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Minimal Effects of Moderate Normobaric Hypoxia on the Upper-Body Work-Time Relationship in Recreationally-Active Women

Tristan Starling-Smith
University of Central Florida

MINIMAL EFFECTS OF MODERATE NORMOBARIC HYPOXIA ON THE UPPER-BODY WORK-TIME RELATIONSHIP IN RECREATIONALLY-ACTIVE WOMEN

by

TRISTAN STARLING-SMITH
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ABSTRACT

PURPOSE: To evaluate the effects of moderate normobaric hypoxia on the parameters of the work-time relationship during upper body exercise in women. **METHODS:** Thirteen recreationally active women (age: 22.7 ± 2.6 y; height: 167 ± 8.6 cm; weight: 66.4 ± 9.7 kg; body fat: 27.6 ± 5% body fat) completed a graded exercise test in both normobaric hypoxia (H; F_iO_2=~14%) and normoxia (N; F_iO_2=~20%) to exhaustion on an arm ergometer to determine $\dot{V}O_2$peak and peak power output (PPO). Each participant completed four constant work-rate arm-cranking tests at 90-120% PPO in both environmental conditions. Linear regression was used to estimate CP and AWC via the work-time relationship during the constant work-rate tests. Paired samples *t* tests compared mean differences between $\dot{V}O_2$peak, PPO, CP and AWC between conditions (N vs. H). Two-way (condition × intensity) repeated measures ANOVA was used to compare total work and time-to-exhaustion. **RESULTS:** H significantly reduced VO2peak (N: 1.73L/min ± .31L/min vs. H: 1.62L/min ± .27L/min, p=.008) but had minimal effects on PPO (N: 78.08W±14.51W vs. H: 75.38W±13.46, p=.089), CP (N: 57.44W±18.89W vs. H: 56.01W±12.36W, p=.546), and AWC (N: 4.81kJ±1.01kJ vs. H: 4.56kJ±.91kJ, p=.510). No significant condition × intensity interactions were noted for total work or time-to-exhaustion (p>.05). **CONCLUSIONS:** Moderate normobaric hypoxia significantly reduced VO_2peak but had minimal effects on CP and AWC using the work-time model.

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CHAPTER ONE: INTRODUCTION

Critical power represents the power output that a muscle group can maintain without exhaustion (Monod and Scherrer, 1965, Monod 1972) and can be extended to larger portions of the total body musculature through various exercise modalities (Moritani, Nagata, DeVries, Muro, 1981; Belasco, Oliveira, Serafini, Silva, 2010; Capodaglia, Bazzini, 1996; Angermann, Hoppeler, Wittwer, Dapp, Howald, Vogt, 2005). Critical power (CP) is often regarded as a fatigue threshold that separates exercise into two distinct intensities in which the activity can be either sustained (<CP) or not (>CP), and has been further defined as the greatest oxidative metabolic rate that can be maintained without reducing the anaerobic working capacity (AWC or W') (Poole, Burnley, Vanhatalo, Rossiter, Jones, 2016; Taylor, Batterham, 2002). In the two parameter model of CP, AWC is characterized as the total work accumulated above CP until failure (Townsend, Nichols, Skiba, Racinais, Periard, 2017). Theoretically, this approach allows for the determination of when failure will be reached during constant work rate tests using a work-time model as shown by (Moritani, Nagata, DeVries, Muro, 1981). Respiratory compensation point (RCP) is defined as the threshold where acidemia surpasses CO_2 as the stimulus for ventilation (Kinnear, Blakey, 2014). RCP and CP are often defined as the interchangeable thresholds occurring at the same power outputs (Bergstrom, Housh, Zuniga, Traylor, Camic, Lewis, Schmidt, Johnson, 2013) and may be used to prescribe exercise intensities for training or competition.

(Monod, Scherrer, 1965) hypothesized that CP is a parameter that depends on oxygen supply, making it susceptible to reductions under hypoxic conditions. Expanding upon this hypothesis, subsequent research has shown that lowering the partial pressure of oxygen caused a reduction in the slope of the work-time relationship which reflects a reduction in CP values (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017; Moritani, Nagata, DeVries, Muro, 1981; Shearman, Dwyer, Skiba, Townsend, 2016). This has since been elucidated further, showing that overall exercise tolerance is reduced during exposure to moderate hypoxia (Dekerle, Mucci, Carter, 2011). Moderate hypoxia is likely sufficient to substantially decrease performance with reductions in CP, VO2, and peak power output during constant load and incremental tests; however, W' may be not affected by the reduced inspired fraction of oxygen (Valli, Cogo, Passino, Bonardi, Morici, Fasano, Agnesi, Bernardi, Ferrazza, Ward, Palange, 2011). These hypoxia-induced performance decrements have been extensively examined using a variety of exercise modalities from treadmill running to cycle ergometry (Dekerle, Mucci, Carter, 2011; Simpson, Jones, Skiba, Vanhatalo, Wilkerson, 2015; Adams, Bernauer, Dill, Bomar, 1975). Most of this research has been conducted using lower body tests, leaving a gap in the extant literature related to the influence of hypoxia on upper body performance measures. The upper body is not capable of the same aerobic performance as the lower body due to multiple morphological differences (Martin, Zeballos, & Weisman, 1991). The upper body musculature has less mass and has a greater type II fiber distribution causing it to rely on anaerobic metabolism earlier than the lower body (Calbet et al., 2003; Sanchis-Moysi et al., 2010; Martin et al., 1991). This combined with smaller diffusion area and larger diffusion distances may cause the upper body to respond differently to hypoxia than the lower body, these differences may be amplified in women due to physiological differences in addition to the previous morphological ones.

Large gender differences exist in overall skeletal muscle mass with men having significantly more than women in both absolute and relative terms (Janssen, Heymsfield, Wang, Ross, 2000). These gender differences are even greater in the upper body (+40% in men compared to women) than lower body (+33% in men compared to women) which are likely to tied differences in performance at both maximal and submaximal intensities. (Martin, Zeballos, Weisman, 1991) found that continuous maximal arm crank exercise represented a lower cardiorespiratory stress compared to maximal leg exercise resulting in lower overall $\dot{V}O_2max$ values. $\dot{V}O_2$ levels during upper body exercise are approximately two-thirds of the values obtained in the lower body, this has been attributed to the utilization of less overall muscle mass to complete the exercise test (Junior, Oliveira, Serafini, Silva, 2010). Additionally, the relatively smaller muscle mass of the upper body fatigues before maximum cardiac output is released (Belasco, Oliveira, Serafini, Silva, 2010). Because attainment of maximum cardiac output is a hallmark of Vo2max and is generally not attained during upper-body ergometry, Vo2 peak, defined as the highest value of VO2 attained during a test, is primarily used to determine maximal aerobic capacity during upper body exercise (Whipp, 2014). (Capodaglio, Bazzini, 1996) successfully utilized the power- or work-time relationship to reliably estimate CP and time to exhaustion.

The effects of acute hypoxia exposure during incremental tests to exhaustion in the upper and lower body have shown that upper body peak power output is affected to a greater degree than lower body peak power output (Angermann, Hoppler, Wittwer, Dapp, Howald, Vogt, 2006). Furthermore, a significant correlation was reported between capillary density and decrements in peak power output during hypoxia showing that more aerobically-trained individuals may be more sensitive to hypoxia. (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017) recently reported that moderate normobaric hypoxia during arm ergometry significantly reduced CP, Vo2peak, and peak power output, while AWC was not affected in recreationally-active men. These results are in agreement with previous research utilizing both male and female participants by (Dekerle, Mucci, Carter, 2012) during lower-body cycling under similar conditions; however, research on the effects of hypoxia on the work-time relationship in women has yet to be fully explored.

Gender differences during exercise testing have been found in oxygen utilization and upper body strength. Furthermore, men possess greater strength in both absolute and relative terms in the upper body due to larger type I and II muscle fiber areas measured by needle biopsy analysis (Miller, Macdougall, Tarnopolsky, Sale, 1992). (Fulco, Rock, Muza, Lammi, Cyerman, Butterfield, Moore, Braun, Lewis, 1999) determined that the adductor pollicis muscle fatigued more slowly and recovered more quickly in women compared to strength-matched men. The researchers postulated that these differences were caused by a greater capacity for oxidative phosphorylation determined by intramuscular enzyme activity in women (Green, Fraser, Ranney, 1984). A follow-up study was performed examining the hypothesis that sex-based differences in adductor pollicis function under hypobaric hypoxia showed lesser impairments in fatigue rate and time-to-exhaustion in women compared to men (Fulco, Rock, Muza, Lammi, Braun, Cymerman, Moore, Lewis, 2001). The adductor pollicis muscle was used to ensure equal absolute force during submaximal muscle contraction and similar O_2 demand between genders during the fatiguing trials. (Wagner, Miles, Horvath, Reyburn, 1979) determined that men and women have an equal ability to perform maximal work up to altitudes of 3,050 m but women have relatively greater hyperventilation with increase altitude resulting in possible differences in CO_2 production. More recently, (Mollard, Woorons, Letournel, Lamberto, Favret, Pichon, Beaudry, Richalet, 2007) elucidated that the primary limiting factor of maximal aerobic performance in women is reduced maximal oxygen transport that cannot be compensated by tissue oxygen extraction. In this study, trained women were shown to be more susceptible to the performance decrements caused by hypoxia than sedentary women. This reduced oxygen transport may have a strong impact on performance variables, such as CP and AWC, in women who are likely affected by hypoxia differently than men.

Sex-based differences in cardiorespiratory endurance have been observed consistently in in the scientific literature with women typically being outperformed by men. Men have a larger depression of the parasympathetic nervous system during exposure to intermittent hypoxia while both sexes when matched for age and body mass index have similar increases in minute ventilation under normobaric hypoxic conditions (Wadhwa, Gradinaru, Gates, Badr, Mateika, 2008)... Changes in the hormonal milieu throughout the menstrual cycle, specifically alterations in progesterone, are often discussed as possible contributors to the sex based differences in aerobic performance. However investigators (Jordan, Catcheside, Orr, O'Donoghue, Saunders, McEvoy, 2000) elucidated there were not any significant differences in poststimulus ventilatory decline measures between men and women or the phases of the menstrual cycle. This suggests that progesterone does not influence aerobic performance in women as previously thought. Women have a greater post-exercise vasodilatory response compared men but this difference likely disappears with age (Casey, Shepherd, Joyner, 2014). Therefore, it is possible that this increased vasodilation in women is the result of compensation for reduced oxygen availability during exercise in hypoxic conditions.

To better understand the influence of hypoxia on upper body performance in women, the purpose of this study was to examine the parameters of the work-time relationship (CP and AWC) as well as maximal (VO2peak) and submaximal (RCP) responses to normoxia and normobaric hypoxia during upper body ergometry. Our hypothesis was that normobaric hypoxia would reduce CP values leading to a larger reliance on AWC while also causing a reduction in VO2peak and a lowering of the power output associated with RCP.

CHAPTER TWO: LITERATURE REVIEW

<u>Hypoxia</u>

Adams, Bernauer, Dill, Bomar, 1975

Effects of equivalent sea-level and altitude training on VO2max and running performance

The purpose of this study was to observe the effects of equivalent sea-level and altitude endurance training on VO2max performance. 12 competitive runners were split into two groups that were matched for VO2max, 2-mile run time and age. The first group trained for three weeks at sea level running 19.3 kilometers a day at 75 percent of their VO2max. The second group matched their distance and intensity but were running at 7000 feet. After three weeks of this training the groups switched places and trained for another three weeks at the swapped altitudes. Post altitude VO2max was 2.8% below sea-level control so it was concluded that there was no effect of endurance training at 7000 feet when compared to equivalently difficult sea-level training on VO2max or 2-mile run performance in conditioned endurance athletes.

Pugh, Gill, Lahiri, Milledge, Ward, West, 1964

Muscular exercise at great altitudes

The purpose of this study was to observe the effects of differing altitudes on oxygen intake, ventilation, and heart rate. Six subjects performed ergometer exercises at varying altitudes over an 8 month expedition. They traveled from sea level to an altitude of 7,440 m performing exercise tests at different heights. It was found that oxygen intake for a given work rate was independent of altitude up to the maximum work rate maintainable for 5 minutes. After this it was found that the subject’s maximum oxygen intake declined at extreme altitudes. Ventilation for light and moderate exercise at a given work rate was independent of altitude but increased as maximum oxygen intake was approached at increasing altitudes. Heart rates were increased at low exercise intensities but maximum heart rates declined at higher altitudes. It was concluded that the reduced exercise capacity at higher altitudes was due to lower cardiac output and lung diffusion as well as the high oxygen cost of extreme ventilation.

Levine, Stray-Gundersen, 1997

“Living high-training low”: effect of moderate-altitude acclimatization with low-altitude training on performance

The purpose of this study was to determine whether living at a high altitude and training at a lower altitude could have performance benefits. The high altitude they used was 2,500 m and the low was 1,250 m. thirty-nine competitive male and female runners were randomized into three different groups, high-low, high-high, or low-low. The first description was where they lived while the second was where they trained. The training consisted of a 2 week lead in period at sea level, then 4 weeks of training at sea level to make sure everyone was starting the experimental trial from the same point. After the 4 week training the participants were divided into in to one of the 3 groups. The participants then trained for 4 weeks in whatever environment they were assigned to, once they finished this they all went back to sea level to perform post testing. The test they conducted was a 5,000 m time trial, this was done multiple times over the next 3 weeks after returning to sea level. After comparing all of the groups and the groups to the pre-test it was found that the high-low group had a significant increase in VO2max as well as red cell mass volume, the 5,000 m time trial also increased proportionally with increases in

VO2max. This study was able to show that living high and training low is an effective way to improve sea level performance by causing the body to acclimate to the altitude while keeping the training intensity high by training at low altitudes.

Dekerle, Mucci, Carter, 2012

Influence of moderate hypoxia on tolerance to high-intensity exercise

This study aimed to observe how the reduction of systemic oxygen affected high-intensity exercise tolerance. 11 participants were recruited, they performed VO2max test on a cycle ergometer and 3-4 time to exhaustion trials in random order, the environment they were in was also randomized into either normoxia or hypoxia. They performed the time to exhaustion trials in order to calculate critical power (CP) and to try and calculate anaerobic working capacity (AWC). They determined that there was no significant differences in AWC between conditions but there was a very large variation in some individuals that had drastic changes in AWC. This may mean that the current definition of AWC being representative of a finite energy store may be incorrect. Their results also showed that the more aerobically fit participants has smaller decreases in CP in hypoxia.

Simpson, Jones, Skiba, Vanhatalo, Wilkerson, 2015

Influence of Hypoxia on the Power-duration Relationship during High-intensity Exercise

The goal of this study was to test hypoxias influence on critical power to determine if the current definition of anaerobic working capacity is correct. This study used 13 females, they completed 5 constant power trials and a 3 minute maximal CP test to get estimates of their CP and AWC in both normoxia and hypoxia. It was found in this study that CP was significantly reduced in hypoxia compared to normoxia but AWC was not when compared in both conditions. They concluded that the changes in AWC were related to the changes in CP relative to VO2peak meaning the definition of AWC might not just mean anaerobic stores like previously thought.

Fulco, Rock, Cymerman, 1998

Maximal and submaximal exercise performance at altitude

The goal of this review article was to assess many of the variables that are affected by hypoxia and what their influences are on performance. Through assessing many studies it was found that decrements in VO2max performance begin around 700m and decrease linearly until about 6300m. It was also noted that individuals of higher fitness levels had larger decrements in VO2max when compared with individuals of lower fitness levels. It was found that there is no difference between men and women when it comes to decrements in VO2max in hypoxia, it was also noted that the limited research controlling for women's menstrual cycle found that there was no significant difference in VO2max values between early follicular and mid-luteal phases of the menstrual cycle. Submaximal oxygen uptake was found to be similar between sea-level and altitude, but relative intensity increases as altitude increases so lower intensities are required to remain submaximal. Maximal power and muscle strength have not been found to be negatively affected by high altitude.

Calbet, Boushel, Radegran, Sondergaard, Wagner, Saltin, 2003

Determinants of maximal oxygen uptake in severe acute hypoxia

The goal of this study was to determine the mechanisms that cause the reduction in VO2max during exercise in hypoxia. Nine lowlanders performed cycle ergometer tests to exhaustion in either normoxia or hypoxia (10.5%). Hypoxia decreased VO2max values by 47% and cardiac output decreased by 17%. Systemic and leg oxygen delivery were reduced by 43 and 47%. The three main mechanisms that account for the reduction in VO2max found in this study were decrease in the partial pressure of inspired oxygen, impairment of gas exchange, and reduction in cardiac output and leg blood flow.

Angermann, Hoppeler, Wittwer, Dapp, Howald, Vogt, 2006

Effect of Acute Hypoxia on Maximal Oxygen Uptake and Maximal Performance during Leg and Upper-Body Exercise in Nordic Combined Skiers

The goal of this study was to test the effects of normobaric hypoxia on VO2max and maximal power output in the upper and lower body. Seven well trained skiers performed upper and lower body ergometer tests in both normoxia and normobaric hypoxia, the lower body test was done using and electronic cycle ergometer while the upper body test used a modified ergometer that allowed the skiers to propel themselves using a double ski pole method. This double pole method utilized the movement of the upper body and the arms to crank the ergometer. Max power was significantly reduced in both exercise modes. Lower body VO2max values were slightly higher than the upper body values. No systematic difference was seen between conditions in either the upper or lower body ergometer test even though lactate and heart rate both suggested they reached exhaustion, but oxygen saturation was significantly decreased in hypoxic conditions during both testing modes. Ventilation was also significantly high during the lower body test compared to upper body testing.

Romer, Heverkamp, Amann, Lovering, Peglow, Dempsey, 2006

Effect of acute severe hypoxia on peripheral fatigue and endurance capacity in healthy humans

The goal of this study was to determine if hypoxia limits exercise performance by contributing to the early fatigue of limb locomotor muscles. Nine competitive endurance athletes performed VO2max test to exhaustion on a cycle ergometer in both normoxia and hypoxia after performing incremental test to determine max power. They were randomized into either normoxia or hypoxia testing on days 1 and 2 and all performed a day 3 which was a normoxic control. Contractile function of the quadriceps was assessed before and up to 70 minutes after each trial. The magnitude of fatigue was greater in hypoxia across all stimulus frequencies when compared with normoxia. Post exercise reduction in maximal voluntary contractions were greater in the hypoxia group but did not reach significance. Time to exhaustion was on average 70% less in hypoxia than normoxia. Perception of limb discomfort and rise of the rating of perceived exertion were both higher in the hypoxia group. A significant correlation was seen between leg fatigue and the rise in the rate of limb discomfort which increased when hypoxia was introduced.

Thake, Simons, Price, 2010

Arterial haemoglobin oxygen saturation and power output are maintained at peak oxygen consumption in upper compared to lower body exercise in normobaric hypoxia

The purpose of this study was to examine the effects of a reduced percentage of oxygen on reductions in VO2peak, peak power output, and oxygen saturation in upper and lower body. They had nine subjects perform three upper and three lower body incremental exercise tests till exhaustion in either normoxia or normobaric hypoxia. Upper body VO2peak was maintained between environments along with peak power output. Decrements were much greater in hypoxia during the lower body tests. This shows that the lower percentage of oxygen does not affect the upper body's exercise capacity or performance as much as it affects the lower body.

Critical Power

Jones, Vanhatalo, Burnley, Morton, Poole, 2010

Critical Power: Implications for Determination of V˙O2max and Exercise Tolerance

The purpose of this review was to establish what is known about critical power and its relationships with anaerobic working capacity and how they are influenced by different exercise interventions and variables. One of the biggest features of this article is its description of the two-parameter critical power model. The aerobic portion which has no capacity limit is defined as critical power and the anaerobic energy portion that is capacity limited, and as long as there is a supply from these energy sources exercise can be maintained at any power output. The relationship between these two is intensity related, if the intensity of exercise is low enough the aerobic portion can keep up with the energy demand sparing the limited supply from the anaerobic system. If the intensity is increased above the critical power threshold the anaerobic energy stores must be utilized in order to provide enough energy to maintain the exercise. The time to exhaustion can be determined by dividing the available anaerobic capacity by the rate at which the energy is required.

Moritani, Nagata, Devries, Muro, 1980

Critical power as a measure of physical work capacity and anaerobic threshold

The goal of this study was to expand upon Monod and Scherrer's definition of critical power and anaerobic working capacity and take it from local muscular exhaustion to total body work using cycle ergometers. Eight males and eight females whom were recreationally active participated in the study. All of the participants performed and incremental exercise test on the ergometer to determine VO2max and anaerobic threshold. Each participant performed three dynamic work tests at different power outputs until fatigue was reached. Hypoxias effects on critical power were also tested, two of the subjects performed the same critical power tests while breathing different percentages of oxygen. The results showed women had a lower average VO2max than the men, the average critical power for men was 203.9 W and 144.5 W for women. There was a significant correlation between anaerobic threshold and critical power and VO2max and critical power. The lowering of the percentage of oxygen showed a clear reduction in the slope of critical power while not affecting anaerobic capacity.

Shearman, Dwyer, Skiba, Townsend, 2015

Modeling Intermittent Cycling Performance in Hypoxia Using the Critical Power Concept

The goal of this study was to test an intermittent critical power model during high intensity exercise in hypoxia. Eleven well trained male cyclists visited the laboratory on 5 occasions during this single-blind, randomized, and counterbalanced study. The first two days of testing randomized the participants into either normoxia or normobaric hypoxia then they performed an incremental test to determine thresholds and VO2peak, after a 30 minute break they performed an all-out three minute test to estimate critical power. The two consecutive days required the participants to perform a high-intensity intermittent test to failure. These tests were 60-s of work with 30-s of recovery until they could no longer perform, this method was used in order to produce failure around 4 minutes based upon the selected critical power model. Results revealed that VO2 peak was reduced by 18% in hypoxia compared to normoxia conditions, peak power output was also significantly reduced throughout the test by 8% in the hypoxic condition during the incremental ramp test. Critical power and VO2 peak were reduced by 9% and 20% respectively in hypoxic conditions during the three minute all out critical power test with no change in the average anaerobic working capacity between conditions. The results of the high-intensity intermittent test showed that the average time constant for restoration of the anaerobic work capacity was significantly longer in the hypoxia group, this shows that they were not able to recover as effectively between exercise bouts when compared with the normoxia condition.

Taylor, Batterham, 2002

The reproducibility of estimates of critical power and anaerobic work capacity in upper-body exercise

This study had two purposes, the first was to apply the linear power versus the inverse of time relationship to upper body exercise, and the second was to test the repeatability of critical power and anaerobic working capacity in the upper body. Sixteen active male subjects participated in this study, none of which were specifically trained in upper-body exercise. These subjects reported to the lab for six total visits where all exercise was done using and adapted upper-body ergometer, the first two days were constant work tests for extended durations (30 minutes at 50W and 20 minutes at 75W), the third and fourth visits consisted of incremental exercise tests to determine VO2peak, and the final two days each consisted of five constant power bouts at specific power outputs performed in a randomized order (85%, 100%, 105%, 115%), the fifth power output was selected to provide a spread of times to exhaustion. It was found that there was a strong relationship between power and the inverse of time during the 5 bouts. R^2 values were .92 (0.05) and .95 (0.05) for the first two bouts. A strong relationship between critical power and anaerobic working capacity was found but issues with the repeatability have been found with these measurements. Critical power has a much higher test-retest coefficient than anaerobic working capacity due to high individual variance. This variance was quantified into examples, an individual with a critical power value of 100 W might repeat the same test and perform anywhere from 85 W to 117 W. Using the same limits of agreement for anaerobic working capacity an individual with an estimated 7500 J AWC could perform anywhere from 4275 J to 12525 J. Overall anaerobic working capacity might be more sensitive to errors in time to exhaustion estimates.

Townsend, Nichols, Skiba, Racinais, Periard, 2017

Prediction of critical power and W′ in hypoxia: Application to work-balance modelling.

The purpose of this study was to develop an equation for critical power and anaerobic working capacity in hypoxia to use in the work-balance model. Nine healthy trained male cyclist completed eight total testing sessions for this study. The first visit consisted of an incremental

VO2max test at 30 W a minute then after a resting period each participant performed a familiarization time trial test. The following five visits consisted of time trials at varying simulated hypoxic levels that were used to determine critical power and anaerobic working capacity (250, 1,250, 2,250, 3,250, and 4,250 m) the order of the participant's condition was counterbalanced using the latin square design. Two high intensity interval training sessions were performed at 250 m and 2,250 m following the participant's time trials at those simulated altitudes. Time trials were used in this study to try and reduce the error that is occasionally seen in time to exhaustion trials. The linear 1/time critical power model was used because it showed the lowest standard error. This study found a significant effect of altitude on both critical power and anaerobic working capacity. It was also shown that hypoxia might affect anaerobic working capacity in a threshold manner because significant decrements were only shown at the highest altitude (4,250 m).

Valli, Cogo, Passino, Bonardi, Morici, Fasano, Agnesi, Bernardi, Ferrazza, Ward, Palange, 2011

Exercise intolerance at high altitude (5050 m): Critical power and W′

The purpose of this study was to elucidate the relationship between work rate and its tolerable duration at high altitude. Two healthy females and four males participated in this study which took place in two phases. The first part of the study took place in Nepal at 5050 m after slowly allowing for acclimatization at lower altitudes during the previous week. Upon reaching maximum altitude the participants were given a day to rest, on the second day a familiarization incremental exercise test was performed, on day 3 the real testing began with another incremental test followed by 3 high intensity constant work rate tests to the limit of tolerance separated by twelve hours of rest. Finally right before departing from the high altitude another incremental test was performed. They then waited three months at sea level to minimize the effects of acclimatization before performing all of the test they did previously again. As expected the ascent to high altitude caused a significant decrease in arterial desaturation. The results of the incremental testing showed that there was no change in the (Delta Vo2/Delta WR). Leg fatigue was also slightly reduced at altitude but it did not reach significance. The constant work rate tests showed that critical power and anaerobic work rate were significantly reduced in high altitude when compared to sea level.

Women

Casey, Shepherd, Joyner, 2014

Sex and vasodilator responses to hypoxia at rest and during exercise

The purpose of this study was to investigate whether sex influences hypoxic vasodilation and if age changes these differences. Fifteen young women and sixteen young men participated as well as six old women and five old men in order to elucidate changes as aging occurs. Every participant performed forearm exercises in normoxia and hypoxia, blood flow and blood pressure were used to calculate forearm vascular conductance. Young women showed a greater vasodilator response at rest and during exercise in relative terms compared to young men. Interestingly these sex based differences seem to disappear with age. This study found that no matter how the vasodilation response was represented the older participants did not have differences between the sexes.

Wadhwa, Gradinaru, Gates, Badr, Mateika, 2008

Impact of intermittent hypoxia on long-term facilitation of minute ventilation and heart rate variability in men and women: do sex differences exist?

This study was conducted in order to elucidate any sex based differences in minute ventilation and sympathovagal balance along with the depression of parasympathetic nervous system activity. Fifteen matched men and women participated in eight 4-minute hypoxia bouts while maintaining hypercapnia followed by a recovery period used to assess the depressed parasympathetic nervous system activity. The results of this study showed similar increases in minute ventilation between men and women when compared with baseline values. Men also showed men showed higher depression of the parasympathetic nervous system and increases in sympathovagal activity unlike the women. In conclusion this study shows some possible sex based differences in physiological response to hypoxia.

Sandoval, Matt, 2002

Gender differences in the endocrine and metabolic responses to hypoxic exercise

The goal of this study was to test the hypothesis that women have blunted responses to hypoxia during exercise compared to men. Fourteen women taking contraceptives and fifteen men matched for Vo2 peak participated in this study. All of the participants performed three 5-minute exercise bouts at percentages of their Vo2 Peak in both normoxia and hypoxia. Measures were take throughout the exercise bouts and after a recovery period, it was found that gender had no effect on cortisol and growth hormone during exercise or during hypoxia. The results of this study show that women did not have the blunted physiological response to hypoxia as hypothesized. This means that some other mechanisms are at play that cause the gender differences in hypoxic environments.

Shephard, Vandewalle, Bouhlel, Monod, 1988

Sex differences of physical working capacity in normoxia and hypoxia

The goal of this study was to examine sex based differences of physical working capacity in both normoxia and hypoxia using multiple exercise modalities. Eight active males and females participated in exercise bouts to exhaustion using both upper and lower body as well as unilateral exercises in normoxic and hypoxic conditions. Since the females were much smaller than the males in this study there were large differences in absolute terms when analyzing the results but once expressed in terms of segmental lean body mass the differences disappeared. The females did show limitations in oxygen transport which was only exacerbated in hypoxic conditions. The females also showed to perform better than the men during tasks that required smaller proportions of total body mass.

Jordan, Catcheside, Orr, O'Donoghue, Saunders, McEvoy, 2000

Ventilatory decline after hypoxia and hypercapnia is not different between healthy young men and women

The purpose of this study was to elucidate how the respiratory-stimulating properties of progesterone effect poststimulus ventilatory decline between genders and menstrual phases. The poststimulus ventilatory decline was measured in twelve men and eleven women in the luteal and follicular phases of their menstrual cycle. The measurements were taken after short periods of both isocapnic hypoxia and normoxic hypercapnia using a breath by breath gas delivery system fitted with a mask. The results of this study showed that there were no differences between genders or the two menstrual phases when looking at any respiratory measurements. It was also determined that gender and menstrual cycle phase did not affect poststimulus ventilatory decline meaning that hormonal changes did not impact this variable.

Mollard, Woorons, Letournel, Lamberto, Favret, Pichon, Beaudry, Richalet, 2007

Determinant factors of the decrease in aerobic performance in moderate acute hypoxia in women endurance athletes

The purpose of this study was to elucidate limiting factors of aerobic performance in trained and sedentary women in normobaric hypoxia and sea level environments. Sixteen healthy sea-level residents (aged 18-40) were divided into trained and untrained groups. The trained group all had Vo2max values higher than 50ml/min/kg while the untrained group all had Vo2max values lower than 45ml/min/kg. All participants completed four maximal cycle ergometer test split by at least 7 days, the first of these test was carried out in normoxia to assure they met the group standards. The following three test were randomized and were either at simulated altitudes of 1000, 2500 or 4500 M. The test started at 40 watts and increased by 25 watts every 2 minutes until exhaustion was reached. The results showed that the trained group had higher Vo2max and maximal power output at every altitude. Decrements in these two variables were significant at and above 1000 m, and (Delta Vo2max) was higher in the trained group at each altitude. This study showed that Vo2max decrements are more important in endurance athletes than in sedentary individuals.

Woorons, Mollard, Lamberto, Letournel, Richalet, 2005

Effect of Acute Hypoxia on Maximal Exercise in Trained and Sedentary Women

This study was performed to examine the physiological responses of trained and sedentary females during maximal exercise at varying altitudes. Fourteen women all of whom were sea-level residents were split into two groups based upon fitness level. All participants completed four maximal cycle ergometer test split by at least 7 days, the first of these test was carried out in normoxia to assure they met the group standards. The following three test were randomized and were either at simulated altitudes of 1000, 2500 or 4500 M. The test started at 45 watts and increased by 25 watts every 2 minutes until exhaustion was reached. Power output and VO2max were higher in the trained group than the sedentary group at all altitudes. The trained group also showed larger decrements in VO2max and heart rate values at increasing altitudes. This study helps confirm that trained women are more susceptible to aerobic decrements in hypoxia than sedentary women, this is in line with what is shown for men as well.

Fulco, Rock, Muza, Lammi, Braun, Cymerman, Moore, Lewis, 2001

Gender alters impact of hypobaric hypoxia on adductor pollicis muscle performance

The purpose of this study was to elucidate the effects of hypoxia on small-muscle exercise performance in women because very little was known about this at the time. It has previously been shown that women may fatigue slower in these small muscle groups and may have a greater capacity for oxidative phosphorylation. The hypothesis of this study was that the women’s performance would be less impaired than the men’s during static contraction of the adductor pollicis in hypobaric hypoxia. Twenty-one healthy women with normal menstrual cycles and 12 healthy men participated in this study. The men and women performed normoxia testing at different sites but they were within 20 m of each other's altitudes and hypoxic testing was performed at 4,300 m in a lab in Colorado. Adductor pollicis muscle testing started with familiarization trials followed by three 5-s baseline maximal voluntary contractions (MVCs) with 1 minute of rest between each. Submaximal testing then proceeded at 50% the force of the MVC in 5 second bouts until the force could not be maintained which was counted as reaching exhaustion. Vo2peak was determined in both conditions by progressive-intensity treadmill running until exhaustion in the men. Vo2peak was determined by progressive cycle ergometer testing until exhaustion in the women. The results showed that MVC's were similar for both genders in both conditions with men having higher MVC values overall. Fatigue rate was faster in hypoxia for men but similar between conditions for women in combination with this time to exhaustion was shorter for men in hypoxia and similar between conditions for women. Overall women were able to maintain MVC force better than men and did not fatigue at the same rate as men in hypoxic conditions displaying that hypoxia does affect men and women differently when it comes to muscle performance.

Schoene, Robertson, Pierson, Peterson, 1981

Respiratory drives and exercise in menstrual cycles of athletic and nonathletic women

The purpose of this study was to determine the influence of midluteal and midfollicular phases of the menstrual cycle on performance. Eighteen women participated in this study, 6 were high performing athletes, 6 normally menstruating controls, and 6 amenorrheic high performing athletes. Plasma progesterone levels were used to track ovulation in the menstruating subjects, these blood samples were taken during resting ventilation testing. The subjects underwent progressive maximal exercise testing in different partial pressures of oxygen on testing days. The results showed that athletes and nonathletes had significant increases in minute ventilation in the luteal compared to the follicular phase and the amenorrheic athletes showed no change between tests. Ventilatory drives were also significantly higher in the luteal phase for both athletes and nonathletes. Nonathletes showed a significantly better maximal performance on the exercise tests when they were in the follicular phase. So even though there were differences between variables during the different phases of menstruation there was no correlation between increasing plasma progesterone and these changing parameters.

Brutsaert, Spielvogel, Caceres, Araoz, Chatterton, Vitzthum, 2002

Effect of menstrual cycle phase on exercise performance of high-altitude native women at 3600 m

The purpose of this study was to determine if the increases in minute ventilation caused by rising progesterone levels during the luteal phase also increases maximal oxygen consumption relative to the follicular phase of menstruation. 30 normally menstruating high altitude residents participated in this study which took place at 3600 m. Exercise testing was scheduled during mid-follicular day 7-9 and mid-luteal days 21-23. The menstrual cycle was tracked using saliva and blood testing throughout the study. Vo2max testing was conducted on an electronically braked cycle ergometer, the test began at 30 watts of resistance and was increased by 20 watts every 3 minutes until exhaustion was achieved. The results of this study showed that there was no significant difference in work output or oxygen consumption during submaximal testing between the follicular and luteal phases in these subjects. It was found that maximal work output was about 5% higher in the luteal phase but Vo2max remained unchanged between phases. This study showed that the menstrual cycle has some effect on ventilation but no effect on Vo2max in hypoxia when high altitude natives were used.

Wagner, Miles, Horvath, Reyburn, 1979

Maximal work capacity of women during acute hypoxia

The purpose of this study was to elucidate the effects of altitude on women's capacity to perform maximal exercise. Six recreationally trained sea-level residents participated in this study in Santa Barbara. Each participant performed two maximal graded exercise test at each altitude (50, 2,130, 3,050 m) which were randomly assigned at 758, 586, and 523 barometric pressures inside an environmental tent. The subjects were kept blind to what altitude they were performing the test in at the time and blood samples were taken before and after testing. Ventilation data was collected throughout using a gas analyzer and energy contribution was determined. The results of this study showed that minute ventilation increased at altitude and Vo2max values decreased in the same environment. Blood lactate, heart rates, and cardiac outputs were unaffected by altitude. Overall this study help show that men and women both suffer from similar decrements in maximal oxygen uptake at altitude and can both perform maximal work at altitudes up to 3,050 m.

CHAPTER THREE: METHODOLOGY

Participants

Fourteen participants were recruited for this study. One participant did not complete the study due to availability issues; therefore thirteen total participants completed the study. All participants met American College of Sports Medicine physical activity recommendations to be classified as recreationally active. Participants refrained from exercising on testing days but were permitted to continue exercising at their usual volumes and intensities as long as residual soreness was not present during testing. Before enrolling in the study, all participants completed a Confidential Medical and Activity Questionnaire, as well as a Physical Activity Readiness Questionnaire (PAR-Q), to determine if they had any physical limitations that would keep them from performing any of the procedures in the study protocol. Potential participants were excluded if they were unable to perform physical exercise as determined by the PAR-Q. Participants were asked to keep their diet and any nutritional supplementation consistent throughout the study. All participants provided informed consent before beginning the study.

Research Design

An acute cross sectional design was used to evaluate the effects of normabaric hypoxia on upper body critical power and anaerobic working capacity. This was determined through the comparison of performances of multitrial constant power tests under normoxia and hypoxia. Each participant visited the Human Performance Laboratory seven times, a familiarization trial, two days of maximal graded exercise tests (GXT) under either normobaric normoxia or normobaric hypoxia, and four days of time to exhaustion trials (TTE) randomized with respect to intensity and environment. On the initial visit paperwork was completed, body composition was measured via bioelectrical impedance analysis device (BIA), then a familiarization trial was performed for the GXT. During the following two visits participants performed GXT's to determine (VO2peak) and Peak Power Output (PPO). During the final four visits participants performed two TTE trials per session. Participants completed the entire study over six weeks with a minimum of 48 hours in between visits.

Testing Methods

Body Composition and Familiarization

Body composition was assessed via multi-frequency bioelectrical impedance analysis (InBody 770, InBody, Seoul, Korea) to determine percent body fat and upper extremity lean mass. A familiarization of the GXT was provided to each subject with the arm ergometer (891E, Monark Upper Body Ergometer, Vansbro, Sweden) before testing sessions took place. Participants performed a five-minute warm-up at 0 W. As adapted from Hill and colleagues (2016), participants were required to maintain a cranking cadence of 50 revolutions per minute (RPM) at an initial workload of 50 W for three minutes. The workload was then increased 10 W every two minutes until the participant was unable to maintain a cadence above 50 RPM for five seconds despite verbal encouragement, or volitional fatigue. Each subject was seated with the crank arm lined up with the center of their glenohumeral joint and positioned so that their arms were extended but not fully locked out during cranking.

Incremental Testing Protocol

An incremental test to volitional exhaustion will be performed on a cycle ergometer (891E, Monark Upper Body Ergometer, Vansbro, Sweden) to determine peak power output (PPO) in watts (W) and peak oxygen consumption (VO_2peak) in liters per minute (L/min). Prior to testing, each participant will be fitted with a heart rate monitor(Garmin Ltd., Canton of Schaffhausen, Switzerland) , to record the participants' heart rate, and a mask that stabilizes a one-way valve around their mouth and nose to collect respiratory gases. All breath-by-breath gas exchange data was collected using a metabolic gas analyzer (Quark CPET, Cosmed, Rome, Italy) and all calibration procedures were carried out as per manufacturer's instructions. In addition, participants will perform these tests inside of a large transparent cubicle to simulate a high altititude environment (At-Home Cubicle, Hypoxico, Inc., New York, NY, USA). Participants sat inside the enclosed tent for at least five minutes prior to the start of each test to acclimate to the environment (Dekerle et al., 2012). Participants were also assessed for oxygen saturation via finger pulse oximeter (CMD50D+, Contec Medical Systems, Qinhuangdao, China) to verify acclimation. The environment for the second and third visits were randomized so that each participant would perform the GXT at a simulated altitude of 500 m (F_iO_2 = 20.1 ± 0.2%, normoxic conditions) and 3250 m (F_iO_2 = 14.0 ± 0.1%, hypoxic conditions). A dehumidifier (DH-35K1SJE5, Hisense International CO., LTD, Quingdao, Shandong, China) was used inside the tent to mitigate extreme increases in relative humidity. The testing environment was monitored via the metabolic gas analyzer's environmental sensor with average values as follows: temperature (24.5 ± 1.87 ˚C), relative humidity (37.7 ± 6.6 %), and barometric pressure (756.8 ± 4.7). The participants performed an unweighted (0 W) three-minute warm up, and then were required to maintain a cranking cadence of 50 revolutions per minute (RPM) at an initial workload of 50 W. Then the workload increased 10 W every two minutes until the participant is unable to maintain a cadence above 50 RPM for a duration of 5 seconds despite verbal encouragement, or volitional fatigue. The power output achieved in the last two-minute stage was recorded as PPO and the highest breath-by-breath oxygen consumption rate will be recorded as VO_2peak. This procedure was performed to exhaustion. RCP was determined using the auto detect feature in the Cosmed software, upon indication of an abnormality using visual inspection RCP was determined manually and is defined as the VO2 value corresponding to the point of departure from linearity of the VE -versus- VCO2 relationship.

Constant Work-Rate

Four high-intensity constant-work rate tests (90, 100, 110, 120 PPO), at different power outputs, were performed under both normoxia and hypoxia within a large transparent cubicle. Trials were randomized for environment and intensities for every testing visit. Participants were exposed to the environment for 5 minutes prior to testing. Following the warm up period, participant's oxygen saturations were tested to confirm acclimation to the environment. All constant-work rate tests began with a five-minute warm-up at zero watts. Prior to testing, each participant was fitted with a heart rate monitor, to record the participants' heart rate, and a mask that stabilizes a one-way valve around their mouth and nose to collect respiratory gases. All gas exchange data was collected using a metabolic gas analyzer. Participant were given a metronome at 100 beats per minute and could also see their RPM on the ergometers digital display to aid in keeping their RPM at 50. Exhaustion were determined to the nearest second at the moment of volitional fatigue or failure to maintain a cranking cadence above 50 RPM for longer than 5 s. The time-to-completion and total work done was calculated during each trial. Linear regression was used to determine the slope of the line from the relationship between time-to-completion and total work. The slope of the line is considered critical power while the y-intercept is considered anaerobic working capacity from the standard multi-trial critical power test.

Critical Power Estimate

Linear regression was used to determine the slope of the line from the relationship between TTE and TW for each set of trials performed under normoxic and hypoxic conditions. According to the work-time model (Smith, Stephens, Hall, Jackson, & Earnest, 1998), the slope of the regression line was considered CP while the y-intercept was deemed AWC.

Statistical Analysis

One participant dropped out due to schedule adherence problems. Therefore, the CP/AWC analysis was conducted with an *n* of 13. Paired-samples *t* tests were used to compare mean differences between $\dot{V}O_2$peak, PPO, and CP while Wilcoxon signed rank test was used to compare the median difference in AWC between conditions (Normoxia vs. Hypoxia). For the constant work-rate tests, a two-way repeated measures ANOVA [environment (normoxia vs. hypoxia) × intensity (90, 100, 110, 120%PPO)] was used to examine differences in mean $\dot{V}O_2$, HR, TTE, and TW. A two-way repeated measures ANOVA environment (normoxia vs. hypoxia) was used to examine differences in mean CP and RCP. In the event of a significant interaction, post hoc analysis included paired samples *t* tests and one-way repeated measure ANOVAs. An alpha level of $p < 0.05$ was considered significant. Normality was assessed via Shapiro-Wilk's test. All analyses were performed using statistical software (IBM SPSS Statistics for Windows, Version 22.0; Armonk, NY: IBM Corp).

CHAPTER FOUR: RESULTS

Statistical Analysis

One participant dropped out due to scheduling conflicts, therefore the CP/AWC analysis was conducted with an *n* of 13. Paired-samples *t* tests were used to compare mean differences in VO2peak, PPO, and CP and AWC. For the constant work-rate tests, a two-way repeated measures ANOVA [environment (normoxia vs. hypoxia) × intensity (90, 100, 110, 120%PPO)] was used to examine differences in mean TTE, TW, and VO2. An alpha level of $p < 0.05$ was considered significant. Normality was assessed via Shapiro-Wilk's test. All analyses were performed using statistical software (IBM SPSS Statistics for Windows, Version 22.0; Armonk, NY: IBM Corp).

Results

All variables exhibited normality according to Shapiro-Wilk's test. VO2peak (p=.008) was significantly greater in normoxia than hypoxia. There was minimal if any effect on PPO (N: 78.08W±14.51W vs. H: 75.38W±13.46, p= .089), CP (N: 57.44W±18.89W vs. H: 56.01W±12.36W, p=.546), and AWC (N: 4.81kJ±1.01kJ vs. H: 4.56kJ±.91kJ, p=.510). No significant condition × intensity interactions were noted for total work or time-to-exhaustion (p> 0.05). The r^2 for the work-time relationship was .947 ± .131 (range .520 - .999) in normoxia and .964 ± .044 (range .898 - .999) in hypoxia. A main effect for environment ($F1, 12 = 6.655, p= .024$) was observed for mean VO2 with normoxia (1.50 ± .26 $L \cdot min^{-1}$) being significantly greater than hypoxia (1.40 ± .23 $L \cdot min^{-1}$) during constant work rate tests. A main effect for thresholds (F = 18.669, p= .001) was observed with RCP (92.0 ± 8.2W) being significantly greater than CP (73.1 ± 18.9W) during constant work rate tests. In addition, a main effect for work-rate intensity was observed for total work with 90% PPO being greater than 100% PPO which was greater than 110% which was greater than 120%

CHAPTER FIVE: DISCUSSION

This investigation is the first to examine the impact of normobaric hypoxia on CP and AWC during upper body exercise in women. Moderate normobaric hypoxia (F_iO_2 ~ 14%; 3250m) significantly reduced $\dot{V}O_2$peak, but had minimal effect on CP and AWC during arm ergometry. The lack of significant differences in CP values is in contrast to previous findings in men (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017). This may be due to physiological differences, specifically oxidative phosphorylation, vasodilatory response, and muscle size/strength, between genders (Fulco, Rock, Muza, Lammi, Cyerman, Butterfield, Moore, Braun, Lewis, 1999; Casey, Shepherd, Joyner, 2014; Miller, MacDougall, Tarnopolsky, Sale, 1992). Notably, similar to previous CP investigations, the work-time relationship was highly linear with r^2 values of 0.947 ± 0.131 (range 0.520 - 0.999) in normoxia and 0.964 ± 0.044 (range 0.898 - 0.999) in hypoxia.

Significant reductions in $\dot{V}O_2$peak during the graded exercise tests and average $\dot{V}O_2$ during the constant work-rate trials were observed in hypoxia during this investigation. Similar reductions in $\dot{V}O_2$peak during normobaric hypoxia in both upper and lower body exercise modalities have been previously reported (Angermann, Hoppeler, Wittwer, Dapp, Howald, Vogt, 2006). These decrements in $\dot{V}O_2$ values are likely caused by reduced oxygen availability due to the lower partial pressure of O_2 (F_iO_2 ~ 14%) used in this investigation. (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017) observed similar results previously in a recent investigation with significantly reduced $\dot{V}O_2$peak values (N: 2.34±0.34L vs. H: 2.27±0.34L, p = 0.040). Although not measured, it is likely that maximal cardiac output and peak blood flow were reduced contributing to the reduced $\dot{V}O_2$ values (Calbet, Boushel, Radegran, Sondergaard, Wagner, Saltin, 2002).

In agreement with previous studies, the current investigation found that AWC was not affected by moderate hypoxia. (Derkerle, Mucci, Carter, 2011) found no significant differences in AWC in lower body cycling at a comparable level of hypoxia (F_iO_2 ~ 15%). There may be a threshold that must be surpassed for hypoxia to affect AWC. After testing at multiple altitudes (250, 1250, 2250, 3250, 4250m), (Townsend, Nichols, Skiba, Racinais, Periard, 2017) showed that AWC during cycle ergometry was only reduced at 4250m. It appears that this threshold remains as a requirement for noticeable effects on AWC during upper body ergometry as normobaric hypoxia simulating an altitude of 3250m had minimal, if any, effect on AWC in the current study examining women and during a recent investigation in men (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017) .

Hypoxic conditions decrease the partial pressure of oxygen which typically results in a reduction of CP determined via the work time relationship (Shearman, Dwyer, Skiba, Townsend, 2016). These hypoxia-influenced reductions have been extensively examined in the lower body using cycle ergometers (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017; Moritani, Nagata, DeVries, Muro, 1981; Shearman, Dwyer, Skiba, Townsend, 2016) and more recently in the upper body (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017) in male participants. However, the current investigation utilizing female participants found no significant differences in CP between hypoxic and normoxic conditions. This disparate finding may have been caused by a multitude of factors, including unique responses to submaximal exercise, greater capacity for oxidative phosphorylation, slower fatigue rate, greater vasodilation, and lower overall upper body strength in women compared to men.

It has been postulated that differences in the capacity for oxidative phosphorylation results in women fatiguing more slowly and recovering more quickly than men (Fulco, Rock, Muza, Lammi, Cyerman, Butterfield, Moore, Braun, Lewis, 1999). For example, women exhibited lesser impairments in fatigue rate and time-to-exhaustion under hypobaric hypoxia during static submaximal intermittent contractions compared to men (Fulco, Rock, Muza, Lammi, Braun, Cymerman, Moore, Lewis, 2001). Interestingly, the differences in CP between normoxia and hypoxia during upper body ergometry in men appeared to be driven by decreased time-to-exhaustion at 90% of peak power output (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017) which did not occur in the current sample of recreationally-active women. Thus, upper body performance-based differences, particularly during submaximal exercise, might have resulted in the limited effect on CP in the current sample of women that are in contrast to previous findings in men.

Women have also shown greater vasodilatory responses to hypoxia during rhythmic forearm exercise compared to age-matched men (Casey, Shepherd, Joyner, 2014). Significant correlations have been reported between strength and muscle cross-sectional area after measuring voluntary strength and muscle fiber type and size (Miller, MacDougall, Tarnopolsky, Sale, 1992). Furthermore, women possess 45% smaller cross-sectional area in the biceps brachii compared to men as well as significantly lower percentages of total cross-sectional areas occupied by type II fibers (Miller, MacDougall, Tarnopolsky, Sale, 1992). This may have been a contributing factor influencing overall CP measures since the biceps brachii is a prime mover during upper body ergometry exercise (Forman, Raj, Button, Power, 2014). Average upper-body CP values in recreationally trained men have been recorded as 90.22±12.88W in normoxia which were significantly reduced (85.26±9.64W) in hypoxia (La Monica, Fukuda, Starling-Smith, Wang, Hoffman, Stout, 2017). The lower overall CP values in the current sample of women (~57W) may be caused by less overall muscle mass than men leading to less upper-body strength (Miller, MacDougall, Tarnopolsky, Sale, 1992). Therefore, lesser muscle mass and greater type I fiber distribution coupled with greater vasodilatory response in women may have limited the influence of hypoxia on CP values.

Respiratory compensation point (RCP) and critical power (CP) have often been treated as interchangeable thresholds occurring at the same power output while differentiating between the heavy and severe exercise intensity domains (Bergstrom, Housh, Zuniga, Traylor, Camic, Lewis, Schmidt, Johnson, 2013). RCP, unlike CP, is able to be determined from a single incremental test while CP requires multiple constant work-rate trials or an all-out effort test (Hughson,Orok, Staudt, 1984; Vanhatalo, Doust, Burnley, 2007). If these thresholds are truly interchangeable, evaluation of exercise intensity domains would be much easier and more time efficient using RCP. Both RCP and CP occur around 80% of maximal oxygen uptake, and numerous studies have been examining intensities either above or below this threshold failing to disassociate RCP from CP (Bergstrom, Housh, Zuniga, Traylor, Camic, Lewis, Schmidt, Johnson, 2013). This current investigation determined average CP occurring at 73% and RCP occurring at 92%. On average CP and RCP appear to be similar; however, a high degree of variability exist between these parameters which limits accurate estimations based on one another (Broxterman, Ade, Craig, Wilcox, Schlup, Barstow, 2015). More recent literature on the topic suggests that RCP and CP are not physiologically equivalent and should not be treated as the same fatigue threshold

(Dekerle, Baron, Dupont, Vanvelcenaher, Pelaya, 2003). (Furthermore, work-rates associated with CP and RCP have been found to be different from one another with CP appearing before RCP. While neither CP or RCP were altered due to hypoxia, the current investigation demonstrated a significant difference in the power outputs between these two thresholds during upper body ergometry in women

In conclusion, this investigation demonstrated that normobaric hypoxia (FiO_2 ~ 14%) had minimal effect on CP and AWC during upper body ergometry in women. This differs from findings previous reported in men under similar circumstances. Gender differences, such as vasodilatory responses and muscle mass, may have dampened the effect of hypoxia on upper body critical power in women. While submaximal fatigue thresholds were unaltered, this study demonstrated that both peak and average $\dot{V}O_2$ were significantly decreased in normobaric hypoxia. Limitations in oxygen availability may have been overcome by the ability of women to more efficiently delivery oxygen to relatively smaller upper body musculature compared to men while allowing similar performance during upper body time-to-exhaustion trials of varying intensities. Overall, this investigation demonstrated normobaric hypoxia alters the rate of oxygen consumption during upper body ergometry but that these decrements to not appear to translate to decreased submaximal or maximal exercise performance. These findings should be used to uniquely inform the design of training programs for women, particularly those aimed at manipulating environmental conditions during upper body exercise.

APPENDIX: FIGURES

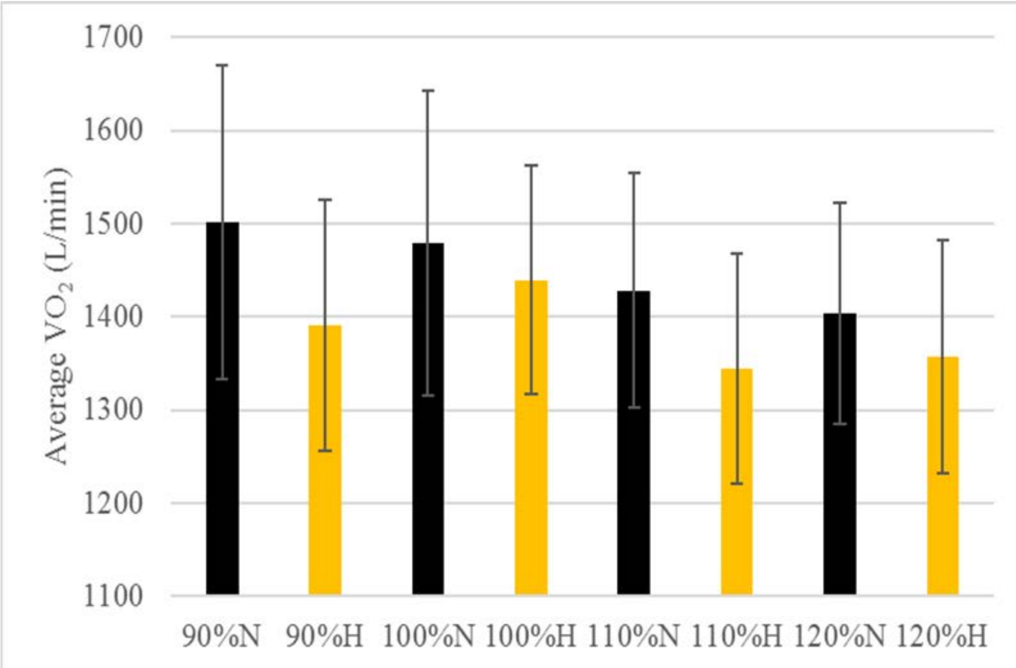

Figure 1: Average absolute VO2 values for time to exhaustion trials.

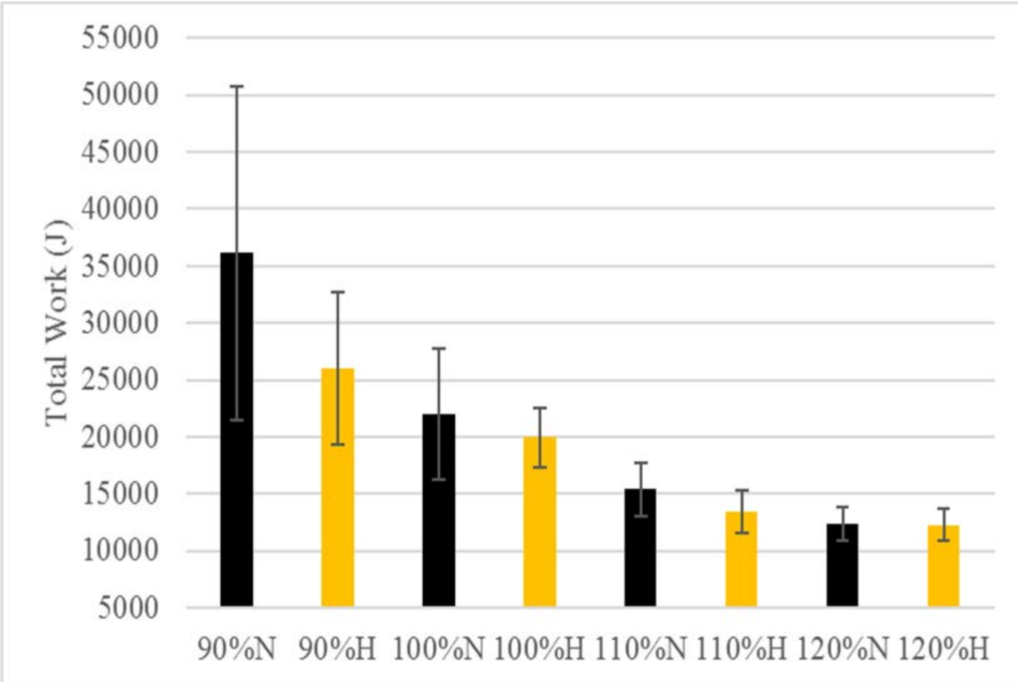

Figure 2: Total work values for time to exhaustion trials.

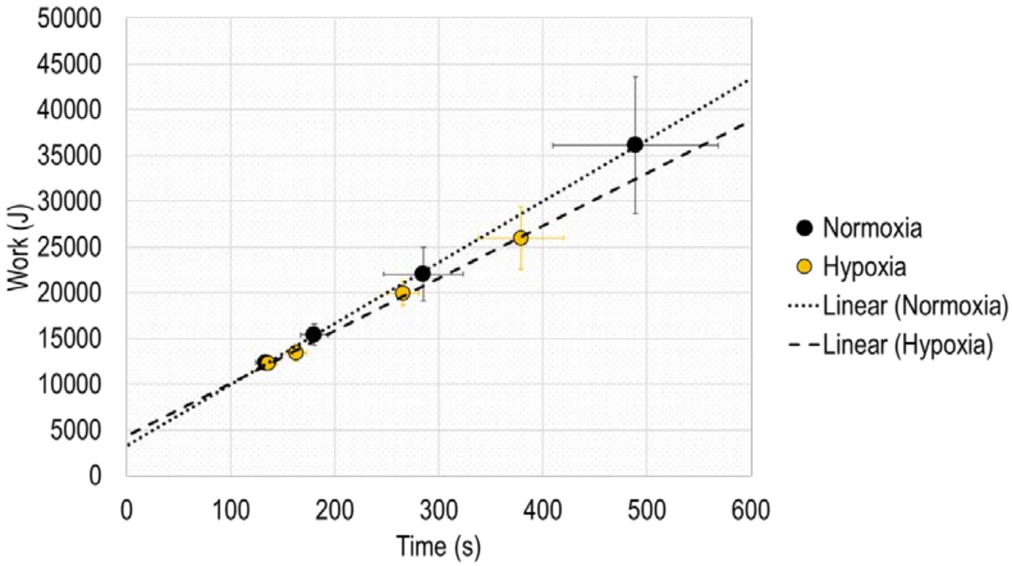

Figure 3: Work-Time relationship between conditions.

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