

SHORT TERM ARRIVAL STRATEGIES FOR ENDURANCE EXERCISE  
PERFORMANCE AT MODERATE ALTITUDE

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## **Abstract**

Endurance performance at altitude is diminished as a consequence of the hypoxic environment. Timing the arrival at altitude prior to such a competition is an important consideration due to time-dependent changes as a result of acclimatization. While the time course of changes over the first few weeks of altitude exposure has been well documented, the changes seen within the first few hours of arrival have not been characterized. As a result, coaches and athletes employ varied arrival strategies in an attempt to maximize performance, notable arrival just prior to the competition or arrival the night before competition.

**Purpose:** To compare cycling 20km time trial performance outcomes and related parameters at altitude after 2 hours and 14 hours of arrival at a simulated altitude of 2500m.

**Methods:** Subjects performed a familiarization 20km time trial, followed every 7 days by a total of 3 overnight stays in an altitude tent. The three random, single-blinded interventions were as follows: 14 hours of hypoxia, 12 hours of normoxia and 2 hours of hypoxia, or 14 hours of normoxia. The two hypoxic trials were followed by a 20km time trial in hypoxia and the normoxic trial was followed by a 20km time trial in normoxia. Ventilatory acclimatization, sleep disturbances, and plasma volume decrements were also measured during the study.

**Results:** No differences were observed in performance times between the two hypoxic trials. Average times to completion for each trial were: 2hr - 36:47  $\pm$  0:47s, 14hr - 36:44  $\pm$  0:50s, CTRL - 35:34  $\pm$  0:39s. After 14 hours, plasma volume decreased by an average of 235 ml more than control, while an additional decrease over control of only 22ml occurred during the

2hr trial.  $\dot{V}_E/\dot{V}O_2$  values for each subsequent 4km were as follows:  $34.4 \pm 7.0$ ,  $33.4 \pm 5.1$ ,  $33.8 \pm 5.5$ ,  $32.9 \pm 4.4$ ,  $35.9 \pm 5.4$  for the 2hr trial and  $32.3 \pm 6.1$ ,  $32.2 \pm 5.8$ ,  $32.7 \pm 5.3$ ,  $32.4 \pm 5.2$ ,  $34.9 \pm 5.6$  for the 14hr trial, respectively (n.s. at any time point). Activity counts during sleep were  $744.7 \pm 30.2$  for the 2hr trial and  $740.9 \pm 31.7$  for the 14hr trial (n.s.).

Conclusion: Differences in endurance exercise performance are not observed at altitude during the first 14 hours of arrival at altitude. While the some of the variables that would be expected to alter performance did show changes within this time frame (e.g. plasma volume loss), they were either not substantial enough to alter performance or acted to counter-balance each other, leaving performance variables equally affected by acute altitude exposure.

## **Chapter 1**

### **Introduction**

The 1968 Olympic Games in Mexico City were marked by the detrimental effects of the moderate altitude (2420 m) on the performance of endurance athletes.<sup>1</sup> Although it had been previously established that performance of endurance athletes at high altitude is diminished as a consequence of the hypoxic ambient environment, this obstacle became abundantly clear even at moderate altitudes. As a result, acclimatization strategies became vital for athletes competing at moderate elevations in order to minimize the performance decrements. The goal of these strategies was primarily to affect adaptations that improved oxygen utilization and delivery. Two disparate reasons for altitude acclimatization became evident: those who trained at altitude to improve sea level performance and those who tried to maximize performance at altitude. While athletes training at altitude are concerned with the long-term benefits of altitude residence, athletes who are simply competing at altitude are typically only concerned with maximizing their performance during the specified competition. This study aims to address the arrival strategies of those athletes competing at altitude.

Arrival at competition altitude at least 14 days prior to the event is the current predominant best-practice recommendation for acclimatization to moderate altitudes for endurance performance purposes.<sup>2</sup> It is believed that two weeks of hypoxic exposure allow for adequate ventilatory acclimatization and for performance measures to return as closely as possible to sea level values. After two weeks of altitude residence many of the short term acclimatization effects, such as peripheral chemoreceptor mediated increases in ventilation,

are nearing completion. This time frame also precedes the detrimental training effects associated with prolonged exercise in hypoxia. The hypoxic ventilatory response has been shown to increase over time after the initial exposure to altitude, which suggests that as close to two weeks of altitude exposure is preferable. However, this time frame is often impossible for team sport athletes or athletes on strict travel schedules for whom arriving at the place of competition two weeks prior is unrealistic. Obviously these later arriving athletes will experience inadequate acclimatization effects which mitigate performance decline at altitude than those athletes who can appropriately acclimatize. For the athletes arriving shortly before competition, a short-term arrival strategy is necessary, although this has not been adequately investigated.

For athletes who logistically can only arrive within a day or two of an altitude competition, there are two primary arrival strategies commonly used with the hope that performance decrements at altitude will be modulated. Most commonly, athletes will arrive at a “typical” time of the day before the competition. It is proposed that in arriving the day prior may hold advantages over arriving the morning of the competition, as any extra time at altitude is beneficial in ventilatory acclimatization that in turn helps maintain oxygen (O<sub>2</sub>) saturation in the blood.<sup>3</sup> However, the increased ventilatory rate also leads to an excessive carbon dioxide (CO<sub>2</sub>) washout and subsequent alkalosis, which eliminates the normal hyperventilatory stimulus. This may in turn lead to intermittent breathing, especially at night, impairing sleep quality before competition.<sup>4</sup> Additionally, the extra hours at altitude will likely cause acute plasma volume loss, which might be mitigated with a shorter term arrival at altitude. As a result, an alternative strategy that is gaining use in the athletic community is to arrive as close as possible to the start time of the altitude competition (aka a “fly in, fly out”

strategy), with the hope that any acute negative effects of altitude exposure are minimized.<sup>5,6</sup> Currently, there are no data examining the potential effects of short term (e.g. 2 hours vs. 14 hours) of acute altitude exposure on performance at altitude.

### **Purpose**

The purpose of this study is to assess the differences in endurance performance of short-term arrival strategies for competitions at moderate altitudes. We also investigate the changes in sleep quality, ventilatory acclimatization, and plasma volume of athletes sleeping at altitude and at sea-level and their relation to performance differences. We attempt to reconcile the disparate consequences of altitude residence to find the optimal time frame that was 16 hours or less for arrival at altitude. Knowledge of the acute effects of altitude exposure in this time frame will help endurance athletes bound by short-term arrival logistics to adequately prepare for competitions at moderate altitudes.

### **Justification for the Study**

The timing of arrival for optimal altitude performance has been well studied in the literature. While some earlier studies did not show improvements in performance with acclimatization,<sup>7,8</sup> more recent studies have, likely due to controls for altitude sickness, iron stores, and detraining (“live-high, train-low”).<sup>2,9-12</sup> Scientists, coaches and athletes generally agree that around 14 days of continuous hypoxic exposure is sufficient for proper acclimatization at moderate altitudes. Yet, the literature on adaptive responses and performance at altitude over shorter periods of time is insufficient. One of the few studies that

considered this issue, Weston et al. (2001) found that the detrimental effects of altitude were lower among athletes after 18 or 47 hours of arrival at an elevation of 1700 meters than they were at 6 hours after arrival.<sup>3</sup> While this study seems to indicate that longer altitude residence is most beneficial, the subjects (youth rugby players) performed a shuttle run test and repeated push up test, which are not objective measures of endurance performance. Our study will employ a time trial for a distance that our subjects (elite cyclists) are accustomed to completing (20-km).

As a result of the acute exposure times of this study, the changes most likely to affect performance include ventilatory acclimatization, decreases in plasma volume, and disruptions during sleep. Altitude residence has been shown to enhance erythropoiesis after a period of time, as long as iron intake is sufficient,<sup>13-15</sup> but this adaptation is not likely to be significant over the course of the acute altitude exposure in this study.<sup>16</sup> It is understood that ventilatory adaptations begin to occur soon after arrival at altitude,<sup>17</sup> but it takes up to two weeks to revert to near sea-level values for many performance variables.<sup>2</sup> It has also been shown that sleep quality is decreased at altitude.<sup>4</sup> Seemingly, an overnight stay at altitude would benefit ventilatory acclimatization, and O<sub>2</sub> delivery and utilization which would improve performance but may also result in more restless sleep which would hinder performance. Plasma volume decreases at altitude as a result of dehydration, diuresis, increased capillary hydrostatic pressures, and plasma protein loss.<sup>18,19</sup> This drop likely impairs cardiac function, decreasing the ability of the blood to deliver oxygen to the periphery, and limiting endurance performance. The time courses of the effects of these three variables need to be outlined to understand the best acute altitude arrival strategies.

With the growing popularity of higher altitude competitions, such as trail and ultra-marathon running, a thorough analysis of short-term arrival strategies is becoming increasingly essential. Coaches and athletes will be able to determine which arrival strategies result in the best possible performance outcomes. In the present study, an effort was made to determine which of the predominant arrival strategies (i.e. evening prior or morning of competition) was most effective at minimizing performance decrements from sea level values.

### **Delimitations**

The study was delimited to the following:

1. Ten male elite endurance athletes, between the ages of eighteen and thirty, with a minimum  $\dot{V}O_{2\max}$  of 55 ml/min/kg on a cycle ergometer.
2. A total of five visits to the lab: a preliminary  $\dot{V}O_{2\max}$  test, a familiarization trial, and 3 blinded trials including sleeping and performing at altitude, sleeping at sea level and performing at altitude, and sleeping and performing at sea level.
3. The use of a hypoxic tent to simulate the hypoxic environment of an elevation of 2,500 m.
4. The use of wrist activity monitors to measure wakefulness during sleep trials.
5. Pre-exercise measures of sleep quality and arterial saturation, pre-sleep and post exercise measures of hemoglobin mass (via carbon monoxide (CO) rebreathing), hemoglobin concentration, hematocrit, arterial oxygen saturation, and body weight.
6. Measures of performance times for 20 km time trial, power output,  $\dot{V}_E$ ,  $\dot{V}O_2$ ,  $SaO_2$ , RER, heart rate, RPE, end tidal partial pressures, and dyspnea during time trials.

7. A data collection period throughout the fall and spring semesters of the 2013-2014 school year.

### **Limitations**

The following limitations were acknowledged with this study:

1. The sample size was relatively small (n=10) given the required number of trials.
2. Physical activities between trials was recommended to fit a particular criteria but not controlled.
3. The use of an artificial normobaric hypoxic tent may have different physiological outcomes than the hypobaric hypoxic environment found at true altitude. Use of normobaric hypoxia during the performance trial may have different outcomes versus the hypobaric hypoxic environment found at altitude.

### **Assumptions**

The study was based on the following assumptions:

1. The physiological adaptations at normobaric hypoxia and hypobaric hypoxia are similar enough for the findings in this study to be relevant.
2. The subjects in this study will have similar adaptive reactions to the hypoxic environment.
3. The subjects will have equal motivation to perform at their best in all performance trials.

4. The self-reporting of the subjects on questionnaires and ratings scales were representative of the actual experiences and effort levels encountered.
5. The subjects followed the investigator's requests to utilize similar routines between each trial.
6. CO rebreathing is a valid method of measuring hemoglobin mass and calculating plasma volume.
7. Subjects will not be exposed to any ambient air at any point during the hypoxic portion of the trials.

### **Hypotheses**

The study was designed to test the following null hypotheses:

1. There is no difference between performance trials of an overnight stay of at least 14 hours at a simulated altitude or an arrival only 2 hours before the simulated altitude trial.
2. There is no difference in sleep quality during the overnight stay and the night preceding the 2 hour pre-trial arrival.
3. There is no relationship between the amount of time spent at altitude and the concentration of hemoglobin in the blood, the hematocrit, or the plasma volume of the subjects
4. There is no relationship between 2 or 14 hours of hypoxic exposure on the average power output during the time trial.
5. There will be no difference in perceived effort (RPE) during the altitude and sea level trials.

6. There will be no difference in ventilatory measures, such as frequency of breathing,  $\dot{V}E$ ,  $\dot{V}O_2$ , RER, and dyspnea between the overnight stay and the 2 hour pre-trial arrival.

### **Definition of Terms**

The following terms are defined to clarify their use in this study:

Acclimatization: Physiological adaptations in response to altitude residence, such as central and peripheral changes that improve oxygen delivery and utilization.<sup>17</sup>

Arterial oxygen saturation ( $S_aO_2$ ): The ratio of oxyhemoglobin to the total amount of hemoglobin present in the blood.<sup>20</sup>

Elite endurance athletes: Individuals who train regularly for competition and have a  $\dot{V}O_{2max}$  of 55 ml/min/kg or higher.

Expired ventilatory volume ( $\dot{V}E$ ): The volume of air expired per minute of time by the subject (in L/min).<sup>21</sup>

Hypoxemia: Deficient oxygenation of the arterial blood<sup>22</sup>

Hypoxia: Decreased partial pressure of  $O_2$  in the ambient environment compared to sea level values.<sup>23</sup>

Moderate altitude: Elevations of 2000 m – 3000 m (as defined by Bartsch et al. 2008)<sup>24</sup>

Oxygen Consumption ( $\dot{V}O_2$ ): The volume of oxygen consumed by the body per 1 minute of time (in ml/min).<sup>25</sup>

Short-term arrival strategies: Methods for maximizing athletic performance in endurance events at altitude when time frame for arrival at altitude is limited to 2-14 hours.

Sleep quality: a measure of the adequacy of sleep dependent on the number of awakenings and disruptions throughout the night.

## **Chapter 2**

### **Review of the Related Literature**

#### Introduction

The physiological adaptations to acute and chronic hypoxia and the resultant effects on exercise performance have been extensively studied. The time course, extent, and factors controlling multiple variables related to altitude acclimatization will interact to ultimately influence exercise performance at altitude. While altitude acclimatization effects have been generally described, the specific time course and magnitude of altitude-mediated performance declines with varying lengths of acute altitude exposure have not been well characterized.

The literature related to the timing of arrival for endurance competitions at moderate altitude is reviewed in this chapter. We hypothesize that with differing lengths of acute altitude exposure, the primary physiologic variables which will influence differences in endurance exercise performance at altitude are magnitude of ventilatory acclimatization, magnitude of plasma volume loss, and differences in sleep quality. Therefore, the review of the extensive literature on altitude acclimatization effects and exercise performance at altitude has been limited and focused on selected topics and presented in the following order: (a) Effects of Acute Exposure to Hypoxia on Performance, (b) Ventilatory Acclimatization to Altitude, (c) Effects of Acute Altitude Residence on Plasma Volume, (d) Effects of Acute Altitude Residence on Sleep Quality and (e) Summary.

## Effects of Acute Hypoxia on Performance

Oxygen transport and delivery directly relates to the amount of work that can be produced by human skeletal muscle. This system, the oxygen transport pathway as Weibel (1984) described it, involves alternating steps of diffusion and perfusion to transport O<sub>2</sub> to the periphery to allow for the muscles to produce work.<sup>26</sup> A four-step process allows for the delivery of O<sub>2</sub> from the ambient air into the mitochondria in the working muscles. The first step is the translation or convection of ambient air to the alveoli. Second, the O<sub>2</sub> diffuses across the alveolar-capillary barrier and binds reversibly to hemoglobin. In the third step, the flow of blood through the arteries transports the oxygenated hemoglobin to the periphery and ultimately the capillaries in the tissue. The final step consists of the diffusion of the O<sub>2</sub> across the blood-gas barrier and into the mitochondria, where it is utilized in the electron transport chain to generate adenosine triphosphate (ATP). Oxygen transport is one of the major determinants of performance in normoxic conditions.<sup>27</sup> Therefore, this process is a critical limiting factor under hypoxic conditions. In hypoxia, there are fewer oxygen molecules transported to the alveoli for each breath taken. This means that while breathing normally, fewer molecules can diffuse into the blood, be transported to the periphery, and be unloaded in the working muscle. Training has been shown to increase blood volume, including both erythrocyte and plasma volume enhancements, which would help to minimize the delivery limitations.<sup>28</sup> However, for acute altitude exposures, this adaptation will not occur.

It has long been known that acute endurance performance is inhibited at moderate and high altitudes and that maximum aerobic capacity is impaired.<sup>8,29-31</sup> The extent of the impairment depends primarily on the magnitude of the elevation, which directly affects the partial pressure of ambient oxygen (P<sub>i</sub>O<sub>2</sub>). The lower partial pressure of ambient O<sub>2</sub> results in

a lower partial pressure of O<sub>2</sub> in the lungs. The binding of O<sub>2</sub> to hemoglobin is driven by a higher partial pressure in the alveoli than the partial pressure in the blood. Consequently, the lower partial pressure in the lung diminishes the saturation of O<sub>2</sub> in the blood. This means that the blood carries fewer molecules of O<sub>2</sub> per unit of volume than it does under normoxic conditions. The functional consequence of these conditions is that O<sub>2</sub> availability and delivery to the working muscles would be lower if other physiological variables remained unchanged. There would be fewer molecules of O<sub>2</sub> available for the mitochondria to exploit in the process of oxidative phosphorylation. In response, cardiac output must be increased to meet the metabolic demand during submaximal exercise. During maximal exercise, less oxygen can be delivered to the periphery and thus oxidative phosphorylation is diminished. The disruption of aerobic energy production results in a faster onset of metabolic disturbances, such as acidosis, accumulation of inorganic phosphate, and intracellular potassium disruption, and ultimately a more rapid decline into exercise failure.<sup>32-34</sup>

A slew of studies came out on the topic of performance and adaptation at altitude in the late 1960s in response to the upcoming 1968 Olympic Games in Mexico City, which confirmed the limiting nature of low oxygen availability. Dill (1966) claimed to produce the first systematic study of maximal exercise in acute exposures to low barometric pressures, and was one of the few studies that measured performance.<sup>35</sup> In this study, the authors participated as the subjects and were given exposure to the hypobaric environment for around 30 minutes or less. The authors compared this data with data from two previous studies on Dill (1962) and Dill and Phillips (1964), which involved exposure time of 2 days and 8 days respectively.<sup>36</sup> The percentage drop in performance for Dill and Phillips in the 1962 study was considerably higher than after an 8-day exposure in the 1964 study. However, Dill

managed to maintain 89% of sea-level performance after 2 days at 535mmHg in 1962 and 88% of sea-level performance after 30 minutes exposure in 1965. Balke (1965) found approximately 6% decrease in maximal oxygen uptake two to three days after arrival at 2,800m.<sup>29</sup> This was despite a substantial rise in pulmonary ventilation in response to the hypoxia. Buskirk (1967) found that  $\dot{V}O_{2max}$  decrements follows a fairly linear trend with increasing altitude.<sup>30</sup> This study found no improvement in aerobic capacity with continued training at altitude. Hansen (1967) showed similar decreases in  $\dot{V}O_{2max}$  in soldiers, but also found that the rate of ascension had no effect on the magnitude of the reduction. The author notes that when the  $PiO_2$  dropped from 150 to 85 mmHg, the  $\dot{V}O_{2max}$  of the subjects was maintained at 83% of sea-level values.<sup>37</sup> This suggests that an increase in ventilation allowed the subjects to maintain a higher than expected  $\dot{V}O_2$  at this elevation, albeit still considerably lower than sea-level values. More recent studies have looked at the factors that affect  $\dot{V}O_{2max}$  decline with acute altitude exposure.<sup>38-45</sup> A paper by Wehrlin and Hallen (2006) nicely compiled the data from a number of these studies that show the reduction in  $\dot{V}O_{2max}$  associated with the magnitude of the altitude exposure (Fig. 1).<sup>46</sup> After reviewing this data – all in highly endurance athletes - it is clear that  $\dot{V}O_{2max}$  is significantly impaired at moderate and high altitudes during acute exposures.

Figure 1. Comparison of  $\dot{V}O_{2\max}$  reduction and altitude

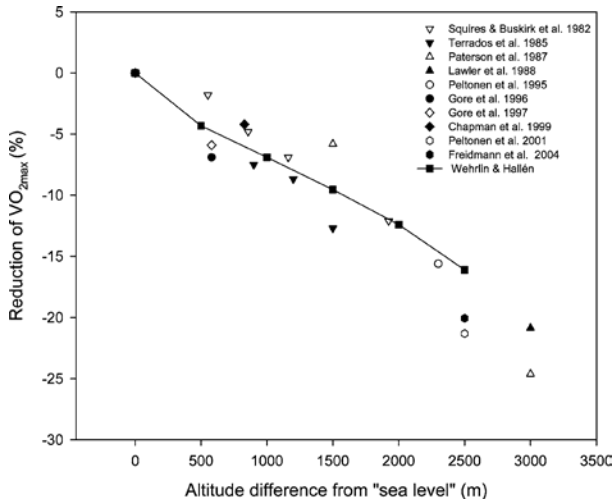


Fig. 1 - Percent decrease in  $\dot{V}O_{2\max}$  from sea level values. “Sea level” in these studies is set at 0 m but varies originally from 0 to 362 m. (Wehrlin and Hallen, 2006)

It is often argued that  $\dot{V}O_{2\max}$  decline at altitude has a strong correlation to decrements in exercise performance at altitude, but there are little data to support this claim. To address this issue, Chapman et al. (2011) studied the relationship between arterial oxyhemoglobin saturation ( $S_aO_2$ ),  $\dot{V}O_2$  during treadmill running at 3000m race pace, and 3000m running performance of elite runners.<sup>47</sup> The investigators in this study found that the extent of the performance decline at altitude (2100m) was significantly related to the drop in  $S_aO_2$  and oxygen uptake between normoxia and hypoxia (17.1%  $O_2$ , equivalent to 2100m). Since significant correlations have already been shown between  $S_aO_2$  reduction and  $\dot{V}O_{2\max}$  impairment,<sup>38,39,48</sup> one can transitively assume that  $\dot{V}O_{2\max}$  decrements and performance impairments would also be strongly correlated. Other studies have shown that maximal exercise performance is impaired significantly during acute altitude exposures. Gore (1997) showed that even an elevation of 580m has been shown to reduce 5-minute cycle ergometer power output by 5.9%.<sup>40</sup> A study by Brosnan showed that female cyclists selected power

outputs that were 5-6% below normal values while breathing hypoxic gas.<sup>49</sup> The performance decrements at moderate altitude are perhaps best shown in a study by Clark et al. (2007), in which  $\dot{V}O_{2peak}$  and 5-min time trial mean power output are compared for increasing elevations. The researchers found that the mean power output and  $\dot{V}O_{2peak}$  at even 1,200m was significantly lower than at 200m of altitude. With the drastically negative effects of hypoxia on endurance performance, it is obvious that maximizing performance by properly acclimatizing to altitude is vitally important for competitive athletes.

The often-suggested “best practice” for maximizing performance at altitude is to arrive at the competition elevation about 14 days prior to the day of the competition. Schuler et al. showed that cycling performance at altitude was significantly improved after 14 days at altitude when compared to performances after 1 day and 7 days of exposure.<sup>2</sup> Also, note that performance did not significantly improve with additional residence at altitude out to 21 days.

Figure 2.

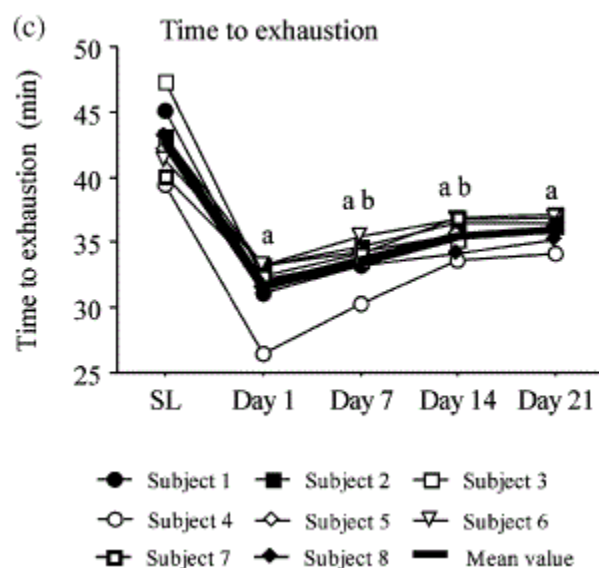


Figure 2. Individual and mean values for c) time to exhaustion at sea level (SL) and on Days 1–21 (Days 1, 7, 14, 21, respectively) of acclimatization. <sup>a</sup> $P < 0.05$  compared with SL; <sup>b</sup> $P < 0.05$  compared with, e.g. Days 7–1, Days 14–7 and Days 21–14.

A helpful review by Fulco (1998) showed that the magnitude of submaximal exercise performance decrement is proportional to both elevation and the duration of altitude residence.<sup>50</sup> Another finding from this study showed that submaximal exercise performance can return to sea level values with increasing duration of altitude residence, without any improvements in  $\dot{V}O_{2\max}$ . A residence period of 14 days allows for the athlete to properly acclimatize without experiencing the substantial detraining effects that can occur with long-term exposure to hypoxia.<sup>6</sup> However, given that not all athletes can arrange travel plans around this time frame, the question of the time course of performance shortly after exposure to altitude becomes relevant. Short-term variations in these performances have not been shown, with the exception of the Weston et al. (2001) study (Figure 3).<sup>3</sup>

Figure 3.

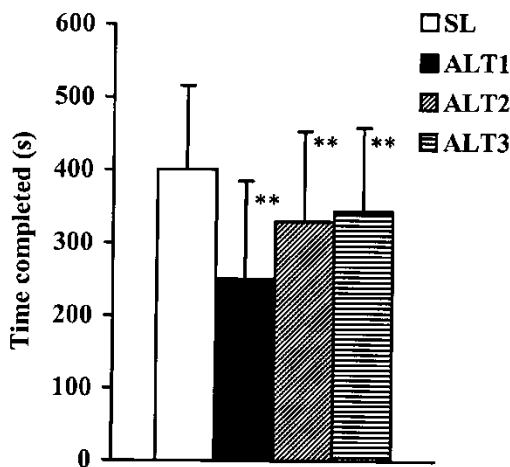


Figure 3—Time completed on the shuttle run (mean ± SD). \* indicates  $P < 0.001$  vs sea level mean.

These researchers showed that performance decrements were greater at 6 hours after arrival than 18 or 47 hours after arrival. They showed that heart rate was greater after 6 hours at altitude for a given submaximal workload than it was at sea-level. They also showed that

time to completion on a shuttle run test was greatest after 6 hours of altitude exposure than at sea-level, after 18 hours of exposure, or after 47 hours of exposure. However, there are some concerns with the design of this study, including the use of non-elite athletes and the team nature of the subject cohort (high school rugby players), and the implementation of a shuttle run test and repeated push-up test to measure performance. Specific to the question of endurance athletic performance, it would be considerably more relevant to study the time course of performance changes during acute altitude exposure by using elite cyclists or runners and measuring time trial performance for moderate to longer distances. Further investigation into the time course of these physiological and performance changes shortly after arrival at altitude is needed.

## **Ventilatory Acclimatization to Acute Moderate Altitude**

In order to effectively minimize the performance decrements at altitude, the time course of the limiting variables and their contribution to the performance limitation must be well understood. As discussed earlier, oxygen transport and delivery is one of the primary limiting variables in endurance performance at altitude. In response to this, the rate of ventilation has been shown to increase - a response that occurs almost immediately with exposure to hypoxia. In order to maintain a similar supply of oxygen as at sea-level, a greater volume of air must be ventilated to accommodate the decrease in number of oxygen molecules with each breath. Peripheral chemoreceptors in the carotid bodies detect a low partial pressure of oxygen in the blood and neural mechanisms are activated to increase the rate of breathing.<sup>51</sup> This increase in ventilation at altitude has been termed the hypoxic ventilatory response (HVR).

The realization that ventilation increases at altitude is not a new concept. Rahn and Otis (1949) observed that while both an acclimatized and unacclimatized subject saw increases in ventilation at altitude, the acclimatized subject had a greater increase than the unacclimatized subject in HVR.<sup>17</sup> This indicates that the gain in the ventilatory response to hypoxia increases with duration of hypoxic exposure. Smith (1986) showed the time course of the ventilatory response in stationary goats.<sup>52</sup> Data from this study showed that arterial PCO<sub>2</sub> dropped until around 8 hours after exposure, after which it appeared to level off. HVR is controlled by several physiological mechanisms, some of which can last long enough to affect future hypoxic exposures, and some of which only last for a few seconds.<sup>53</sup>

The primary mechanism of the HVR is a substantial and complicated process, as outlined by Teppema (2009) in an extensive review.<sup>54</sup> The initiating step in this mechanism is

the sensation of low PO<sub>2</sub> in the blood stream by the carotid bodies located in the carotid arteries. In addition to pressure these complex organs are sensitive to acidosis, hyperkalemia, hypercapnia, hyperthermia, circulating hormones, hyposmality, hypoglycemia, and pharmacological agents.<sup>55,56</sup> In hypoxia, oxygen sensors inhibit potassium channels in the cell membranes of the carotid body, resulting in increased intracellular calcium [Ca<sup>2+</sup>].<sup>57-61</sup> Neurotransmitters are then released which act on the afferent carotid sinus nerves and signal the O<sub>2</sub> decrease to the brain.<sup>57</sup> There does seem to be a general consensus that the neurotransmitters responsible for exciting these afferent nerve endings are acetylcholine and ATP.<sup>62-66</sup> The nerve conduction signal reaches the brain which in turn initiates the increased contraction frequency of the inspiratory muscles.

The HVR begins almost immediately after the onset of hypoxic exposure and then becomes slightly more pronounced throughout the first week of the sojourn.<sup>67</sup> Initially, this increased ventilation leads to a decreased arterial partial pressure of CO<sub>2</sub> and respiratory alkalosis. However, at altitudes below 3,000m this phenomenon appears to be alleviated within the first few days, partially by an increased urinary excretion of sodium.<sup>68,69</sup> Plasma aldosterone levels are reduced as a result of the expulsion of sodium.<sup>70</sup> A paper by Townsend (2002) showed the time course of changes in HVR response as a result of a “Live High Train Low” protocol.<sup>71</sup> HVR was shown to increase for the first 15 days of exposure to hypoxia. Some studies have also shown that ventilation continues to be gradually increased for the first few days at altitude, suggesting an increased sensitivity to the low partial pressure of O<sub>2</sub> and subsequent increased HVR.<sup>72,73</sup> However, none of these studies look at the time course of changes to HVR for the first 24 hours of altitude residence.

The increase in ventilation is not limited to resting conditions, but is also observed during maximal and submaximal exercise.<sup>7,37</sup> The hyperventilation increases alveolar PO<sub>2</sub> nearer to sea-level values, which in turn minimizes arterial oxygen desaturation.<sup>74</sup> The prevention of arterial oxygen desaturation inhibits the reduction of  $\dot{V}O_{2\max}$ . From this, one can presume that the hypoxic ventilatory response acts to modulate performance decrements at altitude.

Despite the potential for improved oxygen delivery and improved performance as a result of the increased ventilation at altitude, there are several complications that accompany this adaptation. The first of these is that increased respiration due to a larger tidal volume leads to greater respiratory water loss.<sup>75</sup> In response, an athlete must drink enough water to replace what will be lost. This could be problematic during long aerobic exercise, when the gastric emptying rate may be exceeded by hemoconcentration due to sweating and changes in oncotic pressure due to an accumulation of proteins in the interstitial fluid. It is generally assumed that gastric emptying rate can be a limitation to hydration status, although this has not been shown in the literature. Another potential problem is that the increased ventilation comes at the cost of greater respiratory muscle work. As well as possible fatigue of the respiratory muscles, the increased work of breathing has been shown to be detrimental to performance by reducing leg oxygen uptake during maximal exercise.<sup>76</sup> The vasoconstriction at this exercise intensity affects cardiovascular adjustment of blood flow away from the skeletal muscle to ensure oxygenation in the respiratory muscles.<sup>77</sup> This has not been shown in submaximal exercise.<sup>78</sup>

In conclusion, we expect the HVR to increase throughout the first 14 hours of exposure to hypoxia. We expect the ventilatory acclimatization to affect an increase in  $\dot{V}_E$ ,

$S_aO_2$ ,  $\dot{V}O_{2max}$ , and performance, all other variables being unchanged. This effect will likely be greater after 14 hours of exposure than it would after only 2 hours of exposure.

### **Effects of Acute Altitude Residence on Plasma Volume**

Within 24 hours of arrival at natural altitude, hemoglobin concentration [Hb] and hematocrit (Hct) start to rise. This is sometimes mistakenly attributed to an increase in the total number of red blood cells (RBCs) in circulation. However, this is not physiologically possible, as a significant increase in erythropoietin would still only lead to an increase in young red blood cells after a number of days. Rather plasma volume is decreased with acute exposure to moderate and high altitudes<sup>79-81</sup> and is responsible for the increased concentration of hemoglobin and hematocrit. Erythrocyte expansion is not seen within the first few days of altitude exposure. Sawka and others (1996) found that erythrocyte volume did not change after 13-days of continuous high altitude exposure and that plasma volume decreased by around 10%.<sup>82</sup> Other studies have shown similar results.<sup>83-86</sup> An adequate plasma volume is quite necessary for cardiac function during maximal exercise and to ensure that blood can be properly transported throughout the circulatory system. Decreased plasma volume will lead to a decline in venous return or preload, which diminishes stroke volume and cardiac output when heart rate remains unchanged or reaches a maximum.

Plasma volume loss at altitude can be attributed to a multiple factors, including dehydration, diuresis, plasma protein loss, and increased capillary hydrostatic pressures. As discussed earlier, diuresis may be a response to the respiratory alkalosis caused by the increased ventilation at altitude, which in turn leads to a loss in total body water. The

dehydration at altitude may also be a result of this diuresis, as well as high energy expenditures and poor access to water. In the Sawka (1996) study, fluid intake was controlled to prevent dehydration and the weight loss observed was not nearly enough to account for the volume loss seen in the plasma.<sup>82</sup> This study showed for the first time that decreases in plasma oncotic pressures and fluid volume were strongly correlated. He suggests that initially this is due to increased capillary permeability, possibly followed later by an increase in protein degradation.

The magnitude of hemoconcentration appears to be related to the degree of hypoxic stress. At higher altitudes, hemoconcentration and plasma volume loss is greater than at lower elevations.<sup>87</sup> In fact, increased hemoglobin concentration from plasma volume loss is commonly believed to be the most important factor contributing to improvement in performance as acclimatization to altitude occurs. Hemoconcentration increases the oxygen carrying capacity of the blood and contributes to increasing arterial oxygen content. The remainder of the improvement in arterial oxygen content can be contributed to increased pulmonary ventilation and alveolar oxygen partial pressure.<sup>87</sup> While the hemoconcentration does increase the oxygen carrying capacity, it does not improve the peripheral oxygen delivery limitations that occur at altitude during maximal exercise.<sup>88</sup> Therefore, increasing the oxygen carrying capacity of the blood and enhancing O<sub>2</sub> transport with acute exposure to altitude via hemoconcentration does not appear fully able to mitigate the decline in maximal exercise performance.

Since the ergogenic effects of blood volume adjustments at altitude after acclimatization do not seem to be related to the increases in oxygen carrying capacity to the periphery, the role of these adaptations must be questioned. One very possible explanation is

that the increased hemoglobin and arterial oxygen content allow for adequate oxygen uptake to occur.

The observation that performance is improved at altitude in response to decreased plasma volume is contrary to what is typically seen at sea level. In fact, it is widely recognized that decreases in body fluids and plasma volume are detrimental to performance. However, it has been shown that longer distance events were more greatly affected by plasma volume loss than events closer to  $\dot{V}O_2$ max effort.<sup>88</sup> This could be due to the fact that a reduced plasma volume impairs thermoregulation by reducing the ability of the blood to reach the capillaries in the skin, and reducing the sweat rate.<sup>89</sup> This would reduce heat transfer with the surrounding environment and possibly induce hyperthermia in longer endurance events. At elevation, overheating is less common due to cooler temperatures. It is also possible that the improvements in performance of increased  $O_2$  transport may outweigh the decrements in performance due to the impaired thermoregulatory ability of the lower plasma volume state.

In conclusion, we expect to see decreases in plasma volume throughout the duration of the altitude exposure in this study. The increase in ventilation would likely lead to a continued state of alkalosis, which would be counteracted with an increase in diuresis throughout the exposure time. We expect the reduction in plasma volume to increase  $C_aO_2$ , but mitigate  $\dot{V}O_2$ max and performance if all other variables remain unchanged. We also expect plasma volume loss to be greater after 14 hours of hypoxic exposure than at 2 hours.

## Effects of Acute Altitude Residence on Sleep Quality

Another possible variable affecting acute altitude performance relates to the changes in sleep quality after overnight residence in hypoxia. A reduction in sleep quality at altitude is occasionally noted by subjects after ascension to high altitudes, particularly in the first few nights.<sup>90</sup> Subjects often describe their sleep as poor quality with occasional awakenings throughout the night, and sporadically, a sensation of suffocation that is alleviated with a few deep breaths.<sup>90</sup> Sleep at altitude is often characterized by periodic breathing, which consists of an increase then sharp decrease in hyperpnea followed by a brief period of apnea. While this periodicity decreases with successive nights at altitude, it has been shown to persist at elevations above 4500m.<sup>91</sup>

Early studies on sleep physiology at altitude showed the alteration of sleep cycles experienced by subjects. Joern et al. (1970) found that at pressures similar to moderate altitudes, sleep stage distribution was altered so that Stages 3 and 4 were almost eliminated and REM sleep was reduced by 50%.<sup>92</sup> Similarly, Reite et al. (1975) showed significant reductions in Stages 3 and 4 and less REM sleep. The authors also noted the presence of periodic breathing among the subjects, although this periodicity disappeared once the subject shifted into REM sleep. Arousals that occurred during the periodic breathing often followed the transition from the apneic to the hyperpneic stages of the periodic breathing cycle.<sup>4</sup> Interestingly, this study showed no significant decreases in overall sleep time and found that these changes were the greatest on the first night of arrival at altitude, and decreased as altitude residence persisted. Subsequent studies have shown similar results.<sup>91,93-95</sup> Although it appears that the increased arousals during sleep at altitude are connected to periodic breathing, the mechanisms that contribute to the shift in sleep patterns are poorly understood.<sup>90</sup>

The mechanism of periodic breathing, though, was first demonstrated by Douglas and Haldane (1909).<sup>96</sup> The authors showed that this breathing pattern was characterized by alternating intervals of hypoxia, which led to hyperpnea, and hypocapnia, which led to apnea. Essentially, the two respiratory responses (hyperpnea to hypoxia and apnea to hypocapnia) are at odds with each other under these conditions. Thus, periodic breathing exhibits a cyclic condition. Hypoxia causes a stimulation of breathing which in turn decreases the partial pressure of CO<sub>2</sub> in the blood. This hypocapnia causes ventilatory drive to be inhibited, leading to apnea, which leads to further hypoxia. During sleep at altitude, this cycle continues to occur, except during REM sleep. They also argued that while the subjects were awake, the rhythmic nature of breathing allowed the subjects to maintain normal breathing patterns, even without the normal respiratory stimuli seen at lower altitudes. During sleep, this rhythm is lost as the strong inhibitory respiratory drive of the hypocapnia caused a predisposition towards apnea. Later studies verified this mechanism.<sup>4,97,98</sup> Some of these later studies also showed that this periodic breathing cycle was dependent on the ventilatory sensitivity of the subject to hypoxic exposure.

While this phenomenon has been shown to persist at very high altitudes (>4,500m), studies have shown that periodic breathing declines during subsequent nights at moderate altitudes.<sup>91,99</sup> It is important to note that this occurs despite the fact that hypocapnia increases over time. As such, it appears that the responsiveness of the ventilatory inhibition by hypocapnia is improved with acclimatization to altitude.

The greatest effect of periodic breathing is the reduction in sleep quality marked by an increase in arousals and awakenings. These sleep disturbances occur primarily when the periodic breathing cycle shifts from apnea to hyperpnea. It is possible that the disturbances

are triggered by apnea-induced asphyxia, the mechanics of the initiation of breathing, or simply as a consequence of the central commands that instigate breathing.<sup>90</sup> It has been shown that at low altitudes, sleeping during ventilatory stimulation by the application of various respiratory loads, as well as hypoxia and hypercapnia, leads to arousals in response to the mechanics of the increased respiratory effort rather than changes in blood gases.<sup>100</sup> This suggests that the mechanics of the periodic breathing cycle may cause the sleep disturbances.

While it is clear that sleeping at very high altitudes results in awakenings and disturbances among most subjects, one would expect to see fewer cases of periodic breathing and sleep disruption as the elevation of residence is decreased. The thresholds at which these effects are seen are not well established. However, a study by Muhm and others (2009) observed the changes in sleep quality at 2,438m, very close to the simulated elevation of the current study. The authors found that although there was a moderately severe occurrence of hypoxemia, there were no observed changes or reductions in sleep quality.<sup>101</sup> Another, more pertinent study that makes use of a normobaric hypoxic tent, which is the method of simulating overnight altitude in the current study, found that subjects reported lower scores on a questionnaire designed to measure quality of sleep. However, more objective measurements made in the study showed no changes in stages 3 and 4 or in REM sleep. Stages 1 and 2 were reported to be significantly shorter than in normal conditions, but the authors acknowledge that this is likely to be due to familiarization to the new environment.<sup>102</sup> While it is unclear if physiological variables are to blame for decreased sleep quality at this moderate altitude, the primary measure of this study is performance, so sleep disruptions due to environmental changes must be acknowledged as well.

## Summary

Endurance performance at moderate altitudes is modulated by the reduced partial pressures of oxygen in the hypobaric environment. Acclimatization strategies are employed by athletes to ameliorate some of the performance decrements. For athletes limited to short-term arrival strategies (i.e. < 24 hours), several factors may alter performance over the first few hours of acute altitude residence. Arrival at altitude is accompanied by an increase in ventilation in response to the hypoxic environment. The increased ventilation is likely to persist for some time after the initial escalation, but the time course over the first 14 hours of altitude exposure are not well characterized. After initial altitude exposure, plasma volume can be expected to decrease, and again, the time course of the decline over the first 14 hours of altitude exposure is not known. The effects of this decrease on performance is somewhat unclear, since the hemoconcentration increases the carrying capacity of the blood, but also limits the venous return to the heart affecting cardiac function. Sleep quality may also be affecting performance with acute exposure to altitude. While the occurrence of periodic breathing is well-documented at high altitudes, it has not been shown at moderate altitudes and sleep quality measures in these studies don't adequately measure the physiological parameters.

The knowledge of these previous studies will allow us to develop and implement a novel study that investigates the physiological and performance changes in short-term arrival strategies at moderate altitude.

## **Chapter 3**

### **Procedures**

This study required subjects to visit the lab on five occasions separated by at least five days. The first two visits to the lab consisted of a qualification trial and a familiarization trial. With the exception of the variation in hypoxic dosage, the subjects performed identical pre-exercise and exercise protocols on each of the final three experimental trials. The protocol for the experimental trials consisted of an overnight stay in a hypoxia-compatible tent, two hours of resting in the laboratory, and a 20km time trial on a cycle ergometer. The experimental trials consisted of: (1). an overnight stay (12 hours) at simulated altitude of 2,500m ( $F_{iO_2} = 16.2\%$ ), two hours at  $F_{iO_2} = 16.2\%$ , a 20km time trial on the cycle ergometer at  $F_{iO_2} = 16.2\%$ ; (2). an overnight stay (12 hours) at 235m (Bloomington) in normoxia, two hours at  $F_{iO_2} = 16.2\%$ , a 20km time trial on the cycle ergometer at  $F_{iO_2} = 16.2\%$ ; (3). an overnight stay (12 hours) at 235m, two hours at 235m, a 20km time trial on the cycle ergometer at 235m. The three experimental trials were randomly assigned and the subjects were blinded to the hypoxic dosage that they received for each trial.

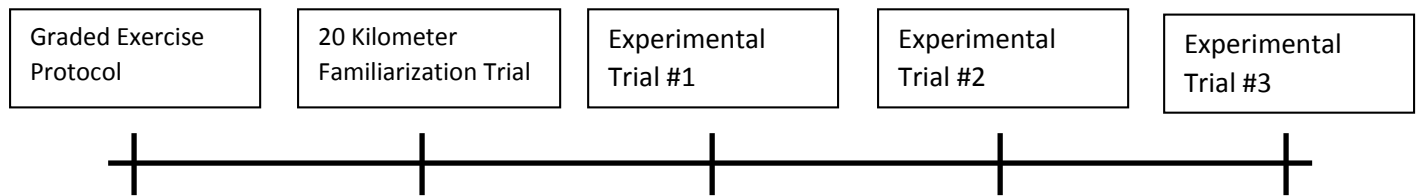
### **Subjects**

The subject pool consisted of healthy, actively training men who were elite endurance runners and cyclists who were non-smokers and had no history of cardiovascular, pulmonary, or renal disease. The minimum requirement for  $\dot{V}O_{2max}$  on a cycle ergometer for inclusion was set at  $55 \text{ ml min}^{-1} \text{ kg}^{-1}$ . A questionnaire was used to determine training status and medical history. Subjects were advised both orally and in writing as to the nature of the experiments and obtained written consent prior to testing, in accordance with policies and

procedures of the Institutional Review Board of Indiana University. Subjects were asked to refrain from strenuous workouts in the 48 hours prior to each time trial, but to otherwise maintain their normal training volume and intensity.

### Timeline Delineating Exercise Protocols

Figure 4. Timeline of Events (minimum)



### Graded Exercise Test Protocol

After arrival at the lab on the first day, subjects were instructed on the use and protocol for an electronically-brake cycle ergometer (Velotron RacerMate) and allowed to adjust the seat and handlebar height as necessary. The subject then sat quietly on the cycle ergometer and was fitted with a heart rate monitor and face mask. Once all equipment was in place, the subject rested for 5 minutes and metabolic data was collected. The initial power output was set at 100 watts for 1 minute. After the first minute, the power output was increased by 25 watts every minute until volitional fatigue.<sup>103</sup> Criteria for determining  $\dot{V}O_{2max}$  included: (1) a heart rate of within 10% of age-predicted maximum; (2) a plateau in oxygen consumption (<150 ml O<sub>2</sub>) with an increase in workload and (3) a respiratory exchange ratio of greater than 1.10. The subject was required to have met two of the three criteria for the  $\dot{V}O_{2max}$  test to be valid. The highest recorded value for  $\dot{V}O_2$  was considered to be  $\dot{V}O_{2max}$ .

### **Familiarization 20-km Time Trial Protocol**

For second visit to the lab, the subject was fitted with a heart rate monitor, and mask. The subject was instructed to traverse the 20 kilometer distance on the cycle ergometer as quickly as possible and with maximum effort. The subject was allowed a 10 minute warm up at 50% of  $\dot{V}O_2$ max before the start of the trial. After the warm up period, the subject was able to set his own power output and cadence, which the subject could change at any point throughout the trial. Metabolic data was collected for the duration of the performance trial. Also, verbal encouragement was provided to the subject throughout the trial. Time to completion and instantaneous power output was collected in addition to the metabolic and ventilatory data.

### **Intervention Trials Protocol**

On the third through fifth lab visits, subjects took part in blinded and randomized trials including: a) 12 hours overnight at 2,500m simulated altitude (normobaric hypoxia) followed by a 2 hour-hypoxic dose in the laboratory and a 20km time trial at 2,500m, b) 12 hours overnight at 235m followed by a 2-hour hypoxic dose at 2,500m in the laboratory and a 20km time trial at 2,500m, and c) 12 hours overnight at 235m followed by a 2-hour normoxic dose in the laboratory and a 20km time trial at 235m.

## **Sleeping Protocol**

For each experimental trial, subjects came into the lab at approximately 1800 hours and after consuming a meal. Subjects were instructed to consume 15ml/kg of water in the hour prior to this. Upon arrival, a urine sample was collected, and specific gravity was measured. A specific gravity of 1.010 was set as the criteria to determine that the subject was euhydrated. Body mass of the subjects was taken after allowing them void and drink water as desired. Beginning at this time point, the volume of urine output was recorded throughout the trial. Subjects then immediately completed the CO rebreath method described in detail later in this section. Subjects wore Actical multi-directional accelerometers on one wrist and a fingertip pulse oximeter on the other wrist prior to entering the altitude tent. Actical data was collected for the duration of the altitude exposure and analyzed from the time the subjects went to sleep until waking the following morning. The time that the subjects attempted to sleep was the same across all three trials. For the sleeping trial in hypoxia, the altitude in the tent was set to a simulated 2,500m by using a commercially available nitrogen generator (Colorado Altitude Systems, Denver, CO) to add nitrogen to the tent until O<sub>2</sub> concentration was 16.2%. The tent was constructed of PVC pipe and plastic sheeting in a cubic formation measuring 2.7m x 2.7m x 1.7m, which was placed over top of a standard queen size bed located in the Human Performance Laboratory. Temperature, O<sub>2</sub>, and CO<sub>2</sub> concentrations in the tent for all trials were continuously monitored via Applied Electrochemistry (Thermox instruments, Pittsburgh, PA) O<sub>2</sub> and CO<sub>2</sub> monitors. The subjects then entered the tent and the subjects were required to remain in the tent except if they needed to defecate (bedside urinals and drinking water were provided in the tent). Subjects were allowed to eat and drink ad

libitum while in the tent. The subjects were also allowed to read, use electronic devices, or listen to music in the tent.

### **Pre-time trial protocol**

The 20k time trial was scheduled for 14 hours after the subject entered the hypoxic tent. Subjects were required to be awake and begin a pre-time trial routine at least two hours prior to the scheduled starting time of the time trial. Subjects were required to remain in the tent until 30 minutes prior to the start of the time trial, but had adequate room in the tent to complete stretching and other pre-warm up activities. For the 12 hours of normoxia / 2 hours of hypoxia trial, 100% nitrogen gas was flowed into the tent beginning 2 hours prior to the start of the time trial, and normally took 15 minutes to equilibrate at the desired simulated altitude. Once awake, the subjects filled out a questionnaire to compare differences in sleep quality and sleep disturbances.

### **Time Trial Protocol**

The cycle ergometer seat was set to the same height the subject used in the familiarization trial, and the subject was fitted with a heart rate monitor. The subject then completed a standardized warm up protocol of 10 minutes of cycling at a workload equal to 50% of  $\dot{V}O_2\text{max}$ , followed by 3-5 minutes of rest to collect resting metabolic and ventilation data. After the 3-5-minute rest period, the subject was asked to begin the time trial and to

attempt to complete the 20-km as quickly as possible. The subject was free to alter cadence or resistance freely throughout. The subject was provided with continuous visual feedback of distance traveled. A verbal notice of kilometers remaining was given each kilometer, starting with 5km to go. During these trials, the subject breathed air containing 16.2% O<sub>2</sub> or room air, and metabolic data was collected every 15 seconds for the duration of the trial. We recorded time to completion at the end of the trial and instantaneous power throughout the trial.

### **Determination of Plasma Volume**

A 2-minute CO rebreathing method, as described by Gore<sup>104</sup> was used to determine total hemoglobin mass, which combined with hemoglobin concentration and hematocrit allowed for the calculation of plasma volume. In brief, we measured initial percent of hemoglobin bound to carbon monoxide (%HbCO) by taking a 100 uL capillary blood sample from a fingertip and using a radiometer OSM3 blood gas analyzer (Radiometer Medical A/S, Copenhagen). The subject was fitted with noseclips, exhaled to residual volume, then placed their mouth on a mouthpiece connected to a homemade spirometer. The subject then inhaled a bolus of 99.5% CO (1 ml/kg body weight) that was delivered using a 100-ml plastic syringe, and rebreathed from the spirometer connected to a 5L anesthetic bag filled with 100% O<sub>2</sub>. The subject then rebreathed from this spirometer for 2 min. After the 2-minute breathe was completed, a handheld parts-per-million (ppm) CO analyzer (Fluke model CO-220, Canada) and a Stead-Wells spirometer (Collins Medical, Braintree, MA) were used to quantify the volume of CO in the spirometer that was not taken up by the body. The %HbCO measurement (via finger prick) was repeated at 6 and 8 min after the start of the rebreath and averaged. A correction was made to account for the volume of CO that was expelled from the

lung after removing the spirometer. This was done by measuring end-tidal CO concentration at the fifth minute after the start of the procedure and multiplying by the estimated alveolar ventilation (15 L/min) between minutes 2 and 5. Plasma volume was calculated from Hbmass and measures of hematocrit and hemoglobin concentration. This CO rebreathing procedure was performed after arrival at the laboratory, before entering the tent for the evening. It was assumed that total Hbmass did not change during the 14 hour tent exposure, and hematocrit measures taken pre- and post-time trial were used to determine changes in plasma volume.

### **Sleeping arterial oxyhemoglobin saturation**

To determine sleeping arterial oxyhemoglobin saturation, we used a fingertip pulse oximeter (Model PC-68A, Shenzhen Creative Industry Co, Ltd., Shenzhen, China). This device consisted of a wristband oximeter and a fingertip probe that measured saturation percentage of oxygen in the blood ( $S_pO_2$ ). Prior to entering the tent, subjects were fitted with the wristband and fingertip probe and data collection was initiated. Subjects wore the device throughout the night, and the device recorded heart rate and  $S_pO_2$  data every 3 seconds.

### **Measures of sleep quality**

To measure the quality of sleep in the altitude tent, wrist activity monitors (Actical, Mini-Mitter Co, Inc., Bend, Oregon) and an altitude-validated survey instrument (the Groningen Sleep Quality Questionnaire) were used.<sup>105</sup> The subjects were given the Actical monitors prior to entering the tent and asked to wear them on their wrist once they went to bed. The starting point for this measure was set at the time the subjects went to bed and the

end point was set at the time the subjects woke up in the morning. The duration of this measurement was consistent for all trials. Upon waking in the morning, the monitors were removed and subjects were asked to fill out the questionnaire immediately. The Actical monitors record movement counts, which were uploaded onto the device's data management software to track disturbances during the night. Total activity counts were recorded during the sleeping period to compare movement in sleep between trials.

### **RPE and Dyspnea scales**

To determine the perception of each subject's exercise intensity, Borg's RPE scale was used.<sup>106</sup> After every the completion of every 4k, we showed a printed version of the scale to the subject and instructed them to point to the number corresponding to their perceived level of exertion. We also used the Modified Borg scale for Perceived Dyspnea as described by Burdon (1982).<sup>107</sup> This scale was shown to the subjects concurrently with the RPE scale at the end of every 4k portion of the time trials.

### **Ventilatory and Metabolic Measurements**

Indirect calorimetry was used to measure ventilatory and metabolic variables via a computer interfaced, open circuit system. A linear pneumotachometer (Hans-Rudolph Inc., Shawnee, KS) was used to measure minute ventilation ( $V_E$ ) on the inspired side of the breathing apparatus. The inspired line was connected to a two-way non-rebreathing valve (#2700, Hans-Rudolph Inc., Shawnee, KS). The hose from the expired side of the mouthpiece was connected to a 5-L mixing chamber. An Applied Electrochemistry S-3A oxygen analyzer

and a CD-3A carbon dioxide analyzer (AEI Technologies, Pittsburgh, PA) continuously sampled 300 cc/min of the dried expired gas from the mixing chamber to measure fractional concentrations of oxygen ( $F_{E}O_2$ ) and carbon dioxide ( $F_{E}CO_2$ ) gas in the chamber. The analyzers were calibrated with a gas of known composition within the expected physiologic range, both before and after exercise testing. These variables were measured and monitored with a data acquisition, control, and analysis software (DASYLab Version 12, Measurement Computing Corporation, Norton, MA). All gas measurements ( $\dot{V}_E$ ,  $\dot{V}O_2$ , and  $\dot{V}CO_2$ ) were corrected to STPD. Heart rate was continuously monitored using telemetry (Model FT1, Polar, Stamford, CT).

### **Statistical Analysis**

Separate one-way repeated measures ANOVAs with Tukey's post-hoc analysis were used to determine differences between means of select dependent variables (e.g. time trial completion time, average power, change in plasma volume, sleep quality) across the three experimental conditions. A two-way repeated measures ANOVA (condition x time) with a priori tests of simple main effects was used to determine differences in time trial variables at each 4km split across the three conditions. An alpha of  $p < 0.05$  was used as the criteria for statistical significance.

## Chapter 4

### Results

#### Subjects

Subject characteristics are shown in Table 1. Ten subjects completed the entire protocol, while two of the originally recruited subjects dropped out due to time constraints and thus were not included in the analysis. In terms of typical mode of exercise used in training, five of the subjects were trained cyclists and five of the subjects were runners. There were no statistical differences between these two groups, so the data for both cyclists and runners was considered together.

Table 1. Subject Characteristics

	Mean $\pm$ SD
Body Mass, kg	70.38 $\pm$ 7.73
Age, yrs	23 $\pm$ 4
$\dot{V}O_2$ Max, ml·kg <sup>-1</sup> ·min <sup>-1</sup>	66.5 $\pm$ 5.2
Hematocrit, %	44.0 $\pm$ 3.0
Total hemoglobin mass, g	967 $\pm$ 106

#### Environmental Parameters

Temperature and  $F_{iO_2}$  in the laboratory and in the tent were closely monitored throughout the study, and there were no significant differences between the hypoxic trials for these variables. The only observed difference between the environmental parameters for the hypoxic and control trials was  $F_{iO_2}$  (Table 2).

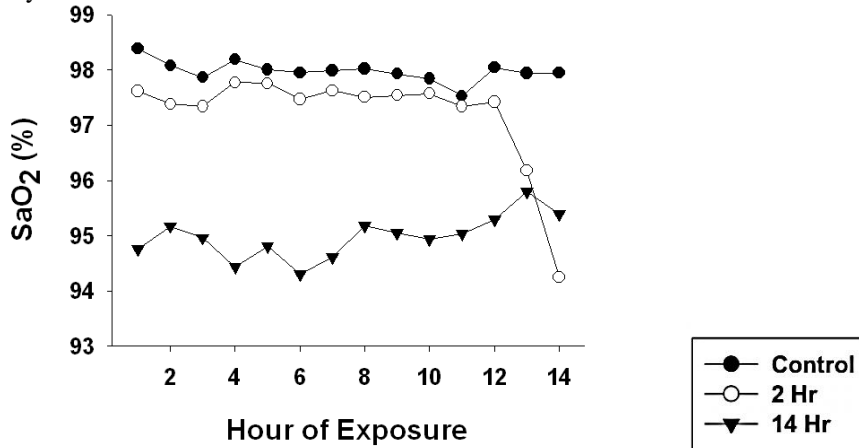
Table 2. Environmental Parameters (Mean  $\pm$  SD)

	Sleep Temperature (°C)	Ride Temperature (°C)	F <sub>I</sub> O <sub>2</sub> – Tent (%)	F <sub>I</sub> O <sub>2</sub> – Ride (%)
2hr	20.2 $\pm$ 0.3	20.4 $\pm$ 1.3	16.2 $\pm$ 0.2*	16.2 $\pm$ 0.0*
14hr	20.2 $\pm$ 0.5	20.0 $\pm$ 1.5	16.0 $\pm$ 0.2*	16.2 $\pm$ 0.0*
CTRL	20.2 $\pm$ 0.3	20.5 $\pm$ 1.2	20.2 $\pm$ 0.2	20.7 $\pm$ 0.2

\* Significantly different from Control (p < 0.05)

During sleep, S<sub>a</sub>O<sub>2</sub> was significantly lower at each time point in the first 12 hours of tent exposure for the 14hr trial than both the 2hr time trial and the control. However when the subjects awoke and were exposed to hypoxia in the 2hr trial, S<sub>a</sub>O<sub>2</sub> dropped abruptly, to levels even lower than the 14hr trial at the time the time trial started. (See Fig. 5)

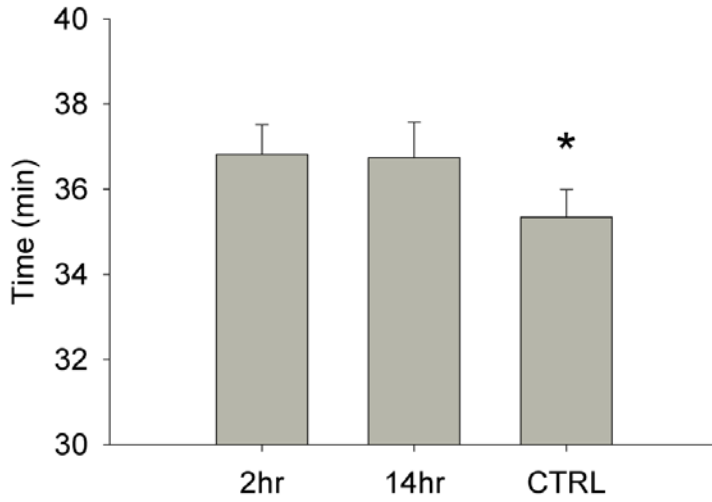
Figure 5. S<sub>a</sub>O<sub>2</sub> during sleep and rest period prior to 20km time trial. Values are means; error bars omitted for clarity.



## Performance

There were no statistical differences in time to completion for the 20km time trial between the 2-hour and 14-hour exposure trials. A mean difference of 4.2s for a 20km ride was observed between the 2hr and 14hr time trials. Performance times were significantly faster in the normoxic control trial than both of the hypoxic trials (See Fig. 6).

Figure 6. 20km Time Trial Performance



Time to completion for subjects in the 20km time trial. Values are means  $\pm$  SD. \* =  $P < 0.05$  compared to both 2hr and 14hr trials.

No differences were seen in overall completion times between any of the three trials. When comparing the two hypoxic trials, no differences in pacing strategy were observed. (See Figure 7 & 8)

Figure 7.

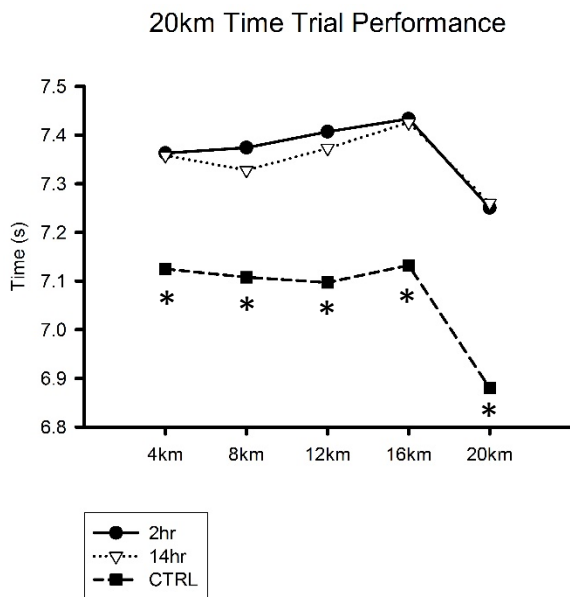
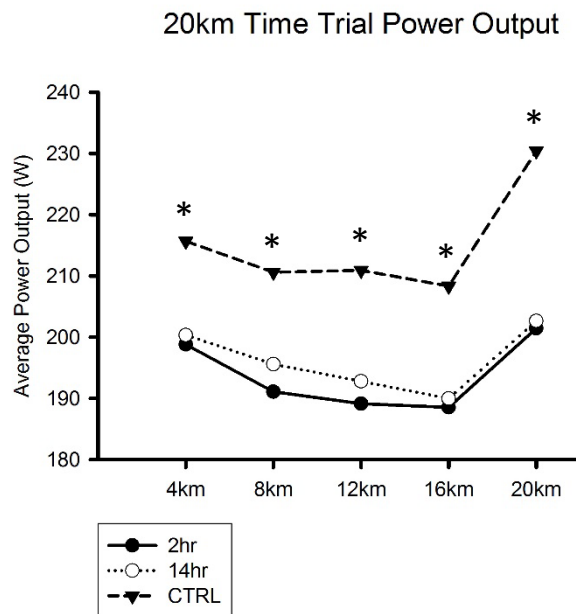


Figure 8.



Performance measures in 4km increments. Figure 3) time to complete each 4km increment (x-axis shows distance ridden at the end of each increment.) Figure 4) Average power for each 4km increment (x-axis shows distance ridden at the end of each increment.). Values are means; error bars omitted for clarity.

\* = Significantly different from 14hr and 2hr,  $p < 0.05$

## Metabolic Variables During Exercise

Few differences were seen between metabolic variables measured during the exercise bout between the 14hr and 2hr trials, although (as expected) many of these measures were significantly different than the control trial. Measures taken during the ride, reported as minute averages at the end of each 4km, are summarized in Table 3.

Table 3. Values displayed as Mean  $\pm$  SD

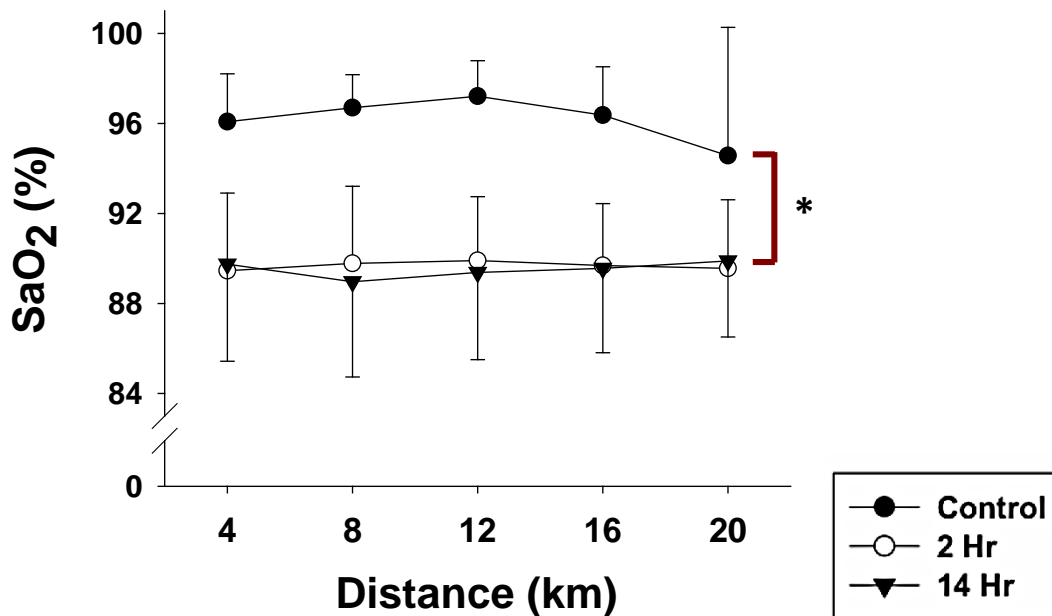
	<i>n</i>	4km	8km	12km	16km	20km
$\dot{V}O_2$ , ml·kg <sup>-1</sup> ·min <sup>-1</sup>						
2hr	10	41.4 $\pm$ 4.7	44.3 $\pm$ 5.3	44.1 $\pm$ 5.2	44.4 $\pm$ 5.8	46.6 $\pm$ 6.4
14hr	10	41.7 $\pm$ 7.4	44.4 $\pm$ 7.8	45.0 $\pm$ 7.4	45.2 $\pm$ 8.0	48.0 $\pm$ 10.3
CTRL	10	42.9 $\pm$ 7.1	45.8 $\pm$ 7.2	46.5 $\pm$ 7.1	46.1 $\pm$ 7.1	49.0 $\pm$ 7.7
S <sub>a</sub> O <sub>2</sub> , %						
2hr	10	89.5 $\pm$ 3.5*	89.8 $\pm$ 3.4*	89.9 $\pm$ 2.8*	89.7 $\pm$ 2.8*	89.6 $\pm$ 3.1*
14hr	10	89.8 $\pm$ 4.3*	89.0 $\pm$ 4.2*	89.4 $\pm$ 3.9*	89.6 $\pm$ 3.8*	89.9 $\pm$ 3.4*
CTRL	10	95.5 $\pm$ 2.0	96.4 $\pm$ 1.5	97.0 $\pm$ 1.7	96.1 $\pm$ 2.4	93.8 $\pm$ 6.2
Heart Rate, bpm						
2hr	10	163 $\pm$ 9	164 $\pm$ 11	167 $\pm$ 13	167 $\pm$ 12	177 $\pm$ 11
14hr	10	161 $\pm$ 11	164 $\pm$ 11	165 $\pm$ 12	167 $\pm$ 16	178 $\pm$ 12
CTRL	10	160 $\pm$ 13	162 $\pm$ 13	164 $\pm$ 14	166 $\pm$ 15	179 $\pm$ 12
$\dot{V}_E / \dot{V}O_2$						
2hr	10	34.4 $\pm$ 7.0*	33.4 $\pm$ 5.1	33.8 $\pm$ 5.5	32.9 $\pm$ 4.4	35.9 $\pm$ 5.4
14hr	10	32.3 $\pm$ 6.1	32.2 $\pm$ 5.8	32.7 $\pm$ 5.3	32.4 $\pm$ 5.2	34.9 $\pm$ 5.6
CTRL	10	31.1 $\pm$ 7.9	30.4 $\pm$ 5.7	30.8 $\pm$ 6.5	29.9 $\pm$ 5.6	34.3 $\pm$ 5.9
$\dot{V}_E / \dot{V}CO_2$						
2hr	10	36.1 $\pm$ 6.7*	36.8 $\pm$ 6.0*	37.3 $\pm$ 6.7*	37.7 $\pm$ 6.3*	38.8 $\pm$ 5.6*
14hr	10	36.3 $\pm$ 5.2*	37.3 $\pm$ 5.4*	38.8 $\pm$ 5.5*	39.3 $\pm$ 5.8*	41.6 $\pm$ 6.5*
CTRL	10	30.9 $\pm$ 5.1	31.8 $\pm$ 5.4	32.8 $\pm$ 5.4	32.7 $\pm$ 5.9	34.7 $\pm$ 5.6
$\dot{V}_E$ , L·min <sup>-1</sup>						
2hr	10	85.2 $\pm$ 4.0	80.8 $\pm$ 6.0	83.6 $\pm$ 5.6	81.6 $\pm$ 4.2	99.5 $\pm$ 3.9
14hr	10	81.4 $\pm$ 4.8	80.4 $\pm$ 7.6	82.6 $\pm$ 5.1	84.3 $\pm$ 3.7	102.1 $\pm$ 7.6
CTRL	10	78.8 $\pm$ 4.0	77.3 $\pm$ 4.8	72.4 $\pm$ 9.9	78.6 $\pm$ 7.2	104.0 $\pm$ 7.8
ETCO <sub>2</sub> , %						
2hr	8	3.96 $\pm$ 0.52*	3.91 $\pm$ 0.53	4.02 $\pm$ 0.45	3.92 $\pm$ 0.42	3.63 $\pm$ 0.28#
14hr	8	4.03 $\pm$ 0.53	3.96 $\pm$ 0.40	3.81 $\pm$ 0.34	3.75 $\pm$ 0.32*	3.51 $\pm$ 0.38*
CTRL	8	4.42 $\pm$ 0.66	4.32 $\pm$ 0.72	4.17 $\pm$ 0.62	4.24 $\pm$ 0.59	3.90 $\pm$ 0.39

\* Significantly different from Control trial ( $p < 0.05$ )

# Significantly different from 14hr trial ( $p < 0.05$ )

During the ride, no differences were seen for  $S_aO_2$  values between the 2hr and 14hr trials. The values for both of these trials were significantly lower than the values for the control trial ( $p < 0.05$ ). (See Fig 9)

Figure 9.  $S_aO_2$  during 20km time trial



Values are means  $\pm$  SD. \*Significantly different than 2hr trial and control ( $p < 0.05$ )

### Ventilatory Acclimatization

Most of the variables for ventilatory acclimatization showed no change between the 2hr and 14hr performance trials. End-tidal  $CO_2$  and  $\dot{V}_E/\dot{V}O_2$  were not significantly different across conditions at any of the time points for any of the trials (See Fig. 10 and 11).  $\dot{V}_E/\dot{V}CO_2$  approached significance for the 14hr trial over the 2hr trial at the 16km and 20km marks ( $p = 0.091$  and  $p = 0.076$  respectively). For the 14hr trial,  $FETCO_2$  was significantly lower than the control trial at the 16km and 20km marks, and significantly lower than the 2hr trial at the 20km mark.

Figure 10. ETCO<sub>2</sub> during time trial

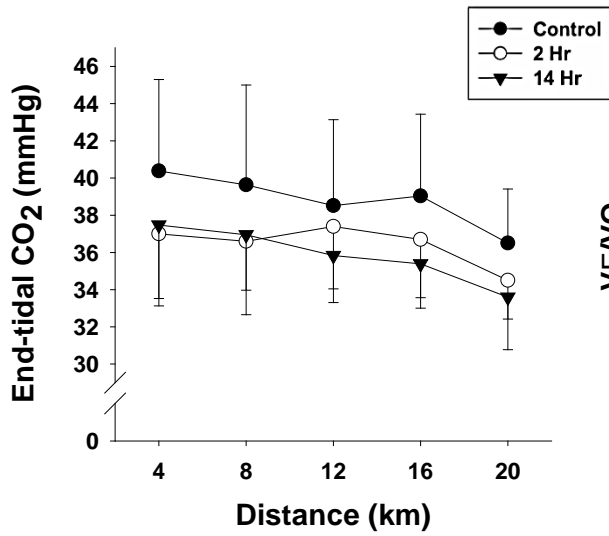
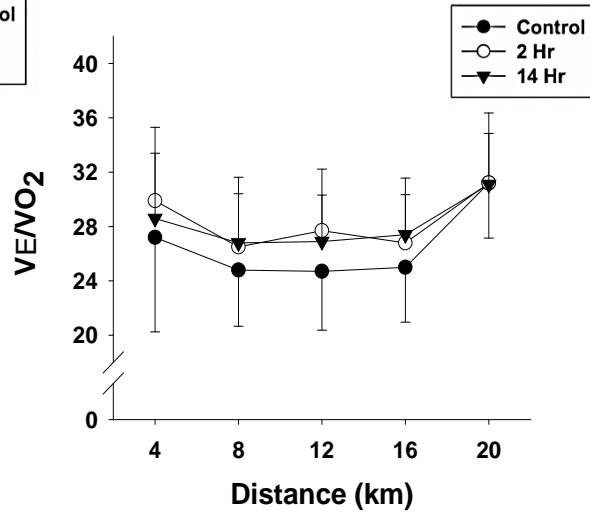


Figure 11. V<sub>E</sub>/V<sub>O<sub>2</sub></sub> during time trial

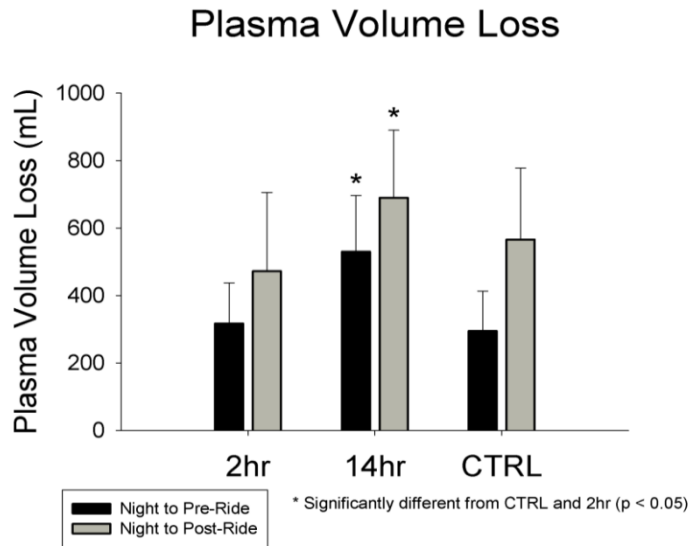


Values are means  $\pm$  SD.

### Changes in Plasma Volume

Plasma volume decreased in all trials from the time the subjects entered the tent until the end of the ride. There was a significantly greater decline in plasma volume at both the pre-ride and post-ride time points during the 14hr trial compared to both the 2hr and control trials ( $p < 0.05$ ). (See *Fig. 12*)

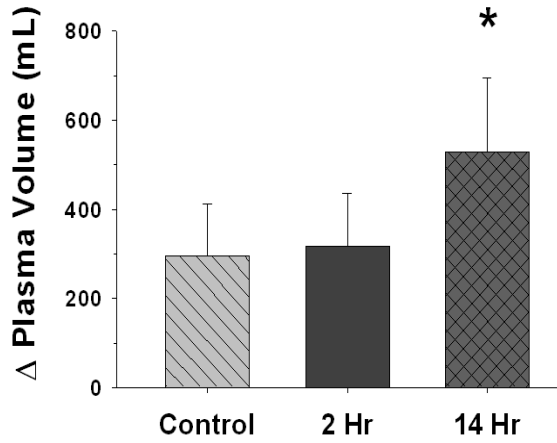
Figure 12. Plasma volume loss from night prior to before and after time trial



Values are means  $\pm$  SD.

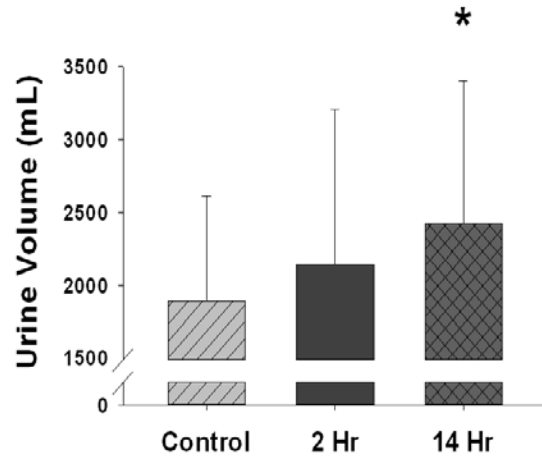
The mean loss in plasma volume overnight during the 14hr trial was 235 ml more (44%) than the plasma volume lost during control. During the 2hr trial, however, only 22ml more (7%) plasma was lost overnight than during control. The difference in plasma volume loss between the 2hr and 14hr time trial (223ml) is very similar to the difference in urine volume for the same two trials (280ml). (See *Fig. 13 and Fig. 14*)

Figure 13. Plasma Volume loss overnight



\*Significantly different than 2hr trial and control (p < 0.05)

Figure 14. Urine volume loss overnight



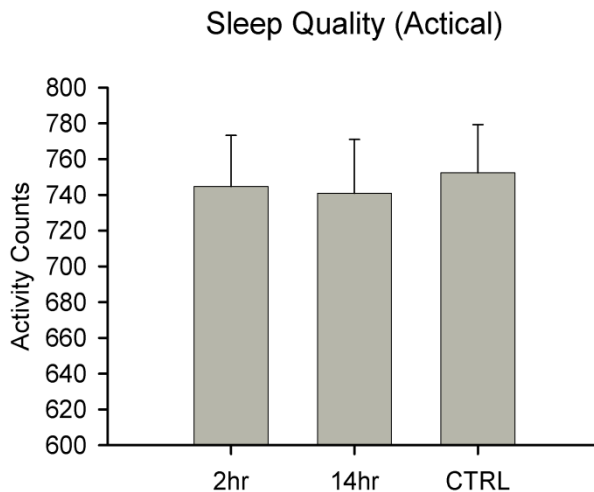
\*Significantly different than 2hr trial and control (p < 0.05)

Values are means ± SD.

### Measure of Sleep Quality

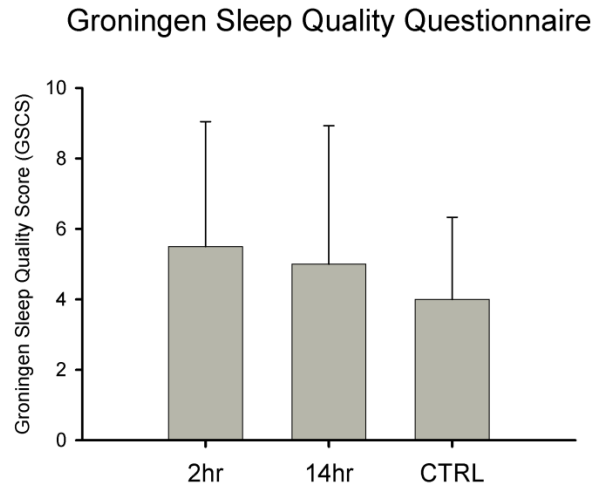
No differences were seen between any of the measures of sleep quality for any trial during this study. Activity counts during sleep were  $744.7 \pm 30.2$  for the 2hr trial,  $740.9 \pm 31.7$  for the 14hr trial, and  $752.3 \pm 28.5$ . Survey data (n=8) also showed no differences in sleep quality between trials. See Fig. 15 & 16.

Figure 15.



Values are means ± SD.

Figure 16.



## Perceived Exertion and Dyspnea

No differences were seen in either of the measures of perceived effort during any of the three trials. Rating of perceived exertion (RPE) was not different with the other trials at any of the time points taken. The same was true for rated dyspnea. (See *Fig. 17 and 18*)

Figure 17. RPE during time trial

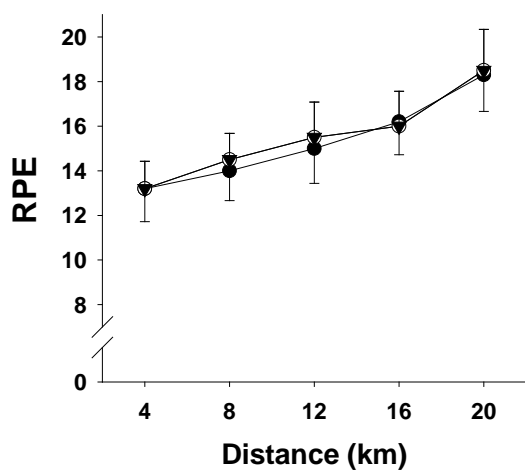
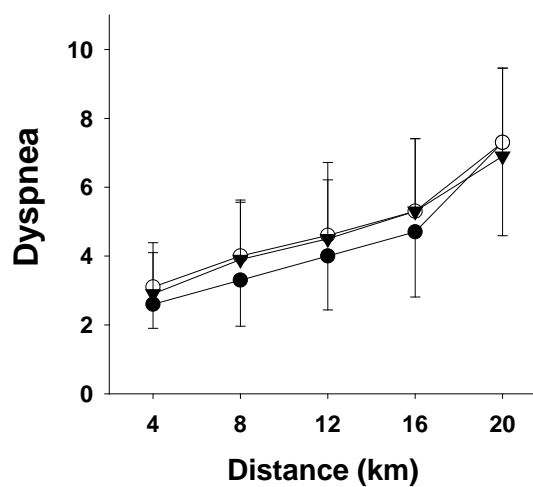


Figure 18. Dyspnea rating during time trial



Values are means  $\pm$  SD.

## Chapter 5

### Discussion

In this investigation, the primary outcome variable was time trial performance, and in this regard, we found no difference between the 14h and 2h conditions. No statistical differences were seen in  $\dot{V}_E/\dot{V}_{O_2}$ ,  $ETCO_2$ ,  $\dot{V}_E$ , or  $\dot{V}_E/\dot{V}_{CO_2}$  between the hypoxic trials, meaning that our study failed to show an increase in ventilatory drive between the two hypoxic trials. Greater plasma volume loss was noted for the longer hypoxic exposure time. While no significant difference was found between the 2hr and control trials, the loss in plasma volume after 14 hours in hypoxia was 223mL more than the 2hr trial. This difference accounted for a 6% decrease in plasma volume between the two trials. As such, the primary outcomes of this study were: a) There were no significant changes in performance times between 14h and 2h of hypoxic exposure, b) plasma volume was significantly decreased after a longer duration at altitude (14h vs 2h), c) ventilation was not different after 14h than after 2h of hypoxic exposure, and d) no identifiable differences were noted for sleep quality between conditions. From a practical performance standpoint, this difference in ride times between hypoxic exposures is of minimal consequence. However, important differences were found between select dependent variables that may help to elucidate the time course of changes seen for this duration of hypoxic exposure. We hypothesized that an increase in ventilatory drive would be beneficial to exercise performance at altitude; however, it appears that any gains may have been offset by the decrease in plasma volume as a result of the 14 hour exposure to hypoxia that produced an increase ventilatory drive during exercise. Since no other studies have looked at the effects of hypoxic exposure on performance at these time points, this finding is novel.

## **Altitude Exposure and Performance**

This study gives an important insight into the time course of the important physiological changes seen with short term exposure to altitude and how those variables may affect performance. Previous work has shown that at least 14 days of hypoxic exposure is ideal for acclimatization for endurance exercise performance at moderate altitude,<sup>2</sup> but many athletes and coaches do not have the resources or flexibility to achieve this duration of acclimatization prior to an altitude competition. Many coaches believe that there is a difference between these brief exposure periods, and this question is the subject of considerable debate.<sup>3</sup> Ventilation, plasma volume, and sleep quality are each known to change significantly with acclimatization to altitude,<sup>4,17,82</sup> but the relationship between the timing and magnitude of these adaptations and performance outcomes have not been clearly elucidated. Many coaches and teams have adopted a “fly in, fly out” strategy,<sup>5,6</sup> in which as little time as possible is spent at altitude both before and after the competition so perceived negative acclimatization responses, such as reduced sleep quality and plasma volume decrements, are mitigated. Conversely, other athletes will typically arrive the night prior to the competition, with little concern about any short term acclimatization effects on performance. While it is clear that 1-2 weeks of altitude residence is preferential to day-prior or same-day arrival for exercise performance at altitude, differences in short term arrival strategies of <24 hours have not been adequately researched.

We hypothesized that 20km cycle performance times in hypoxia (simulated 2500m) would be faster after 14 hours of hypoxic exposure as opposed to two hours of hypoxic exposure. Our findings, though, contradicted this hypothesis as no differences were found in performance between the two trials. Since no differences were seen in pacing strategy, heart

rate, dyspnea, and RPE and the subjects were highly motivated, it can be assumed that the subjects gave equivalent efforts in each of the trial conditions. There are relatively few studies that investigate endurance performance changes at 2500m elevation. One such study, by Wehrlin et al.(2006), demonstrated a 6.3% drop in  $\dot{V}_{O_2\max}$  for every 1000m of elevation change, as well as a 14.3% decrease in time to exhaustion for a supramaximal (107% of  $v\dot{V}_{O_2\max}$ ) exercise protocol for every 1000m of elevation change.<sup>46</sup> However, even fewer studies have looked at submaximal exercise performance at these altitudes. The most pertinent study by Weston et al. (2001),<sup>3</sup> which observed the effects of the time course of altitude exposure on the performance of youth rugby players, suggests that we might see an improved performance in the 14hr trial against the 2hr trial. However, this divergence in our results versus those of Weston et al. could be explained by a variety of factors, including exercise mode, subject characteristics, and exercise duration. The subjects in the Weston study were high school students from a rugby club and performed a push up test and a shuttle run test that only lasted about 5-7 minutes on average, while subjects in the current study were highly trained endurance athletes who performed a 20km cycling time trial. Also, the exposure times for the Weston study were 6 and 18 hours, which may result in different acclimatization responses. In our study, differences were seen between the control trial and both hypoxic trials, suggesting that our simulated altitude was high enough to induce considerable performance decrements.

### **Altitude Exposure and Plasma Volume**

The magnitude of overnight plasma volume decrease was found to be dependent on the duration of altitude exposure. A significant decrease in plasma volume can be assumed to lead to an impairment in cardiac function, as a result of an insufficient preload. After 14

hours of hypoxia, plasma volume dropped 223mL more than after two hours or control. This occurred despite the fact that subjects were allowed to drink water throughout the night. The average overnight plasma volume loss during the 14 hour and two hour trials was 18.5% and 13% respectively. These values are slightly higher than other studies, which report plasma volume loss close to 10% at sea level over the course of 24 hours of bedrest and 4% of this occurring in the first 6 hours. Many of these studies have also shown a fairly large individual variation.<sup>87,108</sup> Armstrong et al. have shown significant performance decrements in distance runners for 5000m and 10000m time trials when plasma volume is decreased by about 10%.<sup>88</sup> Since the reductions in performance from the Armstrong study were substantial (2.62 min for 10000m), it is likely the plasma volume reduction had a practically significant impact on the time to completion for the subjects in this study. If we extrapolate this difference to the 18% plasma volume loss observed for the 14hr exposure in this study, we could estimate a potential difference of 4.85 min difference from control. This method would also suggest a difference of 3.41 minutes between the 2hr and control. Since no changes were seen in performance between the 2hr and 14hr trials, an opposing adaptation is likely occurring at the same time.

### **Altitude Exposure and Ventilatory Changes**

Ventilatory changes during exercise did not appear to be related to the time spent in hypoxia. While no statistical differences were noted, the p-values for  $\dot{V}_E/\dot{V}_{CO_2}$  during the 2hr and 14hr trials were somewhat close to significance over the last two stages of the time trial ( $p = 0.091$  at 16km and  $p = 0.076$  at 20km). Any increase in ventilation that occurred with increased duration of altitude exposure may have facilitated an improved  $O_2$  delivery in relation to the two hour trial. An increase in ventilatory drive can increase the pressure head

for O<sub>2</sub> diffusion in the lung, thus helping to maintain CaO<sub>2</sub>. However, this does not come without consequences, as an increased ventilatory drive also means an increased cost of breathing. At altitude, the partial pressure of O<sub>2</sub> is depressed, resulting in a decreased bulk flow of O<sub>2</sub> into the lungs. Peripheral chemoreceptors in the carotid bodies sense the decreased PO<sub>2</sub> in the arterial blood, and subsequently stimulate the respiratory center in the brain to increase ventilation. This phenomenon, termed the hypoxic ventilatory response (HVR)<sup>109</sup>, would be greater after an increased duration of altitude residence, however our observed changes in ventilatory variables were somewhat unclear. Statistical changes were not seen in the respiratory measures taken, and no definitive increases in ventilatory acclimatization were noted.

### **Altitude Exposure and Sleep Quality**

Sleep quality was not adversely affected by duration of altitude exposure in the current study. There were no differences in activity counts or scores on the Groningen Sleep Quality Questionnaire, and no apparent changes due to altitude duration on this measure. Scores below 2 on the questionnaire are described as “normal” and above 6 as “disturbed”.<sup>105</sup> Since the average scores for all 3 trials were between 4 and 6, it is likely that our subjects experienced somewhat poor quality sleep, regardless of condition. The generally poor sleep may have been due to the ambient lab conditions and the unfamiliarity with the environment for the subjects. Specifically, sleeping in a different bed than their own and the noise of the nitrogen generator and laboratory equipment may have affected sleep responses. It is possible that these conditions masked any possible sleep quality impairments as a result of altitude residence. As a result, it appears that no effect on performance can be attributed to sleep quality changes in this study. Sleep at altitude is often characterized by periodic breathing

which is correlated with more arousals, although sleep is has been shown to be more disrupted at altitude regardless of the amount of periodic breathing.<sup>110</sup> These factors typically lead to sleep disruptions at altitude that reduce the quality of sleep for individuals during altitude residence that do not appear to diminish over the first few nights at altitude.<sup>95,110</sup> However, many individuals experience sleep disruptions in unfamiliar environments regardless of altitude. The current study showed that the disruptions in sleep were not greater at altitude than they were from simply sleeping in a new environment, as there was no difference in sleep quality between the altitude conditions and control (normoxia). No order effect was observed. Our data would suggest that individuals who have to travel to competitions may experience sleep disruptions regardless of the altitude in which they sleep.

## **Implications**

Making broad recommendations for arrival strategies as a result of this study could be complicated by the likelihood for individual variation in response to altitude exposure of this duration. Some of the subjects in this study performed better with 14 hours of exposure and others performed better with only 2 hours, although most of the subjects had almost identical completion times for the two hypoxic trials (7 of the 10 subjects had < 0.3 min difference). Individual variations in physiological adaptations to altitude are likely the cause for the divergence seen between these individuals. Individuals who have a greater increase in ventilatory drive are likely to benefit from a greater time spent at altitude. Individuals who have a small increase in ventilatory drive are likely better off implementing a shorter altitude duration to minimize the effects of plasma volume loss and potential sleep disruption. Conversely, if an athlete experiences a great deal of water loss at altitude, they may wish to forego the increased ventilatory drive associated with longer hypoxic exposure. Practically,

the athlete has the difficult task of balancing these two opposing adaptations and finding the approach that has the greatest benefit to his or her individual physiology.

### **Limitations**

A few notable limitations were observed during this study. Due to logistical difficulties and the blinded nature of this study, the hypoxia was created in normobaria, rather than the hypobaric hypoxia found at actual altitude. The potential differences in responses to the divergent barometric pressures have been well studied in the literature, albeit typically as a pre-acclimatization tool. Hypobaric hypoxia seems to be more effective at bringing about acclimatization than normobaric hypoxia,<sup>111</sup> therefore it is possible that the magnitude of physiologic changes could be greater in hypobaric hypoxia. Another potential limitation is the influence of the laboratory conditions on sleep quality. Many of the subjects noted discomfort and difficulty of sleep within the laboratory that could not be avoided, due to use of the hypoxic gas generator, analyzers, and other laboratory equipment being used in the study. Also, the logistics of having a bed within the tent that could be taken down to allow for movement within the tent meant that a high quality air mattress had to be used instead of traditional bedding.

### **Future Directions**

Future research is needed to adequately quantify the time course of select physiological adaptations to altitude. Additional performance measures at different time points would be beneficial in helping to reveal the interactions of the adaptations to hypoxia over time. Although the current study summarizes the two primary strategies employed by athletes and coaches who have a short window in which to arrive at altitude, additional

research would give a more complete understanding to the mechanisms for acclimatization within this time frame. Also, future studies could work to elucidate differences between individuals, such as magnitude of ventilatory changes, hematological differences, or desaturation. Future studies could also be employed to determine the effects of acclimatization at shorter or longer time trial distances. There may be differences in the short-term acclimatization for more intense exercise, where a higher level of anaerobic energy is utilized. With the increased interest in mountain running and ultra-marathons, studies on acclimatization for longer, lower intensity exercise would also be beneficial to the athletic and scientific communities.

## **Summary**

In summary, the timing of arrival at altitude does not significantly affect endurance performance when the exposure begins less than 14 hours prior to the start of the competition. The longer duration of hypoxic exposure leads to greater plasma volume reductions although this did not seem to affect performance significantly. The findings in this study will be valuable to athletes and coaches who are looking for a best practice recommendation for timing their arrival at altitude. Athletes can choose the strategy that best fits in their schedules and seems the most logistically reasonable without significant effects on performance.

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# Appendices

## Appendix A – Data Set

Subject	Vo2max	Fam_Perf	2hr_Perf	14hr_Perf	Ctrl_Perf	2hr_Diff_Perf(Fam)	14hr_Diff_Perf(Fam)	Ctrl_Diff_Perf(Fam)	2hr_Diff_Perf(Ctrl)	14hr_Diff_Perf(Ctrl)	Fam_Mean_Power	2hr_Mean_Power	14hr_Mean_Power	Ctrl_Mean_Power	2hr_Diff_Perf(Fam)
1	66.70	32.15	35.52	33.98	33.23	3.37	1.83	1.08	2.29	0.75	235.90	209.80	236.00	249.70	26.10
2	64.80	34.24	37.17	37.23	35.80	2.93	2.99	1.56	1.37	1.43	228.00	186.00	185.64	204.80	42.00
3	62.64	33.85	36.16	36.44	35.22	2.32	2.59	1.37	0.95	1.23	236.51	200.04	196.11	212.60	36.47
4	63.40	30.96	34.24	34.14	32.37	3.28	3.18	1.41	1.87	1.78	298.79	228.71	231.56	266.55	70.08
5	75.24	35.53	36.68	35.67	36.48	1.16	0.14	0.95	0.21	-0.81	209.26	193.39	208.10	195.62	15.87
6	63.32	31.75	33.25	33.38	32.42	1.50	1.63	0.68	0.83	0.96	280.78	248.34	245.24	264.44	32.44
7	67.41	36.02	39.55	40.69	36.43	3.53	4.66	0.40	3.12	4.26	213.75	159.44	148.36	195.70	54.31
8	74.04	34.79	36.95	36.81	37.22	2.16	2.02	2.43	-0.27	-0.41	224.23	188.08	190.47	185.07	36.14
9	58.52	38.10	40.52	40.76	38.47	2.42	2.66	0.37	2.05	2.29	174.29	147.57	146.76	169.79	26.71
10	69.55	34.62	38.09	38.35	35.79	3.47	3.73	1.17	2.29	2.56	223.54	174.95	173.84	205.39	48.59
14hr_Diff_Power(Fam)	Ctrl_Diff_Power(Fam)	Fam_Mean_Power	Ctrl_Mean_Power	Fam_Mean_Power	Ctrl_Mean_Power	Fam_Diff_Perf	Ctrl_Diff_Perf	Fam_Diff_Perf	Ctrl_Diff_Perf	Fam_Diff_Perf	2hr_Mean_Power	14hr_Mean_Power	Ctrl_Mean_Power	2hr_Diff_Perf	
-0.10	-13.80	232.64	234.80	235.79	231.94	244.61	198.45	203.54	209.72	210.04	228.71	232.64	234.80	235.79	231.94
42.36	23.20	266.45	234.84	200.83	199.73	244.93	190.05	187.03	176.49	179.49	196.08	201.84	184.61	181.02	168.74
40.39	23.91	262.26	236.01	234.93	223.66	226.85	213.63	194.29	201.05	194.62	197.03	191.88	197.07	197.79	196.29
67.23	32.15	317.48	298.59	286.00	285.15	307.49	246.99	231.75	225.50	216.58	223.48	247.02	225.84	225.84	222.44
1.16	13.64	236.99	200.09	192.13	194.41	225.28	197.74	186.72	185.76	188.59	208.79	218.45	211.00	204.91	198.05
35.53	16.34	264.57	270.86	275.23	289.96	304.90	251.95	244.92	242.40	241.58	261.21	260.42	243.91	236.37	237.32
65.99	18.05	223.33	204.14	205.07	214.08	222.59	190.65	163.21	154.36	143.23	148.58	167.26	150.04	150.17	135.84
33.76	39.15	230.46	225.63	215.68	221.91	227.54	182.67	185.35	177.06	198.84	197.26	189.13	198.01	188.28	185.93
27.52	4.49	172.40	171.49	172.09	174.18	181.46	150.69	146.00	145.07	136.48	160.35	145.51	146.63	138.39	145.67
49.70	18.15	211.87	213.93	227.74	227.85	237.21	165.17	168.02	173.85	175.89	192.83	149.12	163.84	169.20	177.32
14hr_Mean_Power	Ctrl_Mean_Power	Fam_Mean_Power	Ctrl_Mean_Power	Fam_Mean_Power	Ctrl_Mean_Power	Fam_Diff_Perf	Ctrl_Diff_Perf	Fam_Diff_Perf	Ctrl_Diff_Perf	Fam_Diff_Perf	2hr_Mean_Power	14hr_Mean_Power	Ctrl_Mean_Power	2hr_Diff_Perf	
252.75	256.98	235.51	232.22	272.76	272.76	6.891	6.781	6.767	6.825	6.710	7.321	7.148	7.082	7.113	6.858
192.99	207.22	194.42	197.74	202.40	223.05	6.546	6.763	7.220	7.209	6.660	7.450	7.402	7.549	7.499	7.260
197.65	212.90	203.62	205.70	214.61	226.72	6.563	6.761	6.771	6.886	6.870	7.094	7.280	7.177	7.317	7.297
237.15	265.50	263.86	260.99	257.21	286.43	6.103	6.177	6.282	6.281	6.119	6.689	6.795	6.870	6.987	6.897
208.36	203.32	191.92	188.96	182.29	212.67	6.814	7.203	7.318	7.282	6.908	7.437	7.385	7.414	7.358	7.092
248.63	268.46	260.02	259.06	254.85	280.30	6.568	6.423	6.371	6.245	6.139	6.668	6.671	6.696	6.701	6.510
139.95	219.75	192.81	198.16	183.26	185.86	6.992	7.177	7.124	7.017	6.938	7.450	7.790	7.968	8.205	8.137
191.18	171.41	181.22	185.28	183.21	205.49	6.960	6.932	7.019	6.980	6.899	7.539	7.409	7.544	7.215	7.243
158.20	162.57	164.19	165.76	168.67	188.78	7.785	7.635	7.629	7.595	7.455	8.137	8.152	8.160	8.356	7.871
207.58	192.79	196.91	211.78	204.64	221.82	7.368	7.248	7.057	7.142	6.979	7.846	7.708	7.609	7.584	7.340

14hr_Me	14hr_Me	14hr_Me	14hr_Me	14hr_Me	14hr_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	Fam_Me	Fam_Me	Fam_Me	Fam_Me	Fam_Me	Fam_Me	2hr_Me
an_4k_Pe	an_8k_Pe	an_12k_P	an_16k_P	an_20k_P	an_4k_V	an_8k_V	an_12k_V	an_16k_V	an_20k_V	an_4k_V	an_8k_V	an_12k_V	an_16k_V	an_20k_V	an_4k_V	an_8k_V	an_12k_V	an_16k_V	an_20k_V	n_4k_VO
rf	rf	erf	erf	erf	rf	rf	erf	erf	erf	erf	erf	erf	erf	O2	O2	O2	O2	O2	O2	2
6.891	6.782	6.767	6.825	6.709	6.667	6.548	6.762	6.818	6.432	51.94	51.84	51.57	53.69	55.47	37.10					
7.267	7.434	7.502	7.681	7.345	7.193	7.276	7.232	7.176	6.918	50.88	53.84	49.28	47.00	51.72	43.84					
7.399	7.236	7.233	7.284	7.291	7.095	7.148	7.116	6.997	6.862	50.56	53.20	52.05	50.15	48.97	36.83					
6.720	6.864	6.874	6.915	6.771	6.541	6.469	6.502	6.564	6.292	51.57	56.16	54.04	53.44	55.35	45.29					
7.092	7.069	7.143	7.260	7.106	7.234	7.325	7.381	7.486	7.054	54.86	51.67	49.20	49.50	54.65	45.76					
6.580	6.665	6.749	6.749	6.635	6.508	6.501	6.518	6.561	6.333	52.61	58.60	60.56	65.68	69.97	49.85					
7.796	8.061	8.066	8.419	8.344	7.014	7.315	7.246	7.441	7.411	41.63	45.11	44.68	47.25	49.46	37.27					
7.436	7.234	7.378	7.409	7.358	7.735	7.478	7.414	7.444	7.149	43.92	50.28	50.08	52.54	53.82	39.36					
8.248	8.126	8.330	8.153	7.898	7.892	7.771	7.743	7.694	7.370	37.65	43.00	44.34	45.41	46.66	36.22					
8.152	7.805	7.688	7.562	7.144	7.368	7.248	7.057	7.142	6.979	50.63	55.73	58.28	59.63	62.61	42.73					
2hr_Mea	2hr_Mea	2hr_Mea	2hr_Mea	14hr_Me	14hr_Me	14hr_Me	14hr_Me	14hr_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	CTRL_Me	2hr_Me					
n_8k_VO	n_12k_V	n_16k_V	n_20k_V	an_4k_V	an_8k_V	an_12k_V	an_16k_V	an_20k_V	an_4k_V	an_8k_V	an_12k_V	an_16k_V	an_20k_V	an_Ride_	n_Ride_					
2	O2	O2	O2	O2	O2	O2	O2	O2	O2	O2	O2	O2	O2	ao2	ao2					
39.91	40.67	40.96	44.75	44.91	48.74	48.81	48.64	49.54	44.36	50.28	47.21	44.87	49.30	90.00						
47.52	45.68	46.08	49.24	42.71	43.75	43.68	42.56	44.40	43.21	46.32	47.41	46.98	49.25	96.70						
38.11	39.16	39.68	39.87	37.42	39.79	40.74	41.42	43.05	43.56	43.66	44.93	47.64	50.17	85.19						
48.94	47.04	45.13	44.70	41.95	43.07	42.99	43.39	44.93	51.92	51.11	51.28	47.18	45.33	97.09						
47.98	47.07	47.01	51.17	42.04	44.30	43.62	42.24	44.30	41.40	42.73	43.86	41.64	47.11	97.67						
52.81	52.37	53.62	55.94	57.24	58.88	57.31	57.75	62.60	52.12	55.66	55.54	55.76	61.06	96.26						
38.40	36.16	34.61	35.47	33.47	32.48	34.33	31.82	32.96	34.59	36.10	37.01	35.80	35.65	97.01						
43.65	42.81	46.32	47.06	35.85	43.15	44.76	44.77	43.14	32.87	38.53	39.87	40.50	44.46	96.56						
38.92	39.66	39.09	43.15	33.02	35.90	37.47	41.07	46.02	34.94	37.82	38.97	41.12	46.02	94.29						
47.15	49.86	51.04	54.76	47.86	53.54	56.43	58.64	68.74	50.09	55.88	58.75	59.02	61.76	95.72						
14hr_Me	Ctrl_Mea	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour	2hr_Hour					
an_Ride_	n_Ride_5	1_Sleep_	2_Sleep_	3_Sleep_	4_Sleep_	5_Sleep_	6_Sleep_	7_Sleep_	8_Sleep_	9_Sleep_	10_Sleep	11_Sleep	12_Sleep	13_Sleep	14_Sleep					
ao2	ao2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2	SaO2					
92.27	97.73	98.56	98.78	98.74	97.64	98.12	97.80	97.84	97.57	97.68	98.03	97.41	97.67	96.03	94.94					
90.90	98.06	98.39	97.31	98.34	98.52	98.64	98.78	98.79	98.89	98.83	98.88	98.88	98.88	97.26	96.23					
81.96	95.54	97.99	97.89	98.75	98.65	98.29	97.15	97.87	97.74	98.29	97.53	97.71	98.75	98.75	96.44					
84.75	92.75	98.13	96.33	95.78	98.77	98.71	98.70	98.07	98.47	98.71	98.32	98.62	97.13	96.81	95.84					
94.15	97.60	97.58	98.80	96.70	98.11	98.81	98.71	98.35	98.37	98.62	98.91	98.39	98.50	98.46	96.32					
85.82	98.01	93.43	93.67	94.33	94.12	93.72	93.50	93.33	93.67	93.61	93.12	93.28	93.15	90.12	84.44					
92.95	95.21	98.16	97.39	96.92	98.41	97.86	96.69	98.45	98.67	98.48	98.37	98.15	98.54	96.43	94.53					
95.96	97.69	97.84	97.56	97.38	96.61	96.01	96.38	96.19	97.23	97.05	97.24	97.20	97.62	96.34	94.84					
89.05	94.07	97.20	97.38	98.34	98.68	98.45	98.17	98.94	97.55	97.99	98.80	97.37	97.35	94.64	93.68					
88.04	93.71	98.87	98.75	98.09	98.22	98.98	98.81	98.47	96.94	96.16	96.55	96.40	96.65	96.98	95.23					





2hr_VeV/	14hr_VeV/	CTRL_VeV/	2hr_VeV/	14hr_VeV/	CTRL_VeV/	2hr_Mea	14hr_Me	CTRL_Me	2hr_Last	hour_Me	2hr_Mea	14hr_Me	CTRL_Me	2hr_Mea	14hr_Me	CTRL_Me	2hr_Mea	14hr_Me	CTRL_Me
O2	VO2	VO2	O2diff	VO2diff	VO2diff	n_FIO2	an_FIO2	an_FIO2	an_FIO2	an_FIO2	n_Temp	an_Temp	an_Temp	an_Temp	an_Temp	an_Temp	n_Ridefi	an_Ridefi	an_Ridefi
2hr_VeV/	14hr_VeV/	CTRL_VeV/	2hr_VeV/	14hr_VeV/	CTRL_VeV/	2hr_VoI	14hr_VoI	CTRL_VoI	2hr_VoI	14hr_VoI	CTRL_VoI	2hr_VoI	14hr_VoI	CTRL_VoI	2hr_VoI	14hr_VoI	CTRL_VoI	2hr_VoI	14hr_VoI
ss_Pre	s_Post	ss_Post	ss_Post	e	e	ded	ded	RPE	PE	RPE	RPE	RPE	RPE	RPE	RPE	RPE	RPE	RPE	RPE
27.01	28.66	25.53	1.48	2.15	-0.98	15.84	16.23	20.39	15.87	20.47	20.47	20.48	20.60	16.22	20.48	20.60	16.22	20.48	20.60
31.39	33.09	33.89	-0.81	0.89	1.69	16.52	16.21	20.32	16.39	20.44	20.44	21.12	20.30	16.16	20.30	16.16	16.21	20.30	16.16
31.73	29.31	27.28	3.67	1.25	-0.78	16.47	16.16	20.41	16.44	20.56	20.56	20.52	20.61	16.15	20.52	20.61	16.15	20.52	20.61
33.44	27.10	22.78	9.05	2.71	-1.62	16.26	15.85	20.12	16.26	20.28	20.28	19.74	20.36	16.22	19.74	20.36	16.22	19.74	20.36
29.47	37.67	28.71	5.41	13.61	4.65	16.11	15.82	20.01	16.11	19.79	19.79	19.86	19.86	16.21	19.86	19.86	16.21	19.86	19.86
32.01	31.41	28.21	3.94	3.33	0.13	16.02	15.98	20.32	16.02	19.83	19.83	19.77	20.17	16.24	19.77	20.17	16.24	19.77	20.17
41.92	40.29	44.29	-2.92	-4.56	-0.55	16.18	15.95	20.02	16.21	20.19	20.19	19.84	20.18	16.20	19.84	20.18	16.20	19.84	20.18
31.42	32.53	28.75	-1.81	-0.70	-4.48	16.29	15.90	19.99	16.29	19.83	19.83	19.97	19.84	16.19	19.97	19.84	16.19	19.97	19.84
41.35	38.05	35.11	7.96	4.66	1.72	16.18	16.17	20.19	16.19	20.62	20.62	20.57	20.35	16.16	20.57	20.35	16.16	20.57	20.35
38.08	30.95	32.72	-0.96	-8.09	-6.32	16.14	15.99	20.18	16.14	19.90	19.90	19.79	19.82	16.19	19.79	19.82	16.19	19.82	19.82
2hr_USG	14hr_US	CTRL_US	2hr_PV	14hr_PV	CTRL_PV	2hr_PV	14hr_PV	CTRL_PV	2hr_PV	14hr_PV	CTRL_PV	2hr_PV	14hr_PV	CTRL_PV	2hr_PV	14hr_PV	CTRL_PV	2hr_PV	14hr_PV
G	G	G	re_ride	re_ride	re_ride	ost_ride	ost_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride	pre_ride
1.0014	1.0031	1.0023	3648	4166	3758	3401	3306	3610	3305	3483	3128	75.45	75.88	75.33	73.65	74.07	73.65	74.07	73.65
1.0057	1.0040	1.0078	3432	3872	4182	3262	2989	3242	3032	3858	3486	68.83	73.14	71.85	68.35	69.17	68.35	69.17	68.35
1.0009	1.0014	1.0009	3346	3659	4338	3209	3117	3365	3168	2851	2689	75.43	75.60	74.94	73.44	73.14	73.44	73.14	73.14
1.0057	1.0018	1.0049	4338	4938	4452	4034	3508	4060	3950	3937	3835	88.25	88.95	86.57	84.80	85.20	86.57	84.80	85.20
1.0096	1.0081	1.0092	3185	3398	3312	2855	2814	2859	2676	3148	2931	65.32	66.77	65.35	64.48	64.80	65.35	64.48	64.80
1.0083	1.0074	1.0005	3922	3849	4107	3613	3575	3187	2977	3669	3113	71.50	71.09	69.28	70.88	70.10	69.28	70.88	70.10
1.0095	1.0095	1.0053	3423	3257	2938	3029	2971	2896	2876	2766	2719	69.66	69.03	70.11	67.36	68.90	69.03	70.11	67.36
1.0098	1.0092	1.0036	3634	3128	3500	3426	3387	2675	2644	3235	3073	71.51	72.10	71.32	71.55	71.80	71.32	71.55	71.80
1.0057	1.0057	1.0044	4149	3611	3959	3640	3231	3092	2982	3733	3273	66.80	67.07	68.05	65.20	64.51	68.05	65.20	64.51
1.0036	1.0005	1.0092	3232	3348	3131	2789	2681	2912	2717	2936	2660	56.30	56.58	57.75	54.60	55.73	57.75	54.60	55.73
CTRL_Ma	2hr_Mas	14hr_Ma	CTRL_Ma	2hr_Urin	14hr_VoI	CTRL_VoI	FAM_4k	2hr_4k_R	14hr_4k_R	CTRL_4k_R	FAM_8k	2hr_8k_R	14hr_8k_R	CTRL_8k_R	FAM_12k	CTRL_12k	FAM_12k	CTRL_12k	FAM_12k
ss_Pre	s_Post	ss_Post	ss_Post	e	ded	ded	RPE	PE	RPE	RPE	RPE	PE	RPE	RPE	RPE	RPE	RPE	RPE	RPE
73.36	72.73	73.22	72.25	1630	1660	1800	11	13	13	13	13	14	14	14	14	14	14	14	14
69.60	67.70	68.25	68.99	1375	3790	1500	15	14	14	14	16	15	15	15	14	17	15	14	17
73.09	72.84	72.34	72.22	1675	1875	1275	15	13	13	12	16	15	15	15	14	17	15	14	17
84.92	83.83	83.28	84.25	4200	3925	2700	12	12	13	13	15	15	15	15	15	16	15	15	16
63.84	63.82	64.24	63.32	1575	2325	1975	14	13	14	13	14	14	14	14	14	14	14	14	14
68.94	70.07	69.21	67.92	1500	1475	1050	12	12	12	12	13	13	13	13	13	14	13	13	14
68.16	67.07	68.55	68.08	3550	2675	2725	15	16	17	17	17	17	17	18	17	18	17	17	18
71.18	70.80	71.19	70.38	1050	1450	825	13	12	11	12	14	14	13	12	12	12	12	12	15
65.48	63.98	63.93	64.70	3050	3440	2820	12	13	16	13	13	13	13	13	13	13	13	13	15
55.52	54.08	55.20	54.92	1825	1600	2225	13	14	13	13	14	14	15	13	14	14	13	14	14

2hr_12k_RPE	14hr_12k_RPE	CTRL_12k_RPE	FAM_16k_RPE	2hr_16k_RPE	14hr_16k_RPE	CTRL_16k_RPE	FAM_20k_RPE	2hr_20k_RPE	14hr_20k_RPE	CTRL_20k_RPE	FAM_4k_Dyspnea	2hr_4k_Dyspnea	14hr_4k_Dyspnea	CTRL_4k_Dyspnea	FAM_8k_Dyspnea
15	15	15	16	16	17	15	19	20	19	20	2	3	3	2	4
17	17	16	17	17	17	17	19	19	19	17	3	6	4	3	4
17	17	14	18	18	18	17	19	20	19	19	4	4	4	3	6
16	16	17	17	17	18	18	20	19	19	19	3	4	5	4	5
14	14	14	15	14	14	15	15	16	15	16	3	2	3	2	3
14	14	14	15	14	14	15	20	20	20	20	2	2	2	3	2
18	18	18	18	18	19	19	20	19	20	19	3	2	2	3	2
13	14	13	16	14	14	15	17	15	15	16	2	2	2	2	4
15	16	14	16	16	16	19	19	20	20	20	3	3	2	2	3
16	14	15	16	16	15	16	18	17	18	17	3	3	3	3	3
2hr_8k_Dyspnea	14hr_8k_Dyspnea	CTRL_8k_Dyspnea	FAM_12k_Dyspnea	2hr_12k_Dyspnea	14hr_12k_Dyspnea	CTRL_12k_Dyspnea	FAM_16k_Dyspnea	2hr_16k_Dyspnea	14hr_16k_Dyspnea	CTRL_16k_Dyspnea	FAM_20k_Dyspnea	2hr_20k_Dyspnea	14hr_20k_Dyspnea	CTRL_20k_Dyspnea	FAM_4k_HR
4	4	4	4	4	5	4	5	7	6	5	9	10	7	10	
6	5	4	4	5	7	5	6	8	8	6	8	9	9	7	
6	6	4	7	8	7	5	8	8	8	7	9	9	10	10	
6	7	6	7	7	7	7	8	7	8	8	10	9	9	10	
2	4	2	3	2	4	2	3	3	4	3	4	5	5	4	
2	2	2	3	2	3	3	4	2	4	3	9	9	9	167	
3	2	2	3	4	2	2	5	5	2	2	7	5	2	165	
3	3	2	5	3	4	3	7	4	4	4	7	4	5	162	
4	2	3	4	4	3	4	5	4	4	4	7	6	5	161	
4	4	4	4	4	4	5	5	5	5	5	6	7	8	160	
2hr_4k_HR	14hr_4k_HR	CTRL_4k_HR	FAM_8k_HR	2hr_8k_HR	14hr_8k_HR	CTRL_8k_HR	FAM_12k_HR	2hr_12k_HR	14hr_12k_HR	CTRL_12k_HR	FAM_16k_HR	2hr_16k_HR	14hr_16k_HR	CTRL_16k_HR	FAM_20k_HR
157	161	166	161	161	161	167	168	175	165	161	170	173	163	167	185
160	162	168	183	156	169	171	176	165	165	174	179	169	170	176	184
179	172	173	186	181	178	174	186	184	180	176	185	181	184	182	192
179	171	169	185	181	174	177	185	181	177	180	184	182	180	179	196
157	160	141	156	152	157	143	151	150	156	142	148	150	156	139	173
167	170	167	163	166	172	169	176	169	170	171	183	170	175	174	192
157	141	155	167	154	144	152	174	154	137	161	179	152	129	156	189
154	164	147	168	157	164	146	169	152	169	150	170	157	166	152	175
155	142	139	165	158	147	144	171	159	159	148	177	160	171	153	186
166	167	172	167	173	170	172	170	179	172	180	176	179	176	181	190



CTRL_VE/ VO2_12k	CTRL_VE/ VO2_16k	CTRL_VE/ VO2_20k	Age	Starting Weight	Baseline HCT	Baseline Hb	2hr PV	14hr PV	CTRL PV	2hr Ride Temp	14hr Ride Temp	CTRL Ride Temp	2hr_VE/V CO2	14hr_VE/ VO2	CTRL_VE/ VO2	2hr_SaO2 VO2_12k	14hr_SaO2 VO2_16k	CTRL VO2_20k	
24.98	25.01	32.54	26.00	74.50	45.0	1018	3648	3610	3757	21.8	21.0	22.0	28.68	28.66	21.61	26.53			
34.79	34.77	43.70	21.00	69.05	43.3	1018	3431	4080	4181	21.2	22.0	21.2	35.03	38.76	32.12	33.78			
25.56	25.92	31.47	19.00	74.56	46.8	922	3345	3772	3226	22.0	21.9	21.0	31.42	32.60	29.49	30.43			
23.09	22.40	24.87	20.00	86.17	42.0	1036	4338	4881	4452	20.4	19.0	21.2	36.47	36.76	32.07	34.92			
28.37	26.76	29.62	23.00	68.62	44.8	888	3185	3398	3312	19.0	19.4	19.0	33.83	37.33	31.30	35.84			
28.92	27.54	33.02	21.00	68.90	41.4	1071	3922	3849	4107	19.0	19.1	20.3	32.65	35.17	28.56	31.94			
45.23	39.96	42.12	25.00	68.68	47.7	831	3420	3257	2938	20.2	18.8	21.0	45.34	45.27	41.59	47.83			
28.86	28.01	30.21	20.00	71.97	47.6	1108	3634	3128	3500	19.0	19.0	18.9	36.41	36.84	31.47	34.13			
35.29	34.49	38.96	34.00	65.88	38.3	995	4451	3611	4384	22.0	22.0	21.6	46.64	45.78	39.95	46.11			
32.91	34.05	36.51	25.00	55.50	42.6	787	3233	3349	3072	19.0	18.0	19.0	42.21	41.71	34.39	39.66			
2hr_VE/V CO2_8k	2hr_VE/V CO2_12k	2hr_VE/V CO2_16k	2hr_VE/V CO2_20k	14hr_VE/ VCO2_4k	14hr_VE/ VCO2_8k	14hr_VE/ VCO2_12k	14hr_VE/ VCO2_16k	14hr_VE/ VCO2_20k	CTRL_VE/ VCO2_4k	CTRL_VE/ VCO2_8k	CTRL_VE/ VCO2_12k	CTRL_VE/ VCO2_16k	CTRL_VE/ VCO2_20k	2hr_SaO2 VO2_12k	14hr_SaO2 VO2_16k	CTRL VO2_20k	CTRL VO2_12k	CTRL VO2_16k	CTRL VO2_20k
28.43	28.43	30.36	30.99	26.72	27.20	29.71	29.58	30.35	20.37	21.73	22.12	21.85	23.59	88.38	88.45	90.14			
36.34	34.85	34.52	36.24	36.10	39.43	39.31	39.45	44.33	30.40	31.90	33.17	32.55	37.21	88.82143	87.76667	90.45833			
31.41	31.03	31.55	32.21	31.19	31.65	33.21	34.88	33.85	27.84	28.66	28.18	29.15	33.18	83.2625	85.2875	85.0875			
36.85	37.68	36.88	37.56	36.35	36.70	36.60	37.84	38.89	30.38	30.92	32.73	33.01	34.59	87.95	87.3875	88.555			
33.04	32.55	32.55	37.05	39.72	38.57	38.76	36.69	38.95	32.25	32.42	32.16	31.05	31.59	91.825	90.32	90.3575			
32.46	33.32	33.87	36.14	33.60	34.63	35.26	35.87	45.39	28.26	28.41	29.07	28.26	31.80	88.07	87.9775	87.65			
46.11	45.89	44.85	45.73	42.51	46.13	45.81	46.85	47.99	37.57	40.32	43.91	41.71	41.83	95.6775	96.4675	95.975			
36.54	36.64	39.13	40.22	33.89	37.24	37.83	38.75	39.18	30.36	30.78	32.17	31.90	33.02	93.5675	94.5075	91.8875			
46.66	47.61	47.38	47.56	43.03	43.56	46.39	47.51	50.96	38.19	40.09	39.89	40.73	42.87	88.5425	88.49	88.765			
40.36	44.85	46.09	44.24	39.92	38.68	44.80	45.99	46.50	33.74	32.71	35.04	36.48	37.54	88.515	91.1425	90.1925			
2hr_SaO2 16k	2hr_SaO2 20k	14hr SaO2_4k	14hr SaO2_8k	14hr SaO2_12k	14hr SaO2_16k	14hr SaO2_20k	CTRL SaO2_4k	CTRL SaO2_8k	CTRL SaO2_12k	CTRL SaO2_16k	CTRL SaO2_20k	CTRL SaO2_4k	CTRL SaO2_8k	CTRL SaO2_12k	CTRL SaO2_16k	CTRL SaO2_20k			
89.59	88.04	94.15385	93.69231	92.07692	91.30769	89.47368	98.5	97.41935	97.46154	97.14474	97.45161								
89.66667	87.09524	90.74473	90.03667	89.15333	92.71667	91.85	98.3975	98.21	98.3275	97.6275	97.5075								
85.465	86.2925	82.2275	80.6975	81.445	81.8425	83.1375	95.845	96.33	95.0725	95.0375	95.2225								
88.4475	89.8025	84.0075	84.2725	84.605	85.1025	86.01	91.8025	96.76	96.435	92.8125	84.99								
89.2925	89.6775	94.7625	93.405	94.07	94.4275	94.54	97.3275	97.295	97.445	97.425	83.4425								
88.6825	88.4975	88.965	87.01	87.9775	88.3025	92.1525	96.52	98.355	99.5625	99.3475	99.7075								
96.0625	96.9075	94.97	93.585	92.7825	91.6975	90.0325	94.1425	94.8775	98.405	98.205	98.11								
92	92.01	90.86	90.4675	91.945	91.5225	92.9675	97.6525	98.26	97.42	97.605	97.835								
88.8975	89.535	88.395	88.5975	89.66	89.035	88.595	94.2625	94.4025	94.275	93.52	93.75								
88.7825	87.765	88.41	87.965	90.0775	89.6125	90.15	96.32	95.135	97.7075	95.02	97.675								

## Appendix B

### The Groningen Sleep Quality Score (GSQS, 17)

**Source:** Meijman TF, de Vries-Griever AH, de Vries G. *The evaluation of the Groningen Sleep Quality Scale*. Groningen: Heymans Bulletin (HB 88-13-EX), 1988

Instructions: Please circle “True” or “False” to the following statements

- |  |      |       |
|--|------|-------|
| 1. I had a deep sleep last night                                   | True | False |
| 2. I feel that I slept poorly last night                           | True | False |
| 3. It took me more than half an hour to fall asleep last night     | True | False |
| 4. I woke up several times last night                              | True | False |
| 5. I felt tired after waking up this morning                       | True | False |
| 6. I feel that I didn't get enough sleep last night                | True | False |
| 7. I got up in the middle of the night                             | True | False |
| 8. I felt rested after waking up this morning                      | True | False |
| 9. I feel that I only had a couple of hours' sleep last night      | True | False |
| 10. I feel that I slept well last night                            | True | False |
| 11. I didn't sleep a wink last night                               | True | False |
| 12. I didn't have trouble falling asleep last night                | True | False |
| 13. After I woke up last night, I had trouble falling asleep again | True | False |
| 14. I tossed and turned all night last night                       | True | False |
| 15. I didn't get more than 5 hours' sleep last night               | True | False |

(Scoring)

All items are scored true / false

The first question does not count for the total score

One point if answer is 'true': questions 2, 3, 4, 5, 6, 7, 9, 11, 13, 14, 15

One point if answer is 'false': questions 8, 10, 12

Maximum score 14 points, indicating poor sleep the night before

General Study Questionnaire

<b>Name</b>	<b>Date</b>
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<b>Do you consider yourself to be a highly endurance trained individual?</b>	(Circle one)	<b>YES</b>	<b>NO</b>
<b>Were you born at an altitude above 1000m (3300ft)?</b>	(Circle one)	<b>YES</b>	<b>NO</b>
<b>Have you ever lived at an altitude of 1500m (5000ft) or higher for more than 3 months in your lifetime?</b>	(Circle one)	<b>YES</b>	<b>NO</b>
<b>Have you visited an altitude of 1500m (5000ft) or higher anytime in the last 90 days?</b>	(Circle one)	<b>YES</b>	<b>NO</b>

<b>Participant Signature</b>	<b>Date</b>
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Modified Physical Activity Readiness Questionnaire (PAR-Q)

<b>Name</b>			<b>Date</b>
<b>DOB</b>	<b>Age</b>	<b>Home Phone</b>	<b>Work Phone</b>

Regular exercise is associated with many health benefits, yet any change of activity may increase the risk of injury. Please read each question carefully and answer every question honestly:

<b>Yes</b>	<b>No</b>	<b>1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?</b>
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Yes	No	2. Do you feel pain in your chest when you do physical activity?
Yes	No	3. In the past month, have you had chest pain when you were not doing physical activity?
Yes	No	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
Yes	No	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
Yes	No	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
Yes	No	7. Do you know of any other reason you should not do physical activity?
Yes	No	8. Has your doctor ever told you that you have diabetes?
Yes	No	9. Has your doctor ever told you that you have high blood pressure?
Yes	No	10. Has your doctor ever told you that you have high cholesterol?
Yes	No	11. Has your doctor ever told you that you have high blood sugar?
Yes	No	12. Do you smoke?
Yes	No	13. Are you currently inactive?
Yes	No	14. Do you have a father, brother or son with heart disease before the age of 55 years old or a mother, sister or daughter with heart disease before the age of 65 years old?
15. Measure height and weight to determine BMI:		16. Measure resting BP and pulse
Height: _____		BP: _____ Pulse: _____
Weight: _____		

Participant Signature	Date
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**Note to ParQ Reader:**

The following guidelines will be used for exclusion criteria for this study:

A “yes” to any Question except #13 will eliminate the individual from participation.

#15: If over 25 kg/m<sup>2</sup>, the individual will be excluded from participation.

#16: If resting systolic BP > 140mmHg or resting diastolic BP > 90mmHg, the individual will be excluded from participation.

## **Appendix C**

### **INDIANA UNIVERSITY INFORMED CONSENT STATEMENT FOR**

#### **Time to arrive at altitude and short-term pre-acclimatization strategies for competitions at moderate altitude**

You are invited to participate in a research study that will help determine the effects of different exposure times to simulated altitude and the effects on cycle exercise performance, sleep quality, and blood measures. You were selected as a possible subject because you identified that you were a highly endurance trained individual. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

Disclaimer: It is possible that you will not qualify for the study following the completion of the breathing function test or completion of the maximal exercise test.

The study is being conducted by Robert F. Chapman, Ph.D. (Principal Investigator) and Josh Foss in the Department of Kinesiology at Indiana University-Bloomington.

#### **STUDY PURPOSE**

The purpose of the proposed study is to investigate the influence of either 2 hours or 14 hours of exposure to a simulated altitude on exercise performance, sleep quality, and blood measures. We will be examining how your responses to these two simulated altitude conditions compare to each other, as well as compared to normal exposure to room air.

#### **NUMBER OF PEOPLE TAKING PART IN THE STUDY:**

If you agree to participate, you will be one of 20 subjects who will be participating in this research.

#### **PROCEDURES FOR THE STUDY:**

If you agree to be in the study, the following items are included:

An invitation will be extended to visit the Human Performance laboratory a total of 5 times. Each visit will be done at a previously agreed-upon time. The first two visits last about 75 minutes and the

remaining three visits last about 15 hours, which includes an overnight sleep in the lab. You should refrain from exhaustive exercise (exercise that causes significant fatigue) for 24 hours prior to each visit.

#### Visit #1

This visit includes the following tests: a) measures of your height, weight, resting pulse, and resting blood pressure, b) a breathing function test, and c) a maximal exercise test on a cycle ergometer (a stationary bicycle). This visit will last approximately 75 minutes.

#### Visit #2

This visit includes a 20 km (12.4 mile) time trial on a stationary bicycle. This visit will last approximately 75 minutes.

#### Visits #3 through #5

These visits to the lab involve: a) two tests to measure the amount of hemoglobin in your body, b) 12 hours resting in an 8 ft x 8 ft x 6 ft plastic enclosure (which includes a bed for sleeping), c) completing a questionnaire, d) 2 hours of resting either in the plastic enclosure or wearing a face mask connected to breathing tubes, and e) a 20 km time trial on a stationary bicycle. During these visits, the air you breathe will either be room air (with a normal oxygen content) or air with a reduced oxygen content, similar to what you would experience in the mountains at an altitude of 8,000 ft. These visits will last approximately 15 hours, which includes time you can sleep.

Each of these tests are described below.

**Height, weight, and blood pressure measures.** Height will be measured by asking you to stand against a wall and a device will be lowered until it touches the top of your head. Weight will be measured by having you sit on a chair, which is placed on a scale. Blood pressure will be measured by placing a cuff around your upper arm. The cuff will be inflated, squeezing your upper arm, then quickly deflated. A tester will listen to blood moving through your arm using a stethoscope. Your pulse will be measured by a tester who will place his / her fingers on your arm near your wrist, pressing slightly for about 15 seconds.

**Breathing Function Tests.** Tests of breathing function are performed as described by the American Thoracic Society. These tests include the measurement of total lung capacity (the volume of air your lungs can hold), vital capacity (the volume of air you can push out with one maximal breath), FEV<sub>1</sub> (the volume of air you can forcefully breathe out in one second), and maximal voluntary ventilation

(the maximal volume of air you can breathe in 12 seconds). For all of these procedures, you wear nose clips and breathe through either a disposable or a rubber mouthpiece. Rubber mouthpieces and nose clips are cleansed in a detergent and antibacterial solution following each use. The breathing function tests are performed seated in the same body position as you will be completing the exercise test. These procedures will require approximately 15 minutes total.

### **Cycle Exercise Tests.**

**Maximal Exercise Test (visit #1 only).** This exercise test will be completed on a stationary bicycle. Resting measurements will be collected for 5 minutes and followed by a 5 minute warm-up at a pace you select. The test begins with cycling at between 70 - 100 rpm with a light resistance load. Every 2 minutes, a small amount of additional resistance will be added until you can no longer maintain the required power output. The goal is for you to exercise for as long as you can.

**20 km Time Trial (visits #2 through 5).** This exercise test will be completed on a stationary bicycle. For this test, you will be instructed on how to manually change the resistance setting on the bicycle. Resting measurements will be collected for 5 minutes and followed by a 10 minute warm-up at a light intensity. When the test begins, your goal is to complete a distance of 20 km (12.4 miles) in as short of a time as possible. For most trained men, this distance takes between 30 and 50 minutes to cycle. You can manually adjust the resistance and pedal at whatever pace you choose. You will be able to view a screen that shows the distance completed, the time elapsed, your pedal revolutions per minute, and your power output. For two of these tests, the air that you breathe will have a reduced oxygen content, similar to what you would experience in the mountains at an altitude of 8,000 ft. In one of the tests, you will breathe room air with a normal oxygen content. At regular intervals, we will ask you to rate how hard your legs are working and how much effort it takes to breathe. We will have a chart for you to point to, to indicate your selection.

Each of the cycle exercise tests includes wearing a wireless heart rate monitor strap and breathing through a face mask which covers your nose and mouth. Air will flow into and out of your lungs as you breathe through the face mask. The face mask and heart rate monitor are cleansed in a detergent and antibacterial solution following each use. During each cycle exercise test, a fiber optic cable will be placed on your index finger or your ear lobe. This device uses light waves to measure the oxygen levels in your blood.

**Overnight Altitude Tent Exposure:** You will be asked to arrive at the lab at approximately 6pm after eating dinner. After measuring your weight, you will be asked to enter a commercially available altitude tent, commonly used by athletes to simulate an altitude environment at sea level. The tent is a canopy measuring 8ft x 8ft x 6ft with plastic walls and a zipper opening and is placed over the top of a standard full size inflatable air mattress for sleeping.

In one of the three overnights, you will breathe low oxygen air (equivalent to an altitude of 8,000ft) for 14 hours. In a second test, you will breathe room air for 12 hours and low oxygen air (equivalent to an altitude of 8,000ft) for 2 hours. In a third test, you will breathe room air for 14 hours. While in the tent, you will be asked to wear a fiber optic cable on your index finger, which uses light waves to measure the oxygen levels in your blood as well as your heart rate. You will also be asked wear an activity monitor on your wrist, which fits like a wristwatch, to monitor the quality of your sleep.

While in the tent, you will have access to food and drink. If you need to urinate while in the tent, we will have a hand held plastic bottle for you to use, so that we can measure your urine output. Should you need to defecate during your time in the tent, we have a face mask you can wear attached to hoses and a bag of air to breathe. You can then leave the tent and walk approximately 50 feet to the restroom. You will be free to engage in quiet activities in the tent, including things like reading, video watching, internet, etc., but we will ask you to prepare as you normally would in the evening prior to a competition. Fans will be placed in the tent to help control your comfort, and a standard set of bedding / pillows will be available. You may also bring your own bedding if you desire.

You will be woken up if not awake two hours prior to the scheduled start of the 20 km time trial (14 hours after entering the tent). You will be asked to bring your own breakfast foods and drinks, and you will be asked to eat the same morning meal prior to each time trial. Beginning two hours before the time trial, you will have the option of remaining in the tent, or you can go on a face mask if you desire to leave the tent to complete your pre-competition routine.

**Total hemoglobin measures.** This test measures the amount of hemoglobin in your blood. The test begins with you immersing your hand in a bucket of warm water for 5 minutes, after which a sterile needle will be used to prick your finger and a small blood sample (less than 1/16 of a teaspoon) will be collected. Then, you will be asked to wear nose clips, blow all the air out of your lungs, place a mouthpiece in your mouth, then breathe air in and out from a small bag for two minutes. The bag contains pure oxygen with a small amount of carbon monoxide added. At the end of two minutes of breathing air from the bag, you will be asked to remove the mouthpiece, breathe room air, and place your hand back in the bucket of warm water. After two and four minutes of breathing room air, we will prick your finger and obtain a small blood sample (therefore, a total of three finger pricks). You can choose which finger is pricked and if we use the same finger each time or rotate fingers.

This test will be performed twice each on Days #3, #4, and #5. The first test will occur upon arrival to the lab in the evening, just prior to entering the altitude tent. The second test will occur after conclusion of the 20 km time trial the following morning.

**Sleep Quality Questionnaire:** Upon waking on Days #3, #4, and #5, you will be asked to complete a 15 question survey. This questionnaire should take 5 minutes to complete.

**RISKS OF TAKING PART IN THE STUDY:**

While on the study, the risks are:

A slight risk of headache, temporary light-headedness, throat dryness or fainting exists with breathing function testing. As you will be sitting comfortably and carefully monitored, fainting is not likely to occur. You are free to indicate any discomfort and discontinue participation at any time.

Both maximal and moderate level exercise tests of healthy individuals, as described by the American College of Sports Medicine, presents little risk to the subject and does not require medical clearance for subjects under 40. Potential risks and/or discomforts can include episodes of temporary light-headedness, chest discomfort, leg cramps, occasional irregular heartbeats, and abnormal blood pressure responses. The risk of heart attack, although minor, (approximately 1 to 2 in 10,000) does exist. During the test you will be closely monitored for any abnormal changes in heart rate or breathing. You are free to indicate any discomfort and discontinue participation at any time.

There is a slight risk of skin discomfort or irritation from the fiber optic bundles that will be placed on your skin.

There is a risk of blood pooling in your legs and low blood pressure immediately following the cycle exercise tests. After the cycle exercise tests, you will be allowed to cool down on the exercise bike. If at any time during testing you become light headed, you may have to lie down until you feel normal.

Risks associated with taking blood include excessive bleeding, fainting or feeling lightheaded, and possible infection. All blood samples will be taken by qualified individuals. A reasonable effort will be made to minimize the risks associated with drawing blood through the use of proper procedures and sterile techniques.

Breathing low oxygen air involves the risk of lightheadedness, rapid breathing, and dry throat. Sleeping in an altitude tent may involve poorer quality of sleep, headache, nausea, and frequent urination.

Breathing carbon monoxide gas can reduce the levels of oxygen in the blood, however, the dose used in this study is 10 times lower than the dose required to induce life-threatening symptoms. The syringe used to deliver the carbon monoxide gas is not capable of holding an amount necessary to cause the oxygen content of your blood to fall significantly.

All face masks, nose clips, and mouth pieces will be cleaned in detergent and antibacterial solution after each use, minimizing the risk of virus transmission between subjects.

There is a potential risk of loss of confidentiality. Note that the restroom available for subject use is located approximately 50 feet down a public hallway from the lab. While in the hallway, we cannot guarantee confidentiality.

#### **BENEFITS OF TAKING PART IN THE STUDY:**

The benefits to participation that are reasonable to expect are information regarding breathing function, overall level of fitness, and how your performance changes when you go to altitude. Other than this information, you will gain little benefit. All subjects will be provided with feedback concerning their own results and the general findings of the study upon request.

#### **CONFIDENTIALITY**

Efforts will be made to keep your personal information confidential. Data will be stored on password-protected computers in locked rooms with limited public access. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. Your identity will be held in confidence in reports in which the study may be published and databases in which results may be stored.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the IU Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP) who may need to access the collected medical and/or research data.

#### **PAYMENT**

You will be paid a total of \$100 for completing all (5) days of testing. Payment will be made by check and will be delivered by postal mail within approximately 4 weeks of your final testing session. If you

withdraw prior to completing all days of testing or do not qualify for further participation after Day 1 of testing, you will be paid according to the trial(s) you complete or attempt to complete; \$20/trial.

### **COMPENSATION FOR INJURY**

In the event of physical injury resulting from your participation in this research, necessary medical treatment will be provided to you at your own expense. Costs not covered by your health care insurer will be your responsibility. Also, it is your responsibility to determine the extent of your health care coverage. There is no program in place for other monetary compensation for such injuries. However, by signing this form you are not giving up any legal rights or benefits to which you are otherwise entitled.

### **CONTACTS FOR QUESTIONS OR PROBLEMS**

For questions about the study or a research-related injury, contact the researcher Robert Chapman, Ph.D. at (812) 856-2452 or [rfchapma@indiana.edu](mailto:rfchapma@indiana.edu). If you cannot reach the researcher during regular business hours (i.e. 8:00AM-5:00PM), please call the IU Human Subjects Office at (812) 856-4242 or (800) 696-2949.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IU Human Subjects Office at (812) 856-4242 or (800) 696-2949.

### **VOLUNTARY NATURE OF STUDY**

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled. Your decision whether or not to participate in this study will not affect your current or future relations with the investigators or Indiana University.

Your participation may be terminated by the investigator without regard to your consent in the following circumstances: blood pressure, height and weight, breathing function test, or maximal exercise test results that do not meet the criteria for inclusion in the study, an abnormal response to exercise, or an inability to complete the exercise tests. If you leave the study or are removed from the study by an investigator, all data collected to that point will still be included in the study files and data analysis for the study.

**SUBJECT'S CONSENT**

In consideration of all of the above, I give my consent to participate in this research study.

I will be given a copy of this informed consent document to keep for my records. I agree to take part in this study.

**Subject's Printed Name:** \_\_\_\_\_

**Subject's Signature:** \_\_\_\_\_ **Date:** \_\_\_\_\_

(must be dated by the subject)

**Printed Name of Person Obtaining Consent:** \_\_\_\_\_

**Signature of Person Obtaining Consent:** \_\_\_\_\_ **Date:** \_\_\_\_\_

## Curriculum Vitae

### JOSHUA FOSS

3312 N. Stoneycrest Rd, Bloomington, IN 47404 | 765-661-3500 | josh.foss4@gmail.com

### EDUCATION

Indiana University, Bloomington, IN

**M.S. in Exercise Physiology**

2015

Thesis: "Short Term Arrival Strategies for Endurance Exercise Performance at Moderate Altitude"

Indiana Wesleyan University, Marion, IN

**B.S. in Chemistry**

2009

### AWARDS

**SPH Student Research Grant**

March 2014 – July 2014

### TEACHING EXPERIENCE

Indiana University, Bloomington, IN

**Associate Instructor – K409 – "Exercise Physiology"**

2012-2014

Instructed laboratory sections and administered laboratory grades

**Associate Instructor – Activity Courses**

2012-2014

Developed syllabus and overall course structure for select classes, lectured and administered all grades

Indiana Wesleyan University, Marion, IN

**Adjunct Instructor – "Introduction to Organic and Biochemistry"**

2009-2010

Instructed laboratory sections and administered laboratory grades

### RELATED EXPERIENCE

OURLab (now OPKO Lab), Nashville, TN

**Fluorescence In Situ Hybridization Triager**

2010 – 2012

Triaged and prepared urothelial cell samples for testing of abnormalities in DNA sequences and chromosomes using fluorescent probes

Indiana Running Company

**Store Manager**

2014 – 2015

Oversaw all operations at store-level, including staffing, inventory control, loss prevention, marketing, customer and vendor relations

### PUBLICATIONS AND PAPERS

*Career Performance Progressions of Junior and Senior Elite Track and Field Athletes*

Presentation at the Annual Meeting of the American College of Sports Medicine, Indianapolis, IN

May 2013

*Short Term Arrival Strategies for Endurance Exercise Performance at Moderate Altitude*

Presentation at the Annual Meeting of the American College of Sports Medicine, San Diego, CA

May 2015