ABSTRACT

BREIT, J. T. The effects of three varying seat positions and three cadences on six physiological measurements associated with cycling. MS in Exercise and Sport Science - Human Performance, May 1995, 59 pp. (W. Floyd)

Twelve male, categorized United States Cycling Federation (USCF) cyclists (23.1 yrs, 70 in, 163 lbs, 60.37 $\dot{V}O_2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, 4.37 $\dot{V}O_2 \text{ L} \cdot \text{min}^{-1}$) performed 3 submaximal tests while riding a standard, USCF legal road bicycle mounted on a Giant C-Force indoor trainer. Seat position was altered for each submaximal test (Forward = 88 degrees, Middle = 85 degrees, Back = 82 degrees). The Ss cycled at a constant workload of 19 mph throughout all tests. This workload was attained using 3 varying cadences: Fast = 130 rpm, Medium = 90 rpm, Slow = 50 rpm. HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ & $\dot{V}O_2 \text{ L} \cdot \text{min}^{-1}$ were compared with seat position coupled with cadence and cadence independent of seat position. The data were collapsed for each stage of each test. For each S there were 9 submax values for each variable analyzed by a 2-way ANOVA with repeated measures. Significant values were further analyzed using a Tukey's post hoc test. No significant differences in physiological variables were found between 3 seat positions at 3 different cadences ($p > .05$). Significant differences were found between varying cadences ($p > .05$) independent of seat position. These differences demonstrated significant increases in physiological variables at high cadences.

THE EFFECTS OF THREE VARYING SEAT POSITIONS AND THREE CADENCES ON SIX PHYSIOLOGICAL MEASUREMENTS ASSOCIATED WITH CYCLING

A THESIS PRESENTED
TO
THE GRADUATE FACULTY
UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
MASTER OF SCIENCE DEGREE

BY
JEFFREY THOMAS BREIT
MAY 1995

COLLEGE OF HEALTH, PHYSICAL EDUCATION, AND RECREATION
UNIVERSITY OF WISCONSIN-LA CROSSE

THESIS ORAL DEFENSE

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We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

Master of Science in Exercise and Sport Science - Human Performance

The candidate has successfully completed his thesis final oral defense.

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ACKNOWLEDGEMENTS

I would very much like to thank my commitee chairperson Dr. Bill Floyd, and committee member Dr. Richard Pein, whose assistance made the timely completion of this project possible.

I would like to express special gratitude to my good friend and committee member Dr. Jeff Boyle whose friendship has made the last few years memorable.

Finally I would like to express my most sincere gratitude to my exceptional friends and family, Harold and Kathi Breit, Paul and Laurie Timm, John and Irene Steiner, Ralph Breit, and Traci Huseby. I thank you all very much.

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CHAPTER I

INTRODUCTION

Cycling events, especially at highly competitive levels, have always been tests of endurance and efficiency (Coyle et al., 1991). As a result, slight changes in rider position or cadence which may enhance the cyclist's comfort or efficiency can be magnified greatly when considering the length of the event. The cyclist's position must therefore allow for effective use of the respiratory system while allowing for optimal power output from cycling muscles (Hull & Gonzales, 1988). Changes in the biomechanical variables associated with cycling also alter joint angles, muscle lengths, and muscle moment arms (Too, 1991). These factors can ultimately affect the performance of the cyclist.

Technology has constantly pushed cycling equipment to new heights of performance. The advent of composite and exotic frame materials have significantly reduced the weight of modern bikes. Aerodynamic frames and handlebars have significantly reduced the resistance provided by the wind. In fact bike designs have become so extreme the United States Cycling Federation (USCF) cycling association has been forced, for safety sake, to put restrictions on bikes, especially those used in mass start road races.

Typical mass start road races vary in distance from race to race. They are generally considered to be "long" endurance events, consisting of distances approximately 30 - 200 miles in length, depending on the competition level of the race. When considering the length of these competitions it is obvious that endurance and efficiency play a crucial role in optimizing performance.

Much of today's modern equipment has been prohibited from competition. The problem of increasing a rider's efficiency may have to be examined, not for the equipment they use, but in how legal "standard" equipment is used (Zahradnik & Drake, 1991).

Body position and pedaling cadence need to be further investigated (Ryschon & Stray, 1990). This is particularly true in regards to a rider's fore and aft seat positions and how these positions can be optimized by specific pedaling cadences. Typically, research done on this topic has failed to adequately represent typical competitive cycling situations. Research related to these areas has commonly used inappropriate subjects and cadences, and unrealistic cycling equipment. These facts demonstrate a need for research to better represent conditions which accurately depicts "sport specific" cycling conditions.

Statement of Purpose

Aerobic efficiency is a complex topic comprised of many physiological factors (Faria & Cavenaugh, 1978). The factors essential to accurately measuring the aerobic efficiency of a cyclist are: 1) Heart rate (HR); 2) ventilatory equivalent ($\dot{V}_EO_2$); 3) ventilation ($\dot{V}_E$); 4) respiratory exchange ratio (RER); 5) rating of perceived exertion (RPE); and, 6) Oxygen consumption $\dot{V}O_2$ (ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1}). The purpose of this study was to analyze these factors under varying seat positions and cadences using techniques which would accurately depict "sport specific" cycling situations.

Statement of Problem

The problem of this study was to examine the effects of three seat positions at three cadences on HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml · kg^{-1} · min^{-1} during "sport specific" cycling situations.

Hypotheses

The following null hypotheses were tested in this study.

1. There will be no significant difference in HR in subjects cycling at any of three seat positions during submaximal performances by USCF categorized cyclists.
2. There will be no significant difference in $\dot{V}_E$ in subjects cycling at any of three seat positions during submaximal performances by USCF categorized cyclists.
3. There will be no significant difference in $\dot{V}_EO_2$ in subjects cycling at any of three seat positions during submaximal performances by USCF categorized cyclists.
4. There will be no significant difference in RER in subjects cycling at any of three seat positions during submaximal performances by USCF categorized cyclists.
5. There will be no significant difference in RPE in subjects cycling at any of three seat positions during submaximal performances by USCF categorized cyclists.
6. There will be no significant difference in $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1} in subjects cycling at any of three seat positions during submaximal performances by USCF categorized cyclists.

7. There will be no significant difference in HR, in subjects cycling at any of three cadences during submaximal performances by USCF categorized cyclists.
8. There will be no significant difference in $\dot{V}_E$ in subjects cycling at any of three cadences during submaximal performances by USCF categorized cyclists.
9. There will be no significant in $\dot{V}_EO_2$ in subjects cycling at any of three cadences during submaximal performances by USCF categorized cyclists.
10. There will be no significant difference in RER in subjects cycling at any of three cadences during submaximal performances by USCF categorized cyclists.
11. There will be no significant difference in RPE in subjects cycling at any of three cadences during submaximal performances by USCF categorized cyclists.
12. There will be no significant differance in $\dot{V}O_2$ ml $\cdot$ kg^{-1} $\cdot$ min^{-1} & $\dot{V}O_2$ L $\cdot$ min^{-1} in subjects cycling at any of three cadences during submaximal performances by USCF categorized cyclists.

Assumptions

The following assumptions were made in this study:

1. The subjects all gave their best, honest effort when performing each test.
2. The subjects were all healthy and free from fatigue at the time of the test.
3. The subjects had not consumed alcohol within 24 hours prior to the test.
4. The subjects' bicycles used during all tests fit them properly.

5. Testing conditions remained constant for each test and were of equal operating condition.
6. Subjects had not consumed a large meal (over 500 calories) within 3 hours prior to the test.
7. The amount of learning which may have taken place between tests was minimal.
8. The Q-Plex was properly calibrated and in good working condition for each test.
9. The subjects did not receive additional training between tests.
10. Any differences in energy cost due to the physical differences in bicycles used by the subjects were minimal.

Limitations and Delimitations

1. Subjects for this test were categorized USCF male cyclists.
2. All tests were done in an indoor laboratory environment.
3. Individual training methods for subjects were not controlled prior to the tests.
4. To replicate the subjects' actual cycling situation, subjects rode their own bicycles at their standard seat height. However, the same rear wheel was used on each bicycle for each test to assure identical workloads for all tests.
5. The results of this study are restricted to the positions and cadences used during the test for subjects.
6. The influence of testing equipment on the efficiency of the subject due to stress or discomfort was minimal.

Definition of Terms

The following terms were used in this study:

Aft Saddle Position - the aft saddle position, as defined in this study, is a seat position producing an 82 degree angle between the floor and a line passing threw the bottom bracket to the tip of the seat.

Borg Rating of Perceived Exertion Scale - a scale labeled 6 - 20, each number describing a fatigue depicting word or phrase. The numbers of the scale also correlate closely to heart rate and other physiological factors (see Appendix B).

Cadence - cadence is defined for this study as the revolutions per minute of the pedals.

C-Force Indoor Trainer - a device whereby the rear wheel of the bike is mounted atop an axle connected to a fly wheel to provide a constant resistance at a given rear wheel speed. The trainer also helps maintain a stable bike position.

Drop Bar Position - a riding hand position in which the rider's hands grasp the lower position of the bars resulting in a flat back, forward leaning position.

Efficiency - the ratio between the amount of work produced and the amount of energy put into a task.

Heart Rate - the number of heart beats per minute.

Maximal Oxygen Consumption - ($\dot{V}O_2$ max) The maximal amount of oxygen a person can take in, transport, and use per minute per unit of body weight during a maximal exertion.

Q-Plex I - metabolic gas analysis cart used to analyze and measure the body's physiological parameters.

Respiratory Exchange Ratio - a ratio of carbon dioxide produced by the body and oxygen consumed by the body.

Standard Modern Racing Bicycle - consists of basic racing equipment suitable for a mass start race as regulated by USCF standards.

United States Cycling Federation - (USCF) the United States amateur road cycling association.

USCF Cyclist - cyclists currently holding a United States Cycling Federation cycling licenses category 1 - 5.

Ventilation - ($\dot{V}_E$) the volume of air breathed per minute. It is the product of tidal volume and breathing frequency.

Ventilatory equivalent for oxygen - ($\dot{V}_EO_2$) the volume of ventilation per unit of oxygen consumed.

CHAPTER II

RELATED LITERATURE REVIEW

Introduction

Cycling is a very diverse sport. Events such as track cycling, mountain cycling, and road cycling fall under the heading of "cycling." This literature review and study focused on the road cycling aspect of the sport.

Many advancements have been made in the world of cycling over the years. Innovative new products like aerodynamic wheels, composite frame materials, and titanium components have in recent years made bikes lighter, faster, and more responsive (Zahradnik & Drake, 1991).

Although much has been done to advance how the equipment of the bike is made, little has been done to change how the bike is ridden. With the exception of aerodynamic handlebars, which are illegal in most mass start cycling events, the position of the rider on the bike has not changed significantly since the early years of the sport (Too, 1989).

The purpose of this study was to examine the effects of three seat positions at three different cadences on HR, RER, RPE,$\dot{V}_{E}O_2$, $\dot{V}_{E}$, and $\dot{V}O_2$ ml $\cdot$ kg^{-1} $\cdot$ min^{-1} & $\dot{V}O_2$ L$\cdot$ min^{-1} during "sport specific" cycling situations. The areas of literature review of significant importance to this study were: the biomechanics of the cycling position, physiological testing of cycling performance, and the effect cadence has on cycling efficiency.

Biomechanics of Cycling

Cycling efficiency can be affected by many variables. How the rider interacts with the bike is essential, not only for efficiency, but also for the comfort of the rider. The biomechanical variables of cycling essential to rider efficiency and comfort are: (a) seat position; (b) changes in body configuration and orientation; (c) the interaction of workload, power output, and cadence (Too, 1990).

The challenge for biomechanists is to determine in what position should the rider be to take full advantage of not only the respiratory system, but the muscular system as well. Too (1989, 1990) stated that for maximal aerobic energy expenditure and total work output, performance in the 75 degree seat tube angle position was significantly greater than in other positions. Too (1989, 1990) used a seat position in which the rider's back was supported and the rider's seat angle was adjusted by as much as 45 degrees. These studies were done on equipment which did not resemble typical cycling equipment; instead, equipment resembling a recumbent style bike was used. Data gathered using equipment which is not "sport specific" has little practical value for USCF categorized cyclist. Thus, the need for further research using methods which are more "sport specific."

Little information has been gathered by biomechanists on variable seat positions using equipment that resembles actual road bike equipment. This lack of research may be due to the difficulty encountered when adjusting the equipment to accommodate the positions needed for a realistic, "sport specific" test.

The Effect of Cadence on Cycling Efficiency

Cadence and pedal stroke are terms often used together. However, they have two very different meanings. Cadence is the rate at which the pedals are being turned, usually expressed as revolutions per minute (Kroon, 1983). Cadence is very easily measured and many of today's cycling computers measure cadence along with miles per hour. These measurements are then displayed on the computer's view screen mounted on the handlebar. Pedal cadence can be of vital importance to the cyclist since improper pedal cadence can lead to premature muscle fatigue, poor aerobic efficiency, and rider discomfort as well as several strategic performance problems (Gregor & Rugg, 1986).

Many studies have determined what cadences are best given certain cycling situations. According to Coast, Cox, and Welch (1986), optimal cadences for prolonged bouts of cycle ergometery were found to be 60 to 80 rpm. These cadences were found to be optimal for both efficiency and rating of perceived exertion for a group of five trained cyclists. Unfortunately, this study used bike ergometers, not actual road racing cycling equipment. The use of equipment not "sport specific" to competitive cycling may produce data which is also not specific to cycling. This fact demonstrates a need for additional research using "sport specific" equipment.

For cycling bouts of shorter duration and greater intensity, cadences of approximately 80 rpm produced higher $\dot{V}O_2$ max results (Faria & Cavenaugh, 1978). Faria and Cavenaugh (1978) also stated that racing cyclists prefer a cadence of 90 -100 rpm.

These data suggest that when selecting cadences for trained cyclists it may be advisable to choose a cadence which would produce a high $\dot{V}O_2$ while maintaining a rate preferred by the cyclist. Based on the information given in the above studies, cadences of 80 - 90 rpm may be optimal for some trained cyclists.

The pedal stroke of a cyclist is a means of describing the technique used by the cyclist while pedaling (Swain & Wilcox, 1992). Grading a cyclist's pedal stroke is difficult. To date there is no way to determine and grade a cyclist's pedal stroke in a quantitative manner. This fact makes analysis of this aspect of a cyclist's performance difficult. However, this does not mean it should be disregarded as a potential threat to efficiency (Swain & Wilcox, 1992).

Physiological Testing of Cycling Performance

Road cycling is undoubtably an aerobic endurance event. According to Hopkins and McKenzie (1994), performance in aerobic endurance events depends heavily on $\dot{V}O_2$ max and the ability to sustain a high percentage of that max over time. This demonstrates a need for researchers to be able to accurately measure the physiological parameters of the cyclist.

Hopkins and McKenzie (1994) stated that accurate determination of a cyclist's physiological parameters has been shown to aid in the training and ultimately the performance of the cyclist. Coyle et al., (1991) demonstrated a high correlation between max $\dot{V}O_2$ and endurance cycling performance. Research that accurately measures a cyclist's max $\dot{V}O_2$ would provide the potential for tracking and training that physiological parameter.

Bolourchi, Hull (1985) and Hopkins, McKenzie (1994) and Sjogaard, (1984) have suggested that for cyclists, treadmill running and cycle ergometery are both realistic methods of measuring physiological response's to activity. When measuring max $\dot{V}O_2$, treadmill running has shown to provide values 5 -10% greater than cycle ergometery in recreational cyclists (McKay & Bannister, 1976). Hagberg, Mullin, Giese, and Spitznagel (1981) demonstrated that when measuring the max $\dot{V}O_2$ of elite cyclists (65-69 $\dot{V}O_2$ ml $\cdot$ kg^{-1} $\cdot$ min^{-1}) on both a treadmill run and cycle ergometer, values were higher on the cycle ergometer.

These studies demonstrate that physiological analysis of cyclists is possible. They also demonstrate that these analyses can be accurately determined for specific sport populations.

The competitive nature of sport is ever increasing. This results in the need for athletes to achieve consistently greater levels of performance. To accomplish this, training methods need to be as "sport specific" as possible. The exercise research community has an obligation to be equally as "sport specific" and to gain innovative knowledge which can be used to enhance the specific needs of the athlete.

Much of the research (Bolourchi & Hull, 1985; Hopkins & Mckenzie, 1994; Sjogaard, 1984) has been done on equipment not specific to the sport of cycling. These studies do not accurately depict the athlete's true area of expertise.

Advancements in testing equipment which will better simulate specific road cycling equipment are being developed. Somerville and Qiunney (1987) attempted to design a fully adjustable bike ergometer. This ergometer was designed to simulate the typical road racing bicycle geometry. Subjects tested on this ergometer reported a more favorable opinion of the adjustable cycle ergometer over the standard Monarch ergometer. These same subjects also reported a preference of their own bike over the adjustable cycle ergometer.

These studies suggest perhaps the most effective way to test trained cyclists in a "sport specific" manner is to test the subjects using their own cycling equipment. Many studies (Henke, Wehmeyer & de Marees, 1987; Ryschon & Stray-Gunderson, 1991; Swain & Wilcox, 1992) have used subjects' own equipment, or actual cycling equipment replicating the subjects' own equipment. These tests have been performed in various conditions with positive results.

Summary

The ability to go farther, faster, and more comfortably is undoubtably a desire of many cyclists. Modern biomechanical and physiological research has demonstrated the potential for improvement in positioning, pedal cadence, and physiological analysis of the cyclist; improvements to help cyclists achieve optimum performance.

Surprisingly, little has been shown in the literature which demonstrates the physiological response of cyclists at varying cadences when compared to varying seat positions. Even less research has been done testing cyclists using techniques which accurately replicate the specific equipment and techniques used in the sport of cycling. Much of the research done in regards to these variables has tested the two separately. The cyclist's efficiency depends greatly on both of these factors and how they interact.

To measure the efficiency of a cyclist in a laboratory setting that will accurately depict the cyclist's efficiency under natural conditions, the cyclist should be tested using combinations of variables. Variables should accurately depict the conditions experienced in a natural training environment and should include the positioning, cadence, and physical comfort of the cyclist.

Thus, the purpose of this study was to examine the effects of three seat positions at three different cadences on HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1} during "sport specific" cycling situations.

CHAPTER III

METHODOLOGY

Introduction

The purpose of this study was to examine the effects of three seat positions at three different cadences on HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml $\cdot$ kg^{-1} $\cdot$ min^{-1} & $\dot{V}O_2$ L $\cdot$ min^{-1} during "sport specific" cycling situations. This chapter will include a description of the methodology used to complete this study.

Subject Selection and Parameters

This study used 12 male subjects, ranging from 18 to 30 years of age. These subjects all held current USCF category 1-5 racing licenses. Therefore they were assumed to be currently training and competing at the level of their category. These subjects were obtained on a volunteer basis from Wisconsin and Minnesota.

Preliminary Information

Prior to testing, any subject without previous knowledge and experience with all of the equipment used in any part of the study was given an opportunity to perform a practice session of their own design to familiarize themselves with the equipment. Subjects were allowed to practice with the equipment until they felt comfortable. Practice sessions were very brief with the longest lasting about 5 minutes. For comfort and familiarization purposes, subjects tried on the head gear used in the gas analysis test by the Q-Plex I.

Pretest Procedures

Each subject reported to the Human Performance Laboratory at the University of Wisconsin-La Crosse at a predetermined, but not consistent, time of day. Each subject was required to bring to the testing session the following equipment: cycling apparel, cycling shoes, and a personal racing road bike.

Prior to participation in the practice session, subjects were required to read and fill out an informed consent form (see Appendix A).

Prior to testing, all subjects were familiarized with the tests they were to perform. Subjects were also familiarized with any foreign equipment or procedures associated with the testing.

Equipment Selection and Explanation

The following equipment was used for this study: Quinton Q-Plex (Seattle, WA) metabolic cart and related apparatus, Giant C-Force indoor trainer, the subjects' individual racing road bikes with clip-in pedals and personal shoes, Cateye Astrale cycling computer, and UNIQ heart rate monitors.

The Quinton Q-Plex I metabolic cart was used for all gas analyses performed during this study. Subjects were required to wear a Hans Rudolph headset and mouthpiece, as well as a nose clip. Gasses expired traveled through a 6 foot, flexible plastic tube to enter the metabolic cart for analysis.

Subjects performed all tests on their own bike and were performed at the seat height they were accustomed to riding. Seat height was maintained throughout all tests helping maintain the subjects' learned pedal stroke at that seat height. Changing the subjects' seat height might have altered their learned pedal stroke and efficiency may have been effected. It was assumed that each subject was properly fitted for their racing bike.

Each subject's bike was slightly altered for the tests. A standard eight speed rear wheel was fitted on the bike. The wheel consisted of a Continental clincher tire inflated to 120 psi, Mavic open 4 cd rim, Wheelsmith double butted spokes with magnetic sensor attached, and a Mavic 501 free hub.

For all but the maximal oxygen consumption test, subjects used a cycling seat which had been altered. The rails on the bottom of the seat had been straightened and elongated. This seat design allowed for greater adjustability of the seat on the seat post. This increased adjustability was necessary to achieve consistent seat positions among tests.

All tests were done with the subject's bike mounted on a Giant C-Force indoor trainer which required that the rear wheel of the bike be placed in a stand. This stand held the rear wheel against an axle attached to a flywheel and as the tire of the bike revolved, it spun the flywheel. The revolving flywheel provided a constant resistant at any given speed.

Each bike was equipped with a Cateye Astrale cycling computer capable of measuring both the speed of the rear wheel and cadence (rpm of the pedals). These measurements were displayed simultaneously on the computer screen. These measurements were attained by 2 magnets passing by 2 sensors located on the frame of the bike.

UNIQ heart rate monitors were used in all tests to monitor the subjects' heart rate. The electrodes, located on the chest strap, were moistened with distilled water to assure optimal sensitivity.

Testing Procedures and Equipment Assembly

Subjects were tested in the Human Performance Laboratory (HPL) at the University of Wisconsin-La Crosse (UW-L). Upon arrival the subjects were asked to read and fill out a consent form (see Appendix A). The subjects then changed into their cycling clothing which they supplied. The subjects were weighed in their cycling apparel not including cycling shoes. The subjects' height without shoes was also taken at this time. Both height and weight measurements were recorded in English units.

Each subject supplied their own bike to be used during the tests. The subject's bike was altered in that the rear wheel was replaced by the rear wheel described above. In all submaximal tests, the seat was replaced with the test seat described previously.

The bike was mounted on a Giant C-Force indoor trainer. To do this the rear axle of the bike was clamped into the trainer which adapts itself to accommodate any standard bike. The rear wheel was held against the trainer's axle. This allowed for approximately 1.5 cm of contact between the tire and the axle and contact was maintained throughout the testing procedure by maintaining a consistent 120 psi tire pressure. The axle of the trainer was attached to a flywheel. The revolution of the rear wheel resulted in the revolution of the flywheel. The revolving fly wheel provided a consistent resistance at any given speed measured off the rear wheel.

The nature of the trainer resulted in a rear wheel elevation of 3.25 inches. To maintain a level bike position a wooden block 3.25 inches high was inserted under the front wheel.

During all tests the subjects were required to wear UNIQ Heart rate monitors (CIC, Inc.). These monitors consisted of a heart rate watch and a chest strap. The chest strap contained electrodes which detect the heart rate. The watch displayed the measured heart rate. To increase their sensitivity, the electrodes were moistened with distilled water. Heart rate was then read off the watch. These heart rates were recorded on the Q-Plex for further analysis during the final 15 seconds of each minute of all tests.

Gasses expired during the tests were measured using the Quinton Q-Plex I (Seattle, WA). Subjects were required to wear a Hans Rudolph head support, mouthpiece and valve, and nose clip. Gases expired traveled to the Q-Plex by way of a 6 foot flexible plastic tube. The Quinton Q-Plex I analyzes expired gasses by way of a oxygen and infrared carbon dioxide analyzer. These analyzers were calibrated before each test session using the Scholander technique, pnumotachometer, and a IBM PC-AT computer.

Maximal VO_2 Test Procedures

Maximal oxygen consumption tests have been widely accepted as a means to determine aerobic fitness. Protocols used for these tests vary greatly and can be adapted to simulate nearly any aerobic sport. Often these tests are performed using equipment which is not specific to the athlete being tested but may produce an accurate measurement on the average individual. The subjects in this study were trained cyclists. These subjects were currently competing at one of five USCF levels. For this reason this study used a max $\dot{V}O_2$ test protocol which simulated the conditions to which these athletes were most accustomed.

For this test, subjects used their own bike equipped with their own seat, seat position, and seat height. The subjects' height, weight, age, and sex were entered into the Q-Plex. The subjects were then fitted with the Hans Rudolph headset system and attached to the Q-Plex.

The warm up for the max $\dot{V}O_2$ test consisted of a 16 mph workload for five minutes. The subjects then began the first stage of the max test which was a 16 mph workload for two minutes. Workloads were then increased by 2 mph for every two minute work stage until the subjects reached voluntary exhaustion. Subjects were allowed to choose their own cadence to gear ratio to achieve these workloads.

Heart rates were recorded during the last 15 seconds of each minute and ratings of perceived exertion were taken at the end of each stage. The data gathered by the maximal test were accepted as maximum performances only if the tests met the following criteria.

1. Plateau or drop in $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1} or greater
2. Voluntary exhaustion
3. RER of 1.1 or greater
4. An inability to hold the prescribed workload within 2 mph.

Upon the voluntary completion of the test, subjects performed an active cool down on the bike until they felt comfortably recovered. Subjects were then supervised for a minimum of 5 minutes following the subjects' dismount from the bike to assure their safe recovery.

The max $\dot{V}O_2$ test was used in this study for several reasons. The max test was administered to accurately define the physical parameters of the subjects used in this study. Determining the subjects' physical fitness level aided in the design of a workload appropriate for the submaximal tests. The max test was also used as a means by which to attract subjects for the study as many of the subjects volunteered due to the fact they could attain a max $\dot{V}O_2$ score.

Submaximal Tests

Submaximal tests were performed on all subjects. These tests were performed no sooner than 24 hours, and no later than 1 week, following their performance of the max $\dot{V}O_2$ test.

Upon arrival at the University of UW-L HPL, the subject was randomly assigned to one of six groups (see Table 1). These six groups were designed to counterbalance the sequencing of the cadences and seat positions. Twelve slips of paper were put in a hat and numbered 2 x 1-6. The subjects were then asked to select a slip to determine their assigned group. These drawings were done without replacement to assure 2 subjects per group, thus maintaining the counterbalanced format. This counter balanced format was used to assure that there would be no effect on the tested physiological variables due to the order of the trials.

Table 1. Counterbalancing order of tests

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
slow med high	slow high med	med slow high	med high slow	high med slow	high slow med
Subject #4 #7	#8 #9	#5 #2	#1 #12	#3 #6	#10 #11
front back med	med back front	back med front	med front back	back front med	front med back

Following the assignment of groups, the following steps were taken to prepare for the performance of the test. The subject's original bike seat was replaced with a San Marco Strada, standard road racing saddle. The rails on this seat had been straightened to allow for greater variability in the seat's fore and aft position. This was necessary to attain exact seat positions on varying bikes regardless of the geometry of the frame used for the test.

The seat was then set at one of the three randomly assigned seat positions. These positions were determined with the bike horizontal to the floor and a line was passed from the tip of the seat through the center of the bottom bracket to the floor. The angle measured was that of the line as it intersected the floor as shown in Figure 1.

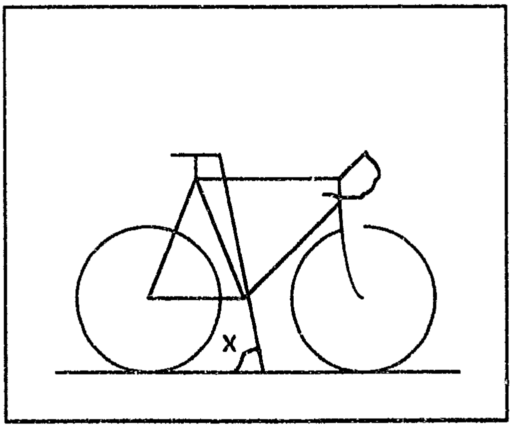

Figure 1. Seat determination set-up, angle measured marked X.

The following seat positions were used: Forward = 88 degrees, Middle = 85 degrees, and Back = 82 degrees. These measurements resulted in approximately 1 inch of seat variation forward and backward from the middle seat position depending on the bike used. The subject's original seat height, as measured by the distance from the center of the bottom bracket to the lowest part of the top of the seat, was maintained for all tests.

The following cadences were used for this study: Fast = 130 rpm, Medium = 90 rpm, and Slow = 50 rpm. The cadences and workloads (mph) were measured using a Cateye Astrale cycling computer which had been calibrated using the chart provided by the Cateye company. This computer measures the speed of the rear wheel and the cadence of the crank arms by one magnet located on the crank arm and one on the wheel. Two sensors mounted on the frame pick up these magnets as they pass and the computer calculates speed and cadence. These measurements are then displayed simultaneously on the computer screen.

Submaximal tests were treated as three independent tests. The subject performed one test at each given seat position. They were then given a minimum of 30 minutes of recovery time before the next test was performed.

Pretest procedures used for the max $\dot{V}O_2$ test in terms of subject preparation were repeated for the submaximal tests. Subjects first performed a warm up which consisted of riding at a workload of 12 mph for 5 minutes. Subjects then rode at 19 mph for each of the three 6 minute stages of the test. Subjects were required to pedal at three varying cadences, Fast = 130 rpm, Medium = 90 rpm, and Slow = 50 rpm, one for each stage, while maintaining the same 19 mph workload.

Metabolic responses were recorded every 15 seconds throughout each stage by the Q-Plex. Heart rate was recorded in the last 15 seconds of each minute. Rating of perceived exertion was recorded in the last minute of each stage (see Appendix B).

Statistical Analysis

Upon completion of all tests, data gathered during each stage of the tests were averaged. During each 6 minute work stage of the submaximal tests the following physiological parameters were recorded every 15 seconds, internally averaged by the Q-Plex and printed every minute: HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml $\cdot$ $kg^{-1} \cdot min^{-1}$ & $\dot{V}O_2$ L $\cdot$ min^{-1}. Upon gathering all the data, the representative 1 min values values for each seat position and cadence were averaged to obtain a value representing each 6 minute work stage (see Appendix C). These values were then analyzed using an independent 2-way ANOVA with repeated measures to determine any significant difference

These same values were also analyzed using a 2-way ANOVA to determine any significant differences between cadences regardless of seat position (see Figures 2-7). The exact location of these differences were identified using a Tukey's post hoc test (see Tables 4-6).

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This chapter will focus on the results of the data gathered during this study. The following variables were measured for each test submaximal: HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1}.

Data were gathered and recorded every 15 seconds throughout all tests and were averaged to obtain minute values for all tests. These averaged data were printed directly by the Q-Plex. Minute values were also averaged to obtain one representative value for each seat position and cadence per subject; essentially one average value for each 6 minute stage. These values were statistically analyzed using a 2-way ANOVA with repeated measures. The ($p > .05$) level of significance was used to accept or reject the null hypothesis. Further analysis to locate significant differences was done using a Tukey's post hoc test.

Subject Characteristics

The physical characteristics of the subjects used in this study are presented in Table 2. These characteristics are described using general descriptive statistics. The physical characteristics of the subjects used in this study are comparable to the physical characteristics of subjects used in other studies which described their subjects as trained cyclists (Coyle et al., 1991; Gregor & Rugg, 1986; Hagberg et al., 1981).

Table 2. Means, standard deviations, and ranges of subjects physical characteristics. (N = 12)

Variable	Mean	SD	Range
Age (yrs)	23.1	2.51	20 - 30
Height (in)	70	2.6	65 - 74
Wt (lb)	163	15.3	135 - 185
$\dot{V}$O2 (ml·kg^{-1}·min^{-1})	60.37	8.23	43.7 - 74.9
$\dot{V}$O2 (L.min^{1})	4.37	.73	3.02 - 5.16

The subjects described in Table 1 were all categorized USCF cyclists. These subjects all participated in various off season training programs consisting of such activities as skiing, cycling, running, in-line skateing, and weight training. All subjects were tested in the last month of their off season, thus they may not have been in top cycling condition at the time of the tests.

Maximal Oxygen Consumption

The maximum oxygen consumption values obtained using the protocol described in this study indicated the subjects were highly fit. Thus, this cycling max $\dot{V}O_2$ protocol appeared to be an acceptable means to gather maximal oxygen consumption data on cyclists in an indoor environment.

Submaximal Physiological Tests

Data were gathered and recorded every 15 seconds. during all submaximal tests. These data were averaged by the Q-Plex to obtain minute value and were averaged for each 6 minute stage to obtain one value representing that stage. The statistical tool used to analyze these values was a 2-way ANOVA with repeated measures. Further analyses of significant values were performed using a Tukey's post hoc test.

Results

The 2-way ANOVA used for the data analysis in this study measured any potential significant differences in HR, RER, RPE, $\dot{V}_{E}O_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1} in three seat positions at three different cadences.

It was found from the collapsed data (see Table 3) that there were no significant ($p > .05$) differences between HR, RER, RPE, $\dot{V}_{E}O_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L · min^{-1} while cycling at three cadences coupled with three seat positions. Thus the data failed to reject the null hypotheses regarding seat position.

Table 3. Means and standard deviations of six physiological variables as affected by seat position and cadence.

Front Position Cadence		HR	RPE	V̇O2	RER	V̇EO2	V̇E
Fast	*	133	11	28.9	0.87	23.3	48.1
	**	14.0	1.9	3.6	.051	3.41	7.9
Med		128	10.7	28.4	0.87	22.6	46.5
		12.3	1.5	4.1	0.43	2.9	7.7
Slow		126	10.6	26.5	0.84	22.2	42.2
		13.4	1.4	2.9	0.05	2.9	6.8
Middle Position							
Fast		136	11.6	30.4	0.88	22.8	48.5
		11.4	1.3	3.3	0.03	3.5	6.1
Med		130	11	29.6	0.88	22.9	48
		9.9	1.3	4.8	0.02	3.21	8.4
Slow		128	10.9	27.8	0.85	21.5	43
		10.7	1.3	3.5	0.03	3.05	6.3
Back Position							
Fast		135	11.9	29.5	0.88	28.3	47.9
		14.1	1.5	3.2	0.04	9.3	7.1
Med		131	11.2	28.1	0.87	22.3	45.9
		12.0	1.11	4.4	0.04	2.72	7.6
Slow		128	10.4	27.1	0.85	22	42.9
		14.0	1.3	3.9	0.04	2.7	7.6

Note. * = Mean ** = Standard Deviation

When data comparing three varying cadences at a given seat position were analyzed using a 2-way ANOVA with repeated measures, a significant difference was found at the ($p > .05$) level. Therefore, these data rejected the null hypotheses regarding cadence effect on HR, RER, RPE,$\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ $ml \cdot kg^{-1} \cdot min^{-1}$ & $\dot{V}O_2$ $L \cdot min^{-1}$. Tukey's post hoc tests were performed to determine where these differences lie in any of the three seat positions (see Tables 4-6). These data are also represented regardless of seat position (see Figures 2-7).

Table 4. Results of Tukey's post hoc test analyzing the effect of cadence variations on $\dot{V}O_2$, HR, RPE, RER, $\dot{V}_e$, $\dot{V}_eO_2$ in the front seat position.

Front seat position

Variable	Slow cadence	Medium Cadence	Fast Cadence
HR	126	128	133 ***
$\dot{V}O_2$	25.55	28.4*	28.9*
RPE	10.65	10.7	11
RER	.84	.87*	.87*
$\dot{V}_E$	42.29	46.5	48.1*
$\dot{V}_EO_2$.	22	22.6	23.35

Note. * = Mean significantly greater than slow cadence

** = Mean significantly greater than medium cadence

*** = Mean significantly greater than slow and medium cadence

Table 5. Results of Tukey's post hoc test analyzing the effect of cadence variations on $\dot{V}O_2$, HR, RPE, RER, $\dot{V}_e$, $\dot{V}_eO_2$ in the middle seat position.

Middle seat position

Variable	Slow cadence	Medium Cadence	Fast Cadence
HR	128	130	136.5***
$\dot{V}O_2$	27.87	29.68*	30.46*
RPE	10.9	11	11.6
RER	.85	.88*	.88*
$\dot{V}_E$	43	48	48.56*
$\dot{V}_EO_2$.	21.5	22.95	22.8

Note. * = Mean significantly greater than slow cadence

** = Mean significantly greater than medium cadence

*** = Mean significantly greater than slow and medium cadence

Table 6. Results of Tukey's post hoc test analyzing the effect of cadence variations on $\dot{V}O_2$, HR, RPE, RER, $\dot{V}_e$, $\dot{V}_eO_2$ the back seat position.

Back seat position

Variable	Slow cadence	Medium Cadence	Fast Cadence
HR	128	131*	135***
$\dot{V}O_2$	27.1	28.1	29.5
RPE	10.4	11.2*	11.9
RER	.85	.87	.88*
$\dot{V}_E$	42.9	45.9	47.9
$\dot{V}_EO_2$.	22	22.3	28.3***

Note. * = Mean significantly greater than slow cadence

** = Mean significantly greater than medium cadence

*** = Mean significantly greater than slow and medium cadence

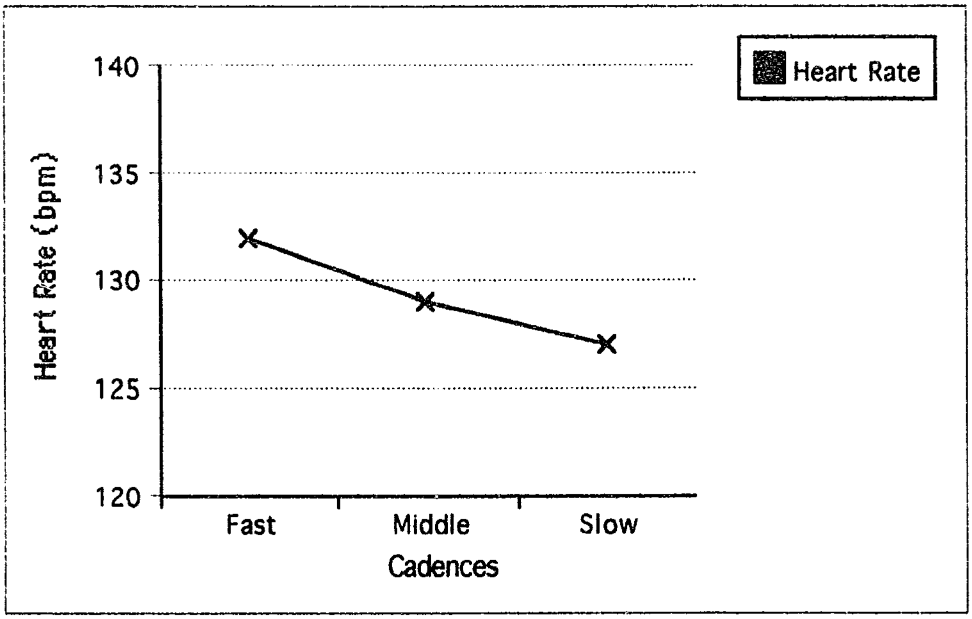

Figure 2. HR means at varying cadances independent of seat positon.

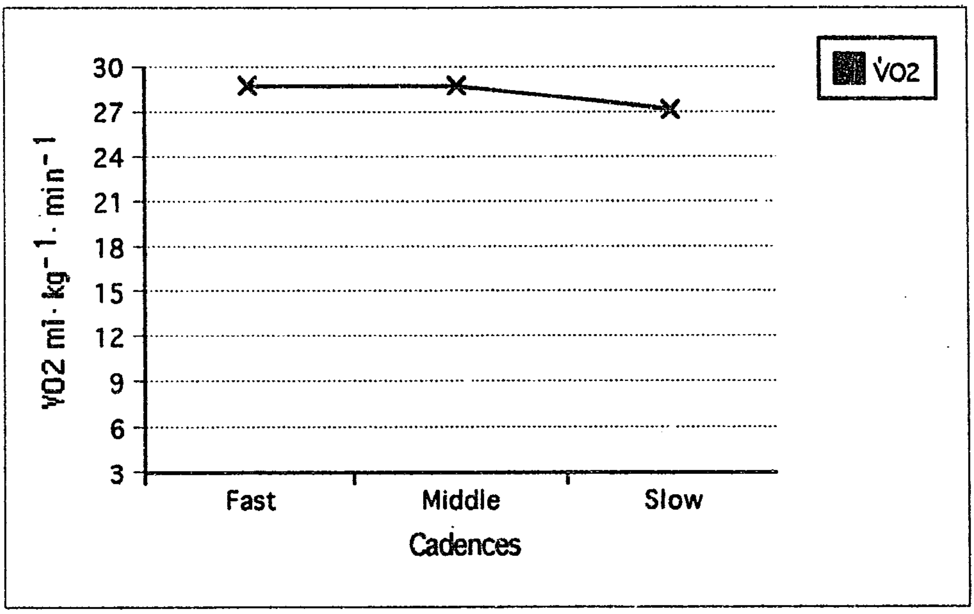

Figure 3. $\dot{V}O_2$ means at varying cadances independent of seat positon.

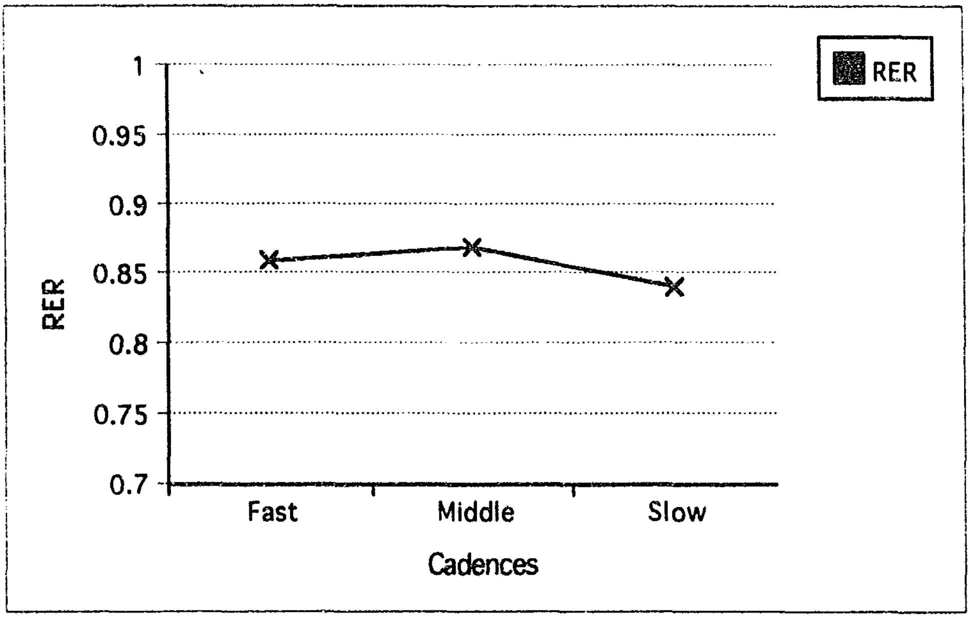

Figure 4. RER means at varying cadances independent of seat positon.

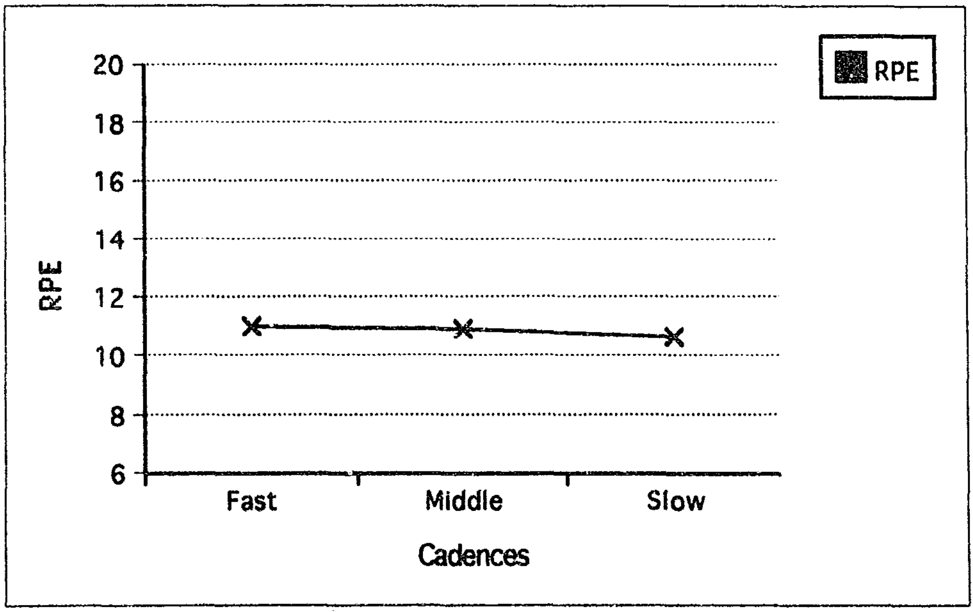

Figure 5. RPE means at varying cadances independent of seat positon.

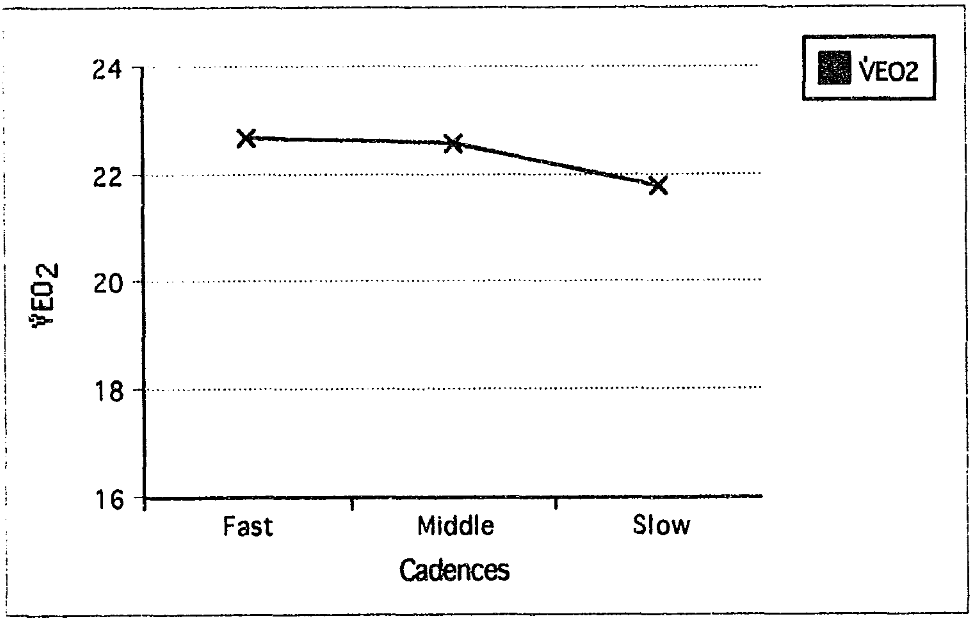

Figure 6. V̇EO2 means at three cadances independent of seat positon.

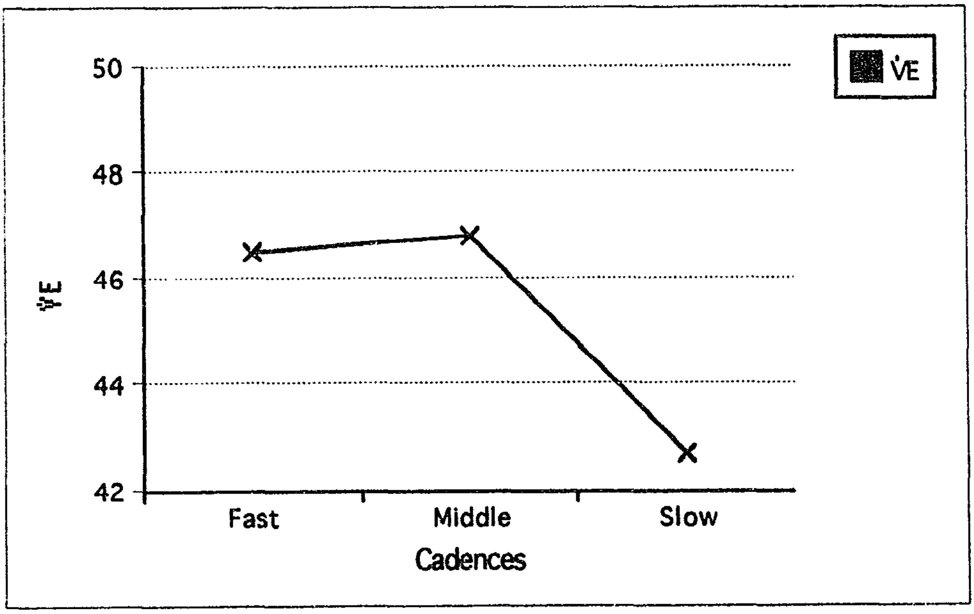

Figure 7. V̇E means at varying cadances independent of seat positon.

Test of Hypotheses

The following null hypotheses were either rejected or failed to be rejected based on the data of this study.

1. There were no significant differences in HR in subjects cycling at any of three different seat positions during submaximal performances by USCF categorized cyclists. The null hypothesis failed to be rejected.
2. There were no significant differences in $\dot{V}E$ in subjects cycling at any of three different seat positions during submaximal performances by USCF categorized cyclists. The null hypothesis failed to be rejected.
3. There were no significant differences in $\dot{V}_EO_2$ in subjects cycling at any of three different seat positions during submaximal performances by USCF categorized cyclists. The null hypothesis failed to be rejected.
4. There were no significant differences in RER in subjects cycling at any of three different seat positions during submaximal performances by USCF categorized cyclists. The null hypothesis failed to be rejected.
5. There were no significant differences in RPE in subjects cycling at any of three different seat positions during submaximal performances by USCF categorized cyclists. The null hypothesis failed to be rejected.
6. There were no significant differences in $\dot{V}O_2$ ml$\cdot$ kg$^{-1}\cdot$ min^{-1} & $\dot{V}O_2$ L$\cdot$ min^{-1} in subjects cycling at any of three different seat positions during submaximal performances by USCF categorized cyclists. The null hypothesis failed to be rejected.

7. There were no significant differences in HR, in subjects cycling at any of three different cadences during submaximal performances by USCF categorized cyclists. This null hypothesis was rejected.
8. There were no significant differences in $\dot{V}_E$ in subjects cycling at any of three different cadences during submaximal performances by USCF categorized cyclists. This null hypothesis was rejected.
9. There were no significant differences in $\dot{V}_EO_2$ in subjects cycling at any of three different cadences during submaximal performances by USCF categorized cyclists. This null hypothesis was rejected.
10. There were no significant differences in RER in subjects cycling at any of three different cadences during submaximal performances by USCF categorized cyclists. This null hypothesis was rejected.
11. There were no significant differences in RPE in subjects cycling at any three different cadences during submaximal performances by USCF categorized cyclists. This null hypothesis was rejected.
12. There were no significant differences in $\dot{V}O_2$ $ml \cdot kg^{-1} \cdot min^{-1}$ & $\dot{V}O_2$ $L \cdot min^{-1}$ in subjects cycling at any three different cadences during submaximal performances by USCF categorized cyclists. This null hypothesis was rejected.

Discussion

This study analyzed what effect seat position, while cycling at a constant workload attained by three cadences, would have on six physiological variables associated with cycling. The data in this study showed no significant change in

HR, RER, RPE,$\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml. kg^{-1}.min^{-1} & $\dot{V}O_2$ L. min^{-1} of cyclist when these variables were manipulated.

This study also examined the effect varying cadences, regardless of seat position, would have on HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml · kg^{-1} · min^{-1} & $\dot{V}O_2$ L· min^{-1} of competitive cyclists. The data in this study were significant at the ($p > .05$) level. Thus the null hypotheses were rejected related to cadence alone.

The results of this study are consistent with that of Coast, Cox, and Welch (1986), which showed optimal cadences to be 60 to 80 rpm. These cadences were shown to be optimal for both cycling efficiency and rating of perceived exertion.

Too (1989, 1990) stated that for maximal aerobic energy expenditure and total work output, performance in a 75 degree seat position was significantly greater than in other positions. These findings were not consistent with the findings of this study. This may be due to the comparatively small seat adjustments made in this study as compared to those made by Too (1990).

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem of this study was to examine the effects of three seat positions at three different cadences on HR, RER, RPE, $\dot{V}_EO_2$, $\dot{V}_E$, and $\dot{V}O_2$ ml $\cdot$ kg^{-1} $\cdot$ min^{-1} & $\dot{V}O_2$ L$\cdot$ min^{-1} during " sport specific" cycling situations. Twelve male USCF categorized cyclists participated in this study. Each subject was required to perform one maximal oxygen uptake test and three submaximal tests.

The statistical analyses used for this study included means and standard deviations of all physiological variables at three different seat positions and three different cadences. The statistical tool used for the determination of significant differences between seat position and cadence on physiological variables, and three varying cadences independently on physiological variables was a 2-way ANOVA with repeated measures. Significant differences in physiological response to varying cadences at equal workloads were further analyzed using a Tukey's post hoc test. The level of significance for all statistical tests was set at $p > .05$.

The results showed no significant differences when comparing seat position with cadences on physiological variables. Significant differences in many of the physiological variables (see Table 4-6) were found when measured at three different cadences independent of seat position (see Figure 2-7).

Conclusions

Based on of the data in this study the following conclusions were made. These conclusions are restricted to the population of subjects used in this study.

1. Varying seat positions of 88, 85, and 82 degrees, coupled with any of three varying cadences; (130, 90, and 50 rpm) performed at a constant workload showed no significant effect on six physiological variables associated with cycling in male USCF categorized male cyclists .
2. At a given workload of 19 mph, cadences of 130, 90, and 50 rpm showed significant effects on six physiological variables associated with cycling in USCF categorized male cyclists.

Recommendations

The variable seat positions used in this study were designed to be applicable to actual competitive (USCF) forms of cycling. This restricted the adjustment of the seat to that which could be physically attained given the general structure of the typical road racing bicycle. This resulted in very slight seat movements of approximately 1 inch forward or backward from the middle position. This subtle change, although drastic from a cyclists point of view, may not have been sufficient enough to demonstrate any significant changes in physiological data regardless of cadence. Perhaps additional research should be done using uniquely shaped racing bikes with unusually extreme geometry.

Cycling is a relatively traditional sport. The general geometry of the bicycle hasn't changed much in the past 50 years. However, there have been some recent advancements in materials and tube shapes which have changed the weight and aerodynamics of bicycles. Unfortunately the geometry of modern (USCF) road racing bicycles has not reached the point which the seat tube geometry could be adequately researched.

Significant differences were found between varying cadence rates on physiological variables. This significant difference demonstrated significantly higher physiological responses to higher cadences than to lower cadences while performing a constant workload. This may suggest that cyclists could conserve energy represented by these physiological variables by maintaining a slower cadence.

Unfortunately, this study did not compare muscular activity to these cadences. Perhaps additional research should be done to determine whether the differences observed in physiological response to these cadences would also elicit changes in muscular activity.

Finally, this study used a relatively specific population of cyclists. The number of cyclists used in this study was only 12. Additional subjects may have been an advantage for the statistical analysis.

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APPENDIX A

INFORMED CONSENT

INFORMED CONSENT FORM
University of Wisconsin-La Crosse

Project Title: The Effect of Three Varying Seat Positions and Three Varying Cadences on Six Physiological Measurements Associated With Cycling.

Principal Investigator: Jeffrey T. Breit

I am agreeing to participate in the physiological analysis of three seat positions and three cadence rates on an indoor bicycle. In this study I will perform 3 submaximal cycling tests of approximately 30 minutes each. I will also be performing one maximal oxygen consumption test.

The maximal test will require me to perform a cycling test at an optional rpm. Workloads measured in mph. will be increased every 2 min. This procedure will be repeated until I reach a voluntary exhaustion.

All submaximal tests will be performed at one constant workload. I will be required to perform three independent tests in a random order. I will be required to pedal at three different cadence rates from each of three different seat positions.

As can be expected with any exercise testing situation, a certain degree of risk is involved. I understand that every effort was made to explain the potential risks and discomforts of exercise testing (muscle strains, soreness, dizziness, breathlessness, etc.). I understand the investigator will answer any and all questions related to procedures, risks, or benefits involved in these tests.

I________________________, being of sound mind and _____ years of age, do hereby consent to, authorize, and request the investigator named above to undertake and perform on me the proposed procedures.

I have read and understand the above document. I have been fully advised of the nature of the procedure and the possible risks and complications involved in it. All of these risks I hereby assume voluntarily.

I hereby acknowledge that no representation, warranties, guarantees or assurances of any kind have been made to me by the University of Wisconsin La Crosse, officers, administration, employees or anyone representing them.

I understand I may withdraw from the above mentioned study at any time.

______________________Date:_____ ________________Date:_____

(SUBJECT) (WITNESS)

APPENDIX B

BORG CATEGORY RPE SCALE

RATING OF PERCEIVED EXERTION SCALE (RPE)

6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

APPENDIX C

SUBMAXIMAL TEST RAW DATA

Raw Data Means and Standard Deviations for Slow Cadence, Front Seat Position

Subject	Heart Rate	RPE	V̇O2	RER	V̇EO2	V̇E
1	146	11.6	32.5	0.88	21.5	56.15
2	130	11.5	23.6	0.90	23.6	44
3	145	12.5	32.4	0.92	21.8	57.5
4	130	11.6	31.6	0.89	24.6	47.3
5	116	11	39.6	0.91	21	44.6
6	145	12.8	26.2	0.83	31.5	52.6
7	119	11	24.2	0.88	22.8	38.31
8	110	11	26.5	0.74	20.8	36.55
9	114	10.8	26.7	0.87	24.3	47.9
10	125	12	27.6	0.91	21.6	38.9
11	109	7.1	27.7	0.87	20.8	42.1
12	129	12	26.6	0.80	22.1	50.01
Mean	126	11.2	27.9	0.86	22.9	46.3
Stdev.	13.4	1.44	2.98	0.05	2.96	6.86

Raw Data Means and Standard Deviations for Medium Cadence, Front Seat Position

Subject	Heart Rate	RPE	V̇O2	RER	V̇EO2	V̇E
1	140	10.6	33.1	0.89	22	57.8
2	126	11.6	20.6	0.88	23.1	38.5
3	152	12.3	35.2	0.95	22.3	63.5
4	135	12.3	34.2	0.91	24.8	52
5	123	11.6	32	0.95	22.3	51.4
6	146	13	25.7	0.83	32.1	52.4
7	123	11.3	26.5	0.91	23.5	43.5
8	118	11.3	31.4	0.84	21.5	45.8
9	114	10.8	29.5	0.91	25	54.5
10	126	12	26.1	0.9	22.1	37.6
11	113	7	29.0	0.86	21	44.0
12	131	12	28.2	0.82	22.6	53.8
Mean	128	11.3	29.3	0.88	23.5	49.57
Stdev.	12.3	1.5	4.18	0.04	2.95	7.79

Raw Data Means and Standard Deviations for High Cadence, Front Seat Position

Subject	Heart Rate	RPE	$\dot{V}O_2$	RER	$\dot{V}EO_2$	$\dot{V}E$
1	145.5	12.8	33.9	0.91	22.6	61.3
2	136	12.6	24.7	0.92	23.8	47.1
3	155	12	36.7	0.96	22.5	67.2
4	140	13	34.5	0.94	25.6	54.4
5	129	13	34.7	0.97	23.3	58.1
6	157	14.6	29.2	0.86	33.1	62.0
7	132	13.3	30.3	0.92	24.1	51.3
8	120	12	31.1	0.83	20.5	43.6
9	112	10.1	27.1	0.93	26.3	52.6
10	130	12	30.1	0.92	22.1	43.3
11	117	7	28.8	0.87	20.6	43.2
12	130	12	26.5	0.8	26.5	55.0
Mean	133	11.3	30.64	0.90	24.25	53.2
Stdev.	14.0	1.90	3.6	0.05	3.4	7.9

Raw Data Means and Standard Deviations for Slow Cadence, Middle Seat Position

Subject	Heart Rate	RPE	V̇O2	RER	V̇EO2	V̇E
1	138	11.6	31.7	0.89	21.1	53.4
2	133	12	23	0.89	23.1	42.6
3	146	13	33	0.93	22	58.8
4	138	12	35.5	0.89	24.1	52.6
5	117	11	29.5	0.86	20.3	43.6
6	137	12.5	25.7	0.87	31.3	51.3
7	120	11	25.6	0.85	22.8	38.9
8	118	11	29.1	.81	21.3	42.3
9	117	11	25.6	.87	23.5	44.1
10	128	11.6	28.6	.9	21.3	39.9
11	113	8	30	0.84	19.5	42.5
12	132	13	28.3	0.85	21	50.3
Mean	128	11.5	28.8	0.87	22.6	46.6
Stdev.	10.7	1.3	3.5	0.03	3.0	6.3

Raw Data Means and Standard Deviations for Medium Cadence, Middle Seat Position

Subject	Heart Rate	RPE	$\dot{V}$O2	RER	$\dot{V}$EO2	$\dot{V}$E
1	138	10.8	33.1	0.91	21.1	61
2	126	12.6	20.8	0.9	22.8	38.3
3	153	12.6	35.2	0.93	22	63
4	139	12.8	36.7	0.93	24.6	55.5
5	124	12	33.2	0.89	21.1	51
6	139	13	24.5	0.89	31.6	48.9
7	126	11.6	27.3	0.9	27	45.4
8	123	11.8	36.1	0.9	24	59.3
9	119	11.3	29.1	0.9	23.8	50.7
10	128	11.5	26.9	0.9	21.3	37.2
11	120	8	29.6	0.84	20.3	43.4
12	134	12	29	0.86	21.3	51.9
Mean	130	11.5	30.1	0.89	23.4	50.47
Stdev.	9.9	1.3	4.8	0.25	3.2	8.4

Raw Data Means and Standard Deviations for High Cadence, Middle Seat Position

Subject	Heart Rate	RPE	$\dot{V}O2$	RER	$\dot{V}EO2$	$\dot{V}E$
1	140	11.5	34	0.93	22.1	58.5
2	142	12.6	25.8	0.92	23.8	49.1
3	156	13	34.1	0.94	22.3	61.5
4	143	13.5	35.8	0.91	24.3	52.5
5	133	12.8	36.5	0.9	22	57.2
6	153	14	29.9	0.9	33.1	63
7	135	12.8	30.6	0.91	28.1	51.2
8	126	11.6	34.2	0.85	21.8	50.8
9	121	12	29.2	0.9	24	51.7
10	136	12.8	31.6	0.93	22.1	45.4
11	118	8.8	29.2	0.88	20.1	42.7
12	135	11.6	27.9	0.84	21.1	49.5
Mean	136.5	11.6	30.4	0.88	22.8	48.5
Stdev.	11.4	1.3	3.3	0.03	3.5	6.1

Raw Data Means and Standard Deviations for Slow Cadence, Back Seat Position

Subject	Heart Rate	RPE	$\dot{V}$O2	RER	$\dot{V}$EO2	$\dot{V}$E
1	149	11.6	35.9	0.91	21.6	61.8
2	134	11.1	24.3	0.9	23.6	45.9
3	146	12.6	32	0.92	21.1	55.3
4	137	11.1	36.7	0.93	24.3	54.8
5	119	11	30.9	0.92	21.5	47.4
6	147	12.8	28.1	0.82	30.6	55
7	116	11.1	24.4	0.88	24	40.5
8	117	11	26.7	0.77	20.6	37.2
9	115	11	27.8	0.87	23.3	47.5
10	125	11.1	28.1	0.9	20.8	38.3
11	108	7.1	28.7	0.86	20.8	43.5
12	128	11.3	26.9	0.83	22.5	50.4
Mean	128	11	29.2	0.87	22.8	48.1
Stdev.	14.0	1.39	3.98	0.04	2.76	7.60

Raw Data Means and Standard Deviations for Medium Cadence, Back Seat Position

Subject	Heart Rate	RPE	V̇O2	RER	V̇EO2	V̇E
1	144	11.1	34.7	0.91	22.1	61.1
2	129	12	21.8	0.89	23.3	41
3	151	11.3	33.3	0.93	21.5	58.4
4	139	12.3	37.2	0.95	24.8	56.7
5	129	11.8	34.4	0.95	22	54.3
6	148	13.1	27.2	0.82	31	53.6
7	127	11.8	26	0.9	23.6	42.9
8	116	11.3	30.4	0.82	21.1	44.1
9	118	11.8	29.4	0.89	24.1	52.5
10	128	12	26.1	0.9	21.6	36.7
11	114	8.5	28.8	0.87	21	45.9
12	130	12.3	28	0.84	22.8	53.8
Mean	131	11.6	29.7	0.88	23.2	50.08
Stdev.	12	1.1	4.4	0.04	2.7	7.6

Raw Data Means and Standard Deviations for Fast Cadence, Back Seat Position

Subject	Heart Rate	RPE	V̇O2	RER	V̇EO2	V̇E
1	150.8	13.1	34.5	0.91	22	60.6
2	140.6	12.8	25.8	0.92	24.5	50.8
3	155	12.3	31.8	0.95	21.3	56.2
4	141	13	35.7	0.95	25	54.9
5	136	12.6	36.9	0.98	23.1	61.5
6	160	14.6	31.3	0.87	33.3	65.6
7	129	13.1	29.9	0.9	24.5	51.2
8	120	12.5	30.9	0.84	21.3	44.8
9	120	11.8	28.8	0.9	24.3	51.5
10	131	13.3	30.2	0.92	22.1	43.2
11	116	8.1	28.6	0.87	21.9	43.7
12	131	12.8	28.7	0.86	23.1	53.0
Mean	135	12.5	31.0	0.90	23.8	53.1
Stdev.	14.1	1.5	3.2	0.04	3.24	7.1

APPENDIX D

INDIVIDUAL MAXIMAL DATA

Raw Data Representing Individual Maximal Oxygen Consumption Tests.

Subject	Age	Height (in.)	Weight	$\dot{V}O_2$ (ml)	$\dot{V}O_2$ (l)
1	20	72	176	64.7	5.16
2	30	69	177	43.7	3.5
3	24	70	179	62.7	5.09
4	21	65	135	57.4	3.51
5	21	72	158	61.6	4.41
6	22	66	177	47.6	3.02
7	23	72	154	59.3	4.14
8	24	71	150	74.9	5.09
9	23	69	161	60.6	4.42
10	23	69	143	63.9	4.14
11	23	72	160	67.1	4.86
12	24	74	185	61	5.11
Mean	23.1	70	163	60.37	4.37
Stdev.	2.51	2.6	15.3	8.23	.73