Research Project: THE EFFECT OF INTERMITTENT HYPOXIC TRAINING ON ATHLETIC PERFORMANCE

Principal Investigator: Sarah Teckman, Department of Kinesiology and Health

You are invited to participate in a research study that will investigate the effect of simulated exposure to altitude on physical fitness. If you decide to participate you will be asked to perform about 20 lab visits that will include maximum exertion treadmill stress tests and body composition measurements as well as being asked to participate in simulated altitude exposure for 15 days (each day requires about 1 hour of time. This will include breathing through a cylinder for 15 minutes at a time. You will also be asked to complete brief questionnaires about your medical history and physical activity habits. If you are under the age of eighteen, have cardiovascular disease, serious lower extremity injury/pain within the past two years, or any other condition that would prohibit you from safely performing any of these tasks, you will not be permitted to complete the study. Participation will require 4 visits to the Biomechanics Lab for treadmill tests: two maximum exertion treadmill running tests, and two treadmill walk/runs at %s of your maximum exertion. At the beginning and end of the study we will take blood samples to document any changes in blood values due to the intermittent simulated exposure to altitude.

There is a small risk of becoming dizzy when performing intermittent hypoxic training. Risk will be minimized and you’re in control of the experimental treatment (you can stop using the rebreather any time if you feel dizzy.) During the activity, you will be monitored for signs of distress by a supervisor. Any contraindicating sign including your desire to discontinue the test will result in the experiment being terminated immediately. You are strongly encouraged to make the research staff aware of any discomfort or concerns you experience during the session. Be aware that should a physical injury result from the research procedures, financial compensation is not available and medical treatment is not provided.

By participating in the study you will be contributing to an important effort to better understand the mechanisms that govern intermittent hypoxic training.

We encourage your cooperation throughout the session, however, your participation is voluntary and you are free to refuse to participate and/or withdraw from the study at any time without being penalized or affecting your relations with Miami University in any way. Any information obtained in connection with this study that can be identified with you will remain confidential and will be disclosed only with your permission. In any written reports, publications or presentations, no participant will be identified by name.

Do you have any questions regarding your participation in the study?

In the future, if you have questions or concerns about the study, please contact Mark Walsh at 513-529-2708 or <walshms@muohio.edu>. If you have general questions about your rights as a research participant, you may also contact Miami’s Office for the Advancement of Research and Scholarship at 513-529-3734 or <humansubjects@muohio.edu>.

You will be provided a copy of this form to keep.
Appendix D

Informed Consent Form

Title of Research Project: THE EFFECT OF INTERMITTENT HYPOXIC TRAINING ON ATHLETIC PERFORMANCE

Principal Investigators: Sarah Teckman, Department of Kinesiology and Health.

This is to certify that I, ___________________________, hereby agree to participate as a volunteer in a scientific investigation as an authorized part of the education and research program of Miami University under the supervision of Dr. Mark Walsh, Ph.D.

The investigation and my part in the investigation have been defined and fully explained to me and I understand the explanation. A copy of the procedures of this investigation has been provided to me and has been discussed in detail with me.

I am above the legally required 18 years of age necessary to participate in this study.

I have been given the opportunity to ask questions and all such questions and inquiries have been answered to my satisfaction.

I understand that I am free to deny answers to specific questions in interviews or questionnaires.

I understand that health information will be collected and will be kept in Mark Walsh’s office and will not be available for others.

I understand that in the event of physical injury resulting from the research procedures, financial compensation is not available and medical treatment is not provided free of charge.

I further understand that I am free to withdraw my consent and terminate participation at any time during the study.

_______________________________________  ___________________________________
Date                                      Date of Birth (optional)

Participant's Signature

I, the undersigned have defined and fully explained the investigation to the above participant.

_______________________________________  ___________________________________
Date                                      Investigator's Signature (or that of official representative)

Participants will be provided a copy of this form to keep.
Appendix E

MEDICAL HEALTH HISTORY

All information you provide is personal and confidential. The information will enable us to better understand you and your health and fitness habits as well as inform you of any potential risks.

NAME _________________________________________ ID_________________________ DATE ______/_____/_______

Address ___________________________________________________________________________________________________

City, State Zip ______________________________________________________________________________________________

Employer __________________________________________________________________________________________________

Phone (H)________________________(W)___________________________Email_________________________________________

Date of Birth _____/_____/_____ Male _______ Female ________

Emergency Contact___________________________ Phone ___________________ Relation ______________

Physician’s Name ____________________________ Phone ________________________ Fax __________________________

GENERAL
Height _________ ft. Weight _________lbs.

Any unexplained significant weight loss/gain . . . Within the last 6 months Within the last year NO

If yes, please explain:
What was your most recent blood pressure reading? _________/_________ mm Hg Date ______________________

Do you currently exercise? YES NO

If yes, how long have you been exercising regularly?

_____________________________________________________________

What exercise do you do and how often?

MEDICAL DIAGNOSES

Have you ever had any of the following?

Heart attack YES NO

Angina YES NO

Asthma YES NO

Anemia YES NO

Osteoporosis YES NO

Cardiovascular surgery YES NO

Currently pregnant YES NO

Emphysema YES NO

Allergies YES NO (inflammation of a vein)

Please list all known allergies:

Any special conditions not listed above:

If you answered, “YES” to any of the above Medical Diagnoses,

It is RECOMMENDED that you consult with your physician before beginning your exercise program.

MEDICATIONS

Please list any medications you are currently taking including but not limited to prescriptions, allergy medications, ergogenic aids, diet supplements, vitamins, minerals, etc.

Medication _____________________________ _____________________________ _____________________________

Reason _____________________________ _____________________________ _____________________________

Dosage _____________________________ _____________________________ _____________________________

MAJOR RISK FACTORS
1. Are you a man over the age of 45 or a woman over the age of 55, YES NO
2. Has your father or brother experienced a heart attack before age 55? YES NO
3. Has your doctor ever told you that you might have high blood pressure? YES NO
4. Do you have cholesterol above 200 ml/dl? YES NO
5. Do you have impaired fasting glucose (diabetes)? YES NO
6. Are you physically inactive (i.e., you get less than 30 minutes of physical activity on at least 3 YES NO
days per week
7. Do you currently smoke or have you quit smoking in the last 6 months?
   I smoke (#)________cigarettes per day/week (circle one) for _______years. YES NO
   I smoked (#)_______cigarettes per day/week (circle one) _____years ago.
8. Are you > 20 pounds overweight? YES NO

If you are a man over the age of 45 or a woman over the age of 55
OR if you answered “YES” to two (2) or more of the above Major Risk Factors,
It is RECOMMENDED that you receive physician’s clearance before beginning your exercise program.

MAJOR SIGNS/SYMPTOMS
SUGGESTIVE OF CARDIOVASCULAR AND PULMONARY DISEASE
1. Pain discomfort (or anginal equivalent) in the chest, neck, jaw, arms, or other areas
   that may be due to ischemia (decreased blood flow) YES NO
2. Shortness of breath at rest or w/mild exertion YES NO
3. Dizziness or syncope at rest or w/mild exertion YES NO
4. Orthopnea/paroxysmal nocturnal dyspnea (labored breathing) at rest or w/mild exertion YES NO
5. Edema (excessive accumulation of tissue fluid) YES NO
6. Palpitations or tachycardia (sudden rapid heart beat) YES NO
7. Intermittent Claudication (lameness due to decreased blood flow) YES NO
8. Known heart murmur (abnormal heart sound) YES NO
9. Unusual fatigue or shortness of breath with usual activities YES NO

If you answered, “YES” to any of the above Major Signs and Symptoms listed above
Or have known cardiovascular, pulmonary, or metabolic disease (see below for descriptions),
It is STRONGLY RECOMMENDED that you seek physician’s clearance before beginning your exercise program.
Cardiovascular – cardiac, peripheral vascular, cerebro-vascular disease
Pulmonary – Chronic obstructive pulmonary disease, asthma, interstitial lung disease, or cystic fibrosis
Metabolic Disease – Diabetes mellitus (types 1 and 2), thyroid disorders, renal or liver disease.
I understand this Health History Questionnaire has been provided to me for the purpose of helping me better understand any potential
risks associated with a workout program. I also understand I should share this information with my physician and seek his or her approval prior to beginning an exercise program. I understand the information I have provided will be maintained in my membership
file for use in case of a medical emergency. My signature signifies that all of the above is true, to the best of my knowledge. Any information left unanswered was done so intentionally. If any of the above information changes, I agree to submit these changes in
writing to this facility’s wellness professional for an update to my membership file.
Signature: ______________________________ Date: __________Received by:_____________________________
Date:__________
I understand this Health History Questionnaire has been provided to me for the purpose of helping me better understand any potential
risks associated with a workout program, to share with my physician in order to obtain his or her approval before beginning an exercise
program, and to be maintained as part of my membership file in case of a medical emergency. I do not want to complete this
questionnaire and understand I assume full responsibility for any risks associated with my participation in an exercise program.
Signature: ______________________________ Date: __________Received by:_____________________________
Date:__________
Wellness Representative Signature: ______________________________ Date: __________ Notes Attached: ______
Note: All Major Risk Factors, Signs and Symptoms classifications are taken directly from Whaley, Mitchell H, ed. *ACSM’s Guidelines for Exercise Testing and Prescription*, Phila
Hypoxia Training: Fall 2011

**VO₂max Test**

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Comments:
Hypoxia Training: Fall 2011 Interval Test

ID: _____________________________  M or F  Date: ________ Time: _____
Age: _______  Bodyweight: ______ Kg  Height: ______ cm
VO₂max _________  Date: ______________  Workload:
Speed: _________________________  Grade: _________________________
Temperature: ___________  Humidity: ________  Pressure: ______________

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**Hypoxia Training: Fall 2011 Interval Test: POST**

ID: _____________________________ M or F Date: ____________ Time: ______

Age: _______ Bodyweight: _______ Kg  Height: _______ cm

VO$_2$max _______ Date: _____________ Workload:

Speed: __________________________ Grade: _______________________

Temperature: _______ Humidity: _______ Pressure: _____________

Calibration for Flow: _______ _______ _______ _______ _______ _______
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