

The Effect of Altitude on the Anaerobic Energy System During a Maximal 60 Second Sprint on a Cycle Ergometer

Original Research

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Abstract

Introduction: The purpose of this study is to examine the effect of altitude on the anaerobic performance during a maximal 60s sprint on a cycle ergometer. **Methods:** Seven female and 12 male college students volunteered to participate in the study. Each participant performed two separate 60s Wingate tests, once at an elevation of 90 m (~300 ft), and once at an altitude of 2,438 m (8,000 ft). Testing at altitude was simulated by an Everett Summit II Hypoxic Generator. Each subject was given a minimum of seven days between each test to ensure that they were well rested and recovered from the previous bout. Peak power, mean power, relative peak power, relative mean power, and fatigue index were measured. Data were analyzed via a paired sample t-test. **Results:** Significant differences were noted for both mean power ($p = 0.012$) and relative mean power ($p = 0.008$) for the sprint at 2,438 m (8,000 ft) of altitude. All other measured variables were not statistically significant ($p > 0.05$). **Conclusion:** This study, found no effect on peak power, relative peak power, or fatigue index in 2,438 m (8,000 ft) of altitude during a 60s maximal effort bout. However, mean power was reduced in altitude conditions. These results highlight that altitude exposure may reduce mean power during an acute, maximal bout of exercise.

Key Words: altitude, anaerobic performance, wingate

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Introduction

In altitude conditions, a person experiences a progressive decrease in atmospheric pressures as they increase altitude, which severely limits oxygen availability and utilization in the tissues and working muscles, and often causing significant impairment in performance³⁰. The majority of works to date have empathized the impact of altitude on aerobic performance. Previous literature has stated an impairment in aerobic power during events such as 400 m²⁵, 800 m and marathon distance running (10,000 m)⁴⁰ cycling endurance sets (3 × 10-min endurance set (5-min recovery) and a repeat sprint session comprising three sets of 6 × 15-s sprints¹² track and field events (100-m, 100-m hurdles, 200-m hurdles, pole vault, high jump, shot put, discus, hammer throw, etc)²⁶ at altitudes greater than 1500 m. Furthermore, several studies have also reported VO₂ max impairments with moderate altitudes^{13,24,31,38-40,47}. More recently, Wehrlein and Hallen⁴⁹ investigated the effects of different altitudes (300-2800 m) on VO₂max and

concluded that the majority of the reduction in VO₂max was due to the reduced oxygen availability in such hypoxic environments.

While an abundant amount of research has been conducted on aerobic performance less is known about acute, anaerobic performance. Coudert¹⁶ found no differences in maximal anaerobic mechanical external power measured at high altitudes up to 5,200 m during intense short-term exercises: (1) jumps on a force platform and (2) 7-10 s sprints (force-velocity test) which solicit alactic metabolism but also lactic pathway. Coudert¹⁶ stated that in regard to exercises of duration equal or more than 30 s (i.e. Wingate test), conflicting results may exist. Conflicting results are often attributed to lower participation of aerobic metabolism during tests of 30 s or longer, as aerobic metabolism (despite the event being more “anaerobic” in nature) could interfere with anaerobic performance. Girard et al.²³ stated repeated sprint ability is more altered at high altitudes (>3000-3600 m) compared with low-to moderate altitudes (<3000 m). More recently, simulated altitudes of ~2000-3000 m have been associated with fewer repeated cycling repetitions and larger decrements in either peak or mean power (5-10%) compared to sea-level conditions^{7,45}. Billaut and colleagues⁸ examined the effects of muscle deoxygenation and reoxygenation in the prefrontal cortex and vastus lateralis on repeated-sprint cycling performance (10, 10 s sprints) in altitude (F₁O₂ 0.13) and normoxic conditions (F₁ O₂ 0.21).

Muscle re-oxygenation, mechanical work and repeated sprint performance was attenuated in the altitude condition. Fatigue development was also shown to significantly decrease at the most severe hypoxic conditions (~4100 m) in motorized sprint performance (10 x 6s)¹¹. However, evidence is inconclusive examining anaerobic performance outputs such as peak power and mean power in moderate (> 1500 m) to high altitude conditions (> 2400 m), as only a few investigations in this range have been conducted to date^{1,7,11,21,43}. Further, both elite and recreationally trained athletes engage in events all over the world that involve high-altitude performance, thus, understanding its effect on power production is crucial.

Thus, the purpose of this study seeks to investigate the impact of high altitude conditions on a 60 second Wingate cycling sprint. The purpose of the 60 second sprint, versus a traditional 30 second Wingate, was previous research to date has noted a 60s maximal bout has been shown to be optimal for achieving not only peak power but involves anaerobic and aerobic contribution (more than a 30s Wingate) during this one, single test²¹. Given the oxygenation strain high altitude induces, the aim was to implement a test that is known to stress both systems, so that we may better understand the impact of altitude on fatigue. Therefore, the aim of this study is to identify the impact of hypoxic conditions (2438 m) on anaerobic capacity (mean and peak power and fatigue index) compared to sea level (0.305 m). The 60s sprint test was used to assess an individual's lower-body peak power, anaerobic capacity, and the reduction of power, known as fatigue index⁵¹. As a result of the limited oxygen availability, our hypothesis is: peak power will not be compromised, however, mean power, and fatigue index at an elevation of 2438 m (8,000 ft) during a maximal bout of exercise will decrease compared to sea-level conditions.

Methods

Participants

A power analysis conducted with G*POWER 3.1 (Universitat Kiel, Germany) determined that 27 participants were needed in the present study for a power of 0.80, with an effect size of 0.5 and an $\alpha = 0.05$. Nineteen college (20.1 \pm 0.9 yrs.) recreationally trained individuals participated in this study; 7 male and 12 females (body mass (BM) 72.47 \pm 17.73 kg, height 173.96 \pm 8.75 cm). Inclusion criteria specified that subjects were moderately trained (> 3x a week of a combination of endurance and resistance training for at least 3 months), without injury in the last three months, and who were not specifically trained in cycling. Exclusion criteria specified individuals who were > 25 years old, had a history of asthma or other exercise health related concerns, or a positive physical activity readiness questionnaire (PAR-Q). Our focus was to investigate young adults (18-25); this age group was also used in a previous study investigating the Wingate test to predict short-term high-intensity performance in the field of exercise physiology testing³⁴. Recruitment of young healthy individuals was to minimize the risk for adverse health events as well as used a convenience sample, as this study was collected at a university. Participants were asked to maintain their typical training habits or dietary intake for the duration of the study which could have impacted their performance in the study. All participants

provided written informed consent prior to participation and the Institutional Review Board at Georgia College & State University, Milledgeville approved the protocol.

Protocol

General Design

This was a three-week single-blinded randomization study, subjects un-knowing of which condition they were going to be in which was divided into two distinct sessions; (1) 60s sprint maximal effort test in altitude condition 2,438 m (8,000 ft); (2) 60s Wingate maximal effort test in sea level (100 m). Nine participants performed the control first and ten participants performed the hypoxic condition for their first visit. The participants were unaware of the change in altitude; however, the researchers knew the condition prior to testing. Between testing weeks, subjects were asked not to change their exercise habits to prevent any major changes in training status. Both conditions were performed during the daytime between 9AM-5PM EST. Subjects were instructed to eat a “light- meal” before testing and not to consume food or caffeine for three hours prior. To ensure reliability, subjects performing the testing on the same day and time each week. During session one, subjects completed PAR-Q and an informed consent form (IRB protocol #10586). If positive signs/symptoms were documented by the subject, that subject was excluded from the study. Before the exercise bouts, body mass, height, and age were recorded.

Testing procedures and standardization

All subjects wore clothes they were comfortable exercising in, such as dry fit, light material clothing, and sneakers. Prior to the maximal bout, subject’s body mass (balance beam scale) and height were recorded. Subjects were fitted for their optimal seat height on the Monark 915E cycle ergometer by aligning the seat at the level of the participant’s iliac crest. Each subject completed both trials (with and without altitude) in the Hypoxico Altitude Tent (Hypoxico Inc, New York, New York) in order to keep the testing environment consistent. The temperature (20- 22°Celsius) and humidity (35-50%) of both conditions were recorded and held consistent for both trials. An experienced researcher was always present in the altitude chamber to ensure safety, monitor symptoms of the participant, record oxygen saturation (O₂) using a finger pulse oximeter (ChoiceM Med MD300C2, Bristol, PA), and control for any variables that may compromise study results. Prior to taking O₂ readings within the hypoxic environment, an oxygen sensor (Handi Oxygen Monitor, Hypoico, Inc., New York, NY), was calibrated two hours prior to testing to ensure reliability and validity. This was done to ensure the altitude tent was at 2,438 m (8,000 ft) of elevation prior to testing at altitude.

Sprint testing

Each subject was given a 3-minute warm-up period on the unweighted Monark 915E cycle ergometer, at 50 revolutions per minute. Resistance for assessment of both peak power and mean power for the 60s test was based on previous research²¹ 0.05 kg per pound of body weight for the entire duration of the test, regardless of sex. After the warm-up period, 0.05 kg of weight per pound of body weight was added onto the Monark weight basket. The testing procedure consisted of the subjects performing a 10-second countdown phase and a 60s all out pedaling phase. The first five seconds of the countdown were intended for the subjects to begin pedaling at a comfortable cadence (>50 rpm) and become situated on the ergometer; the last five seconds was intended for the subjects to maximally “spin-up” at a maximal cadence. At the end of the 3-minute warm up, the subjects pedaled at their maximum speed against the resistance calculated per subject. All subjects were instructed to continue to maximally pedal for the entire 60s without stopping. Peak power and anaerobic capacity were assessed using Wingate software and recorded in watts (W) and watts per kilogram body weight (W/kg). The peak power recorded was the maximal power output achieved during the first 5 seconds of the test⁵¹. The anaerobic capacity, or mean power, was recorded and averaged over the entire 60s tests⁵¹. The difference in power output from highest (i.e, peak power) to lowest (i.e., minimum power) was recorded as the percent drop-off, or fatigue index⁵¹. After completion of the test, subjects performed a ‘cool down’ by walking around the perimeter of the exercise science lab for 5 minutes while being monitored by the principal researcher in the case of any medical emergencies. This protocol was performed both sea level and hypoxic condition. However, in the altitude condition, subjects were asked sit for five minutes prior to the warm-up in the tent at 2,438 m (8,000 ft) to ensure familiarization to the new oxygen saturation.

Altitude Tent

The test was performed within a customized tent (Hypoxico. Inc., New York, NY) designed to mimic a hypoxic environment when accompanied with two hypoxic generators (Hypoxico Inc., Everest Summit II, New York, NY). The tent is enclosed entirely with openings for hypoxic air to be pumped into the tent. Once the tent is entirely closed, the hypoxic air is pumped into the tent until the desired oxygen content is met to mimic the 2,400-2,500 m elevation. This level of elevation was maintained throughout the entire test for all participants.

Statistical Analysis

The power data was collected via Wingate software (Lode Ergometry Manager v9). A paired sample t-test was conducted to determine if a statistically significant difference exists between peak power, mean power, relative mean power, relative peak power, rate to fatigue, minimum power, and time to peak power in a 60s Wingate test in altitude and sea-level conditions. Cohen's *d* effect size was calculated to assess the magnitude of the model¹⁵. The following scale was used: small effect $d = 0.2$, medium effect $d = 0.5$ and large effect $d = 0.8$ ¹⁵. The data was inputted into a SPSS program (23.0). The alpha level is set at $p = 0.05$.

Results

Table 1 presents the means and standard deviations from the participants, and Table 2 shows the paired-sample t-tests in both conditions. There was a statistically significant difference observed in the mean power at $p < 0.05$ and relative mean power mass at altitude at $p < 0.05$. No statistical significance ($p > 0.05$) was found for peak power, fatigue index, minimum power, time to peak power, and relative peak power. Cohen's *d* effect size revealed a medium effect for rate to fatigue, time to peak power, and relative peak power (Table 2).

Table 1. Descriptive Statistics of Participants

Variable	<i>N</i>	<i>M</i>	<i>SD</i>
AGE	18	20.10	0.90
BODY MASS (kg)	18	72.47	17.73
HEIGHT (cm)	18	173.96	8.75

Table 2. Descriptive Statistics of 60s Wingate at Altitude and Sea Level

VARIABLES	SEA LEVEL	ALTITUDE	p VALUE	COHEN'S <i>d</i>	EFFECT SIZE <i>r</i>
MEAN POWER (W)	344.11 ± 95.35	331.52 ± 102.04	0.01*	0.13	0.06
PEAK POWER (W/sec)	660.11 ± 227.88	626.16 ± 227.88	0.19	0.15	0.07
RATE TO FATIGUE (W/sec)	8.92 ± 3.92	7.95 ± 4.31	0.08	0.24	0.12
TIME TO PEAK POWER (s)	4.24 ± 1.24	3.80 ± 1.30	0.16	0.35	0.17
RELATIVE MEAN POWER (W/kg)	4.7 ± 1.00	4.51 ± 1.06	0.01*	0.18	0.09
RELATIVE PEAK POWER (W/kg)	8.86 ± 2.19	8.29 ± 2.34	0.07	0.25	0.12

*Note. Values are mean ± SD. W = Watts, W/kg = watts/body mass, s = seconds

Discussion

The purpose of this research study was to measure and examine the effects that altitude has on specific variables of the anaerobic energy system contribution during a maximal 60s sprint on a cycle ergometer.

This study found that the mean power and relative mean power were the only variables significantly affected at this specific altitude 2,438 m (8,000 ft). Mean power indicates how much power an individual was able to maintain throughout the duration of the test⁶. Mean power is lower at altitude due to the inability to maintain as much power throughout the entire test compared to sea-level^{20,51}. Based on these results, altitude likely has a negative effect on the aerobic energy production during a sixty second sprint test, compromising mean power productivity. Peak power, relative peak power, and fatigue index resulted in a lack of significance at this specific altitude of 2,438 m (8,000 ft). Thus, these variables were unaffected by completing a 60s sprint test at altitude.

The body undergoes several physiological responses in a hypoxic environment. Hypoxia is defined as a physiologic state of deoxygenation in the body's tissues caused by either environmental factors, such as increased elevation, or intrinsic factors, such as chronic obstructive pulmonary disease or congenital defects^{1-3,7,17-19,25,27,32,35,36,41-43,50}. In response to hypoxia, some of the physiological adaptations or responses may be altered, including, increased cardiac output, elevated heart rate, decreased cerebral oxygenation, increased cerebral blood flow velocity, decreased cerebrovascular autoregulation, increased muscle sympathetic discharge, increased skeletal blood flow, decreased peripheral blood oxygenation (SpO₂), decreased skeletal muscle oxygenation, and reduced muscle force-generating capacity^{5,18,27}. Based on our findings, mean power was reduced at an altitude of 2,438 m (8,000 ft). This could be due to a decreased oxygen availability and utilization at altitude thus, affecting the ATP turnover rate to maintain power output. At altitude, the subject's physiological responses and aerobic system was likely stressed which could have affected the mean power rate⁴⁶. Thus, without sufficient oxygen to supply the working muscles, the mean power output steadily decreased in the hypoxic environment.

Throughout the sixty second bout, all three energy systems performed a role. Typically, in a traditional 30 second Wingate test, the ATP-Phospho-Creatine System (ATP-PCr) and anaerobic glycolysis systems contributes most of the energy production⁴⁴. However, in this study, the aerobic system played a more substantial role around 50-60 seconds of the test^{16,21,22}. The aerobic energy system requires oxygen to produce greater ATP than the other energy systems to keep the muscles firing over a longer duration to avoid fatigue. Due to the lack of oxygen at altitude, the mean power could have been affected due to the lack of sufficient time for the aerobic system to operate at 2,438 m (8,000 ft) and keep up with the body's rapid demand for ATP energy.

Peak power in the Wingate test was unaffected by the change from sea-level to altitude. The peak power recorded is the maximal power output achieved in the first 5 seconds of the test⁵¹. Because the peak power is measured within the first five seconds of the test, it was likely unaffected due to the lack of strain on the aerobic energy system. Although controversy exists between physiologists over the measurements of the components of the energy systems, namely, the power, capacity, and relative contribution of each system during exercise, it has been generally accepted that with an exercise period of maximal effort of up to 5 to 6 seconds duration, the anaerobic phosphagen energy system dominated in terms of the rate and proportion of total ATP regeneration in this study⁴. Since this energy system does not require oxygen, the decrease in oxygen saturation would therefore have no effect on the peak power. The phosphagen system primarily supplies the ATP necessary to supply the body with energy during the first five seconds of exercise or physical exertion, which is the exact time that the peak power was measured⁴⁸. It can be stated that the phosphagen system was primarily responsible for supplying energy to the muscles and allowing them to exert the maximal amount of power without being affected by the oxygen level.

While our study does have many limitations to highlight, we still feel it is an important contribution to the literature as altitude research is scarce, especially at high altitude. A limitation of our study may be that the sample size was small and underpowered, and we did not perform a familiarization trial of the 60s Wingate test, which is a limitation. However, since there was a randomization of order of tests performed, if there was any familiarization needed, it is possible that the randomization may have eliminated the learning effect associated with the test. Further, we did not have an equal number of men and women, and men tend to have higher strength and power, while women, more resilience to fatigue. Since we only advertised this study via the University, one way to increase variability in testing is by opening the altitude test participation to the general population. We also only assessed college aged

physically active individuals (3x a week of a combination of endurance and resistance training for at least 3 months). Future research should aim at investigating a broader range of individuals (sedentary and athletes). We did not specify what “light-meal” meant, and this could be different for everyone. Furthermore, if caffeine was consumed 3h prior to testing, this could have a substantial effect on the data due to its potential ergogenic effects and peak bioavailability (Karayigit 2017). We also did not collect prior training habits (i.e., prior cycling experience (frequency and duration)) or dietary intake leading up to the test. As a result of the lack of surveillance, there is no knowledge since we did not ask the specifics of what the volunteer consumed prior to testing and could have affected the performance of the test. Future research studies should involve a familiarization trial of the 60s Wingate test, a larger sample size, control for ergogenic caffeine intake, and ensure participants are eating a similar meal prior to each of their trials.

Mean power and relative mean power were the only variables affected in hypoxic conditions at an altitude of 2,438 m (8,000 ft). However, it is not known to what extent, if any, the longer overall test duration used in the present study affected the physiological responses altitude. In agreement with a previous study²⁰, mean power output for 5-600s and 15, 60, 240 and 600 s were lower during the 14-d race at moderate-to-high altitude (2000-3000m and above 3000m). Results implicated the decrease of mean power (>240s) is likely the result of impairment of the aerobic system contribution at higher altitudes. An increase in altitude is associated with a reduction in arterial oxygen availability and oxygen delivery during exercise²⁰ Morton & Cable³³ showed, short term hypoxic training (30 min of cycling exercise occurring three times per week for 4 weeks) had no effect on anaerobic mean power performance in an incremental cycling test (10 x 1-min bouts at 80% maximum workload maintained for 2 min (W_{max}) during the incremental exercise test) post-training at sea level to altitude (2750 m)³³. The results could be attributed to a long-term familiarization exercise protocol in altitude conditions. Contrary, triathletes performed maximal 5-min time trial performance at 200, 1,200, 2,200, and 3,200m. Mean power decreased by 7.0% per 1,000m of altitude¹⁴. However, shorter duration (<60s) mean power performance research in moderate-to-high altitude is lacking; thus, minimal comparisons are available to date. The results state that the attenuation of mean power performance is reduced at an altitude of 2,438 m (8,000 ft) conditions possibly due to decreased oxygen availability providing sufficient energy at a constant rate to maintain power output.

Media-Friendly Summary

This study shows implications for athletes training their mean power in high altitude conditions. Future research should aim at investigating mean power output during a longer duration or even at a higher altitude (>8,000 ft) to elicit a greater effect of the aerobic system. Furthermore, future research should aim at investigating the differences in peak power and mean power output in males and in females in hypoxic conditions.

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