Physiological and Performance characteristics of Elite Mountain Bike Cyclists

Kelly Linaker

A thesis submitted in partial fulfilment of the requirements for the degree of Masters of Applied Science in Sports Studies at the University of Canberra.

ABSTRACT

Cross-country (XC) mountain bike (MTB) riding is a new cycling discipline and research examining the physiological demands of MTB racing is limited. The purpose of this study was to comprehensively measure physiological characteristics, to identify the performance demands of XC and time trial (TT) MTB racing and to simulate a field MTB race in the laboratory to measure the physiological responses associated with racing.

Twelve male and four female elite MTB cyclists volunteered to take part in this study. Subjects completed maximal aerobic power and, anaerobic power and capacity tests. MTB race data was collected during TT and XC competitions with SRM MTB power cranks fitted to the subjects MTB. Five male MTB cyclists ($\dot{V}O_{2max}$ 72.0 ± 4.6 ml·kg·min^{-1}, maximum power output (MPO) 5.40 ± 0.30 W·kg^{-1}, maximum heart rate (HR_{max}) 189 ± 7 bpm) performed two laps of a MTB course in the field using their race bikes with MTB SRM power cranks fitted. A laboratory MTB race simulation was performed using a wind braked ergometer. Cyclists attempted to match the average and peak power output (W·kg^{-1}) achieved in the field trial in the laboratory. Power output (PO), heart rate (HR) and cadence (revolutions per minute, rpm) were measured during field and laboratory trials, while oxygen uptake ($\dot{V}O_2$) was determined only during the laboratory simulation.

Results showed TT MTB racing is significantly shorter in duration and distance than XC racing and significantly higher for power output and heart rate, with more time spent above anaerobic threshold (16.0 ± 2.4 and 22.8 ± 4.3% time) and MPO (38.4 ± 5.2 and 26.5 ± 9.4% time) than XC racing ($p<0.05$). Mean power output and heart rate between the field and laboratory trials were similar (4.18 ± 0.55 and 4.17 ± 0.15 W·kg^{-1} respectively, 175 ± 9 and 170 ± 8 bpm). Time spent below 2 W·kg^{-1} and above 6 W·kg^{-1} for the field and laboratory trials accounted for ~32% and ~30% of the total time, respectively. During field and laboratory trials, cyclists utilised 77.8 and 77.3% of MPO, 93 and 90% of HR_{max}, respectively. There was a significant difference between mean cadence in the field and laboratory trials (60.3 ± 9.1 and 75.2 ± 7.0 rpm, respectively, $p<0.05$). The cadence band of 60-69 rpm

showed a significant difference between the time spent in that band from the field (14.6%) to the laboratory (4.6%). The time spent above a cadence of 80 rpm in the field was 29.8% compared to the laboratory at 62.0% of the time. Mean and peak $\dot{V}O_2$ for the simulation was 57.5 ± 3.3 and 69.3 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively, with cyclists sustaining an average of ~80% $\dot{V}O_{2max}$.

In summary, MTB competition requires multiple short-high intensity efforts and places high demands on both the aerobic and anaerobic energy systems. The power output and heart rate responses to a MTB field race are similar when simulated in the laboratory, although in the laboratory higher cadences are selected for the higher power outputs than the field.

CERTIFICATE OF AUTHORSHIP OF THESIS

Except where clearly acknowledged in footnotes, quotations and the bibliography, I certify that I am the sole author of the thesis submitted today entitled –

Physiological and Performance characteristics of Elite Mountain Bike Cyclists

I further certify that to the best of my knowledge the thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

The material in this thesis has not been the basis of an award of any other degree or diploma except where due reference is made in the text of the thesis.

The thesis complies with the University requirements for a thesis as set out in http://www.canberra.edu.au/secretariat/goldbook/forms/thesisrqmt.pdf

……………………………………………………
Signature of Candidate

……………………………………………………
Signature of chair of the supervisory panel

Date: ……………………………………

ACKNOWLEDGMENTS

I would like to thank the following people for support whilst undertaking this Masters Thesis:

- The subjects who willingly gave their time and effort to the study.
- Tammie Ebert who wholeheartedly supported me, generously gave of her time and made me see the end in sight.
- Dr. David Martin for his enthusiasm and invaluable support in the pursuit of my research and in furthering the boundaries of sports science.
- Associate Professor Alan Roberts who had confidence in me to complete a Masters research project and advice throughout the study.
- Mr Damian Grundy, Australian National Mountain Bike Coach for his support, organisation and financial assistance.
- Dr. Mark Sayers, Daryl Adair and University of Canberra staff for their assistance in the final stage of the thesis.
- Cindi Hinch for her invaluable help with understanding the statistics needed for this thesis.
- Ben Rattray, Nining Kusanik and Paul Montgomery who assisted me throughout the data collection process.
- Dr Allan Hahn and the Department of Physiology, Australian Institute of Sport for their assistance and use of resources, and always taking an interest.
- Jennifer Towie for encouraging me to focus and finish this thesis.
- The Gadi Research Centre and the Centre for Sports Studies at the University of Canberra who allowed this thesis to take place.
- Ed Holinger for always believing in my ability and continually being there for me to help find my way.
- My family who I could not have made it through without and friends for their tireless support through this process.

DEDICATION

This Masters Thesis has been accomplished in the memory of Garry Payne, a mountain bike cyclist who tragically passed away during a training accident while cycling. Without Garry's influence on me this research project would not have been contemplated.

CONTENTS

CHAPTER TWO REVIEW OF LITERATURE

CHAPTER THREE STUDY 1: PHYSIOLOGICAL CHARACTERISTICS OF MOUNTAIN BIKE CYCLISTS

CHAPTER FIVE STUDY 3: MOUNTAIN BIKE RACE SIMULATION

CHAPTER SIX CONCLUSIONS AND RECOMMENDATIONS

APPENDICES

PUBLICATIONS

- Physiological responses of well-trained cyclists to field and laboratory mountain bike race simulations. KL Linaker, DT Martin, E Lawton, B Rattray, AD Roberts. Med Sci Sports Exerc. 2003 Suppl 35 (5) pg S35 (Abstract).

  Presented at the American College of Sports Medicine Conference in San Francisco, USA in May 2003.

- Can the Power Output-Cadence relationship during MTB racing be replicated in the laboratory?

  Presented at the National Cycling Coaches Conference in Canberra, Australian Institute of Sport in December 2002.

- A comparison of the physiological demands of well-trained cyclists to field and laboratory mountain bike race simulations. KL Linaker, DT Martin, E Lawton, B Rattray, AD Roberts. J Sci Med Sport. 2002 Suppl 5 (4) pg 39 (Abstract).

  Presented at the Sports Medicine Australia Conference in Canberra, Australia in October 2002.

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AIS	=	Australian Institute of Sport
Ave	=	Average
BLa	=	Blood lactate
bpm	=	Beats per minute
cm	=	Centimetres
d	=	Day
ES	=	Effect size
h	=	Hour
hPa	=	HectaPascals
HR	=	Heart rate
ITT	=	Individual Time Trial
kg	=	Kilograms
$km \cdot h^{-1}$	=	Kilometres per hour
$l \cdot min^{-1}$	=	Litres per minute
m	=	Metre
$ml \cdot kg^{-1} \cdot min^{-1}$	=	Millilitres per kilogram of body mass per minute
min	=	Minute
$mmol \cdot L^{-1}$	=	Millimoles per litre
MPO	=	Maximum power output
MTB	=	Mountain Bike
OBLA	=	Onset of blood lactate accumulation (4 $mmol \cdot L^{-1}$)
PO	=	Power Output
RPE	=	Rating of perceived exertion
rpm	=	Revolutions per minute
s	=	Second
SD	=	Standard deviation
TT	=	Time trial
$\dot{V}O_2$	=	Oxygen uptake

$\dot{V}O_{2max}$	=	Maximum oxygen consumption
W	=	Watt
$W \cdot kg^{-1}$	=	Watts per kilogram of body mass
UCI	=	Union Cycliste Internationale
ºC	=	Degrees Celsius

CHAPTER ONE INTRODUCTION

1.1 INTRODUCTION

Mountain bike (MTB) cross-country racing requires unique technical skills, pacing strategies, the ability to maintain a high work rate and to endure adverse environmental conditions. Cross-country riding occurs in forests, on fire-road trails, gravel roads, walking tracks (single-track) and involves avoiding and riding over obstacles such as logs, rocks, ditches and drop-offs. Racing usually begins with an uphill mass start, therefore it is crucial to have good position when the course narrows for the first single-track section. A XC race is normally contested with five – seven laps of a 6 – 10 km circuit course, dependent on the category. The Union Cycliste Internationale (UCI) have set minimum and maximum duration times for XC races for elite men of 2 – 2:15 h and 1:45 - 2 h for elite women (UCI, 2004a).

A XC MTB race is an endurance event, which may involve short bursts of high-intensity efforts at the start of the race, during sprinting and when hill climbing. It would therefore seem that MTB cyclists need the endurance characteristics of a road cyclist and the sprint capabilities of a track cyclist. In addition to this, are the unique technical skills required to ride a MTB. To fully understand the demands of competition; exercise duration, intensity and effort frequency need to be quantified (Broker, 2003). Characterising the demands of racing will assist the coach in designing a specific training program. Sports such as swimming and running can be comprehensively measured and analysed because the event is conducted over the same distance. Few studies have quantified the physiological and performance characteristics of the competitive/elite MTB cyclist as competitive racing is highly variable due to the environmental conditions and different course designs (Wilber et al., 1997, Heller and Novotny, 1997, Baron, 2001, Impellizzeri et al., 2002, Lee et al., 2002, Stapelfeldt et al., 2004). This makes it difficult for coaches to use competitive performance to monitor changes in training status or physiology. Changes in fitness may remain undetected, therefore physical fitness needs to be assessed in a controlled environment.

To identify the important characteristics required for mountain bike cyclists to race competitively, physiological monitoring or testing needs to be conducted. It is important when monitoring athletes to determine the most appropriate method of testing the required characteristics. Physiological assessment must be sport specific, valid and reliable to reflect the energy requirements of the sport in a controlled environment (Jeukendrup, 2002a). In the laboratory, endurance athletes' physiological characteristics are usually evaluated using a continuous, incremental test to exhaustion (Craig et al., 2000). From this test maximal and threshold values are determined for oxygen uptake ($\dot{V}O_2$), power output (PO), heart rate (HR) and blood lactate concentration (BLa).

Testing $\dot{V}O_{2max}$ as a measure of endurance capability of cyclists has been employed over a number of years (Foster and Daniels, 1975, Faria et al., 1989, Craig et al., 1993, Hopkins and McKenzie, 1994, Lucia et al., 1998, Lee et al., 2002). A valid and reliable method of evaluating a cyclist's physiological and performance potential (Padilla et al., 1996) has been identified in the laboratory on a cycle ergometer. Even though this is the case, many researchers believe that $\dot{V}O_{2max}$ alone does not predict performance in endurance events (Foster and Daniels, 1975, Burke, 1980, White et al., 1982a, Coyle et al., 1988, Telford et al., 1990, Tanaka et al., 1993, Lucia et al., 1998).

The parameters measured during a maximal oxygen consumption test are reported as absolute values of maximum power output (MPO) and volume of oxygen ($\dot{V}O_{2max}$), which give an indication of a cyclist's potential. To compare between cyclists, the physiological values are expressed relative to their anthropometric characteristics, such as power-to-weight because it plays an important role in performance, particularly when hill climbing (Swain, 1994). Although this test is the most recognised for determining maximal endurance capacity, amongst an elite homogeneous group with similar maximal values the submaximal results will show variations between cyclists (Coyle et al., 1988). As a result, this type of testing may not be able to predict the results of MTB competition due to the nature of the discipline where technical ability plays a major role. However, variables determined during a $\dot{V}O_{2max}$ will serve as a guide to the minimal requirements needed to be successful in the sport.

Traditionally, physiological testing was only conducted in the laboratory and was costly with access difficult for some cyclists. As a result, field based testing has become a popular alternative (Jeukendrup, 2002a). A modest amount of field testing had been conducted over the last twenty years for cycling but the recent advent of commercially available PO devices has made data collection much easier (Palmer, 2002). Previously, PO was measured only in the laboratory using cycle ergometers whilst measuring other variables such as HR, BLa, $\dot{V}O_2$ and rate of perceived exertion (RPE) (Broker, 2003).

Before PO devices were used on bicycles, scientists indirectly estimated PO for training and racing from physiological measures such as HR taken during a laboratory test (Padilla et al., 2000). In cycling, speed is a poor gauge of exercise intensity because a low speed is typically related to demanding hill climbing and maximum speed occurs with steep descents when the power output is minimal (Broker, 2003). Exercise intensity during MTB competition is mainly still measured using HR monitoring, as few athletes have PO devices. The recorded HR values can be compared to individual laboratory testing data. It has been said that HR reflects the physiological stress of the cyclist rather than the true intensity of the effort (Achten, 2002). As a result, exercise intensity is best measured using PO (Broker, 2003). This is especially true for MTB because of the extreme terrain variations encountered during racing, resulting in wide ranges in PO because of the highly intermittent style of racing (Stapelfeldt et al., 2004).

The limitations of field testing are the reliability of the results and the validity of the test (Palmer, 2002). To increase the probability of a reliable and valid test, the test conditions need to be standardised before and during the test. Due to the limited amount of field testing it has been difficult to show a relationship between field and laboratory testing results.

Further applications of PO devices are to characterise course profiles and to assist with pacing strategies. A course profile can be divided into sections (eg. uphill, descent) to characterise the PO, cadence, speed and HR of each effort corresponding to the different sections. The number of efforts per lap can be determined by the length and duration of each effort. This information would be particularly useful for simulating race conditions during training or in the laboratory in preparation for an important race such as the World Championships or Olympic Games.

1.2 AIMS

The aims of this thesis are to:

1. Extend the existing data describing the physical and physiological characteristics of competitive MTB cyclists by examining females MTB cyclists and including anaerobic fitness traits.

2. Identify the performance demands of cross-country and time-trial MTB racing for elite male MTB cyclists.

3. Simulate a field MTB race in the laboratory to measure the physiological and metabolic demands of MTB racing.

1.3 HYPOTHESES

1. Mountain bike cyclists will possess similar aerobic capacities as road cyclists and anaerobic capacities similar to track cyclists. Male MTB cyclists will have greater physiological characteristics than female MTB cyclists.

2. Cross-country and time-trial MTB racing will generate a similar SRM profile for power output and cadence while the mean power output for TT racing may be higher than XC racing because of the shorter time period.

3. Power output and cadence measured from a field test should be replicable in a laboratory simulation and cyclists will race the field test lap at anaerobic threshold.

1.4 LIMITATIONS

This study is limited by:

- The small sample size (this limitation is evident, especially for females, throughout the sports science literature).
- The number of MTB SRM power crank sets (only 3 were available for use in Australia).
- For the field MTB test, the cyclist's were split into two groups and the test was conducted on different days because of the number of SRM cranks.
- The MTB SRM power crank used only 2 front chain-rings instead of 3, which limited the amount of gears to 18 instead of 27. Also the diameter of the power crank restricted the size of the smallest chain-ring, therefore determining the smallest gear to be used.
- The dynamic characteristics of the Hayes windbraked ergometer for the laboratory simulation.
- Not having a portable gas analysis system for use in the MTB field test.

1.5 DELIMITATIONS

The scope of this study is limited to male and female MTB cyclists competing at a national or international level.

1.6 DEFINITIONS OF TERMS

Anaerobic glycolysis	Nonoxidative replenishment of ATP resulting in the breakdown of carbohydrate to lactic acid.
Anaerobic power	The rate of ATP production through the anaerobic energy systems (ATP-CP system and anaerobic glycolysis).
Anaerobic capacity	The maximal amount of ATP formed by anaerobic processes during exercise.

Individual Time Trial (ITT)	Where a cyclist has to cover a fixed distance in the fastest possible time.
Lactic acid (BLa)	The end product of the breakdown of carbohydrates via anaerobic glycolysis.
Lactate Threshold	The exercise intensity that elicits a non-linear increase of 1 $mmol{\cdot}L^{-1}$ of BLa above average baseline lactate values.
Maximal oxygen consumption ($\dot{V}O_{2max}$)	The maximal rate at which ATP can be consumption resynthesised via aerobic metabolism.
Onset of Blood Lactate Accumulation (OBLA)	The exercise intensity eliciting a BLa of 4 $mmol{\cdot}L^{-1}$.
Percent body fat	The relative proportion of body at contributing to overall body mass expressed as a percentage.
Power	Force multiplied by displacement determines the work done and divided by time yields power.
Power:mass	The rate of doing work expressed with respect to body mass.

CHAPTER TWO REVIEW OF LITERATURE

2.1 INTRODUCTION

Published scientific review papers have addressed many aspects of competitive cycling with a focus on road cycling. The purpose of this review is to study the sport of MTB in reference to other more comprehensively studied cycling disciplines (road and track cycling).

2.1.1 History

The first bicycles were built in the 19th century and with the advent of technology, riders saw beyond the practicalities of the two-wheeled invention for more than transportation and bicycle racing was embraced. The first record of an organized race took place outside of Paris in 1868 and was successful, so more races were scheduled (Jeukendrup, 2002a). The popularity of cycle racing saw the sport grow in Europe and spread to the United States. In 1891, Henri Desgrange (later the organizer of the first Tour de France) set the first World Hour Record at a speed of just over 35 $km \cdot h^{-1}$ (Jeukendrup, 2002a).

Competitive cycle racing is one of the few sports where performance is determined by human physical output in direct interaction with a mechanical device (McLean and Parker, 1989). Cycling made its Olympic debut in Athens in 1896 and in 1984 the Los Angeles Olympics saw the introduction of a women's road race. A track event for women was added to the program for the Seoul Olympics in 1988. The International Olympic Committee (IOC) included the XC MTB event to its program in 1994 and it was contested for the first time at the 1996 Atlanta Olympic Games.

Bicycles were first made of wood and later steel and weighed between 15 and 25 kilograms. Now, bicycles are made of aluminium or carbon fibre and weigh between seven and nine kilograms. Whereas the first bicycles did not have gears, today road bikes have between 18 and 20 gears, and mountain bikes 18 and 27 gears (Jeukendrup, 2002a).

Professional cycle racing combines extremes of exercise duration, intensity and frequency and is therefore, one of the most demanding sports of today. Riders have to perform on a variety of surfaces (track, road, cross-country), terrains (level, uphill and downhill) and race situations (criteriums, sprints, time trials, mass-start road races) (Jeukendrup et al., 2000). These races range from a 200 m sprint lasting ~10 s to a 2 ½ h race over rough terrain to a three wk stage race, such as the Tour de France cycling up to 5000 km.

2.1.2 Professional Road Cycling

Road cycling events vary in duration from a five min prologue, to a six h road race to a three wk stage race (Tour de France, Giro d'Italia, Vuelta a Espana), covering up to 220 km each day. Most world class cyclists participate in a combination of these events with an emphasis on their best discipline. At times road racing requires cyclists to ride for a designated team leader foregoing individual success in long stage races. Professional road cyclists spend many hours training and racing covering approximately 35,000 – 45,000 km each year (Lucia et al., 2003). Road cyclists require a high level of technique and exceptional physiological attributes for success, with high demands placed on the ventilatory, metabolic and cardiovascular systems. Both the aerobic and anaerobic capacities are stressed during competition, with the majority of time spent at submaximal exercise intensities.

2.1.3 Track Cycling

Track racing has been around since the last century with the first World Championships occurring in 1895 (UCI, 2003b). Dynamic skills and tactics are vital to the success of cyclists during track events. Track cyclists are the power players, whose image is the embodiment of strength and speed (UCI, 2003b). Track cycling consists of two distinct race categories: sprint (<1000 m) and endurance (>1000 m). Events range from a 200 m flying sprint lasting ~10 s to the 50 km points score lasting ~1 h. In addition, there is a prestigious One Hour record where competitors complete an Individual Time-Trial (ITT) to cover the greatest distance possible (Jeukendrup et al., 2000).

2.1.4 Mountain Bike

Mountain bike cycling, also known as off-road cycling, is the newest addition to the sport of cycling as a recreational and competitive sport that was conceived in the early 1980's in

Marin County, California. There are three main disciplines of MTB: XC, downhill (DH) and four-cross (4X). According to UCI regulations, a XC course should be a minimum of 6 $km \cdot h^{-1}$ (UCI, 2004a) in distance for one lap.

Downhill mountain biking involves descending down a mountain on courses with a mixture of single-track, fire road, field traks, forest tracks and rocky tracks (UCI, 2004a). Downhill cycling is a highly technical sport, both in terms of the skill required to succeed and the level of equipment needed (Richards and Worland, 1997). The time of a DH run is short and in competition last a maximum of seven minutes involving short anaerobic bursts (Crowther, 1999) with the length of a course between 1.5 and 3.5 km (UCI, 2004a).

A 4X competition consists of qualifying round stage races where four qualifying riders compete on a shared short DH type course (UCI, 2004a). The winner and second place rider of each round automatically qualify for the next round, until there are only four riders left in the competition for the final.

The UCI recognized mountain biking as a sport in 1990, when it sanctioned a World Championship event in Purgatory, Canada. The first World Cup Series for MTB began in 1991 with a nine-race circuit. Cross-country racing was the only MTB discipline until 1993 when DH was introduced.

In summary, the three main disciplines of cycling (road, track and MTB) are thought to have completely different identities except that there is crossover between events of one discipline to another (eg. PO for track sprinters is similar to DH MTB riders and a road TT is similar to XC MTB racing in terms of physiological requirements).

2.2 PHYSIOLOGICAL CHARACTERISTICS OF ROAD, TRACK AND MOUNTAIN BIKE CYCLISTS

2.2.1 Anthropometry

Anthropometry is the measurement of the size and proportions of the human body. Measurements include: height, body mass, skinfolds, bone widths, bone lengths and muscle girths. In many sports the physique of an athlete can be considered an important determinant of success (Foley et al., 1989). Few studies have solely concentrated on investigating the anthropometry of competitive cyclists (Foley et al., 1989, McLean and Parker, 1989). More often the anthropometric analysis of cyclists has been carried out as part of a comprehensive physiological data analysis such as in preparation for the 1980 Moscow Olympic Games. Great Britain conducted a longitudinal study of anthropometric and physiological characteristics of their road and track teams (White et al., 1982a, White et al., 1982b), refer Table 1 and Table 2, respectively. The riders were tested pre, early and mid-season and put into a selected or non-selected group for the Olympic team. White et al. (1982a) reported the differentiating features between the select and non-select group were height (mean±SE: 174.1 ± 1.9 and 176.8 ± 2.2 cm), body mass (66.0 ± 2.1 and 69.1 ± 1.8 kg) and percent body fat (7.6 ± 0.6 and 9.6 ± 0.7 %), respectively which favoured the select group. Furthermore the select group demonstrated significant body composition changes during the competitive racing season. The anthropometric characteristics of the track sprint cyclists (White et al., 1982b) are in contrast to the results of the British road cyclists (White et al., 1982a) because there was an increase in body mass throughout the season accompanied by a reduction in percent body fat.

Foley et al. (1989) conducted a detailed anthropometric analysis upon 36 competitive male cyclists and divided them into four categories: sprint, pursuit, road and time trial according to their competitive strengths. A number of distinct significant musculoskeletal differences were detected between the four groups of cyclists. The sprint cyclists were significantly shorter and more mesomorphic than the other three groups ($p < 0.05$). The time trialists were the tallest, most ectomorphic, had the longest legs ($p < 0.01$) and had the highest leg length to height ratio ($p < 0.05$) than the other groups. The pursuit and road cyclists were found to have similar physiques. Foley et al. (1989) speculated that the shorter limb lengths and higher mesomorphy ratings of the sprinters are an advantage in generating power and obtaining a high cadence and conversely, longer limbs may convey an advantage in time trialling where higher gear ratios tend to be used. From the results of the study, it was reported that since the different forms of competitive cycling place different demands upon the body, each form of cycling may require a different optimum physique rather than a general cyclist's physique for all types of competition (Foley et al., 1989).

Table 1: Anthropometric characteristics of road cyclists (Mean±SD).

Reference	Description	Sex	N	Age (yr)	Height (cm)	Mass (kg)	Body Fat (%)
Foster & Daniels 1975	Category I US	M	4		181.3	69.9	7.1
White et al. 1982a	British Olympic road squad	M	16	22.0±0.6 (SE)	175.7±1.6 (SE)	69.7±1.6 (SE)	10.6±0.7 (SE)
Burke 1980	US National Team	M	12		180.3±5.7	67.1±7.7	8.8±2.0
Foley et al. 1989	Professional, cat I-III British Road	M	16		179.2±1.8 (SE)	69.2±1.5 (SE)	
Foley et al. 1989	Professional, cat I-III British TT	M	6		186.3±3.0 (SE)	76.0±2.8 (SE)	
Telford et al. 1990	National Australia Team		17		178.0±4.2	71.6±5.6	
Tanaka et al. 1993	Category II US	M	9	23.0±0.9	179.3±1.5	71.8±2.3	6.2±0.6
Hopkins & McKenzie 1994	Competitive cyclists	M	8	25.2±3.3	183.0±5.6	75.0±5.7	
Wilber et al. 1997	US National Road Team	M	10	23±3	182±6	72.6±6.4	4.7±0.8
Lucia et al. 1998	Professional cyclists	M	25	25±2	177.1±4.2	69.2±5.3	
Lucia et al. 1998	Elite (amateur) cyclists	M	25	23±3	176.1±3.9	67.3±6.3	
Lucia et al. 1999	Professional team	M	8	26±3	180.1±3.7	68.9±5.2	8.3±0.2
Padilla et al. 1999	Professional team	M	24	26±3	180±6	68.2±6.6	
Fernandez-Garcia et al. 2000	Professional cyclists	M	18	28.8±3.6	177.1±4.1	68.6±4.9	8.1±1.4
Burke 1980	US National Team	F	7		167.7±10.7	61.3±8.5	15.4±4.7
Pfeiffer et al. 1993	1990 Tour of Idaho cyclists	F	13	28.0±2.8	168.7±5.2	61.1±3.7	15.7±2.0
Tanaka et al. 1993	Category II-IV US	F	6	28.2±2.1	168.8±1.4	64.6±2.5	15.8±1.3
Wilber et al. 1997	US National Road Team	F	10	26±5	171±5	60.4±3.6	11.9±1.8

Table 2: Anthropometric characteristics of track cyclists (Mean±SD).

Reference	Description	Sex	N	Age (yr)	Height (cm)	Mass (kg)	Body Fat (%)
White et al. 1982b	British Olympic track sprint squad	M	8	20.9±0.1 (SE)	175.7±2.1 (SE)	74.0±2.6 (SE)	12.2±0.5 (SE)
Foley et al. 1989	Professional, cat I-III British Sprint	M	7		169.2±2.5 (SE)	71.1±2.8 (SE)	
Foley et al. 1989	Professional, cat I-III British Pursuit	M	7		180.6±1.7 (SE)	74.5±2.5 (SE)	
McLean & Parker 1989	National level Sprint (Aus)	M	14	23.7±4.6	178.4±4.1	76.2±7.4	
McLean & Parker 1989	National level Endurance (Aus)	M	17	21.5±3.6	177.1±5.0	70.0±4.7	
Telford et al. 1990	National Australian Team		14		178.3±4.4	75.0±7.5	
Craig et al. 1995	Australian Track Endurance	M	12	20.3±1.7	178.7±3.0	73.3±5.4	9.3±1.6
Craig et al. 1995	Australian Track Sprint	M	6	19.5±1.8	180.5±4.3	79.3±5.5	10.0±1.6
Schumacher & Mueller 2002	German Olympic 4000m pursuit	M	7		186.4±3.3	77.9±4.1	

To further analyse the relationship of optimum physique for different competitions, McLean and Parker (1989) studied 35 track cyclists who competed at the 1987 Australian Track Cycling Championships to determine possible variations in anthropometric characteristics between cyclists of sprint and endurance events. Sprint cyclists were found to be significantly heavier (76.2 ± 7.4 and 70.0 ± 4.7 kg) and stronger (258.0 ± 44.4 and 216.4 ± 30.5 Nm, isometric knee extension, tested at 115° of flexion) than endurance cyclists. The sprint cyclists also had significantly larger chest, arm, thigh and calf girths than the endurance cyclists. Even so, there was no significant correlation between any of the anthropometric parameters and performance in any individual event.

Mujika and Padilla (2001) compiled results from two previous studies they had conducted (Padilla et al., 1999, Padilla et al., 2000) and found wide ranging values for physical characteristics of road cyclists. The average age of a typical male professional cycling team was 26 yr, ranging between 20 yr as a neoprofessional up to 33 yr for the most experienced cyclists. There was also large variability for height (mean 180 cm, range 160 – 190 cm) and body mass (mean 68.8 kg, range 53 – 80 kg). Due to the large diversity of anthropometric characteristics, 'specialists' have developed within teams to perform under different racing conditions and in varied terrain. For example, a sprint specialist on the road will be protected for the final sprint, if a breakaway occurs, team mates will chase it down and control the race from the front of the peleton. A study was conducted to determine if there was a difference between professional road cyclists in their specialist roles of flat terrain, time trial, all terrain and uphill riders. Padilla et al. (1999) found that uphill cyclists (62.4 ± 4.4 kg) were significantly lighter than flat terrain, time trial and all terrain cyclists (76.2 ± 3.2, 71.2 ± 6.0 and 68.0 ± 2.8 kg), respectively and had lower body surface area and frontal area. The uphill cyclists were significantly shorter (175 ± 7 cm) than the flat terrain (186 ± 4 cm) specialists.

There have been relatively few studies to identify the anthropometric characteristics required for a mountain bike cyclist to be competitive at an international level. Table 3 presents the available data of anthropometric characteristics of mainly National level MTB cyclists. The male US National team MTB cyclists studied by Wilber et al. (1997) were the oldest 29 ± 4 yr, while cyclists from the remaining studies ranged in age from 20.0 – 24.4 yr. In June 2004, the average age for the top 10 UCI ranked male MTB cyclists was

Table 3: Anthropometric characteristics of mountain bike cyclists (Mean±SD).

Reference	Description	Sex	N	Age (years)	Height (cm)	Mass (kg)	Body Fat (%)
Wilber et al. 1997	US National XC Team	M	10	29±4	176±7	71.5±7.8	5.8±1.1
Heller & Novotny 1997	Czech National Team	M	10	20.0±4.1	175.6±5.5	65.7±3.1	6.4±1.2
Baron 2001	Austrian Elite National Level	M	25	22.5±4.4	179.0±5.1	69.4±6.5	
Impellizzeri et al. 2002	Italian National Level*	M	9	21±4	174.6±3.4	64.3±4.8	4.7±1.4
Lee et al. 2002	Australian Internationally Competitive	M	7	24.4±3.4	178±0.1	65.3±6.5	6.1±1.0
Stapelfeldt et al. 2004	German National Team	M	9	21.2±1.8	179.9±5.9	69.4±4.7	
Wilber et al. 1997	US National XC Team	F	10	31±2	162±5	57.5±4.7	13.2±2.0
Stapelfeldt et al. 2004	German National Team	F	2	28.5±2.1	170.5±2.1	63.0±1.4	

* Summer Test Sessions

28.0 ± 4.1 yr (range 23 - 35 yr) (UCI, 2004b). The Austrian MTB cyclists (Baron, 2001) studied were the tallest at 179.0 cm and the Italian MTB cyclists studied by Impellizzeri et al. (2002) were reported to be the shortest (174.6 cm), have the lowest body mass (64.3 kg) and the lowest percent body fat (4.7%).

The majority of female anthropometry data is a result of US and Australian research (Burke, 1980, Pfeiffer et al., 1993, Tanaka et al., 1993, Wilber et al., 1997, Martin et al., 2001). The body composition of female road cyclists has been similar for over 20 yr. The average age of female cyclists in 1993 was approximately 28 yr (Tanaka et al., 1993) (Pfeiffer et al., 1993) which is comparable to Australian females in 2001, 25.6 ± 4.6 yr (Martin et al., 2001). Female MTB cyclists tend to be slightly older (31 ± 2 yr) than road cyclists (26 ± 5 yr) but are not significantly different (Wilber et al., 1997).

The average height of US female road cyclists ranges from 168 to 171 cm (Burke, 1980) (Wilber et al., 1997) in comparison with the US MTB cyclists at 162 cm (Wilber et al., 1997). Internationally competitive Australian female road cyclists are similar for height in the range of 162 to 174 cm (Martin et al., 2001). The average body mass of the US and Australian National Teams ranged from 57.5 to 61.3 kg for road and MTB. The average percent body fat of competitive female road cyclists from two US studies was 15.4 ± 4.7%and 15.7 ± 2.0% (Burke, 1980) (Pfeiffer et al., 1993) using hydrostatic weighing and 11.9 ± 1.8% using the skinfold method (Wilber et al., 1997). Likewise, the average percent body fat of the US MTB female cyclists was 13.2 ± 2.0% (Wilber et al., 1997), also using the skinfold method.

In summary, the average age, height and weight for elite male cyclists is 20 to 29 yr, 169 to 186 cm, 67 to 80 kg and 5 to 12% body fat. Within cycling disciplines, track cyclists tend to be younger, heavier and have a higher percent body fat than road or MTB cyclists. On average MTB cyclists are older, shorter, lighter and have a lower percent body fat than road and track cyclists.

2.2.2 Aerobic Power

Maximal oxygen uptake ($\dot{V}O_{2max}$) is one of the most frequently used measures of athletic endurance ability (Foster and Daniels, 1975, Burke, 1980, Coyle et al., 1988, Tanaka et al., 1993, Heller and Novotny, 1997, Lucia et al., 1998, Martin et al., 2001, Lee et al., 2002). A cyclist would hope to have a high ability to consume oxygen to deliver as much power as possible to the working muscle (Palmer, 2002). Oxygen uptake can be quantified in absolute (total oxygen consumed per min) or relative (oxygen consumed per kilogram of body mass per min) terms. A rider who wants to achieve a high PO for a short duration would hope to have a high absolute $\dot{V}O_{2max}$, in contrast to an endurance rider (who would require a low body mass to assist in climbing) and would hope to have high relative $\dot{V}O_{2max}$ (Palmer, 2002).

2.2.2.1 Maximal Aerobic Power

Continuous incremental test protocols have commonly been employed for the evaluation of physiological variables during maximal efforts. There are many variations of this test including: time for each stage (1 to 5 min), the power increment of each stage (25 to 50 W), cadence selection and ergometer type. The choice of test protocol at the Australian Institute of Sport for endurance athletes to determine $\dot{V}O_{2max}$ uses increments of 50 W every 5 min for male athletes (Craig et al., 2000).

$\dot{V}O_{2max}$ values for professional road cyclists are typically above 5.0 $L \cdot min^{-1}$, or 70 $ml \cdot kg^{-1} \cdot min^{-1}$ (see Table 4), with corresponding W_{max} values of greater than 430 W and 6 $W \cdot kg^{-1}$. Lucia et al. (1999) reported a group of professional cyclists to have a mean $\dot{V}O_{2max}$ of 5.1 $L \cdot min^{-1}$ (74 $ml \cdot kg^{-1} \cdot min^{-1}$), whereas values for most competitive road cyclists are approximately 4.9 $L \cdot min^{-1}$ or 68 $ml \cdot kg^{-1} \cdot min^{-1}$ (Tanaka et al., 1993). Padilla et al. (1999) reported data on a professional road cycling team, estimating $\dot{V}O_{2max}$ (from power output) to be 78.8 ± 3.7 $ml \cdot kg^{-1} \cdot min^{-1}$ with individual scores ranging from 69.7 to 84.8 $ml \cdot kg^{-1} \cdot min^{-1}$ with a resultant W_{max} of 501.2 ± 24.8 W (7.3 $W \cdot kg^{-1}$). These results are similar to values

Table 4: Maximal oxygen consumption values for road cyclists (Mean±SD).

Reference	Description	Sex	N	$\dot{V}O_{2max}$ (L·min^{-1})	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	W_{max} (W)	W_{max} (W·kg^{-1})	HR_{max} (bpm)	BLa_{peak} (mmol·L^{-1})
Foster & Daniels 1975	Category I US	M	4	5.21	74.4				
White et al. 1982a	British Olympic road squad (select)	M	3		78.6±0.9 (SE)	403±68 (SE)	6.1±0.8 (SE)	195±2 (SE)	
White et al. 1982a	British Olympic road squad (non-select)	M	11		70.3±2.0 (SE)	403±23 (SE)	5.9±0.4 (SE)	191±3 (SE)	
Telford et al. 1990	Australian National		17	4.87±0.37	68.4±4.6	406±27	5.6±0.5		
Tanaka et al. 1993	Category II US	M	9	4.98±0.14 (SE)	69.4±1.3 (SE)				
Hopkins & McKenzie 1994	Competitive cyclists	M	8	5.05±0.39	68.0±3.0				
Wilber et al. 1997	US National Team	M	10	5.09±0.43	70.3±3.2	470±35	6.5±0.3	200±11	11.8±1.7
Lucia et al. 1998	Professional cyclists	M	25	5.1±0.6	73.9±7.4	466.0±30.8	6.7±0.4	190±7	7.4±1.5
Lucia et al. 1998	Elite (amateur)	M	25	4.9±0.4	72.9±5.7	428.6±31.7	6.4±0.5	192±8	9.4±3.0
Lucia et al. 1999	Professional team	M	8	5.1±0.4	74.0±5.8	501.2±24.8	7.3*	191±8	
Padilla et al. 1999	Professional team	M	24	5.36±0.47	78.8±3.7	431.8±42.6	6.3±0.3	192±6	9.8±1.9
Lucia et al. 2000	Professional road climbers	M	8	5.0±0.6 (SE)	78.6±2.0 (SE)	480.6±12.3 (SE)	7.5±0.2 (SE)	189±3 (SE)	
Lucia et al. 2000	Professional time trial cyclist	M	6	5.2±0.2 (SE)	72.0±2.6 (SE)	521.7±21.5 (SE)	7.3±0.1 (SE)	185±4 (SE)	
Padilla et al. 2001	Professional cyclists	M	17			433±48	6.3±0.3	194±5	9.9±1.9
Burke 1980	US National Team	F	7	3.58*	57.4±6.6				
Pfeiffer et al. 1993	1990 Tour of Idaho cyclists	F	13	3.91±0.22	64.2±4.0			185±3	
Tanaka et al. 1993	Category II-IV US	F	6	3.37±0.13 (SE)	52.5±2.8 (SE)				
Wilber et al. 1997	US National Team	F	10	3.85±0.30	63.8±4.2	333±21	5.5±0.5	188±11	10.2±2.5

* Estimated

SE = Standard Error

recorded for professional hill climbers and TT specialists (refer Table 4) for $\dot{V}O_{2max}$ and W_{max} by Lucia et al. (2000), which are amongst the highest reported values for road cyclists.

Correlations between $\dot{V}O_{2max}$ and cycling performance have been studied for sometime, while the strength of the correlation varies between studies. One of the earlier studies (Foster and Daniels, 1975) in the area reported a significant correlation (r = 0.93) between $\dot{V}O_{2max}$ (absolute and relative) and speed for a 16.1 km TT. Data from Pfeiffer et al. (1993) indicated that the level of aerobic power, specifically relative $\dot{V}O_{2max}$ may account for as much as 82% of race performance in elite female cyclists competing in events that involve significant amounts of climbing. It was also reported that with respect to a 14 day stage race, relative $\dot{V}O_{2max}$ demonstrated a stronger and more frequent relationship with finish time than did any other single variable, including absolute $\dot{V}O_{2max}$.

Elite athletes of the same discipline tend to be homogeneous in terms of $\dot{V}O_{2max}$, therefore this variable seldom accounts for differences in performance as reported in earlier studies (Coyle et al., 1988) (Coyle et al., 1991) (Barbeau et al., 1993). Lucia et al. (1998) studied the physiological characteristics of elite and professional cyclists and reported $\dot{V}O_{2max}$ values in the range of 70 – 80 $ml \cdot kg^{-1} \cdot min^{-1}$, with no significant difference for either group. Indeed, once a certain performance level is reached ("under 23-elite" category), further increases in training intensity and volume (professional category) are no longer associated with improvements in $\dot{V}O_{2max}$ (Lucia et al., 1998).

If road cycling teams competing in a 1 day or stage race incorporate similar strategies and tactics, it should not be surprising that the rider with the highest aerobic capacity may not necessarily win the event. Thus, attempts at predicting success based on physiological variables may be of limited value (Pfeiffer et al., 1993). Lucia et al. (1998) suggested that high values of $\dot{V}O_{2max}$ are required for successful performance in both elite and professional cyclists. However, other physiological parameters such as the ability to maintain high percentages of $\dot{V}O_{2max}$ during prolonged periods might have more relevance to success in endurance cycling (Coyle et al., 1991).

In comparison to road cyclists, descriptive $\dot{V}O_{2max}$ data for track cyclists is lacking. A possible reason could be that track cyclists are known to be the power athletes of the cycling world and therefore different more specific tests are used for physiological and performance analysis. However, aerobic power contributions to track cycling events range from 5% in the 200 m sprint to 85% in the 4000 m individual pursuit and to >95 % in the 1 h record (Jeukendrup et al., 2000). Reported average $\dot{V}O_{2max}$ values for Australian track cyclists range from 62 - 72 ml·kg^{-1}·min^{-1} for both sprint and endurance cyclists (Craig et al., 1993, Craig et al., 1995, Telford et al., 1990). The gold medal German 4000 m pursuit team at the 2000 Olympics had an average $\dot{V}O_{2max}$ of 67.6 ± 2.7 ml·kg^{-1}·min^{-1}, with a range of 65 – 73 ml·kg^{-1}·min^{-1} (Schumacher and Mueller, 2002). Craig et al. (1993) found a significant correlation between $\dot{V}O_{2max}$ and the 4000 m individual pursuit. This lead the authors to believe that the maximal exercise intensity an athlete can achieve during a $\dot{V}O_{2max}$ test is an important variable for predicting athletic potential for that event. After further research Craig et al. (2000) suggested prerequisites for successful world class cyclists to be in excess of 80 ml·kg^{-1}·min^{-1} for males and 70 ml·kg^{-1}·min^{-1} for females.

Cycling is a sport where power-to-body mass ratio is of critical importance. When hill climbing the lightest cyclist will have an advantage having less body mass to carry up the hill. Padilla et al. (1999) investigated four specialist groups of road cyclists values from an incremental maximal laboratory test to determine PO and estimate $\dot{V}O_{2max}$ values. The highest absolute W_{max} values were measured in flat terrain specialists (461 ± 39 W), which were higher than all terrain (432 ± 27 W) and significantly higher than uphill specialists (404 ± 34 W, $p<0.05$). The TT group also produced significantly higher W_{max} (457 ± 46 W) than uphill specialists. When expressed relative to body mass, the uphill group had the highest power-to-body mass (6.47 ± 0.33 W·kg^{-1}), which was significantly greater than flat terrain (6.04 ± 0.29 W·kg^{-1}) with no differences for TT and all terrain specialists (6.41 ± 0.12 and 6.35 ± 0.18 W·kg^{-1}, respectively).

From the PO values Padilla et al. (1999) estimated $\dot{V}O_{2max}$ values from an incremental maximal laboratory test and found that flat terrain (5.67 ± 0.44 $L \cdot min^{-1}$) and TT (5.65 ± 0.53 $L \cdot min^{-1}$) specialists had significantly higher absolute $\dot{V}O_{2max}$ values than uphill cyclists (5.05 ± 0.39 $L \cdot min^{-1}$) although none of these was significantly difference from all terrain (5.36 ± 0.30 $L \cdot min^{-1}$) specialists. When $\dot{V}O_{2max}$ was calculated relative to body mass, flat terrain cyclists (74.4 ± 3.0 $ml \cdot kg^{-1} \cdot min^{-1}$) was significantly lower than TT, all terrain and uphill specialists (79.2 ± 1.1, 78.9 ± 1.9 and 80.9 ± 3.9 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively). It had been suggested that a power-to-body mass ratio above 5.5 $W \cdot kg^{-1}$ was a necessary prerequisite for top-level competitive cyclists (Palmer et al., 1994). However, the suggested value would not be intended for professional cyclists as this value seems to be slightly low for professional cycling, according to the Padilla et al. (1999) study (mean value of 6.34 $W \cdot kg^{-1}$, with a lowest value of 5.58 $W \cdot kg^{-1}$). Padilla et al. (1999) also reported that absolute W_{max} values are recommended for prediction of performance in short events on level terrain such as prologue time trials, whereas values at lactate threshold (LT) (Hagberg and Coyle, 1983) and onset of blood accumulation (OBLA) (Sjodin and Jacobs, 1981) appear to be more appropriate for longer time trials and uphill cycling.

Exercise responses to maximal aerobic power testing for MTB athletes have shown similar results to road cyclists (refer Table 5). Wilber et al. (1997) and Lee et al. (2002) compared road and MTB cyclists in their studies. Wilber et al. (1997) found female road cyclists possessed significantly greater absolute and relative $\dot{V}O_{2max}$ and HR_{max} values than the female MTB cyclists. Interestingly, the difference in $\dot{V}O_{2max}$ did not result in a significant difference for maximal power output for the female road and MTB cyclists (5.5 ± 0.5 and 5.4 ± 0.4 $W \cdot kg^{-1}$, respectively). Male road cyclists produced significantly higher absolute and relative power than MTB cyclists at LT and at W_{max} although $\dot{V}O_{2max}$ values were similar. The average $\dot{V}O_{2max}$ values in the study by Lee et al. (2002) were similar to some of the highest reported values for road cyclists (Wilber et al., 1997, Lucia et al., 1998, Lucia et al., 1999, Padilla et al., 2000). Although absolute $\dot{V}O_{2peak}$ was lower in MTB than road cyclists, when expressed relative-to-body mass the MTB cyclists (78.3 ± 4.4

Table 5: Maximal oxygen consumption values for mountain bike cyclists (Mean±SD).

Reference	Description	Sex	N	$\dot{V}O2_{max}$ (L·min^{-1})	$\dot{V}O2_{max}$ (ml·kg^{-1}·min^{-1})	W_{max} (W)	W_{max} (W·kg^{-1})	HR_{max} (bpm)	Lactate (mmol·L^{-1})
Wilber et al. 1997	US National XC Team	M	10	4.99±0.44	70.0±3.7	420±42	5.9±0.3	192±12	10.4±2.7
Heller & Novotny 1997	Czech National Team	M	10	4.89±0.31	74.1±3.4	419±29.5	6.3±0.3	191±6	10.4±1.7
Baron 2001	Austrian Elite National Level	M	25	4.75±0.3$^{\psi}$	68.4±3.8	382±26$^{\psi}$	5.5±0.4		
Impellizzeri et al. 2002	Mountain Bikers*	M	9	4.88±0.42	75.9±5.0	368±31	5.7±0.5	191±5	
Lee et al. 2002	Australian Elite Competitive	M	7	5.1±0.5	78.3±4.4	413±36	6.3±0.5	189±5	10.1±2.6
Stapelfeldt et al. 2004	German National Team	M	9		66.5±2.6	368±25	5.3±0.3	193±10	
Wilber et al. 1997	US National XC Team	F	10	3.33±0.27	57.9±2.8	313±24	5.4±0.4	178±7	8.7±2.2
Stapelfeldt et al. 2004	German National Team	F	2		59.4±1.7	300±28	4.8±0.4	186±11	

* Summer Test Sessions

$^{\psi}$ Estimated from data presented.

ml·kg^{-1}·min^{-1}) produced significantly higher results than the road cyclists (73.0 ± 3.4 ml·kg^{-1}·min^{-1}). The highest $\dot{V}O_{2peak}$ reported amongst the MTB cyclists was 87.0 ml·kg^{-1}·min^{-1} and the lowest 74.5 ml·kg^{-1}·min^{-1}. The MTB cyclists possess similar values for $\dot{V}O_{2max}$ and W_{max} to reported uphill road cycling specialists (Padilla et al., 1999, Lucia et al., 2000). The most recent study to report physiological data for MTB cyclists is by Stapelfeldt et al. (2004) with German national team riders. Results for absolute and relative W_{max} and relative $\dot{V}O_{2max}$ for males are the lowest reported results of all MTB literature. Absolute and relative W_{max} values for the female German MTB cyclists (Stapelfeldt et al., 2004) are lower than the US female cyclists (Wilber et al., 1997) although relative $\dot{V}O_{2max}$ is similar (59.4 ± 1.7 and 57.9 ± 2.8 ml·kg^{-1}·min^{-1}, respectively).

In summary, the average $\dot{V}O_{2max}$, W_{max} and HR_{max} values for male road cyclists range from 70 to 79 ml·kg^{-1}·min^{-1}, 5.6 to 7.5 W·kg^{-1} and 189 to 200 bpm. Professional cyclists display higher values than elite and amateur cyclists and specialist climbers have greater maximal aerobic capacity than TT specialists. There is a lack of data pertaining to the aerobic capacities of track cyclists however $\dot{V}O_{2max}$ ranges from 62 to 73 ml·kg^{-1}·min^{-1}. $\dot{V}O_{2max}$ values for male MTB cyclists range from 66.5 to 79 ml·kg^{-1}·min^{-1} with a corresponding W_{max} of 5.3 to 6.4 W·kg^{-1}. Female road and MTB cyclists average $\dot{V}O_{2max}$ ranges from 57 to 64 ml·kg^{-1}·min^{-1} and a W_{max} of 4.8 to 5.5 W·kg^{-1}.

2.2.2.2 Anaerobic Threshold

Blood lactate accumulation is often measured during a $\dot{V}O_{2max}$ test and its deflection points are plotted against workload, which are thought to closely relate to endurance performance (Craig et al., 2000). The numerous methods and terms used to describe similar characteristics in the BLa workload curve demonstrate that the threshold concept is not easy to interpret. Anaerobic threshold (AT) is used broadly so for the purpose of this review it refers to the general break point of the BLa workload curve. Cycling performance has been directly correlated with threshold values (Coyle et al., 1988, Coyle et al., 1991, Craig et al., 1993).

Hopkins and McKenzie (1994) found a significant relationship between PO at ventilatory threshold with TT performance time (40 km; 61.7 ± 2.3 min) and average PO (359 ± 31 W) during the 40 km ITT race ($r = -0.81$ and $r = 0.81$, respectively) with eight competitive cyclists.

The $\%\dot{V}O_{2max}$ an athlete can maintain during competition is readily accepted as an important predictor of performance, and is thought to be closely related to anaerobic threshold values (Coyle et al., 1988, Coyle et al., 1991). The importance of threshold values is further supported by the observation that well-trained athletes do not achieve the same high level as elite cyclists, 66.0 ± 4.3 $\%\dot{V}O_{2max}$ (Coyle et al., 1988) and 89.6 ± 2.7 $\%\dot{V}O_{2max}$ (Fernandez-Garcia et al., 2000).

Further to the findings of elite cyclists maintaining a higher $\%\dot{V}O_{2max}$ than well-trained cyclists, professional cyclists are able to maintain higher threshold values than elite cyclists. Lucia et al. (1998) reported significantly higher threshold values for professional cyclists (87.0 ± 5.9 $\%\dot{V}O_{2max}$) compared to elite cyclists (80.4 ± 6.6 $\%\dot{V}O_{2max}$). Mean values of PO, respiratory ratio and ventilation corresponding to the ventilatory threshold were also significantly higher in the group of professional cyclists. Lucia et al. (1998) interpreted the results as the professional cyclists being able to work at higher intensities before BLa occurs than for elite cyclists. Secondary to that finding was that ventilatory threshold may represent an important performance factor in endurance events by establishing the $\%VO_{2max}$ at which anaerobic threshold occurs which may determine the cyclist's potential for prolonged physical activity. A limitation of the study by Lucia et al. (1998) was the laboratory results (ie. $\%\dot{V}O_{2max}$) were not correlated with performance (ie. 40 km TT).

Anaerobic threshold values reported for MTB cyclists are presented in Table 6. Impellizeri et al. (2002) and Lee et al. (2002) have reported similar high anaerobic threshold values to road cyclists of 87.0 ± 1.8 and 86 ± 6 $\%\dot{V}O_{2max}$ (PO: 5.0 ± 0.4 and 5.2 ± 0.6 $W \cdot kg^{-1}$, respectively). The US National MTB team have reported anaerobic threshold values of 77.1 ± 6.4 $\%\dot{V}O_{2max}$ and 3.8 ± 0.3 $W \cdot kg^{-1}$ (Wilber et al., 1997). The use of different methods for determining

Table 6: Anaerobic threshold values from maximal oxygen consumption tests for mountain bike cyclists (Mean±SD).

Reference	Description	Method	Sex	N	$\%\dot{V}O_{2max}$	PO (W)	PO ($W \cdot kg^{-1}$)	HR (bpm)	$\%HR_{max}$	Lactate ($mmol \cdot ^{-1}$)
Wilber et al. 1997	US National XC Team	Lactate Threshold	M	10	77.1±6.4	271±29	3.8±0.3	166±13	86.4±4.2	2.9±1.1
Heller & Novotny 1997	Czech National Team	PWC 170	M	10		284±28	4.3±0.3			
Baron 2001	Austrian Elite National Level	OBLA – 4 $mmol \cdot L^{-1}$	M	25			4.7±0.6			
Impellizzeri et al. 2002	Mountain Bikers*	OBLA – 4 $mmol \cdot L^{-1}$	M	9	87.0±1.8	322±15	5.0±0.4	178±7	93.3±1.5	
Lee et al. 2002	Australian Internationally Competitive	D-max modified	M	7	86±6	339±31	5.2±0.6	172±11		3.3±0.7
Stapelfeldt et al. 2004	German National Team	1.5 $mmol \cdot l^{-1}$ above aerobic threshold	M	9		295±25				
Wilber et al. 1997	US National XC Team	Lactate Threshold	F	10	83.8±5.6	204±20	3.6±0.3	155±8	87.2±2.7	2.6±0.7
Stapelfeldt et al. 2004	German National Team	1.5 $mmol \cdot l^{-1}$ above aerobic threshold	F	2		226±22				

* Summer Test Session

anaerobic threshold may in part explain the discrepancies between different studies of cyclists.

In summary, anaerobic threshold can be an important factor in determining between homogenous cyclists of the same $\dot{V}O_{2max}$. Anaerobic threshold has been correlated with cycling performance, mainly in TT type races or tests. From the research conducted it appears that professional cyclists are able to maintain a high anaerobic threshold during performance (~87% $\dot{V}O_{2max}$), whereas competitive or amateur cyclists may work at ~66 to 77% of $\dot{V}O_{2max}$. Overall, MTB cyclists display comparable aerobic characteristics to road cyclists.

2.2.3 Anaerobic Power and Capacity

By riding in a bunch, a cyclist in a mass start event may achieve as much as 39% reduction in energy expenditure (McCole et al., 1990). Therefore, the first cyclist to cross the line in a bunch sprint may not be the one with the highest aerobic power but be determined by sprinting ability. An athlete may rely on good endurance capabilities to race competitively, but a large proportion of success in road cycling and mountain biking depends on anaerobic capabilities (Palmer, 2002). Anaerobic power is recognised as an important physiological factor in the performance capacity of athletes involved in short-term explosive events (White and Al-Dawalibi, 1986). Explosive anaerobic power is essential to performance in track cyclists and may play a significant role in breakaway attempts, hill-climbing and final sprints during road races. Mountain bike racing may also rely on the anaerobic system when starting the race, hill climbing and sprinting past slower riders.

A popular test used by many laboratories to measure anaerobic power is the standard Wingate protocol (Bar-Or, 1987). This test requires the athlete to complete as much work as possible in a 30 s sprint test. Peak power and average power in the 30 s are given to equate to anaerobic power (maximal power generated by the muscle) and anaerobic capacity (total power the muscle can produce using anaerobic sources) (Palmer, 2002). An athlete's ability to sprint is believed to rely on anaerobic power and capacity. There are many variations of testing anaerobic power. One such variation of the Wingate test is a 10 s sprint test described by Ellis et al. (2000).

Tanaka et al. (1993) measured the peak and mean PO of road cyclists using the Wingate test and reported US category II male cyclists to have a peak PO of 13.9 ± 0.2 $W{\cdot}kg^{-1}$ (994.1 ± 38.0 W) and mean PO of 11.2 ± 0.2 $W{\cdot}kg^{-1}$ (804.1 ± 28.9 W). Female category II – IV road cyclists produced a peak PO of 12.2 ± 0.7 $W{\cdot}kg^{-1}$ (783.7 ± 49.5 W). Czech MTB cyclists (Heller and Novotny, 1997) produced similar results to Tanaka et al. (1993) using the Wingate test with peak PO values of 14.7 ± 1.0 $W{\cdot}kg^{-1}$ and 963.9 ± 87.5 W.

Using a modified test Vandewalle et al. (1987) studied track and road cyclists using short maximal sprints (~6 s) and found the track sprinters (1150 ± 127 W, 16.8 ± 1.2 $W{\cdot}kg^{-1}$) to have significantly higher absolute and relative PO than the road cyclists (849 ± 109 W, 12.5 ± 1.0 $W{\cdot}kg^{-1}$). The results of a 10 s sprint test for Austrian MTB cyclists reported the peak PO to be 14.9 ± 1.1 $W{\cdot}kg^{-1}$ (Baron, 2001). This result was lower than track cyclists and higher than the road cyclists previously reported (Vandewalle et al., 1987).

Vertical jump is another test used to measure anaerobic power by explosive leg strength which is required in all cycling disciplines at various stages of a race. White and Al-Dawalibi (1986) examined international-elite cyclists (45.0 ± 5.3 cm) and found a significantly greater ($p>0.05$) vertical jump than Category I cyclists (42 ± 3 cm) and Category II and III cyclists (41 ± 4 and 42 ± 4 cm, respectively). In comparison Vandewalle et al. (1987) found track cyclists to have a higher vertical jump (63 ± 4 cm) than the athletes in the study of White et al. (1986). The result for the track cyclists was 29% higher than the road cyclists (49 ± 6 cm) tested in the same study. In contrast, Telford et al. (1990) measured the vertical jump of Australian national track and road cyclists and no significant difference was found (47.5 ± 4.7 and 44.3 ± 6.7 cm). Telford et al. (1990) suggested the similarity of the results might have been due to the similarity of training of these cyclists over the road racing season, which had just been finished.

The methods used to assess vertical jump for each of the following studies were different. White and Al-Dawalibi (1986) measured vertical jump by a retractable tape attached around the waist during a half squat/leg extension manoeuvre, with zero height at standing ground level. Whereas Vandewalle et al. (1987) measured vertical jump using a fast counter movement jump with the jump height equalling the difference between body height and the level reached by the head during the peak of the jump. Even though different methods have been employed to measure vertical jump, the researchers are essentially measuring the difference between standing height and jump height. No methodical explanation was given for vertical jump in the study by Telford et al. (1990).

Maximal accumulated oxygen deficit (MAOD) is a test commonly used to describe anaerobic capacity (Martin et al., 2001). The method of measuring MAOD was determined by Medbo et al. (1988). Anaerobic capacity is the total power that the muscle can produce using anaerobic sources (Palmer, 2002). The existence of a significant anaerobic energy contribution during a cycling event is often indicated by a high post-competition BLa level, 12 – 22 $mmol \cdot L^{-1}$ depending on the event (Burke et al., 1981, Neumann, 1992).

Craig et al. (1993) reported a significant correlation ($r = -0.50$) between the 4000 m individual pursuit and relative MAOD using a 5-min protocol. No significant difference in MAOD occurred when assessed by either a 2 or 5 min protocol (61.4 ± 7.3 and 60.2 ± 12.5 $ml \cdot kg^{-1}$, respectively). Further to this study, Craig et al. (1995) investigated the relationship between the time required to fully utilise the anaerobic capacity and the event specificity of the cyclist. When the results of sprint and endurance cyclists were combined for MAOD, no significant difference was found. If the groups were separated, the sprint cyclists achieved a significantly greater ($p < 0.05$) MAOD 66.9 ± 2.2 $ml \cdot kg^{-1}$ for the 70 s duration test compared to the endurance cyclists of 57.4 ± 6.7 $ml \cdot kg^{-1}$. A modified MAOD was performed with members of the Australian national women's road cycling team which resulted in a mean MAOD of 50.6 ± 9.9 $ml \cdot kg^{-1}$ with a range of 39.6 to 73.1 $ml \cdot kg^{-1}$. The reliability of the MAOD test measured at 110% and 120% of $\dot{V}O_{2peak}$ was investigated by Weber and Schneider (2001). Both the 110% and 120% tests were found to be highly repeatable for time to exhaustion (226 ± 13 and 223 ± 14 s: 158 ± 11 s and 159 ± 10 s) and MAOD (2.62 ± 0.19 and 2.54 ± 0.19 L: 2.64 ± 0.21 and 2.63 ± 0.19 L), respectively.

Anaerobic power and capacity was predominantly investigated in track cyclists because of the explosive nature of the events but has become part of the routine testing of road cyclists, who also require explosive bursts during racing. Track cyclists have higher peak and mean PO when measured using a Wingate or short sprint test than road or MTB cyclists. Vertical jump is also higher for track cyclists (63 cm) than for road cyclists (41 – 48 cm). MAOD for track sprint cyclists was found to be ~67 $ml \cdot kg^{-1}$ compared to the value of 58 $ml \cdot kg^{-1}$ for track endurance cyclists. A group of female road cyclists were found to have an average MAOD of 50.6 $ml \cdot kg^{-1}$. There has been no published data for vertical jump or MAOD for MTB cyclists.

2.3 COMPETITION DEMANDS

The physiological demands of cycling relate to a variety of factors, including aerobic and anaerobic capacity, submaximal parameters, muscular strength and endurance, and body composition (Faria, 1984). Cycling performance depends on a complex interaction of many physiological (i.e. an athlete's $\dot{V}O_{2max}$, LT, economy of movement, gross mechanical efficiency); environmental (wind, velocity, temperature, humidity, altitude); and mechanical (type of bicycle, wheels, tyres and components) variables (Jeukendrup et al., 2000). For instance, in road cycling, the winner is not always the strongest, lightest or one with the highest $\dot{V}O_{2max}$.

Heart rate monitors over the past few decades have become an addition to the cyclist's equipment, to control and monitor the intensity of training sessions and races. Heart rate measurements may become powerful and accurate indicators of exercise intensity when related to other physiological parameters (Achten, 2002) such as $\dot{V}O_2$ and BLa because direct measurements of $\dot{V}O_2$ during outdoor exercise are difficult to measure (Palmer et al., 1994). However, HR shows a linear relationship with $\dot{V}O_2$ uptake allowing the extrapolation of data to accurately estimate the physiological responses to exercise.

One of the most exciting developments in the science of cycling has been the introduction of devices to measure PO during cycling (Jeukendrup, 2002b). Previously, scientists only used laboratory-based ergometers to control cycling power while measuring other variables such as HR, $\dot{V}O_2$, perceived exertion, pedal forces and muscle recruitment pattern (Broker, 2003). Now there are a variety of different commercially available power output devices to chose from such as the SRM powermeter (Schoeberer Resistance Measurement: Julich, Germany), Power Tap (CycleOps: Madison, WI), Polar Power ® (Polar Electro, Finland) and Ergomo (Ergomo, USA).

2.3.1 Road Cycling

Heart rate data during cycling competition was first published by Palmer et al. (1994). Seven amateur cyclists were chosen from competitors entered in the Giro del Capo, a 4 d stage race. Six of the seven cyclists recorded higher HR_{peak} while racing than during an incremental $\dot{V}O_{2max}$ test. The HR recorded during the 16.0 km ITT increased to 182 ± 5 bpm after ~2 min and stayed there for the duration (mean time: 22:47 ± 00:33 min). Heart rate during a 5.5 km hill climb rose to 173 ± 5 bpm after ~2 min of the climb then remained between 171 and 191 bpm. The mean intensity of the hill climb was estimated to be ~89% of $\dot{V}O_{2max}$ from the incremental test, which was the same for the ITT. The HR responses for the two mass-start road races were similar (81.9 ± 9.6% and 78.6 ± 8.9% of field HR_{peak}). Any increase in gradient was accompanied by an increase in HR and vice versa for descents. The mean HR for the first road stage (110 km) was 157 ± 18 bpm (~71% of $\dot{V}O_{2max}$) and for the second (105 km) was 151 ± 17 bpm (~66% of $\dot{V}O_{2max}$). The majority of the race for the individual events (ITT, hill-climb) was spent between 91% and 100% of HR_{max} (81 – 100% of $\dot{V}O_{2max}$) in contrast to the longer road stages being raced between 71% and 90% HR_{max} (51 – 90% $\dot{V}O_{2max}$).

During the mass-start road stages, Palmer et al. (1994) observed random and variable changes in frequency and amplitude of the HR response to the differing exercise intensities. These stochastic physiological responses were thought to be reflections of the course terrain but on closer investigation were found to be a result of group dynamics of the cyclists. The stochastic nature of bunch riding and the differences in HR_{peak} recorded in the field and laboratory raises the question of the validity of “steady-state’ laboratory testing to prescribe training intensities or predict performance in events that are largely stochastic in nature (Palmer et al., 1994).

Lucia et al. (1999) studied the HR response of eight professional cyclists during 22 competition stages of the Tour de France and calculated the time spent in three exercise intensity zones. The average total amount of time spent by the subjects in zones below, at and above anaerobic threshold were ~71, 23 and 8 h, respectively. The relative contributions to total race time was 70, 23 and 7%, respectively. The winner of the 63 km ITT was able to sustain a near maximal workload (>90% $\dot{V}O_{2max}$) for ~70 min. The same subject also spent ~80 min (~22%) above threshold for a high mountain stage and ~50% of time below threshold. Overall, Lucia et al. (1999) found the exercise intensity decreased in the following order: time trials > high mountain stages > medium mountain stages > flat stages.

Fernandez-Garcia et al. (2000) investigated 18 professional cyclists competing in the 1995 Vuelta a Espana and the 1996 Tour de France. This study was the first to evaluate HR response during two professional multi-stage cycling races involving top level cyclists. The mean HR values for the Vuelta and Tour was found to be similar; overall (134 ± 18 and 134 ± 19 bpm), flat stages (127 ± 10 and 126 ± 14 bpm), mountain stages (130 ± 8 and 135 ± 10 bpm) and ITT (171 ± 11 and 166 ± 12 bpm), respectively. Fernandez-Garcia et al. (2000) are in agreement with Lucia et al. (1999) that the competition data supports the idea that professional cycling is a long-duration, high intensity sport, with a high involvement of aerobic metabolism.

Time in the intense aerobic (IA=70-90% $\dot{V}O_{2max}$) category was 75.2 ± 47.6 and 79.6 ± 48.3 min daily for the Vuelta and the Tour, respectively. Whereas, time spent in the moderate aerobic (50-70% $\dot{V}O_{2max}$) category was 97.2 ± 57.4 and 89.5 ± 54.9 min. The time spent above the anaerobic threshold (>90% $\dot{V}O_{2max}$) contributed to ~20 min. Based on the race HR responses and laboratory tests, it was found that each cyclist spent about 93 min in flat stages and 123 min in mountain stages (32% of the total stage time in flat and 40% in mountain stages) riding at an intensity greater than 70% of $\dot{V}O_{2max}$, and between 18 and 27 min of this time was at an intensity greater than 90% of $\dot{V}O_{2max}$, depending on the type of stage. Overall, nearly 75% of each stage was spent above 50% $\dot{V}O_{2max}$.

Fernandez-Garcia et al. (2000) found that during ITT's, cyclists spend on average 20 min above 90% of $\dot{V}O_{2max}$ (16.7 min during the Vuelta and 23 min in the Tour) in comparison to Lucia et al. (1999) who reported a contribution of approximately 7% over 87.5% of $\dot{V}O_{2max}$, and 23% of time between 71.2 and 87.5% of $\dot{V}O_{2max}$. Fernandez-Garcia et al. (2000) also had a greater contribution (12% during the Vuelta and 16.7% during the Tour) over 90% of $\dot{V}O_{2max}$ and between 70 and 90% of $\dot{V}O_{2max}$ (29.4 and 29.1%).

The HR data from this study support the findings of Palmer et al. (1994). Although in contrast to the conclusion of Palmer et al. (1994), Fernandez-Garcia et al. (2000) found that the HR response was related to course profile rather than being stochastic. They also noted that the time spent above anaerobic threshold was roughly 20 min regardless of stage type, which may mean that anaerobic capacity, could be limited and/or limits performance.

Padilla et al. (2000) focused on investigating the exercise intensity of different competition time trials. Eighteen professional road cyclists were monitored for HR in nine races from 1993 to 1995. The time trials included: prologues (<10 km), short TT (<40 km), long TT (>40 km) and uphill TT (~40 km). The prologue produced the highest HR of all time trials, 177 ± 5 bpm (89 ± 3 %HR_{max}) which was significantly greater than the short TT (172 ± 9 bpm, 85 ± 5 %HR_{max}), long TT (162 ± 6 bpm, 80 ± 5 %HR_{max}) and uphill TT (158 ± 7 bpm, 78 ± 3 %HR_{max}). These results may not be entirely indicative of the intensity used for competing in TT events because although the aim of a TT is to achieve the shortest possible time to cover a fixed distance a cyclist may not race at their fastest pace. The only cyclists that race a TT event maximally are those who have a realistic chance of winning the stage or are competing for a top position in the final overall standings. This group represents no more than 15-20% of the cyclists (Padilla et al., 2000).

Padilla et al. (2001) also studied exercise intensity in mass-start road races of 17 professional cyclists in the major 3 wk stage races from 1994 to 1995. The stages were classified into three categories: flat, semi-mountainous or high mountain and the average HR for each was 119 ± 10, 130 ± 9 and 135 ± 9 bpm, respectively. This corresponded to ~51, 58 and 61% of HR_{max} and ~57, 65 and 69% HR_{OBLA} for flat, semi-mountainous and high mountain stages, respectively. Power output during these stages was estimated from the incremental $\dot{V}O_{2max}$ test and found to be 192 ± 45, 234 ± 43 and 246 ± 44 W (~45, 53 and 57% W_{max}).

The average $\%HR_{max}$ values recorded by Padilla et al. (2001) for all three categories was much lower (51 to 61%) than ~80% for mass-start road stages by Palmer et al. (1994). Padilla et al. (2001) explained the difference by the duration of the stage, 302 – 355 min compared to >165 min (Palmer et al., 1994) and also the method used to determine HR_{max}. Percent time and total time spent above (1.0 ± 2.3%, 3 ± 7 min) and at (3.8 ± 4.8%, 13 ± 15 min) HR_{OBLA} in high mountain stages and (1.4 ± 2.3%, 4 ± 7 min above HR_{OBLA} and 3.3 ± 3.3%, 9 ± 9 min at HR_{OBLA}) for semi-mountainous stages was significantly higher than in flat stages (0.7 ± 1.2%, 2 ± 4 min above HR_{OBLA}, 1.2 ± 1.5%, 4 ± 4 min at HR_{OBLA}).

To summarise, HR monitoring is a useful tool to determine exercise intensity during TT and mass-start road competitions by relating racing demands with laboratory-based maximal and submaximal reference values (Mujika and Padilla, 2001). The highest HR values were attained during TT stages. Professional cyclists spend less time at high HR, but during decisive moments in racing, HR can be near maximal and sustained for relatively long periods (Achten, 2002).

There is very little published data describing the demands of women's cycling competition. Trewin et al. (abstract 1999) studied the PO demands of Australian women during two World Cup road races and compared the requirements for a top 20 placing versus a non-top 20 placing. On average, the women raced for 169 ± 2.5 min and achieved respectable results (28 ± 21 place, range 1^{st}–57^{th}). The following race characteristics were collected on 12 cyclists: 3.3 ± 0.3 $W \cdot kg^{-1}$ average PO, 13.8 ± 2.6 $W \cdot kg^{-1}$ peak PO, 27 ± 4% of race time spent <0.75 $W \cdot kg^{-1}$ and 9 ± 3% of race time spent above 7.50 $W \cdot kg^{-1}$. No more than 10% of race time was accumulated in any other power band. Differences for PO were only significant for top 20 vs non-top 20 in the lowest and highest PO bands. Cyclists in the top 20 spent more time >7.50 $W \cdot kg^{-1}$ (11 ± 2 vs 7 ± 2%, $p < 0.01$) and less time <0.75 $W \cdot kg^{-1}$ (24 ± 4 vs 29 ± 3%, $p = 0.05$) than non-top 20 cyclists. The top 20 cyclists also produced a higher average PO (3.6 ± 0.4 vs 3.1 ± 0.1 $W \cdot kg^{-1}$). The data indicates that the top 20 placed cyclists spend more time in the higher power bands and less time recovering than non-top 20 cyclists.

In summary, HR monitoring during road races has shown that higher HR values and $\%\dot{V}O_{2max}$ are present in TT or climbing stages than longer road stages (~182 vs 151 bpm and ~89 vs 66% $\dot{V}O_{2max}$). Time spent above 90% $\dot{V}O_{2max}$ during a road stage of a major road tour contributed to ~20 min, compared to ~94 min in the moderate aerobic zone (50-70% $\dot{V}O_{2max}$) and ~77 min in the intense aerobic zone (70-90% $\dot{V}O_{2max}$). While PO devices are readily available now, the majority of competition data has been monitored using HR.

2.3.2 Track Cycling

The power output required for successful track cycling performance depends upon variables such as bicycle speed, bicycle structure and design, the cyclist's size and position, and environmental factors (Craig and Norton, 2001). Until the recent advent of the SRM power meter, mathematical models were used to estimate the mechanical power requirements of the different track cycling events. The first to report SRM power output profiles for track cycling was Broker et al. (1999). They collected data on seven male national team cyclists of the United States 4000 m pursuit team. The 4000 m pursuit involves four cyclists competing against the clock from a standing start. The time stops when the first three riders cross the line and each rider takes a turn in the lead. The test protocol involved two teams performing flying 2000 m pursuits at ~60 $km \cdot h^{-1}$, which was estimated as a gold medal time for the Olympics. When cycling at this speed, the average PO for the riders in position one to four were 607 ± 45, 430 ± 39, 389 ± 32 and 389 ± 33 W, respectively. Due to the effect of drafting the second, third and fourth riders were only required to produce 71, 64 and 64% of the PO maintained by the lead rider.

Data collected on elite Australian team pursuit cyclists during the 1998 World Cup (Jeukendrup et al., 2000) showed a lower average PO of 581 W for the lead rider compared with 607 W found by Broker et al. (1999). The discrepancy can possibly be explained by the differences in riding speed. The pursuit team in the study of Broker et al. (1999) rode at 60 km·h^{-1}, whereas the competition speed of the World Cup race was 56 – 58 km·h^{-1}. The average PO data from the team's pursuit assists in providing the minimum requirements when selecting riders. The power profile from a team's pursuit reveals the stochastic nature of the event. Instantaneous PO at the start of the event was ~1250 W and dropped to <1000 W after the first 8 – 10 s of the race (Jeukendrup et al., 2000). Depending on the rider's position in the team, the PO fluctuated between 600 – 650 W when in the lead position to 350 – 400 W when following other team members. Despite the variations in PO, cadence was held within a narrow range regardless of position (Craig and Norton, 2001).

In contrast, the power profile for a rider competing in the individual 4000 m pursuit (3000 m for women) are much more even than for the 4000 m team pursuit. A narrower range exists for the PO required to ride competitively, with the PO during the first 5 – 10 s of the 4000 and 3000 m similar (~1000 W: (Jeukendrup et al., 2000)). Even though the female race distance is shorter, the PO is considerably lower for the remainder of the race (363 – 381 W) compared to the male rider (475 – 500 W).

Broker et al. (1999) used a mathematical model to predict the average PO required of a cyclist to ride the 4000 m individual pursuit in a time of 4:31 min with a body mass of 79.2 kg and height of 1.82 m to be 479 W. Jeukendrup et al. (2000) reported from unpublished observations that this estimate agreed with the average PO data collected on Australian riders competing in international events with comparable race times.

Schumacher and Mueller (2002) reported on the theoretical background and training concepts of the Olympic 2000 world record breaking team pursuit ride by the German team. They deemed that in sporting disciplines where competition ranking is determined by racing times (such as track cycling, swimming or running), prognosis of future winning times through analysis of past winning times of the same event and their historical progression is possible. Using mathematical equations, Schumacher and Mueller (2002) calculated an average team pursuit power of 521 W to ride a 4 min pursuit time (speed 60 km·h^{-1}, body mass 79 kg and height 186 cm). As a result, the rider in position 1 needs to have a PO of ~670 W and 450 W for positions 3 and 4 to win this discipline at the 2000 Olympic Games. The German riders performed a flying 2000 m similar to Broker et al. (1999) 3 d before the Olympic race using two different gears in 1:58.7 min (gear 53 x 15) and 1:55.9 min (gear 53 x 14) that corresponded to average power outputs of 480 W and 513 W, which is higher than the average PO of 454 W found by Broker et al. (1999).

A female cyclist during a 200 m flying qualification sprint at a World Cup event produced peak and average PO values of 1020 and 752 W, respectively (Craig and Norton, 2001). Power output at the end of the 200 m was 568 W, speed and cadence peaked at 63.5 $km \cdot h^{-1}$ and 150 rpm, with an average cadence of 142 rpm. Craig and Norton (2001) have also measured a power profile for the 1000 m TT of an elite male during international competition. Peak power output was 1799 W at the start of the event and finished with a PO of 399 W (78% decay). Average PO for the event was 757 W with an average cadence of 127 rpm.

In contrast to road cycling, the majority of published track cycling competition demands has been a result of PO data collection. Power output data for track cycling is more meaningful to coaches than HR data because of the short duration events and PO provides specificity of the cyclists' performance. The data has shown that track endurance cyclists are able to produce ~1250 W at the start of a 4000 m teams pursuit. Average PO for the four riders depending on position ranges from 607 to 389 W. Peak power output during track sprint events for males and females can exceed 1700 and 1000 W, respectively.

2.3.3 Mountain Bike

Mountain bike cyclists usually compete at least once a week for 9 months of the year, for a total of 30-40 competitions (Impellizzeri et al., 2002). The racing includes: XC, short-track, TT, marathon and stage races. Impellizzeri et al. (2002) were the first to publish data relating to the profile of exercise intensity in XC MTB races. They collected HR data on five male MTB cyclists competing at three international races and one national championship (2 races in winter, 2 in summer). The race data was analysed in relation to an incremental maximal oxygen consumption test. Three intensity zones were established from the maximal test: EASY (HR below LT), MODERATE (HR between LT and OBLA) and HARD (HR above OBLA). The absolute race time spent in the EASY, MODERATE and HARD zones was 27 ± 16, 75 ± 19 and 44 ± 21 min, respectively which corresponds to 18 ± 10, 51 ± 9 and 31 ± 16% of total race time. Two statistically significant differences were found between races. The first was that the absolute and relative time spent in the EASY zone during race 3 was lower than race 1 and 2. The second was the absolute and relative time spent in the HARD zone during race 2 was lower than all other races. No obvious effect of season was found so it was concluded by Impellizzeri et al. (2002) that the differences between HR intensity of the races was related to the specific characteristics of the different courses. The average HR of the four races was 90 ± 3% of HR_{max} which corresponded to 84 ± 3% of $\dot{V}O_{2max}$. Analysis of laps during the third and fourth race found a significant increase in lap time with the average HR decreasing significantly as the races progressed.

The latest published data relating to PO demands during MTB competition has been investigated by Stapelfedlt et al. (2004) with the German national MTB XC team. SRM power cranks were used to measure PO during XC competition with 9 males and 2 females. The average PO over 15 races for the male cyclists was 246 ± 12 W (3.5 ± 0.2 $W \cdot kg^{-1}$) with a range of 218 ± 25 to 281 ± 32 W over an average duration of 2:08 ± 0:17 (h:mm). The female cyclists averaged 193 ± 1 W (3.1 ± 0.2 $W \cdot kg^{-1}$) with an average duration of 1:48 ± 0:04 (h:mm). Stapelfedlt et al. (2004) established that PO during a MTB XC race is of a highly variable nature will values oscillating from 50 to 400 W. In contrast to the PO, HR showed little variation during competition. The competition results were related to laboratory testing of $\dot{V}O_{2max}$ to determine the distribution of time in certain zones. The time spent: below aerobic threshold, between aerobic and anaerobic threshold, between anaerobic threshold and maximum, and above maximal values was 39 ± 6, 19 ± 6, 20 ± 3 and 22 ± 6%, respectively.

In summary, there is limited competition data for MTB cyclists because the sport is still in its infancy. Cross-country racing has a high aerobic capacity requirement, which was shown with cyclists competing at an average of 90% HR_{max} and 84% of $\dot{V}O_{2max}$. Male MTB cyclists raced at an average of 246 W over a 2hr duration compared to female cyclists using an average of 193 W over 1:48 hr duration.

Overall, competition demands of cycle racing are individual for each discipline and even for each event. It is possible to use HR monitoring for long road stages and XC MTB races because of the duration but HR data would not be useful for assessing the demands of track racing. With the advent of PO monitors, more accurate and meaningful data can now be sampled and analysed across all cycling disciplines and events.

2.4 ASSESSMENT OF PHYSIOLOGICAL CAPACITIES

Performance tests are an integral component of assessment for competitive cyclists in practical and research settings (Paton and Hopkins, 2001). Most cycling tests are performed on a stationary ergometer and measure power against sliding friction, electromagnetic braking or air resistance. Portable ergometers (eg. SRM crank) allow power to be measured by the drive train from the cyclist's own bike in real or simulated competitions on the road or MTB, on the velodrome or in the laboratory. For monitoring performance changes, an ergometer must be reliable and accurate. Research has shown that the SRM crank fulfils these requirements (Gardner et al., 2004), hence it is the power meter of choice for the Australian MTB team (Personal communication). Peak power in incremental tests and mean power in all-out sprints have the lowest reported random error (~1%) and measures derived from constant-power tests to exhaustion and TT are also reliable tests (Paton and Hopkins, 2001). An essential component of athletic testing is determining the reliability of a measure so real changes in performance as a consequence of an intervention can be discriminated from those associated with technical measurement error (Bishop, 1997).

2.4.1 Road Cycling

Maximal oxygen uptake is a good predictor of performance in a heterogeneous group of athletes, but is frequently recognised that individuals with a similar $\dot{V}O_{2max}$ can differ considerably in relation to performance (Coyle et al., 1988, Coyle et al., 1991). It is believed that athletic performance velocity during endurance exercise is determined by the highest steady-state rate of $\dot{V}O_{2peak}$ that can be tolerated (Coyle et al., 1988). It is not uncommon for an athlete to achieve their highest $\dot{V}O_{2max}$ after the initial few years of intense training and following this other adaptations need to be made for further improvements in performance (Lucia et al., 1998).

Coyle et al. (1988) studied fourteen endurance athletes who possessed similar $\dot{V}O_{2max}$ values to determine if endurance performance is related to BLa response during submaximal exercise. The athletes were separated into a high and low group according to their %$\dot{V}O_{2max}$ at LT (1 mmol·L^{-1} increase in BLa above baseline). The characteristics for the high and low group were 68.6 ± 3.2 and 66.0 ± 4.3 ml·kg^{-1}·min^{-1} $\dot{V}O_{2max}$, and 81.5 ± 4.8 and 65.8 ± 4.6 %$\dot{V}O_{2max}$ at lactate threshold, respectively. The endurance performance test was determined as the length of time the cyclist could maintain ~88% of $\dot{V}O_{2max}$. Cycling at this work rate required the high group to work slightly above their lactate threshold intensity (8%), whereas the low group exercised at 34% above their lactate threshold. The time to fatigue was significantly greater for the high group (60.8 ± 7.6 min) compared to the low group (29.1 ± 12.2 min) and BLa was significantly lower for the high group in comparison to the low group (7.4 ± 1.7 and 14.7 ± 2.4 mmol·L^{-1}). From these findings, Coyle et al. (1988) suggested that submaximal performance is closely related to the factors that control muscle glycogenolysis and BLa, and therefore the differences in performance ability during high-intensity submaximal cycling are highly related (r = 0.96) to lactate threshold $\dot{V}O_2$.

Continued work in the same area by Coyle et al. (1991) investigated real time 40 km TT performance and a 1 h laboratory performance test. Fifteen male United States category I and II cyclists were separated into two groups according to their best time for a 40 km TT. Group 1 performed the 40 km TT significantly faster (10%) than group 2 (53.9 ± 1.7 and 60.0 ± 2.8 min). The laboratory performance test was designed to determine the highest average work rate for 1 h that was best correlated to $\dot{V}O_2$ at lactate threshold (r = 0.93). Group 1 maintained a significantly higher (11%) work rate than group 2 during the test (346 ± 20 and 311 ± 27 W, respectively), which also resulted in a 9% higher average $\dot{V}O_2$ (4.54 ± 0.28 and 4.18 ± 0.38 L·min^{-1}). The 40 km TT performance was highly correlated (r = -0.88) with the average absolute work rate maintained during the laboratory test and closely related to the average $\dot{V}O_2$ maintained in absolute terms (r = -0.834) but not in relative terms.

Hawley and Noakes (1992) examined if there was a relationship between peak power output (PPO) and $\dot{V}O_{2max}$ during a laboratory test to exhaustion. A highly significant relationship was found (r = 0.97), therefore athletes without access to measuring oxygen uptake can predict their $\dot{V}O_{2max}$ from an incremental test when PPO has been determined. The study also involved the assessment of the relationship between PPO and 20 km TT. It was found that PPO achieved during the laboratory incremental test can be considered a valid predictor of cycling times over 20 km on a flat course (r = -0.91) within a heterogenous group of cyclists.

Subsequent to the previous study of Hawley and Noakes (1992), Hopkins and McKenzie (1994) investigated the relationship between measures of laboratory performance and a 40 km ITT with eight male competitive cyclists. They found subjects to maintain a calculated PO of 359 ± 31 W during the TT which was within 18 W of PO measured at ventilatory threshold in the laboratory. Time trial performance was closely related to PO at ventilatory threshold (r = -0.81) and $\dot{V}O_{2max}$ (r = -0.73) but not to measures of $\dot{V}O_2$ at ventilatory threshold or W_{max}. This is contrary to the findings of Hawley and Noakes (1992) who found a significant relationship between W_{max} and TT performance, which may be a result of the homogenous athletes used in this study. Laboratory data can provide general information about TT performance but cannot predict a winning performance (Hopkins and McKenzie, 1994).

Performance tests became popular for use in intervention studies in the mid 1990's, but there was no uniform endurance performance test that existed, therefore Jeukendrup et al. (1996) investigated the reproducibility of three different endurance performance tests. The exercise protocols were: (A) continuous exercise at 75% W_{max} until exhaustion, (B) a preload of 45 min at 70% W_{max} followed by a 15 min TT to perform as much work as possible and (C) a 1 h TT to complete as much work as possible. The coefficient of variation was calculated for protocols A, B and C and found to be 26.6%, 3.5% and 3.4%, respectively. The reproducibility of protocol A was poor and the test was shown to be unreliable. One reason for this poor reproducibility may be psychological factors such as motivation, monotony and boredom. The TT protocols appear highly reproducible possibly because there is a known endpoint (ie. a certain target amount of time or work to complete).

A 1 h endurance performance test has been previously studied (Coyle et al., 1991) with the aim of enerating the highest power output in the allocated time. Average absolute PO was highly correlated with actual 40 km TT performance and although the test was found to be valid, the reliability was not reported. The reliability of a 1 h performance test was then investigated by Bishop (1997). Twenty trained female subjects ($\dot{V}O_{2peak}$: 47.4 ± 7.2 ml·kg^{-1}·min^{-1}) completed two trials in which they had to generate the highest possible power for 60 min of cycling. Although there was no significant difference between the average PO for trial 1 (180 ± 18 W) and trial 2 (180 ± 21 W), there was considerable variation between trials for individuals. Bishop (1997) reported that average absolute PO across the two trials showed high reliability (intra-class correlation = 0.97) and a low coefficient of variation (2.7%), which supports the suggestion that TT protocols may result in more reliable performance evaluation than time to fatigue tasks (Jeukendrup et al., 1996). The reproducibility of the average absolute PO from this study supports the work of Coyle et al. (1991) who validated the 1 h endurance performance test.

Studies have investigated the relationship between laboratory tests and TT performances, and the reproducibility of performance tests, but it has yet to be determined if the use of “steady-state” laboratory tests are a reliable means of testing for field performance when competition is of a stochastic nature. Palmer et al. (1997) were the first to use a variable PO protocol in TT performance testing. The testing involved a stochastic protocol using a varied work rate between 35.8 and 82.3% of PPO for 150 min, and for comparison, a steady-state protocol with a work rate of 58% PPO for 150 min, both followed by a 20 km TT. Although no significant differences were observed in HR between the steady-state and stochastic trials (153 ± 6 and 150 ± 11 bpm, respectively), subjects were significantly faster (26:32 and 28:08 min:s) and produced higher power outputs (340.3 ± 44.2 and 302.5 ± 42.3 W) in the TT following the steady-state protocol.

Schabort et al. (1998) extended the design of a stochastic protocol for testing cyclists. Eight well-trained subjects ($\dot{V}O_{2max}$: 64.8 ± 5.7 ml·kg^{-1}·min^{-1}) completed three trials of a

100 km stochastic TT. During the 100 km, subjects were required to sprint for 1 km at 10, 32, 52 and 72 km, and sprint for 4 km at 20, 40, 60 and 80 km. The sprints were included as an attempt to replicate the surges and sprints that exist in road racing. The protocol was shown to have high reproducibility (r = 0.93, between-test correlation for 100 km time) and also for the mean sprint performances. Schabort et al. (1998) suggested protocols that allow subjects to choose their own work rate during a simulated competitive effort are more reliable than tests in which a fixed workload is imposed. This finding is in agreement with Jeukendrup et al. (1996) who reported that TT testing was more reproducible than a continuous test and in discrepancy with Palmer et al. (1997) who found that a steady-state protocol prior to a TT resulted in a faster time than a stochastic pre-load. Although it has been shown by Schabort et al. (1998) that it is possible to reproduce a laboratory test of cycling performance that simulates the variable power demands of competitive road cycling, the protocol does not allow for time spent in recovery, on descents or bunch riding which all reduce the power output.

Leidl et al. (1999) examined simulated TT performed at constant and variable powers consisting of the same work and time requirements. Nine subjects performed two 1 h trials, one requiring a constant effort equivalent to 78.5 ± 1.7% of the subject's $\dot{V}O_{2max}$, and the second was variable, requiring alternating 5 min periods of 95% and 105% of mean power throughout the test. No significant differences were observed between the two trials for $\dot{V}O_2$ (3.33 ± 0.11 and 3.26 ± 0.12 $L \cdot min^{-1}$, constant and variable respectively), HR (158 ± 3 and 159 ± 3 bpm), mean BLa (4.2 ± 0.7 and 4.3 ± 0.7 $mmol \cdot L^{-1}$) and RPE (13.9 ± 0.4 and 14.1 ± 0.4). Liedl et al. (1999) reported that although the mean BLa value did not differ between the constant and variable power trials, higher BLa values were recorded during the 105% stages when compared to the 100 and 95% stages, which were similar. With regard to $\dot{V}O_2$ the reverse was true, lower $\dot{V}O_2$ values were recorded during the 95% stages compared to the 100% and 105% stages which were the same. This led the authors to conclude that the variable power trial was conducted with a greater reliance on anaerobic glycolysis. This observation is of particular importance when considering road racing where power outputs are variable due to the tactics and dynamics involved with bunch riding. Professional cycling teams have specialist riders they protect for a sprint finish, therefore throughout the race these riders need to be spared from the constant changes of pace and utilisation of anaerobic glycolysis to conserve for the finish.

In summary, road cyclists with similar $\dot{V}O_{2max}$ values may have very different performance capabilities because cyclists use varying percentages of their $\dot{V}O_{2max}$. Tests can be used to predict $\dot{V}O_{2max}$ from PPO for cyclists with access to laboratory equipment. Further to this finding, is that specific laboratory testing (eg. stochastic or steady-state tests) can be used to predict TT performances.

2.4.2 Track Cycling

The validity of a velodrome field test was evaluated by Padilla et al. (1996) consisting of repeated stages of (2280 m) with an initial speed of 28 $km \cdot h^{-1}$ increasing by 1.5 $km \cdot h^{-1}$ interspersed with 1 min recovery periods until exhaustion. Twelve male competitive road cyclists performed maximal cycling tests on the velodrome and in the laboratory. Power output and $\dot{V}O_2$ for the velodrome test was estimated using established mathematical equations. No significant differences were observed between the velodrome and laboratory maximal values for PO (372 ± 50 and 365 ± 36 W), HR (195 ± 8 and 196 ± 9 bpm) and $\dot{V}O_{2max}$ (4.49 ± 0.56 and 4.49 ± 0.46 $L \cdot min^{-1}$). Maximal BLa was significantly higher in the velodrome test (13.5 ± 2.1 $mmol \cdot L^{-1}$) than the laboratory (11.8 ± 3.1 $mmol \cdot L^{-1}$) which could be explained by the different protocols used for the two tests. Padilla et al. (1996) reported that velodrome HR was higher at submaximal intensities representing 40, 50 and 60% of $\dot{V}O_{2max}$ and BLa was higher at 60, 70 and 80% of $\dot{V}O_{2max}$. Maximal cycling speed in the velodrome showed the highest correlation with laboratory $\dot{V}O_{2max}$ (r = 0.93) when expressed in relative terms. Padilla et al. (1996) stated that when road cyclists are tested in the laboratory, physiological values should be expressed in relative terms to more accurately predict cycling performance under specific field conditions.

2.4.3 Mountain Bike

Energy expenditure of cyclists using various MTB suspension systems was studied by Berry et al. (1993). The study involved cyclists riding on a treadmill with a board attached to form a 'bump' at 6.5 mile per h at a grade of 4% using no, front, and full (front and rear) suspension systems. The lowest energy expenditure was found with no bump, regardless of no or full suspension ($\dot{V}O_2$: 1.71 ± 0.14 $L{\cdot}min^{-1}$, HR: 117 ± 6 bpm). The highest energy expenditure occurred with the bump and no suspension (2.79 ± 0.20 $L{\cdot}min^{-1}$ $\dot{V}O_2$, 155 ± 6 bpm HR). The study was restricted to a single suspension design used at a single speed in uphill riding, therefore it is difficult to prove a performance advantage for racing.

Suspension systems will lower levels of energy expenditure and physical stress because the rider will not be subjected to the full impact force of bumps and vibrations and a rear suspension system may assist in minimising energy loss when pedalling over rough terrain because the rear wheel stays in contact with the ground (Seifert et al., 1997). Seifert et al. (1997) followed on from the work of Berry et al. (1993) and compared muscular stress, energy expenditure and TT performance when riding three different types of suspension systems. Twelve MTB cyclists rode on a flat, looped course with 45 fabricated bumps at a velocity of 16 $km{\cdot}h^{-1}$ for 63 min using a rigid frame, front suspension and full suspension bikes. Expired air was collected three times during the test. Mean HR was significantly higher for the rigid bike compared to the front and full suspension bikes, 154 ± 16, 146 ± 16 and 147 ± 15 bpm, respectively. No significant differences were found for absolute or relative $\dot{V}O_2$ for the three types of suspension systems.

Three separate TT efforts were also completed by seven riders (climb: 0.76 km, descent: 0.76 km) and a XC TT: 10.44 km) using the three types of bikes outlined above. The XC course was a 2.61 km loop performed four times. The finishing time for the XC TT on the front suspension bike was significantly faster than the rigid or full suspension systems, 30.9 ± 2.0, 32.3 ± 3.6 and 32.3 ± 3.2 min, respectively. A possible explanation for this difference is that the front suspension system allowed the cyclist to maintain or increase velocity while at the same time allowing for absorption of shock and vibrations. No differences in finishing time were observed for the climb or descent time trials for any suspension system and no significant differences were found for mean or HR_{peak} between suspension systems during any of the time trials.

The majority of contemporary mountain bikes are equipped with front or dual suspension systems. Even with the significant advances in MTB suspension systems, little is known about the effect these systems have on rider performance. Due to the fact that ~70% of race time in North American MTB XC courses is spent hill climbing, MacRae et al. (2000) investigated the effects of front and dual suspension systems on $\dot{V}O_2$, PO and other physiological variables. Six sub-elite male MTB cyclists rode uphill on an asphalt and off-road course. The asphalt trial was 1.62 km at 14.2% grade and the off-road trial was 1.38 km at a gradient of 11.3%. A portable gas analysis system was used to measure $\dot{V}O_2$. No significant differences were found for the asphalt and off-road course for total ride time, average HR and peak BLa for either front or dual suspension bikes. The average $\dot{V}O_2$ cost in absolute and relative terms was not different for the two suspension bikes during the asphalt (3.6 – 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$) or off-road course (3.8 – 3.9 $ml \cdot kg^{-1} \cdot min^{-1}$). The average PO for the front suspension bike, irrespective of the course, was significantly lower than the dual suspension bike for asphalt (267 ± 44 and 345 ± 45 W) and off-road course (266 ± 45 and 342 ± 49 W). The cyclists performed the uphill trials at ~84% of $\dot{V}O_{2peak}$ and ~92% of HR_{max} regardless of road condition or bicycle type; at ~69% and ~88% of PPO as determined from the $\dot{V}O_{2max}$ test and at ~30% and ~38% of Wingate PPO for front and dual suspension bikes, respectively.

The results from the study of MacRae et al. (2000) extend the findings of Seifert et al. (1997) who reported no difference in oxygen cost of riding a front and dual suspension bike on a flat, looped course with manufactured bumps. Unfortunately, they did not measure $\dot{V}O_2$ or PO during the uphill TT of the study to be able to compare results. MacRae et al. (2000) expected the $\dot{V}O_2$ data to track the PO data or at least the $\dot{V}O_2$ responses would follow the PO trends. Instead, attainment of steady metabolic rates by the second min of each cycling trial with no changes thereafter occurred.

When using a cycle ergometer in the laboratory, $\dot{V}O_2$ and HR respond linearly to changes in PO. Following on from the study of road cycling TT performance (Palmer et al., 1997), the mean HR response throughout the 150 min paced ride (steady-state and stochastic) and subsequent 20 km TT was not significantly different. Although mean PO during the TT was significantly higher following the steady-state ride without a change in HR. The study by MacRae et al. (2000) showed a similar dissociation between PO and HR and additionally between PO and $\dot{V}O_2$. The usual relationship between PO, cardiovascular and metabolic responses observed in a laboratory setting appear to change when cyclist's perform in the field (MacRae et al., 2000).

Mountain bike cycling, like road and track cycling have environmental and mechanical issues to consider when analysing physiological capacities but there is the added dimension of suspension systems with the MTB. There are various types of suspension systems: no suspension, front, front and rear or the use of a lockout system, and each will type will alter the physiological demands placed on the body. From initial studies examining the physiological effects of suspension systems on the body, there appears to be little difference between a front suspension and a front and rear suspension bike.

It is important to assess the physiological capacities of athletes to determine what is important and relevant to performance in specific disciplines and events. Only then can tests be developed for the measurement of physiological capacities of cyclists. This will ensure that scientists are collecting the most appropriate and relevant information for use by the coaches and athletes.

2.5 SUMMARY

Cycling has a long history with road and track cycling, with an established compilation of anthropometric and physiological characteristics that are relevant and essential for success in these disciplines. Evaluating competition demands of cycling was previously limited to HR monitoring but with the recent advent of power measuring devices, performance can be analysed with a high degree of accuracy and precision. It is crucial to understand the physiological capacities required for each discipline and event of cycling so physiological and performance tests can be specific. This allows coaches and athletes opportunities to adjust and improve training sessions and race craft.

As can be seen in this review, there is limited information available pertaining to MTB cyclists compared to the more established cycling disciplines of road and track cycling. Based on this review, it appears that MTB cyclists posses high aerobic and anaerobic power and capacity. Although endurance based, it appears that the sport may have a unique degree of technical variability due to the different courses being used. Some aspects of the equipment are also unique, such as the suspension.

Coaches and athletes could benefit from more research specifically examining the unique aspects of MTB competition such as the cadence-power relationships and the influence of terrain, environment and training on MTB specific fitness.

CHAPTER THREE
STUDY 1: PHYSIOLOGICAL CHARACTERISTICS OF MOUNTAIN BIKE CYCLISTS

3.1 INTRODUCTION

The first study was designed to measure the anthropometric (stature, body mass, body fat) and physiological characteristics ($\dot{V}O_{2max}$, MAOD, anaerobic power) of male and female MTB cyclists competing at a national and international level for comparison with previous published MTB research and for the use of physiological parameters in study two and three.

3.2 METHODS

3.2.1 Sample and Subject Preparation

Sixteen elite MTB cyclists (12 males, 4 females) volunteered to participate in this study. All cyclists were registered with the Australian Cycling Federation and were competing in the National MTB Series Competition in Elite, Under 23 or Under 19 Men, and Elite Women categories. Eight of the male cyclists had been selected to represent Australia at the 2001 World Cross-country Mountain Bike Championships. One cyclist won the 2001/02 Elite men National XC Series competition. Three female cyclists, including an Olympian were competing internationally at World Cup and World Championship competitions.

The experimental protocol was approved by the University of Canberra Committee for Ethics in Human Research at its meeting on 26th February 2001 and by the Australian Sports Commission Ethics Committee at its meeting on 1st May 2001. All subjects were fully informed of the procedures (Appendix A.1) involved in the study prior to signing an Informed Consent document (Appendix A.2).

Testing was carried out during July and December of 2001. All physical and physiological testing sessions in Canberra were conducted at an altitude of approximately 600 m.

Subjects were requested to avoid any vigorous exercise in the 24 h period prior to testing. Subjects were also requested to abstain from caffeine, food and smoking in the 2 h prior to testing. Diet was not controlled prior to testing for the cyclists because they were completing different tests each day. Verbal encouragement was given throughout each exercise test to all subjects.

3.2.2 Anthropometry

The subject's physical characteristics were measured on the first morning of testing. Subjects presented in a fasted state and were measured by a Level 1 anthropometrist accredited by the International Society for the Advancement of Kinanthropometry (ISAK).

Stature

Stature was measured using a wall-mounted Stadiometer (Holtain Limited, Crymych, Dyfed, Britain) and Stretch method (Norton and Olds, 1996) Subjects wore minimal clothing and no shoes. The subject stood with feet and heels together, buttocks and upper part of the back positioned against the stadiometer. The head was placed in the Frankfort plane (Norton and Olds, 1996) and the measurer placed their hands along the jaw of the subject with the fingers reaching to the mastoid processes. The subject was instructed to take and hold a deep breath while the measurer gently applied upward lift through the mastoid processes. The stadiometer slide was brought firmly down on the head, crushing the hair as much as possible and stature was recorded to the nearest 0.1 cm.

Body Mass

Body mass was measured in a standing position on electronic scales (Digital Weighing Scale, Model DS-410, Teraoka Seiko CO. Ltd, Tokyo, Japan). Subjects wore minimal clothing and no shoes. The subjects were instructed to stand in the centre of the scales with their mass distributed evenly on both feet and to look directly ahead (Norton and Olds, 1996). The measurement was recorded to the nearest 0.1 kg.

Skinfolds

Skinfold sites were measured according to the method described by Norton and Olds (1996). Harpenden skinfold calipers (British Indicators, W. Sussex, Great Britain) were used after landmarks had been located and marked. Seven skinfold sites were measured:

Triceps, Subscapular, Biceps, Supraspinale, Abdominal, Anterior Thigh and Medial Calf. These measurements were totalled to provide the sum of seven skinfolds (mm). The TEM for skinfold data collection is 2.2%.

Percent Body Fat

The percent body fat was estimated from the sum of seven skinfolds using a regression equation (Norton and Olds, 1996) modified from the original work of Withers et al. (1987).

3.2.3 Maximal oxygen consumption

To determine $\dot{V}O_{2max}$, each subject performed a continuous, incremental exercise test (Craig et al., 2000) on an electrically braked cycle ergometer (Lode Excalibur, Lode, Groningen, The Netherlands) equipped with a racing saddle, drop handle bars and the subject's own clipless pedal system. The TEM for the LODE ergometer is –0.7%. The Lode ergometer was configured to match the exact dimensions of the cyclist's competition MTB, using the following measurements: seat height (from top of the seat to centre of the pedal crank); distance from the seat nose to the handlebars; and the horizontal distance between the centre of the pedal crank and a weighted line dropped from the seat nose. The Lode ergometer produces a constant workload provided the pedalling cadence is maintained within the range of 30 to 120 rpm (Wilber et al., 1997). Subjects were allowed to self-select cadence within the range of 70 – 120 rpm and they completed a 5 min warm-up against a resistance of 75 W. The test commenced at an initial workload of 100 W, and 50 W increments were applied at 5 min intervals with the test being terminated when the cadence fell below 70 rpm or volitional exhaustion occurred.

Oxygen uptake was measured continuously during the incremental test using an automated Maximal Oxygen Uptake System (MOUSe, Australian Institute of Sport, Canberra, Australia). The system consists of a one-way respiratory valve (Hans Rudolph Model R2700, Kansas City, MO, USA); 2 m of 5.1 cm internal corrugated tubing and two 150 L aluminised Mylar bags (Scholle Industries, Elizabeth, South Australia) operating in rotation for gas collection; a precision calibrated piston with real-time measurement of temperature and pressure for volume measurement of each bag; and Ametek (Pittsburgh, PA, USA) oxygen (Model S-3A) and carbon dioxide (Model CD-3A) analysers for gas analysis. The analysers were calibrated before each test using three alpha grade gases of known composition (BOC Gases, Canberra, Australia) that spanned the physiological range. All calibrations were within the ± 0.03% of the target gas compositions.

$\dot{V}O_2$ values were calculated using standard algorithms for consecutive 30 s periods and summed for the determination of $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$). $\dot{V}O_{2max}$ was determined as the highest sum of any two consecutive 30 s $\dot{V}O_2$ sampling periods occurring at the end of the test.

Capillary blood samples were obtained for the determination of BLa at rest, 30 s before the completion of each work stage and at the conclusion of the test. Approximately 50 µl of blood was drawn from a sterile finger puncture using a heparinized capillary tube and analysed for BLa ($mmol \cdot L^{-1}$) using a Blood and Oximetry Analyser (ABL 725, Radiometer Medical A/S, Copenhagen, Denmark), which had been calibrated with known standards. Anaerobic threshold was identified using a modification of the D_{max} method, using customized software (ADAPT, Australian Institute of Sport in-house software, Canberra, Australia). The modified D_{max} is the point on the polynomial regression curve that is the greatest perpendicular distance from a straight line connecting the workload preceding a 0.4 $mmol \cdot L^{-1}$ rise in BLa above baseline to the final workload (Bourdon, 2000).

Heart rate was measured via telemetry using a Polar HR monitor (Sports Tester, Polar Electro OY, Kempele, Finland) operating on a 5 s sample interval. The HR was recorded manually during the last 10 s of each work stage, as well as at the conclusion of the test.

At the completion of each work stage the Rating of Perceived Exertion (RPE) according to the Borg scale (6 – 20: (Borg, 1970)) was shown to the subject and they were required to nominate their level of exertion by pointing to the appropriate value.

Maximal power output was calculated using the following equation (Kuipers et al., 1985):

$$W_{max} = W_f + (t/300 \text{ s} \times 50 \text{ W})$$

where W_{max} = maximal power output (W), W_f = power output (W) of last complete stage, t = duration (s) of final incomplete stage, 300 s = workload duration (s) and 50 W = workload increment (W).

3.2.4 Maximal Accumulated Oxygen Deficit (MAOD)

Anaerobic capacity was determined using an MAOD test which comprised of an incremental continuous submaximal effort of 4x4 min at 1.5, 2.5, 3.5 and 4.5 $W \cdot kg^{-1}$; a 4 min rest consisting of 2 min active recovery (50 W) and 2 min passive recovery (0 W); and a 4 min supramaximal (all-out) effort, which was modified from the protocol of Gore at al. (2001). During the submaximal effort, the Lode ergometer was operated in the "hyperbolic" mode, which provides a constant workload independent of pedal cadence. During the supramaximal effort, the Lode ergometer was operated using the "linear" mode, which is set with a linear factor (gearing) to provide a nominal workload (at a pedal cadence of 100 rpm) of ~120% of W_{max} calculated from the $\dot{V}O_{2max}$. Workloads for all subjects were programmed individually into the Lode ergometer controller.

Oxygen uptake was measured continuously during the MAOD test using the automated Maximal Oxygen Uptake System (MOUSe, Australian Institute of Sport, Canberra, Australia) described in 3.2.3. $\dot{V}O_{2peak}$ was determined as the peak rate of oxygen consumption from the sum of any two of the highest consecutive 30 s $\dot{V}O_2$ measures during the 4 min supramaximal stage of the test.

The energy demand of the supramaximal stage was estimated from linear regression analysis using group mean data for the 4 submaximal work stages of the test, using the following equation:

$$\dot{V}O_2 = 0.0111 * W + 0.8237 \quad (r^2 = 0.9994)$$

where, W = power output at the end of each min during supramaximal stages.

MAOD was determined according to the procedures of Medbo et al. (1988) with the supramaximal stage of the test as the difference between the estimated oxygen requirement of the work achieved (derived from the power versus $\dot{V}O_2$ regression equation) and the measured $\dot{V}O_2$ (summed across the eight 30 s $\dot{V}O_2$ measures).

Capillary blood samples were obtained for the determination of BLa at rest, 30 s before the completion of each submaximal work stage and 3 min following the completion of the supramaximal stage as previously in 3.2.3. Heart rate and RPE was recorded during the last 10 s of each submaximal work stage and at the completion of the supramaximal stage.

3.2.5 Anaerobic Power

10 second Sprint Test

The 10 s cycle ergometer test was used to measure explosive/alactic power. The test was conducted on a windloaded cycle ergometer fitted with an SRM power crank to measure power output. The warm-up consisted of cycling for 5 min and at the end of each minute the subject was instructed to sprint for 5 s at approximately 60, 70, 80, 90 and 95% of their maximum power output. Prior to starting the test, the SRM powermeter was calibrated and the sensor on the wheel and receiver on the frame aligned. The subject was instructed to assume a standing, stationary position with pedals at a 45° angle to horizontal (Ellis et al., 2000). A countdown of "3, 2, 1, GO" was given and the subject had to achieve and sustain as much power as possible during the 10 s, measured using a stopwatch. Peak power output (W) and average PO (W) were recorded once the powercontrol unit was downloaded onto a computer using the SRM Training System software program.

Capillary blood samples were obtained for the determination of BLa at rest and 3 min after completion of the test. Approximately 5 μl of blood was drawn from a sterile finger puncture into a reagent strip to be analysed for BLa (mmol·L^{-1}) using a Blood Lactate Analyser (Lactate Pro, Arkray Incorporated, Globis Division, Kyoto, Japan).

Vertical Jump

Vertical jump was assessed using a Yardstick (SWIFT Yardstick, SWIFT Performance Equipment, NSW, Australia). The subject stood side on to the Yardstick jumping device and keeping their heels on the ground, fully elevated the arm to displace as many vanes as they could reach to gain a zero reference point and the number was recorded. An arm swing and countermovement was used to jump as high as possible with the subject displacing the vane at the height of the jump (Ellis et al., 2000). The subject performed a minimum of three trials and continued if improvements were being made. The height of the vertical jump (cm) was taken as the difference between the reaching height of the subject and the level reached by the hand at the peak of the highest jump.

3.2.6 Statistical Analysis

Descriptive data are presented as the mean ± standard deviation (SD), range and number of subjects (n). Effect size (ES) statistics were calculated using an equation from Thomas and Nelson (2001) to determine the differences between the cyclists results from this study compared to cyclists from previous research. The following scale was used to interpret the ES data (Cohen, 1988):

ES < 0.2 – no effect

ES between 0.2 and 0.5 – small effect

ES between 0.5 and 0.8 – moderate effect

ES > 0.8 – large effect.

3.3 RESULTS

3.3.1 The Sample

Twelve male and four female subjects completed the anthropometry and maximal oxygen consumption test and eleven male subjects completed the anaerobic power tests. Only five of the twelve male subjects completed the MAOD test. Only two female subjects have anaerobic threshold data because the females completed the same protocol as the male subjects for $\dot{V}O_{2max}$ which involves longer workloads and as a consequence there was not enough data to delineate a threshold point.

3.3.2 Anthropometry

The anthropometric characteristics of the subjects are reported in Table 7 and 8. The male cyclists show a large range for age, height, body mass and percent body fat. The sum of seven skinfolds for the female cyclists was also wide ranging.

3.3.3 Maximal oxygen consumption

Results from the maximal oxygen consumption test are provided in Table 9. Among the responses of the male subjects are large variations for each parameter. The physiological responses were higher for males than females for all parameters except for BLa.

The physiological responses at anaerobic threshold from the maximal oxygen consumption test are provided in Table 10. Once more the responses of the male subjects show wide variations for each parameter, which may partly be influenced by the physical characteristics. The physiological responses between males and females were similar for the $\%\dot{V}O_{2max}$ (82.2% vs 83.9%) and HR (178 bpm vs 177 bpm). It is important to note that data for only two female subjects were obtained for AT.

3.3.4 Maximal accumulated oxygen deficit

The physiological responses for MAOD are provided in Table 11. The mean MAOD of the cyclists is 43.6 $ml \cdot kg^{-1}$, ranging between 25.2 and 55.1 $ml \cdot kg^{-1}$. This range highlights the difference in aerobic and anaerobic capabilities of the cyclists. The $\dot{V}O_{2peak}$ of 74.9 $ml \cdot kg^{-1} \cdot min^{-1}$ is higher than the average $\dot{V}O_{2max}$ of 71.9 $ml \cdot kg^{-1} \cdot min^{-1}$ from the $\dot{V}O_{2max}$ test. During this test, the subjects averaged ~110% of their W_{max} for 4 min.

3.3.5 Anaerobic Power

The anaerobic power responses for vertical jump and the 10 s sprint test are provided in Table 12.

TABLE 7: Anthropometric characteristics of male MTB cyclists.

Subject	Age (yr)	Height (cm)	Body mass (kg)	Skinfolds (mm)	Body Fat (%)
1	19.3	183.4	67.8	40.5	7.2
2	24.2	184.2	70.4	45.9	8.1
3	22.1	170.7	61.9	56.6	10.0
4	25.8	175.0	64.3	40.4	7.2
5	28.5	175.9	71.6	40.1	7.2
6	18.4	182.3	69.4	38.9	7.0
7	17.5	180.7	71.7	46.7	8.3
8	21.0	168.0	58.4	33.5	6.1
9	22.1	185.7	70.6	34.2	6.2
10	21.5	169.2	63.1	33.9	6.1
11	18.3	179.3	66.4	37.4	6.7
12	16.8	167.7	51.0	32.2	5.8
Mean	21.3	176.8	65.5	40.0	7.2
SD	3.5	6.7	6.2	7.0	1.2
Range	16.8 – 28.5	167.7 – 185.7	51.0 – 71.7	32.2 – 56.6	5.8 – 10.0

TABLE 8: Anthropometric characteristics of female MTB cyclists.

Subject	Age (yr)	Height (cm)	Body mass (kg)	Skinfolds (mm)	Body Fat (%)
1	25.0	172.9	56.2	69.8	12.2
2	25.1	165.6	62.8	69.3	12.2
3	24.1	169.1	59.6	40.9	7.3
4	26.5	164.1	55.3	60.5	10.6
Mean	25.2	167.9	58.5	60.1	10.6
SD	1.0	3.9	3.4	13.5	2.3
Range	24.1 – 26.5	164.1 – 172.9	55.3 – 62.8	40.9 – 69.8	7.3 – 12.2

TABLE 9: Maximal oxygen consumption responses of MTB cyclists. (Mean ±SD).

	Male		Female	
	Mean (n = 12)	Range	Mean (n = 4)	Range
$\dot{V}O_{2max}$ ($L \cdot min^{-1}$)	4.88 ± 0.28	4.44 – 5.17	3.34 ± 0.50	2.74 – 3.92
$\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	74.6 ± 5.6	66.5 – 87.0	56.9 ± 5.5	49.6 – 62.4
W_{max} (W)	369 ± 25	315 – 405	263.8 ± 22.9	240 – 290
W_{max} ($W \cdot kg^{-1}$)	5.64 ± 0.52	5.09 – 6.96	4.51 ± 0.16	4.3 – 4.6
HR_{max} (bpm)	197 ± 9	184 – 211	189 ± 6	184 – 197
Lactate ($mmol \cdot L^{-1}$)	12.3 ± 3.3	8.5 – 21.0	12.6 ± 1.6	10.4 – 14

TABLE 10: Anaerobic threshold responses of MTB cyclists. (Mean ±SD).

	Male		Female	
	Mean (n = 12)	Range (n = 12)	Mean (n = 2)	Range (n = 2)
$\dot{V}O_2$ (ml·kg^{-1}·min^{-1})	61.4 ± 5.7	53.2 – 75.6	53.4 ± 1.4	52.4 – 54.4
% $\dot{V}O_{2max}$ (%)	82.2 ± 3.2	76.2 – 86.9	83.9 ± 5.6	83.9 – 91.8
D-max$_{mod}$ (W)	300 ± 24	239 – 329	238.0 ± 2.8	236 – 240
D-max$_{mod}$ (W·kg^{-1})	4.44 ± 0.46	3.87 – 5.62	3.89 ± 0.19	3.76 – 4.03
% W$_{max}$ (%)	78.6 ± 3.9	71.9 – 85.4	84.3 ± 4.2	81.4 – 87.3
Heart rate (bpm)	178 ± 11	157 – 198	177 ± 0	
% HR$_{max}$ (%)	90.3 ± 3.4	83.7 – 94.7	95.9 ± 0.4	95.7 – 96.2
Lactate (mmol·L^{-1})	4.2 ± 0.9	2.5 – 5.8	5.3 ± 0.2	5.1 – 5.4

TABLE 11: Maximal Accumulated Oxygen Deficit Test responses of male MTB cyclists. (Mean ±SD).

	Mean (n = 5)	Range (n = 5)
O_2 Deficit ($ml \cdot kg^{-1}$)	43.6 ± 13.3	25.2 – 55.1
$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	74.9 ± 4.1	71.0 – 81.2
HR_{peak} (bpm)	191 ± 9	180 – 202
La_{peak} ($mmol \cdot L^{-1}$)	13.0 ± 2.2	9.6 – 15.0
Average PO (W)	404.1 ± 27.3	374.5 – 432.1
Average PO ($W \cdot kg^{-1}$)	6.02 ± 0.32	5.55 – 6.42

TABLE 12: Anaerobic power responses of male MTB cyclists. (Mean ±SD).

	Mean (n = 11)	Range (n = 11)
Vertical Jump (cm)	49 ± 8	33 – 59
Peak Power (W)	1172 ± 233	748 – 1478
Peak Power ($W \cdot kg^{-1}$)	17.8 ± 2.1	14.0 – 20.9

3.4 DISCUSSION

This study has provided additional information about the anthropometrical and physiological characteristics of elite/well-trained MTB cyclists and for the first time presents data collected on Australian female MTB cyclists and anaerobic power/capacity.

3.4.1 Anthropometry

The male MTB cyclists in this study are similar to the reported values of MTB cyclists for anthropometric characteristics. They were similar in age to the Italian and German national teams (Impellizzeri et al., 2002, Stapelfeldt et al., 2004) and track cyclists but younger than reported road cyclists. Their height was similar to the US national MTB cyclists (Wilber et al., 1997) with body mass similar to the Czech and Australian cyclists (Heller and Novotny, 1997, Lee et al., 2002). The percent body fat of the MTB cyclists in this study was higher than all reported data for MTB athletes. The female MTB cyclists from this study were younger and had less percent body fat than previously reported MTB athletes with their height and body mass within the range of reported data (Wilber et al., 1997, Stapelfeldt et al., 2004). They were similar in height to US road cyclists (Burke, 1980) although younger, lighter and with a lower percent body fat than US female road cyclists (Pfeiffer et al., 1993, Tanaka et al., 1993, Wilber et al., 1997).

The male MTB cyclists in this study were comparable in height to professional road cyclists (Lucia et al., 1998) in particular to road climbing specialists (Padilla et al., 1999, Lucia et al., 2000). They were also lighter in body mass on average than most road cycling groups but yet again similar to climbing specialists (Padilla et al., 1999). These findings are not surprising considering the uphill specialists are smaller and lighter than other specialists (eg. flat terrain, all terrain, TT) and excel in mountainous stages of road racing. Cross country MTB racing has a considerable emphasis on climbing also with the advantage going to the smaller and lighter cyclists on climbing courses. Percent body fat results from this study were similar to road cyclists, lower than track cyclists and higher than MTB cyclists (Fernandez-Garcia et al., 2000, Craig et al., 1995, Wilber et al., 1997). The comparison of percent body fat can be misleading when comparing between studies because scientists use different methods, techniques and instruments to calculate results. However, percent body fat for elite road cyclists and MTB cyclists range from 4.7 to 8.3%

and 4.7 to 6.4%, respectively (Wilber et al., 1997, Lucia et al., 1999, Impellizzeri et al., 2002, Heller and Novotny, 1997).

In summary, the male and female MTB cyclists in this study display comparable results for anthropometry to previously tested MTB cyclists. The anthropometric characteristics of male MTB cyclists were most similar to the climbing specialists of road cycling.

3.4.2 Aerobic Power

The average absolute $\dot{V}O_{2max}$ for the male MTB cyclists in this study was lower than professional road cyclists (small ES) but similar to a group of elite road cyclists (no ES) (Lucia et al., 1998). However, when $\dot{V}O_{2max}$ is expressed relative to body mass the current MTB cyclists possess similar values to elite and professional cyclists (Lucia et al., 1998, Lucia et al., 1999) but lower than road climbing specialists. The MTB cyclists also possessed higher relative $\dot{V}O_{2max}$ values than road cyclists (Telford et al., 1990, Hopkins and McKenzie, 1994, Wilber et al., 1997) with a large ES of 0.92 to 1.39. There was an exception in the current MTB group with one cyclist having a $\dot{V}O_{2max}$ of 87.0 $ml \cdot kg \cdot min^{-1}$ which is certainly amongst the highest reported values for cyclists and endurance athletes (Bergh, 1987, Padilla et al., 1999, Lucia et al., 2000). The MTB cyclists produced higher maximal aerobic power than track cyclists who ranged from 62 – 72 $ml \cdot kg \cdot min^{-1}$ (Craig et al., 1993, Telford et al., 1990, Schumacher and Mueller, 2002).

Maximal power output was lower than road cyclists in both absolute and relative terms (large ES, ~3.4 in absolute terms and ~2.2 in relative terms) (Wilber et al., 1997, Lucia et al., 2000) for the MTB cyclists in this study. When interpreting maximal values, consideration needs to be given to the test protocol used because higher power outputs will typically ensue when a test is of short duration (eg. 1 min increments: Lucia et al. 2000). A similar protocol using 1 min increments was employed for the US and Czech MTB cyclists with resultant W_{max} values of 5.9 and 6.34 $W \cdot kg^{-1}$ (Heller and Novotny, 1997, Wilber et al., 1997). Possible reasons for lower maximal power output values for the MTB cyclists may be due to their development in training years as a cyclist and also the distinct difference in training terrain and the resultant effect on neuromuscular recruitment and patterning (Wilber et al., 1997). Regardless, the maximal power output results were similar to the results from other MTB studies (Impellizzeri et al., 2002, Stapelfeldt et al., 2004).

The average maximal HR obtained during the $\dot{V}O_{2max}$ test for the MTB cyclists was higher (moderate to large ES, 0.60 to 0.91) than most road cyclists except for a group of US national road cyclists, 200 ± 11 bpm (Wilber et al., 1997). The MTB cyclists in this study also have higher HR_{max} than all reported data for MTB cyclists, 189 and 193 bpm (Lee et al., 2002, Stapelfeldt et al., 2004), with a large and small ES, respectively. The difference may partly be explained by the young age of the MTB cyclists (21.3 ± 3.5 yr) in this study, compared to the average age of 23 to 26 years for road cyclists (Wilber et al., 1997, Lucia et al., 1998, Lucia et al., 1999, Padilla et al., 1999) and 24 years for MTB cyclists studied by Lee et al. (2002).

Maximal BLa for the MTB cyclists in this study was found to be higher than road and MTB cyclists (Lucia et al., 1998, Padilla et al., 1999, Lee et al., 2002, Heller and Novotny, 1997) (large ES). Possible reasons for this discrepancy may be a result of the years of endurance training to be able to accumulate and clear BLa, and also the protocol used for collecting the BLa sample (eg. 1-5 min after completion of test). Years of muscular endurance training can influence performance in several ways. As muscles become stronger, they contract at a smaller fraction of their maximum voluntary force and allow perfusion to readily occur. This is turn, allows a given effort to be sustained without recourse to the anaerobic activity that would cause an accumulation of lactate and a decrease of muscle force (Shephard, 1992). Furthermore, endurance training increases the local activity of aerobic enzymes, which facilitates a continuation of aerobic metabolism at low partial pressures of oxygen, encouraging the metabolism of fat, with a resultant sparing of intramuscular glycogen (Shephard, 1992). In addition, Neumann (1992) reported that endurance training improves the blood supply of the muscles because capillarisation is increased.

The research conducted on female cyclists is minimal compared to male cyclists, therefore the data from this study is adding support to the current literature. The female MTB cyclists of this study have an almost identical average absolute $\dot{V}O_{2max}$ value (3.34 ± 0.50

L·min^{-1}) to that of Tanaka et al. (1993) and Wilber et al. (1997), 3.37 ± 0.13 SE and 3.33 ± 0.27 L·min^{-1}, respectively. When $\dot{V}O_{2max}$ is expressed relative to body mass the MTB cyclists are similar for aerobic power to US national road cyclists from 1980 (Burke, 1980) but lower than the latest US national road team in 1997 (Wilber et al., 1997), although similar to the reported values of MTB cyclists (Wilber et al., 1997, Stapelfeldt et al., 2004). Maximal power output values for the female MTB cyclists in this study are lower than all reported values (Stapelfeldt et al., 2004, Wilber et al., 1997) regardless of the data being interpreted in absolute or relative terms. The main reason for this large discrepancy is due to the test protocol used for the female cyclists in this study. Testing of the female athletes was in conjunction with another research project, which was investigating male and female physiological responses to the protocol using 50 W increments every 5 min. This was a challenging workload for the female athletes. Due to the length of the stages, the athletes may have fatigued earlier than with shorter stages and smaller increments. The average maximal HR value is higher for the females in this study compared to Wilber et al. (1997) and Stapelfeldt et al. (2004), which can be attributed to the younger age of the cyclists from this study for HR difference and BLa is similar to the values reported in these studies.

Anaerobic threshold, more commonly known as lactate threshold or ventilatory threshold is used in the determination of endurance capability. It has been demonstrated that threshold values are better predictors of performance, especially when testing a homogeneous group of athletes (Coyle et al., 1988, Coyle et al., 1991). Lucia et al. (1998) found a significant difference between professional and elite road cyclists for ventilatory threshold, with professional cyclists able to maintain a higher $\%\dot{V}O_{2max}$, although $\dot{V}O_{2max}$ was almost identical. The D-max$_{mod}$ used to delineate anaerobic threshold as a $\%\dot{V}O_{2max}$ in this study (~82%) is lower than professional road cyclists but similar to elite road cyclists (Lucia et al., 1998). It is difficult to interpret results between studies because of the different terms and methods employed to measure anaerobic threshold. The MTB cyclists in this study were able to sustain a higher anaerobic threshold than US and Czech national cyclists for $\%\dot{V}O_{2max}$ and PO (Wilber et al., 1997, Heller and Novotny, 1997) but lower than Impellizzeri et al. (2002) and Lee et al. (2002). The anaerobic threshold for the female MTB cyclists in this study was almost identical to the US national MTB cyclists for the $\dot{V}O_2$ at threshold (83.9 ± 5.6 and 83.8 ± 5.6 %$\dot{V}O_{2max}$). Interestingly, at threshold the US cyclists had a lower absolute and relative PO, HR and %HR_{max} compared to the cyclists in this study. A contributing factor would be the BLa that the US cyclists were working at when at anaerobic threshold (2.6 ± 0.7 mmol·L^{-1}: Wilber et al. 1997), which is lower than the female cyclists in this study (5.3 ± 0.2 mmol·L^{-1}).

It can be seen from this study that Australian MTB cyclists have comparative $\dot{V}O_{2max}$ values to road cyclists, although their power is lower in both absolute and relative terms. Maximum HR and BLa were higher for the cyclists in this study than for road and MTB cyclists, which may partially be explained by the young age of the group tested and the lower number of training years.

3.4.3 Anaerobic Power and Capacity

Anaerobic power may be a necessary component required of elite level MTB cyclists to be competitive. There are many times during a MTB race when anaerobic power would possibly be used. The PPO (1172 ± 233 W, 17.8 ± 2.1 W·kg^{-1}) from a 10 s test for the MTB cyclists in this study is higher than reported values from the literature for absolute and PPO of road and MTB cyclists (Tanaka et al., 1993, Heller and Novotny, 1997, Baron, 2001). Using a modified sprint test, Vandewalle et al. (1987) reported similar results for track sprint cyclists (1150 ± 127 W, 16.8 ± 1.2 W·kg^{-1}). Caution has to be used when comparing anaerobic power results because of the different methods used such as a Wingate (30 s) or 10 s sprint tests. The vertical jump produced by the MTB cyclists in this study was lower than track cyclists (Vandewalle et al., 1987) but similar to road cyclists, 44 – 49 cm (White and Al-Dawalibi, 1986, Telford et al., 1990).

Anaerobic capacity was measured using the MAOD test, as Palmer (2002) had stated that a large proportion of success in mountain biking depends on anaerobic capabilities. Race duration for endurance track cyclists is approximately 4 – 4:30 min which is similar to the 5 min protocol for testing MAOD used by Craig et al. (1993). The 5 min protocol resulted in an O_2 deficit value of 60.2 ± 12.5 ml·kg^{-1}, which was not significantly different to a 2 min protocol, 61.4 ± 7.3 ml·kg^{-1}. In a further study by Craig et al. (1995) there was a significant difference for O_2 deficit between track sprinters and track endurance cyclists (66.9 ± 2.2 and 57.4 ± 6.7 ml·kg^{-1}, respectively). The MAOD for the MTB cyclists (43.6 ± 13.3 ml·kg^{-1}) in this study was lower than both track sprint and track endurance cyclists and also lower than Australian female road cyclists (50.6 ± 9.9 ml·kg^{-1}). The MAOD resulted in an average peak $\dot{V}O_2$ of 74.9 ± 4.1 ml·kg·min^{-1}, which is higher than the $\dot{V}O_{2max}$ of the 5 cyclists (71.9 ± 3.4 ml·kg·min^{-1}). Correspondingly the average absolute and relative PO values (404.1 ± 27.3 W and 6.02 ± 0.32 W·kg^{-1}, respectively) reached in the MAOD test was higher than in the $\dot{V}O_{2max}$ test (362.0 ± 14.8 W and 5.4 ± 0.3 W·kg^{-1}, respectively) to manage the workload of 120%W_{max}. Three of the five cyclists reached a higher HR_{max} value in the MAOD test compared to the standard $\dot{V}O_{2max}$ test. A possible reason for the lower MAOD results for the MTB cyclists compared to the track cyclists may result from training specificity. Track cyclists would be better able to produce 2 to 5 min efforts, as they are similar to race duration and training efforts, whereas MTB racing is believed to consist of continuous short high intensity efforts.

In summary, the MTB cyclists in this study were able to produce high PPO's during a 10 s sprint test, which were greater than previous studies with road and MTB cyclists. MTB cyclists may not be able to reach the absolute PPO of track sprint cyclists but are comparable when adjusted for body weight. The test protocol for MAOD can be from 2-5 min which is better suited to track cyclists as these are close to their competition times. It can be seen that MTB cyclists do possess the capacity for short anaerobic efforts.

3.5 SUMMARY

In summary, the MTB cyclists in this study are generally younger, shorter and lighter than previously studied road and track cyclists. They have also produced aerobic power values similar to road cyclists and anaerobic power and capacity values similar to track cyclists.

CHAPTER FOUR
STUDY 2: COMPETITION DEMANDS OF MOUNTAIN BIKE RACING

4.1 INTRODUCTION

Heart rate monitoring during racing has been used to describe the demands of road and MTB competition. However, only a few studies have documented the PO demands of competitive road cycling and the PO demands of MTB competition are relatively unknown. To the author's knowledge, there is only one study that has investigated the demands of MTB competition using instrumented cranks while racing (Stapelfeldt et al., 2004). Stapelfeldt et al. (2004) reported mountain bike races to be competed at a high intensity with significant time spent above AT with exhibited large deviations in power output. The races monitored by Stapelfeldt et al. (2004) were all XC MTB events lasting between 1:48 – 2:19 hr. The purpose of the present study was to identify the performance demands of XC and TT MTB racing using SRM power cranks.

4.2 METHODS

4.2.1 Sample and Subject Preparation

Four male MTB cyclists participated in this study (mean ± SD; $\dot{V}O_{2max}$: 71.9 ± 3.4 $ml \cdot kg^{-1} \cdot min^{-1}$, MPO: 5.4 ± 0.3 $W \cdot kg^{-1}$, HR_{max}: 186 ±6 bpm). All cyclists were registered with the Australian Cycling Federation and were competing in the National MTB Series Competition in the Elite Men's category. One of the cyclists's won the 2001/02 Elite Men's National XC Series competition.

The experimental protocol was approved by the University of Canberra Committee for Ethics in Human Research and the Australian Sports Commission Ethics Committee. All subjects were fully informed of the procedures involved in the study prior to signing an Informed Consent document (Appendix A.2).

Testing was carried out during July, August and December of 2001. Racing was conducted at various locations: Blue Range - Canberra and, Killingworth and Yarramundi -

New South Wales. Subjects used their own bicycles fitted with a power measuring device for all testing. Practice of the MTB courses occurred one day prior to the TT race. The TT race was always on the Saturday followed by the XC race on the Sunday. Individuals undertook a self-selected warm-up prior to each race (ie. a warm-up generally consisted of riding at LT and increasing to AT, including sprints).

4.2.2 MTB SRM power crank

The equipment used to collect power (W), cadence (rpm), heart rate (bpm), speed (km·h^{-1}) and distance (km) data was the MTB SRM power crank (Schoeberer Resistance Measurement: Julich, Germany: refer Figure 1). This system has been designed to simultaneously record and display these variables on a powercontrol unit mounted on the bicycle's handlebars for visual display. The SRM crank is an instrumented device with eight strain gauge strips, which determines power output via the deformation when force is applied to the pedals (see Figure 2). This deformation is proportional to the torque applied and power is calculated from the product of the torque of the pedals and the angular velocity. The accuracy of measurement for the MTB SRM power crank is ± 2% (Schoberer, 1998).

Each SRM crank was calibrated using a dynamic calibration rig developed by the Australian Institute of Sport (Canberra, Australian Capital Territory, Australia). The calibration was essential in determining the relationship between torque (Nm) and the measured frequency of the crank in hertz (Hz) because each crank has an individual slope relationship. This value must be entered into the Powercontrol for the power to be read accurately. Preceding each testing session, the SRM crank was zeroed. The zero offset represents the frequency when no force is applied to the pedals and is due to the deformation of the metal in the crank which the Powercontrol meter registers as a torque. Checking the zero offset ensures that this frequency is subtracted from the value generated when torque is developed due to cycling. To zero the SRM crank, the calibration mode was obtained by pressing the Mode and Set button simultaneously and the crank was spun backwards. The Set button was pressed when a stable reading was acquired.

Figure 1. A MTB SRM power crank (www.srm.de) and an SRM fitted to a cyclist's MTB.

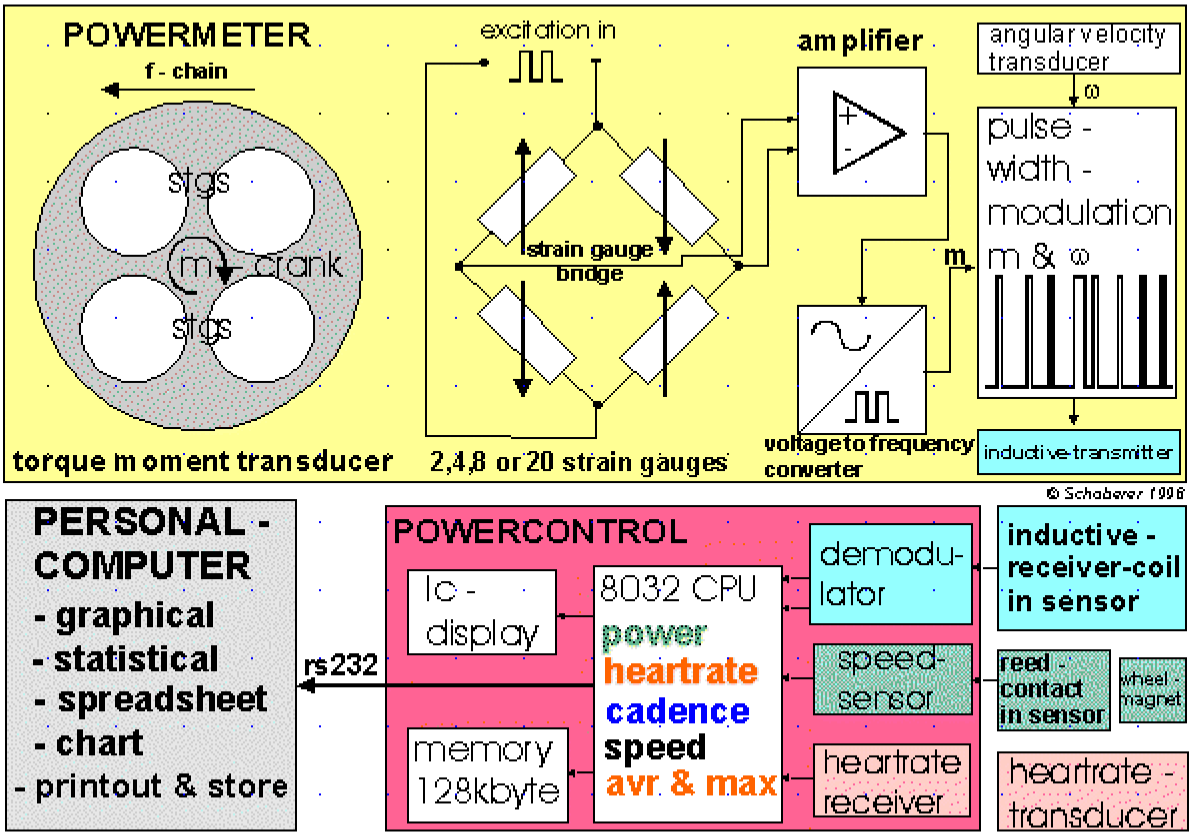

Figure 2. Internal instrumentation of the SRM power crank (SRM Training Manual 2001).

The following equation is used to determine power, taking into account the slope and zero offset reading of the crank (SRM Training Manual 2001):

$$\text{Power} = \frac{(\text{measured frequency} - \text{zero offset}) \times \text{cadence} \times 2\pi}{\text{Slope} \times 60}$$

Cadence was measured using a reed-contact switch, which was activated once every pedal revolution by a magnet. The cadence and power information was used to create a pulse width modulated electrical signal that was transmitted to the Powercontrol via a sensor cable. Speed and distance was measured by a magnet attached to the front wheel, which was tripped once every pedal revolution and calculated from the diameter of the wheel, previously entered into the Powercontrol. The information was then downloaded using a serial port cable and a specific software program (SRM Training System, version 6.00i) for subsequent analysis and to provide a visual display of a testing session or race.

4.2.3 Sports Tester Polar® Heart Rate Monitor

A Sports Tester Polar® HR monitor (Polar Electro Oy, Finland) was used to record HR in conjunction with the SRM power crank. HR was determined via a polyurethane transmitter placed around the cyclist's chest which sent a pulse to a wrist receiver. The HR monitor was started simultaneously with the SRM crank to allow a power, cadence, distance and HR profile to be developed. HR was recorded at a frequency of 1 Hz, which is the same sampling frequency of the SRM power unit even though the Sports Tester HR monitor can measure at a sampling frequency of 5 Hz. The 1 Hz sampling frequency was used for analysis. Data from the Polar® HR monitor was downloaded via a serial cable and analysed with specific program software (Polar Precision Performance SW, Polar Electro, Finland).

4.2.4 Race analysis

Race analysis was conducted using a specially designed "in-house" (AIS Cycle) software program to determine average data; time in relative power bands for 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10 and >10 W·kg^{-1}; peak power output (PPO); time in cadence bands for <40, 40-49, 50-59, 60-69, 70-79, 80-89, 90-99 and >100 rpm; time spent below anaerobic threshold (4.0 W·kg^{-1}), between anaerobic threshold and W_{max} (4.0 – 5.5 W·kg^{-1}) and >W_{max} (5.5 W·kg^{-1}) for TT and XC races. The values of 4.0 and 5.5 W·kg^{-1} correspond to D-max$_{mod}$ and W_{max} as measured from the maximal oxygen consumption test.

4.2.5 Statistical Analysis

Data are reported as mean ± standard deviation. The analysis of race data has been described in 4.2.4. A one-way analysis of variance (ANOVA) was used to determine significant differences for PO and cadence between the TT and XC races. An unpaired t-test was used to determine significant differences for time, distance, power, cadence, HR, and time below, at and above anaerobic threshold between the TT and XC races. Statistical significant was set at $p \leq 0.05$.

4.3 RESULTS

4.3.1 The Sample

Four male subjects competed at three race venues and completed a total of seven TT races and seven XC races. The physiological characteristics describing the subjects are only for three subjects, as one subject didn't complete a $\dot{V}O_{2max}$ test. The TT analysis for HR and speed includes five of the seven subjects due to interference of sensors and analysis for the XC racing includes six of the seven subjects for HR and speed.

4.3.2 Comparison between Time Trial and Cross Country racing

Racing characteristics for TT and XC are provided in Table 13. The TT racing was significantly shorter in time and distance than XC racing (~15 min and ~2h, ~5 and ~38 km, respectively). The TT style of racing produced significantly higher average values for absolute and relative PO and HR see Table 13. Although speed and cadence where higher in TT racing there was no significant difference. Both absolute and relative PPO was similar for TT and XC racing. The percent of total time spent in 1 W·kg^{-1} power bands for TT and XC racing are displayed in Figure 3. The spread of time spent in the different

Table 13: Comparison between TT and XC MTB races (Mean ±SD).

	TIME TRIAL	CROSS COUNTRY
N	7	7
Average time (h:min:s)	0:14:55 ± 1:29*	2:03:49 ± 9:56
Average distance (km)	5.1 ± 0.7*	38.2 ± 2.9
Average power (W)	304 ± 23*	259 ± 37
Average power:mass ($W \cdot kg^{-1}$)	4.4 ± 0.3*	3.7 ± 0.5
Average cadence (rpm)	73 ± 6	68 ± 6
Average heart rate (bpm)	182 ± 5*	171 ± 7
Average speed ($km \cdot h^{-1}$)	19.6 ± 0.7	18.5 ± 1.9
Peak power (W)	1243 ± 160	1254 ± 365
Peak power:mass ($W \cdot kg^{-1}$)	17.9 ± 1.9	18.1 ± 5.1
% Total time below 4.0 $W \cdot kg^{-1}$ (%)	45.5 ± 4.9	50.7 ± 8.3
% Total time between 4.0-5.5 $W \cdot kg^{-1}$ (%)	16.0 ± 2.4*	22.8 ± 4.3
% Total time above 5.5 $W \cdot kg^{-1}$ (%)	38.4 ± 5.2*	26.5 ± 9.4

* Significantly different to Lab, ($p<0.05$).

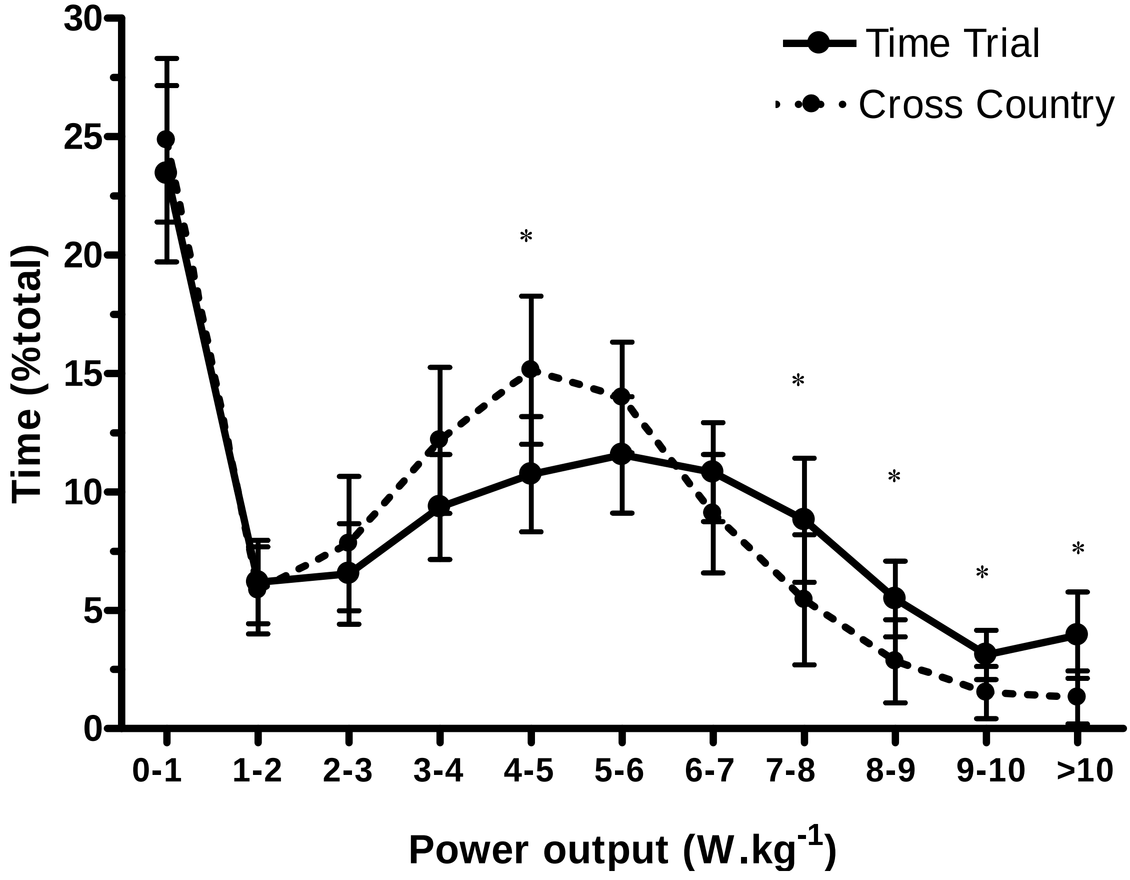

Figure 3. Time spent in power output bands during Time Trial and Cross Country MTB racing (Mean±SD). *significant difference ($p<0.05$).

power bands was more evenly distributed for the TT style of racing. More time was spent below 1 $W{\cdot}kg^{-1}$ than any other power band for TT and XC racing, 23.4% and 24.9%, respectively. Apart from the 0-1 $W{\cdot}kg^{-1}$, the greatest average percent of total time spent during the TT (11.6%) was in the 5-6 $W{\cdot}kg^{-1}$, while for the XC it was 4-5 $W{\cdot}kg^{-1}$ (15.1%). During XC racing a significantly greater amount of time was spent in the 4-5 $W{\cdot}kg^{-1}$ PO bands than for TT racing, whereas a significantly smaller percent total time was spent in PO bands above 7 $W{\cdot}kg^{-1}$. During TT racing, a significantly greater percent total race time was spent above 10 $W{\cdot}kg^{-1}$ (4.0%) compared to XC racing (1.3%).

The percent of total time spent in 10 rpm cadence bands for TT and XC racing are displayed in Figure 4. There were no significant differences for the time spent in each cadence band for both TT and XC races and the time spent in each band followed a similar trend. The percent total time spent <40 rpm for TT and XC racing was 16.0% and 18.8%, respectively and >100 rpm was 11.2% and 7.4%, respectively. The highest average time spent in a cadence band was the 80-89 rpm range, which for TT and XC racing was 21.3% and 20.5%, respectively.

The time spent below anaerobic threshold (4.0 $W{\cdot}kg^{-1}$) for TT and XC racing was 6.7 min and 63.1 min, respectively, which was equivalent to ~50% of the total time of the race for both TT and XC. A significantly less percent total time was spent between 4.0 and 5.5 $W{\cdot}kg^{-1}$ for TT than XC racing which equated to 2.4 and 28.2 min, respectively. In contrast a significantly greater percent total time was spent above W_{max} (5.5 $W{\cdot}kg^{-1}$) for TT rather than XC racing. In absolute time, 5.7 ± 1.1 min was spent above 5.5 $W{\cdot}kg^{-1}$ for TT racing compared to 32.1 ± 9.3 min for XC racing.

A typical race profile from the SRM power crank downloads are shown in Figure 5 for TT racing and Figure 6 for XC racing.

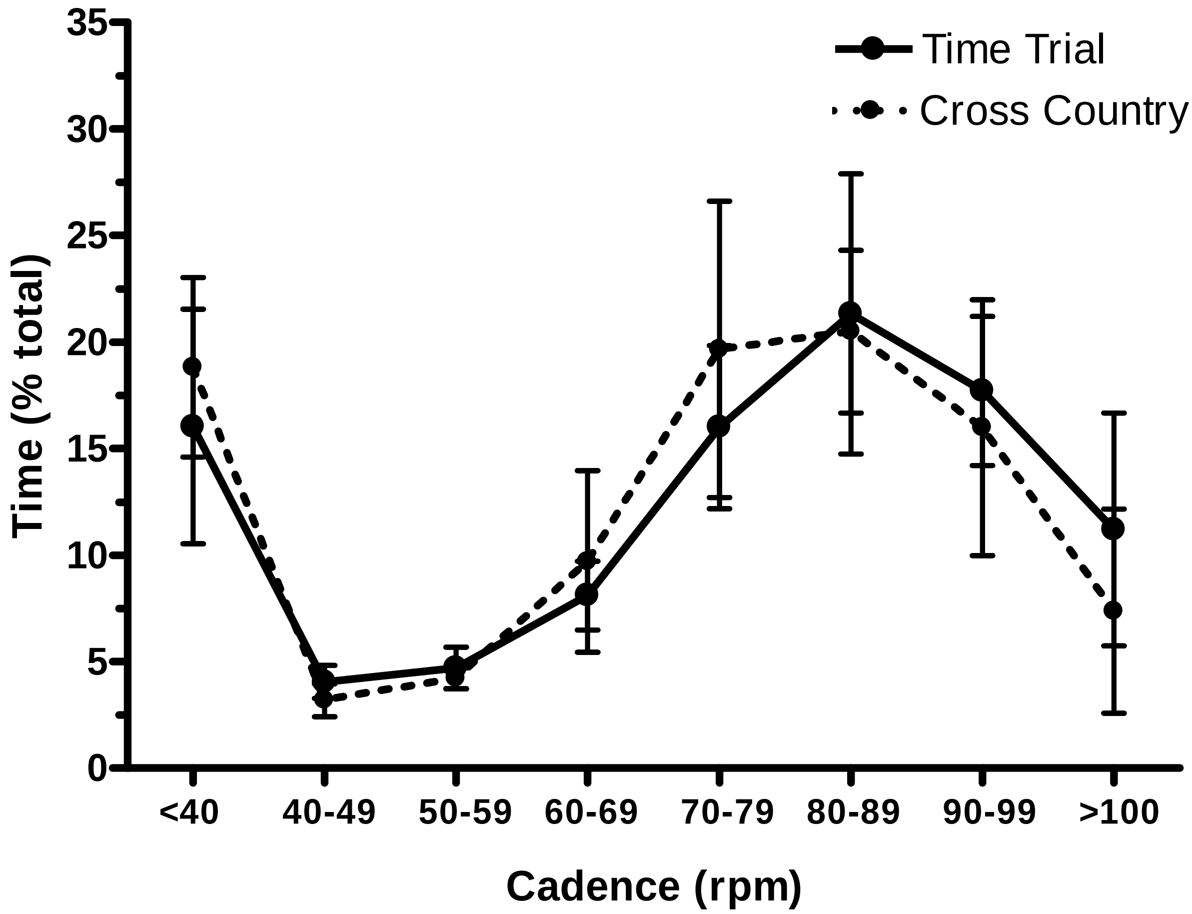

Figure 4. Time spent in cadence bands during Time Trial and Cross Country MTB racing (Mean±SD).

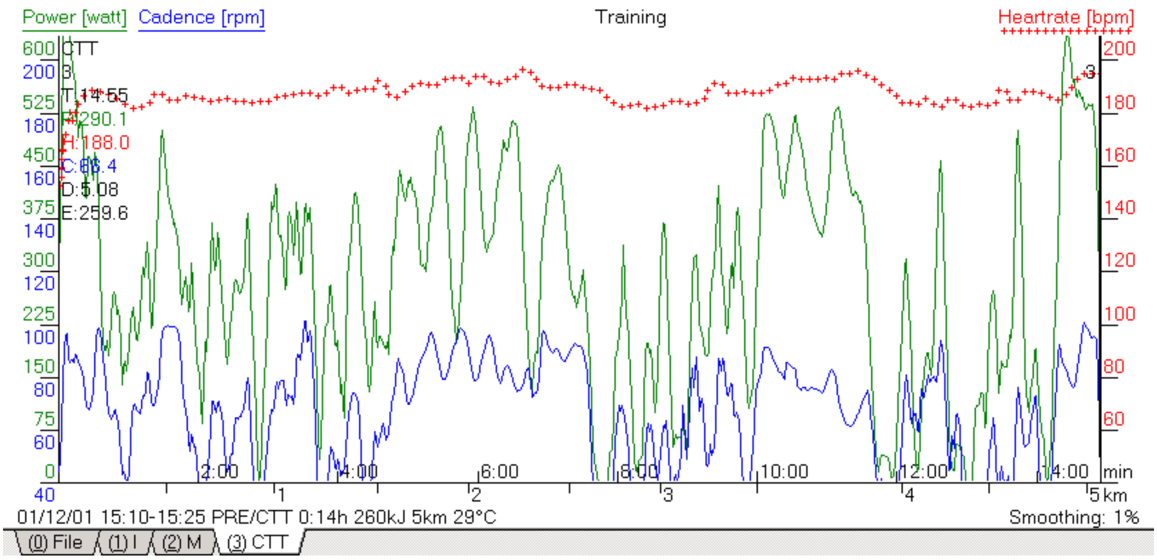

Figure 5. SRM profile of MTB Time Trial racing (Green = power, Blue = cadence, Red = heart rate).

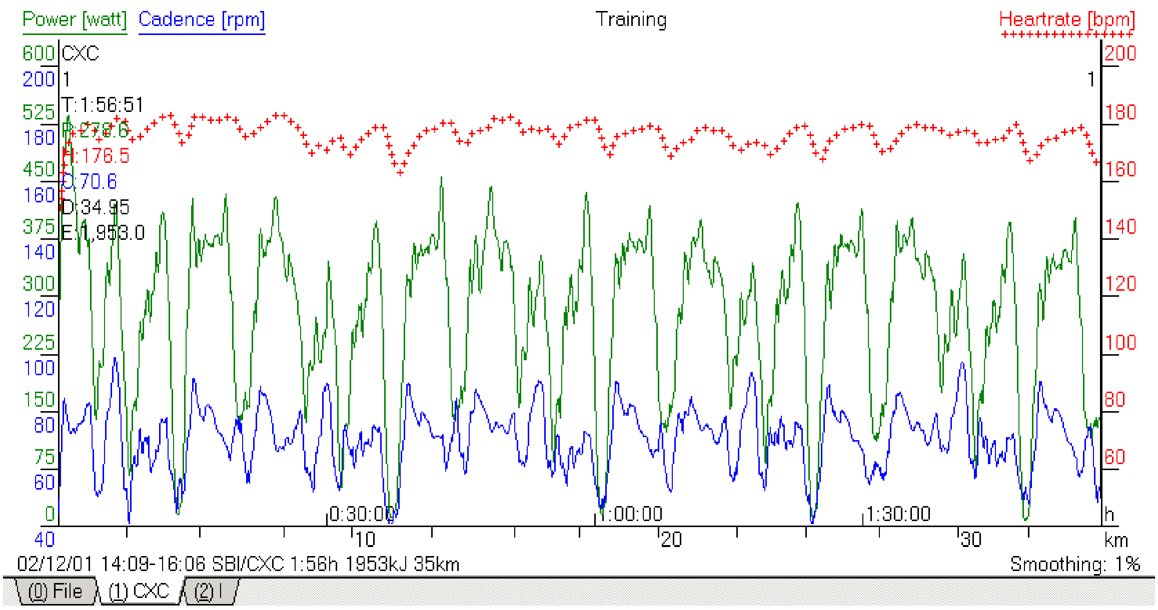

Figure 6. SRM profile of MTB Cross Country racing.

*

4.4 DISCUSSION

Prior to the invention of portable power measuring devices, HR monitoring was used to describe the demands of competition for cyclists (Achten, 2002). Due to the linear relationship between HR and $\dot{V}O_2$, extrapolation of data from laboratory testing can be used to estimate the physiological responses to exercise (Lucia et al., 1999). Factors such as cardiac drift, day-to-day variability, temperature and dehydration can have an effect on HR (Achten, 2002), therefore results need to be interpreted with regard to the conditions. Power output can be indirectly estimated from training and racing using the HR values measured during a laboratory test (Padilla et al., 2000). Power measuring devices on the bike allow a true reading of exercise intensity which can be analysed (Broker, 2003).

Research examining endurance performance in the laboratory has attempted to replicate the stochastic or intermittent nature of cyclists competing in the field (Jeukendrup et al., 1996, Palmer et al., 1997, Schabort et al., 1998, Liedl et al., 1999). Palmer et al. (1997) investigated the effects of steady-state versus stochastic exercise (150 min) on subsequent cycling performance (20 km TT) and found no significant difference in mean HR for either trial (153 ± 6 and 150 ± 11 bpm, respectively). However, a significant difference in time to complete the TT (1:36 min faster) and a greater average mean PO for the steady-state trial compared to the stochastic trial (340.3 ± 44.2 and 302.5 ± 42.3 W) was demonstrated. Constant versus variable power during endurance cycling was analysed by Liedl et al. (1999) over two 1 h trials. Constant power was maintained at 100% of mean PO and the variable power trial consisted of the subject alternating every five min at 95 and 105% of mean PO. No significant difference was found for mean $\dot{V}O_2$, HR, BLa or RPE between the two trials. It is inconclusive as to whether PO can be indirectly estimated from training and racing using HR monitoring because of the highly intermittent nature of racing. Therefore more research needs to be conducted with laboratory tests that more accurately reflect the racing environment.

Another benefit of using a power measuring device such as the SRM power crank is the frequency with which data is collected (0.1 s to 60 sec), whereas the HR monitor collects data at 5, 15 or 60 s intervals. A further application of power measuring devices is the ability to profile and characterise certain MTB courses to assist with pacing strategies.

With appropriate methodology, a course can be profiled accordingly to account for ascents, descents, flat and technical sections and to characterise the PO, cadence, HR and speed of each effort. The length and duration of each effort could be analysed into the number of efforts per lap.

The power output profile from both the TT and XC MTB racing in this study showed that this style of racing is of a highly intermittent nature and if analysed per lap, each lap would produce a similar profile and similar lap time. From the SRM profile, an association can be seen between PO and cadence. As PO increases, cadence also increases and occurs when riding flat sections or when climbing. Both PO and cadence decrease when descending or riding technical sections. When climbing, a high PO is required with a concomitant high cadence to maintain the gear needed to ascend the hill at slower speeds. Higher values of power over 1000 W generally occur at the start and finish of the race and lower readings of 0 W generally occur when descending or riding technical sections. Heart rate during races is typically maintained within 10 bpm regardless of ascending or descending. When descending one would expect that HR would decrease when there is a decrease in workload that occurs in bunch riding during road racing but the descents during MTB are shorter and due to the technical and skill aspect of many descents HR stays elevated. This could be a result of psychological factors (a high level of concentration is required for technical sections) and the isometric contractions of arm and leg muscles for the absorption of vibrations (Stapelfeldt et al., 2004).

There was a significant difference in duration and distance between TT and XC racing, although the average XC race time for males (2:03:49 ± 9:56 h:min:s) was similar to the XC races analysed with the German male cyclists (2:08 ± 0:17 h:min, Stapelfeldt, et al, 2004) and shorter in duration to the Italian races (~2:30 h:min, Impellizzeri, et al. 2002). There was a significant difference for both average absolute and relative PO for TT and XC racing, which would be attributed to the duration and distance of the course. The average absolute and relative PO for XC racing values from this study (259 ± 37 W and 3.7 ± 0.5 $W \cdot kg^{-1}$) is similar to those of the German MTB cyclists (246 ± 12 W and 3.5 ± 0.2 $W \cdot kg^{-1}$) from the study by Stapelfeldt et al. (2004). The PPO from the TT and XC races was comparable (1243 ± 160 and 1254 ± 365 W, respectively) which is similar to reported values from a 4000 m team pursuit (Jeukendrup et al., 2000) starting the race with PO values of approximately 1250 W.

The amount of time spent in different intensity zones can be an important tool for monitoring athlete performance and training (eg. to control overtraining). There was no significant difference between the time spent below anaerobic threshold (>4.0 $W{\cdot}kg^{-1}$) for TT and XC races in this study. The values chosen of 4.0 and 5.5 $W{\cdot}kg^{-1}$ for exercise intensity correspond to anaerobic threshold ($Dmax_{mod}$) and W_{max}, respectively from the maximal oxygen consumption test. There was a significantly greater amount of time spent between anaerobic threshold and maximal power during XC racing (22.8 ± 4.3%) compared to TT racing (16.0 ± 2.4%). The reverse was found for the time spent above maximal power, with TT racing spending a significantly greater amount of time above (38.4 ± 5.2%) compared to XC racing (26.5 ± 9.4%). Stapelfeldt et al. (2004) also calculated the distribution of time during racing according to PO from a $\dot{V}O_{2max}$ test and was in agreement with the average distribution of time spent at different intensity zones to this study for anaerobic threshold to maximal power (20 ± 3 and 22.8 ± 4.3%) and above maximal power (22 ± 6% and 26.5 ± 9.4%), respectively.

Further analysis for power output included dividing PO into 1 $W{\cdot}kg^{-1}$ bands to determine the amount of time spent in different zones. The two types of MTB racing showed a similar profile with ~25% of total race time spent below 1 $W{\cdot}kg^{-1}$. This occurs when descending or during technical sections of the course when there is very little or no pedalling. Cross country racing accumulated significantly more time in the 4-5 $W{\cdot}kg^{-1}$ bands than TT racing and vice versa for all PO bands above 7 $W{\cdot}kg^{-1}$. The greater amount of time spent above 7 $W{\cdot}kg^{-1}$ for TT racing is a result of the short duration type race, coupled with high intensity efforts. Cadence was also divided, into bands of 10 rpm and no significant differences were found between TT and XC racing. Interestingly, although the majority of time was spent in the 80-89 rpm range for TT and XC racing (21.3 ± 6.6 and 20.5 ± 3.8% total time), average cadence was 73 ± 6 and 68 ± 6 rpm, respectively.

The use of analysing PO and cadence into bands can enable coaches and athletes to monitor racing and training efforts specifically. If coaches can understand the physiological demands required of the cyclists during competition, they can incorporate these particular aspects into an athletes training program. It may be useful to analyse a number of athletes on a variety of different courses to determine if individual cyclists spend the same amount of time in each PO or cadence band, irrespective of the race course. Due to the infancy of MTB research, it is not specifically known how physiological relationships exist during racing with the high intermittency (eg. HR-$\dot{V}O_2$, does the relationship exist as seen in the laboratory?). The performance demands measured during racing may assist in designing a sport-specific MTB test that is relevant to the event and to provide valuable information for coaches and athletes when assessing cyclists progression throughout the season and the years.

The average HR for the TT and XC races was 182 ± 5 and 171 ± 7 bpm, which corresponds to 98% and 92% HR_{max} calculated from the $\dot{V}O_{2max}$ test. This finding is concurred by Stapelfeldt et al. (2004) and Impellizzeri et al. (2002) who reported the average HR during XC competition as 91% and 90% of HR_{max}, respectively. These studies confer that MTB is an intense aerobic activity for which near maximal exertion is required for the duration of the race. The exercise intensity is similar to short TT races (>16 km) in road cycling (Palmer et al., 1994, Padilla et al., 2000). Consideration should be used when comparing HR values when presented as a percent of HR_{max} due to the many methods of selecting HR zones and also the sampling rate used for data collection as some studies have used a 5 s (Impellizzeri et al., 2002) sampling rate and other studies have used 15 s (Fernandez-Garcia et al., 2000, Padilla et al., 2001).

In contrast to PO, HR during MTB racing shows little variation and is more constant. Heart rate may increase slightly whilst climbing but there is no significant decrease when descending, whereas Fernandez-Garcia et al. (2000) reported that HR during road races traces the course profile. Road stage racing requires much lower HR values than MTB racing, overall HR in the Vuelta a Espana and Tour de France was 134 ± 18 and 134 ± 19 bpm, respectively (Fernandez-Garcia et al., 2000), which has also been conferred by Padilla et al. (2001). Time trial racing is the exception to mass start road races with an average HR of 166 – 177 bpm (Fernandez-Garcia et al., 2000). Once during the Tour de

France, Lucia et al. (1999) reported a cyclist competing in a 63 km ITT to sustain a near maximal workload for ~70 min at a high workload (>90% $\dot{V}O_{2max}$).

Unfortunately due to the number of cyclists competing in each race it was not possible to compare the power requirements for top 5 compared to the outside the top 5. This type of analysis has been conducted with Australian female road cyclists with a number of riders using SRM power cranks during competition (Trewin et al., 1999, Martin et al., 2001). Women in the top 20 of international road races spent less time below 0.75 $W \cdot kg^{-1}$ and more time above 7.50 $W \cdot kg^{-1}$ than the riders placing outside the top 20. This type of analysis would ultimately increase the understanding of MTB racing but more cyclists and races would be needed for this type of analysis.

The SRM profile of every MTB race circuit will be dissimilar because of the different demands placed on the cyclists depending on: lap distance, number of laps, altitude gain, terrain type (ie. gravel, rocky, bush tracks), environmental conditions (ie. muddy, dry) and technical ability. From the research conducted in this study, it has not been shown that an individual spends a particular amount of time in each power or cadence band. From the current data it can be summarised that the SRM profile of a MTB race doesn't necessarily determine the winner of a MTB race, as the winner may have lower PO because they can ride more efficiently and therefore don't need to expend as much energy for particular sections of the course. Generally, the winners of MTB races are adaptable and competitive in all conditions (personal observation), although certain athletes may excel for example in muddy conditions. To confirm this, a larger sample size of SRM MTB profiles would need to be collected from cyclists while competing.

4.5 SUMMARY

In summary, MTB racing requires multiple short-high intensity PO efforts and places high demands on both the aerobic and anaerobic energy systems. Average power output values for racing are similar to reported values for MTB males. High peak power outputs were produced in the TT and XC events (>1200 W) similar to the PO required at the start of the 4000 m team pursuit, despite the substantial duration of both races (approx 15-120 min).

Power output and cadence are independent of speed and HR stays reasonably constant despite the stochastic nature of power output during MTB racing.

CHAPTER FIVE
STUDY 3: MOUNTAIN BIKE RACE SIMULATION

5.1 INTRODUCTION

Competition analysis can help coaches and athletes refine preparation and competition strategies. There are many variables which can be monitored during racing such as speed, power and heart rate; however, a variety of different PO profiles can produce a similar HR response and often speed does not reflect the actual intensity of the race, as it is affected by factors such as wind and course topography (Broker, 2003). It is therefore important when assessing performance under simulated race conditions as seen in the laboratory that power output is the measure of intensity. Unfortunately, published research examining the validity of laboratory based course simulations is not available. The purpose of this study was to compare PO, cadence and physiological indicators of exercise intensity during a laboratory power output-based MTB race simulation with data collected in the field.

5.2 METHODS

5.2.1 Sample and Subject Preparation

Five male MTB cyclists participated in this study (mean ± SD; age: 23.6 ± 3.4 yr, $\dot{V}O_{2max}$ 72.0 ± 4.6 $ml \cdot kg^{-1} \cdot min^{-1}$, W_{max} 5.4 ± 0.3 $W \cdot kg^{-1}$, HR_{max} 189 ± 7 bpm). All cyclists were registered with the Australian Cycling Federation and were competing in the National MTB Series Competition in the Elite/Under 23 category. One of these cyclists's won the 2001/02 Elite men's National XC Series competition.

The experimental protocol was approved by the University of Canberra Committee for Ethics in Human Research and the Australian Sports Commission Ethics Committee. All subjects were fully informed of the procedures involved in the study prior to signing an Informed Consent document (Appendix A.2).

Testing was carried out during July of 2001. Both tests were conducted in Canberra with the field (FIELD) test at Majura Pines and laboratory (LAB) test at the AIS. Subjects completed the field test 24-48 h prior to the laboratory test and were requested to avoid any other vigorous exercise in the 24 h period prior to testing. Subjects were also requested to abstain from caffeine, food and smoking in the 2 h prior to testing. Verbal encouragement was given throughout both tests to all subjects. Subjects used their own bicycles fitted with a dynamically calibrated MTB SRM power crank for all testing.

5.2.2 Field Testing (FIELD)

The FIELD test consisted of subjects riding a 6.3 km National level MTB course to simulate race competition. The course consisted of different sections including: fire road and single track; steep ascents and descents; and technical sections. The subjects were taken on an orientation lap of the course. The cyclists self-regulated their warm-up before the FIELD test so it was similar to a warm-up before racing. The FIELD test consisted of the cyclists racing two laps on the course which were separated by a 20 min rest period. The subjects were instructed to treat each effort as the first lap of a normal race.

Prior to each lap, a capillary blood sample was taken from the fingertip for analysis of BLa using a Lactate Pro analyser as described in section 3.2.5. The SRM power crank was zeroed at the start line. A countdown was given and the subject started as if it were a race. During each lap the SRM powercontrol unit continuously recorded PO, cadence, speed and distance at 1 s intervals. Heart rate was recorded using a Polar Sports Tester monitor in conjunction with the SRM power crank.

The total lap time was recorded when the subject crossed the finish line and they continued to cycle lightly for 1 min, when a BLa sample was taken and RPE recorded. A measure of RPE was not taken during the FIELD test because the cyclists would need to have stopped or slowed substantially during the test to obtain a reading. The SRM power crank was zeroed again before the second lap. The data from both laps was downloaded onto a computer using the SRM Training System software program as described in 4.2.2.

5.2.3 Laboratory Simulation (LAB)

This test was designed to replicate the MTB field race in the laboratory while incorporating the measurement of $\dot{V}O_2$. The faster of the two laps from the FIELD was used for the computer laboratory simulation. The data was entered into an Excel spreadsheet to calculate the average and peak power output, and average and peak cadence for each 5 s interval of the lap. This data was transformed for entry into Cycling Simulation Labview software (Australian Institute of Sport, Canberra, Australia) with the course profile displayed on a laptop computer (see Figure 7 and 8). This was individually programmed for each cyclist.

The rear wheel of the cyclist's mountain bike was removed and the frame was attached to a windtrainer ergometer (Hayes Cycle Ergometer, Australian Institute of Sport, Canberra, Australia) with four wind vanes attached (see Figure 9). The same MTB SRM power crank was used for the MTB FIELD and LAB test for each cyclist. The laptop computer was placed in front of the bike set-up for the cyclist to obtain a visual image of the course profile and to receive instant visual feedback as the test was performed.

Prior to the test, a capillary blood sample was taken for determination of BLa using the Lactate Pro analyser (Section 3.2.5). The subject conducted the warm-up on their MTB in the laboratory to allow for familiarisation using the laptop screen for visual feedback of the MTB laboratory simulation. The SRM power crank was zeroed before the test started.

The test consisted of the subject attempting to match the average PO for every 5 s block and to make an explosive effort once during that 5 s block to reach the PPO. Cadence was self-selected by the cyclist in an attempt to replicate PO. When the PO on the course profile dropped below 100 W the cyclist was instructed to stop pedalling to replicate the times in the field when pedalling ceased such as on descents or technical sections.

During the test, the SRM powercontrol unit continuously recorded PO, cadence and HR at 1 s intervals in conjunction with the Polar Sports Tester for HR. Oxygen uptake was monitored continuously during the MTB race simulation to assess the physiological demands of race simulation using the MOUSe gas analysis system, as described in Section

Figure 7. Set-up of the laboratory simulation.

Figure 8. Display of course profile for power output and cadence.

Figure 9. The Hayes Cycle Ergometer used for the Laboratory Simulation.

3.2.3. Verbal encouragement was given to cyclists throughout the test to aid in matching the PO requirements seen in the field as closely as possible. On completion of the test, the subject continued to cycle lightly for 1 min when a BLa sample was taken and RPE recorded. The data was downloaded onto a computer using the SRM Training System software program for analysis.

5.2.4 Statistical Analysis

Data are reported as mean ± standard deviation. Typical error of measurement (TEM) and coefficient of variation (CV) were determined for Lap 1 and Lap 2 of the FIELD trials for mean PO (% time spent in 1 $W \cdot kg^{-1}$) and cadence (% time spent in 10 rpm bands) using a spreadsheet available at www.sportsci.org (Hopkins 2000). A one-way analysis of variance (ANOVA) was used to determine significant differences for PO (1 $W \cdot kg^{-1}$ bands), cadence (10 rpm bands) and HR (each 10% of total race time) between the TT and XC races. Statistical significant was set at $p<0.05$.

5.3 RESULTS

5.3.1 The Sample

All five subjects completed the FIELD and LAB tests. Power output and cadence was assessed from all five subjects for both tests. The HR data was assessed on four subjects for both the FIELD and LAB, as one subject's data wasn't recorded because of interference with the HR monitor.

5.3.2 Reliability Data

The reliability for PO and cadence from Lap 1 and Lap 2 FIELD trials are presented in Figures 10 and 11 respectively. The TEM for PO of the two FIELD trials was 1.3 W with a CV of 13.8%. The TEM for cadence of the two FIELD trials was 1.2 rpm with a CV of 7.2%. The mean lap time for the fastest FIELD trial was 21:04 ± 0:46 min:s.

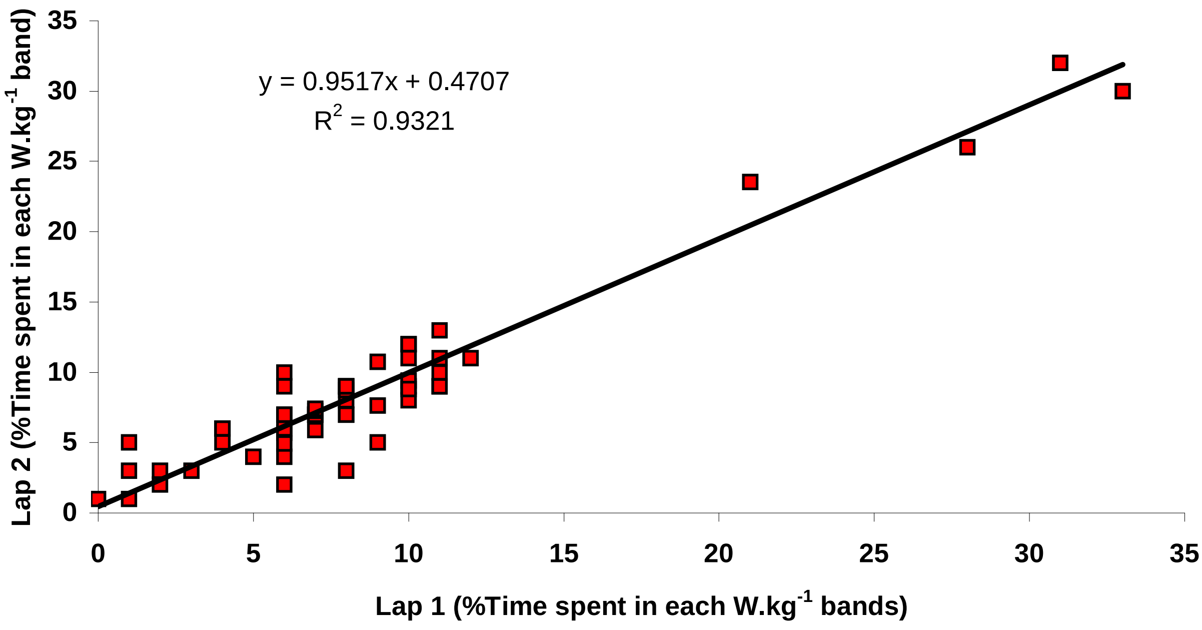

Figure 10. Comparison of power output for Lap 1 and Lap 2 of the FIELD trials.

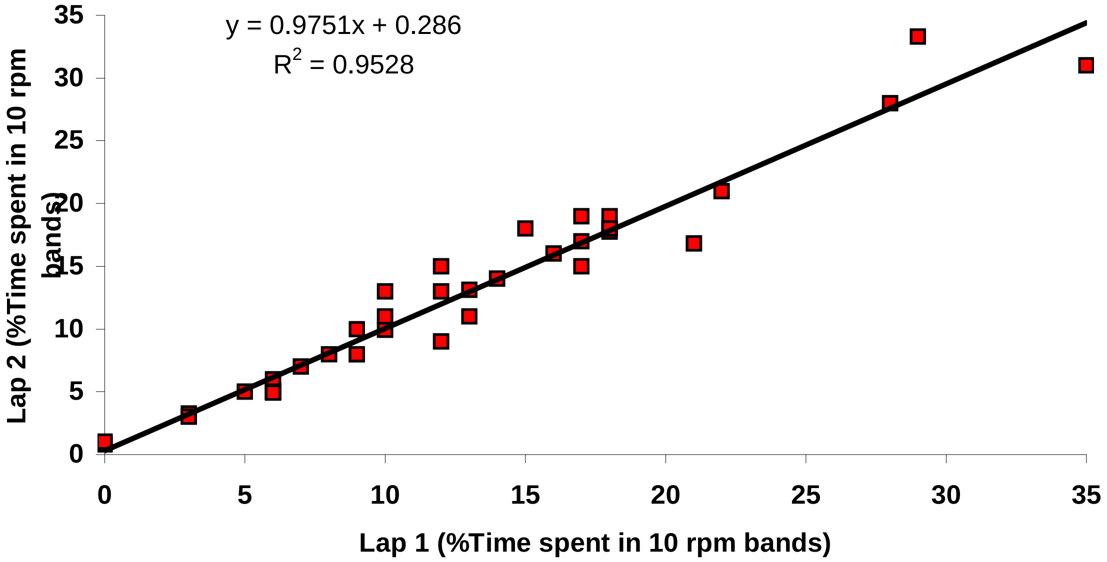

Figure 11. Comparison of cadence for Lap 1 and Lap 2 of the FIELD trials.

5.3.3 Comparison between Field and Laboratory

Physiological responses of the subjects to the FIELD and LAB tests are summarised in Table 14. The $\%W_{max}$ and $\%HR_{max}$ was calculated using the results from the maximal oxygen consumption test. The average PO and HR were lower for the FIELD and LAB tests than for the $\dot{V}O_{2max}$ test (4.44 $W \cdot kg^{-1}$ and 178 bpm, respectively). The $\dot{V}O_2$ results are reported only for the LAB because no gas analysis system was used in the FIELD. The BLa reading was significantly higher at the conclusion of the LAB than for the FIELD test. There was no significant difference for average PO for the FIELD and LAB tests. However, within the power bands there was a significant difference for 4-5 and 7-8 $W \cdot kg^{-1}$ between the FIELD and LAB (refer Figure 12). There was a significant difference between the average cadence for the FIELD and LAB tests and also between four of the cadence bands (60-69, 70-79 and 90-99 rpm, $p<0.05$), refer Figure 13. There were no significant differences found for HR in relation to the race time between the FIELD and LAB (Figure 14). Oxygen consumption during the LAB test is shown in Figure 15. The average $\dot{V}O_2$ for the LAB test (57.5 $ml \cdot kg^{-1} \cdot min^{-1}$) was similar to the $\dot{V}O_2$ found at anaerobic threshold (58.7 $ml \cdot kg^{-1} \cdot min^{-1}$) from the maximal oxygen consumption test. The $\dot{V}O_{2peak}$ (69.3 $ml \cdot kg^{-1} \cdot min^{-1}$) from the LAB test is similar to the value found for $\dot{V}O_{2max}$ (72.0 $ml \cdot kg^{-1} \cdot min^{-1}$).

5.3.4 Environmental Conditions

The mean environmental conditions of temperature (ºC), barometric pressure (hPa) and humidity (%) were recorded when the subject started the first trial using an electronic thermometer-hygrometer. For Group 1 on the first day of FIELD testing the temperature, pressure and humidity was 5ºC, 931 hPa and 89% and for Group 2 on the second day, 11.3ºC, 934 hPa and 81%. The corresponding environmental conditions in the laboratory for the first day of LAB testing for temperature, pressure and humidity was 14.8ºC, 932 hPa and 48% and for the second day of testing, 19.5ºC, 945 hPa and 48%. The mean temperatures for the FIELD tests were significantly lower than experienced during the LAB tests. The FIELD temperatures are characteristic of typical racing environments.

TABLE 14: Physiological responses from the FIELD and LAB tests of male MTB cyclists. (Mean ±SD).

	FIELD (n = 5)	LAB (n = 5)
Ave PO ($W \cdot kg^{-1}$)	4.18 ± 0.55	4.17 ± 0.15
$\%W_{max}$	77.8 ± 13.3	77.3 ± 4.2
Ave Cadence (rpm)	60.3 ± 9.1 *	75.2 ± 7.0
Ave HR (bpm)	175 ± 9	170 ± 8
$\%HR_{max}$	93 ± 4	90 ± 3
Ave $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)		57.5 ± 3.3
$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)		69.3 ± 4.4
BLa_{peak} ($mmol \cdot L^{-1}$)	8.9 ± 3.0 *	13.4 ± 2.2
RPE	16.8 ± 3.7	17.2 ± 3.0

* significant difference to LAB ($p<0.05$)

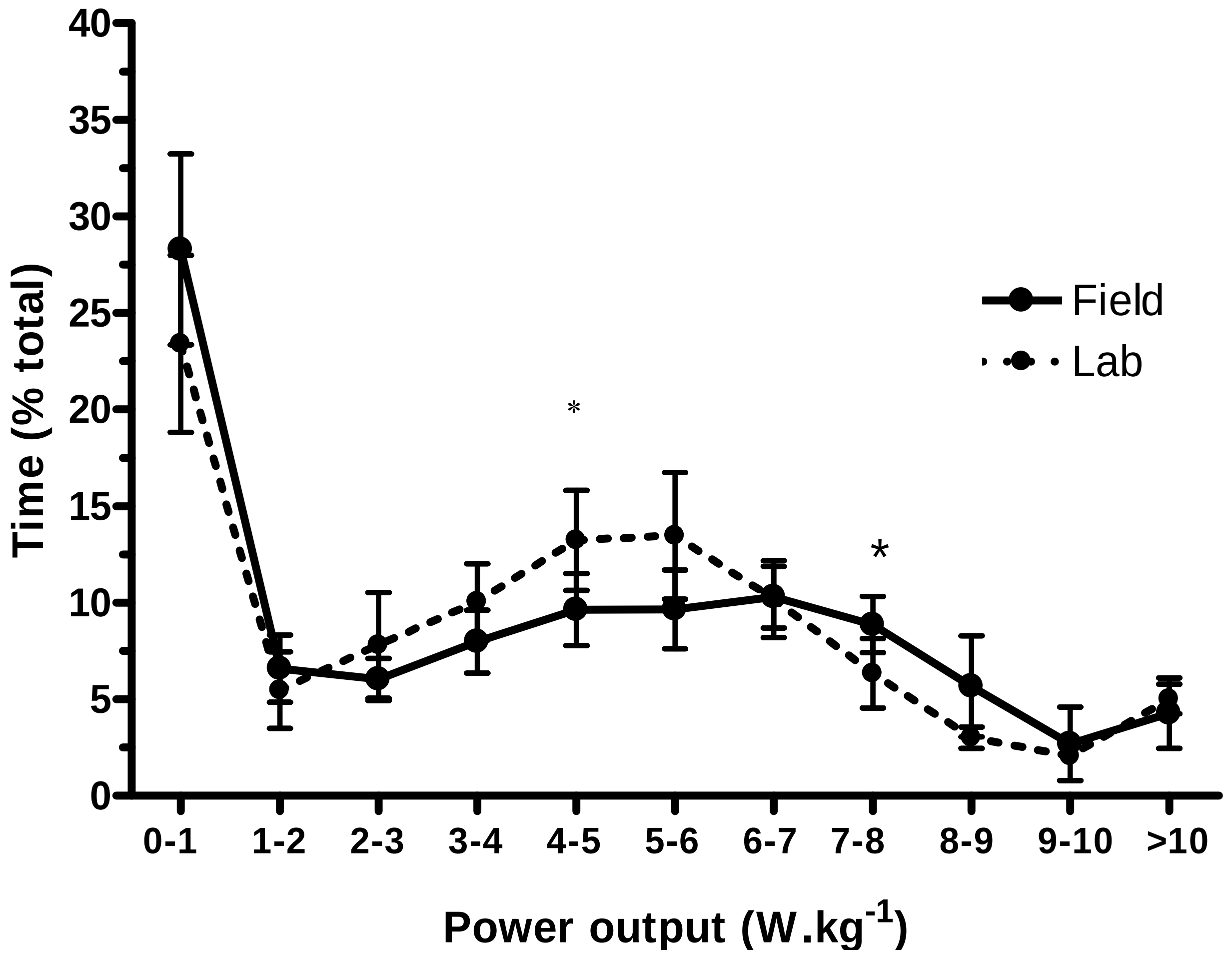

Figure 12. Time spent in power output bands for the FIELD and LAB test.
*significant difference (p<0.05). Values are (Mean±SD).

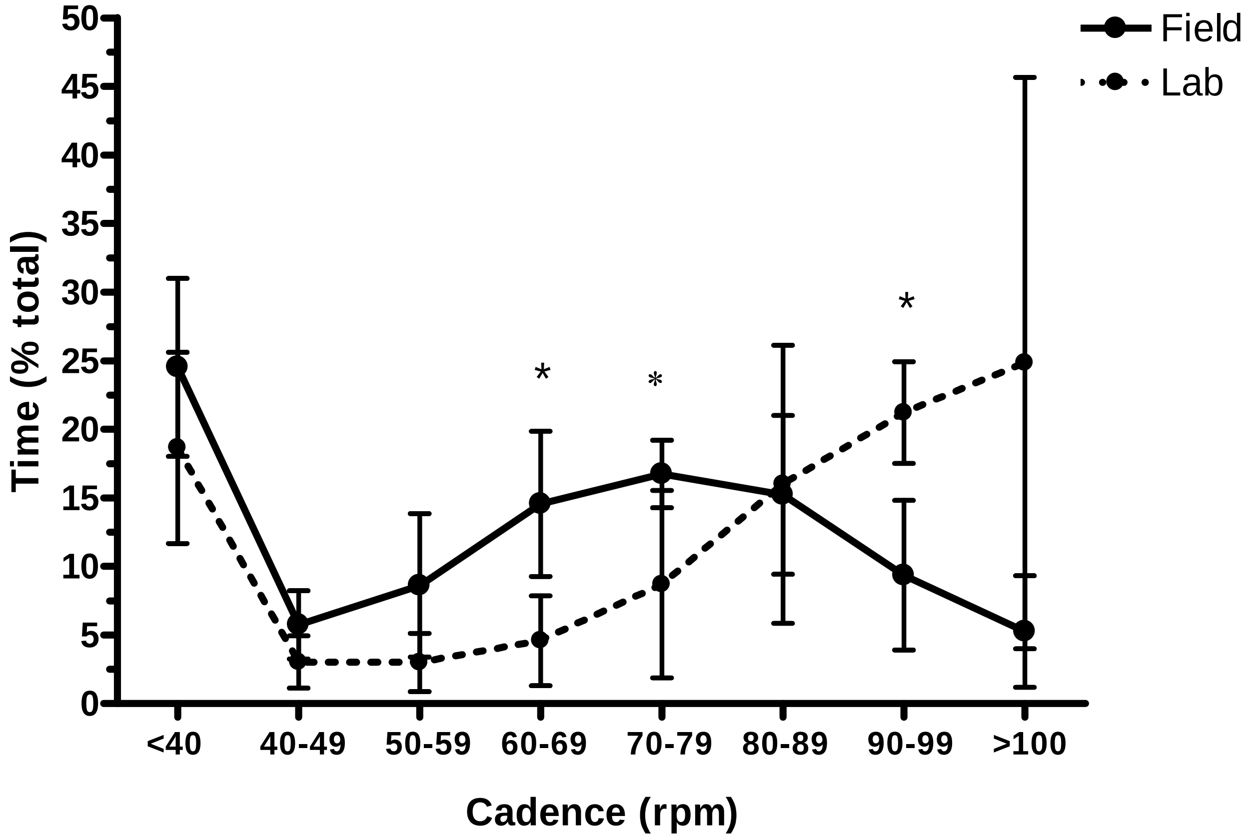

Figure 13. Time spent in cadence bands for the FIELD and LAB test.

*significant difference ($p < 0.05$). Values are (Mean±SD).

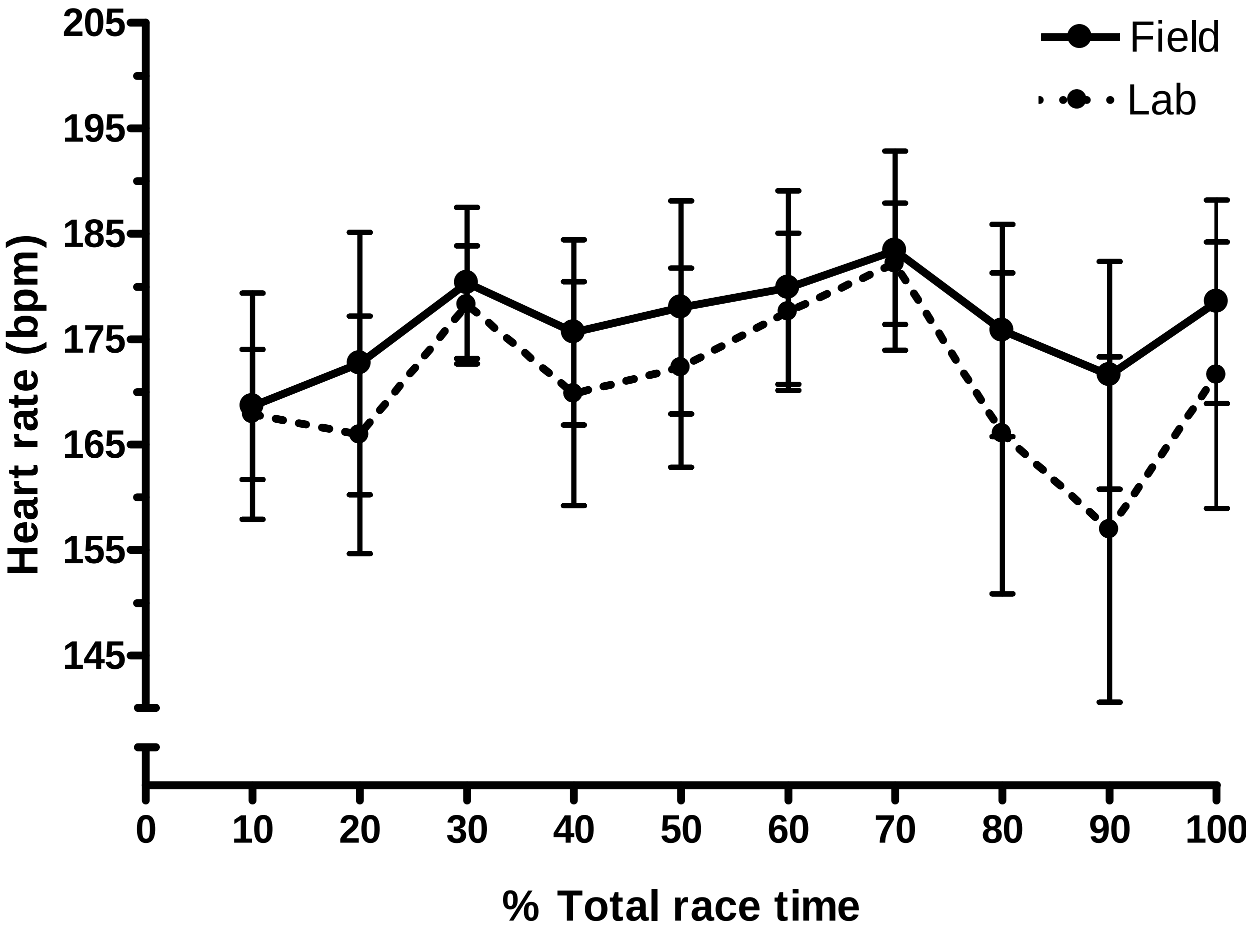

Figure 14. Heart rate during the FIELD and LAB test. Values are (Mean±SD).

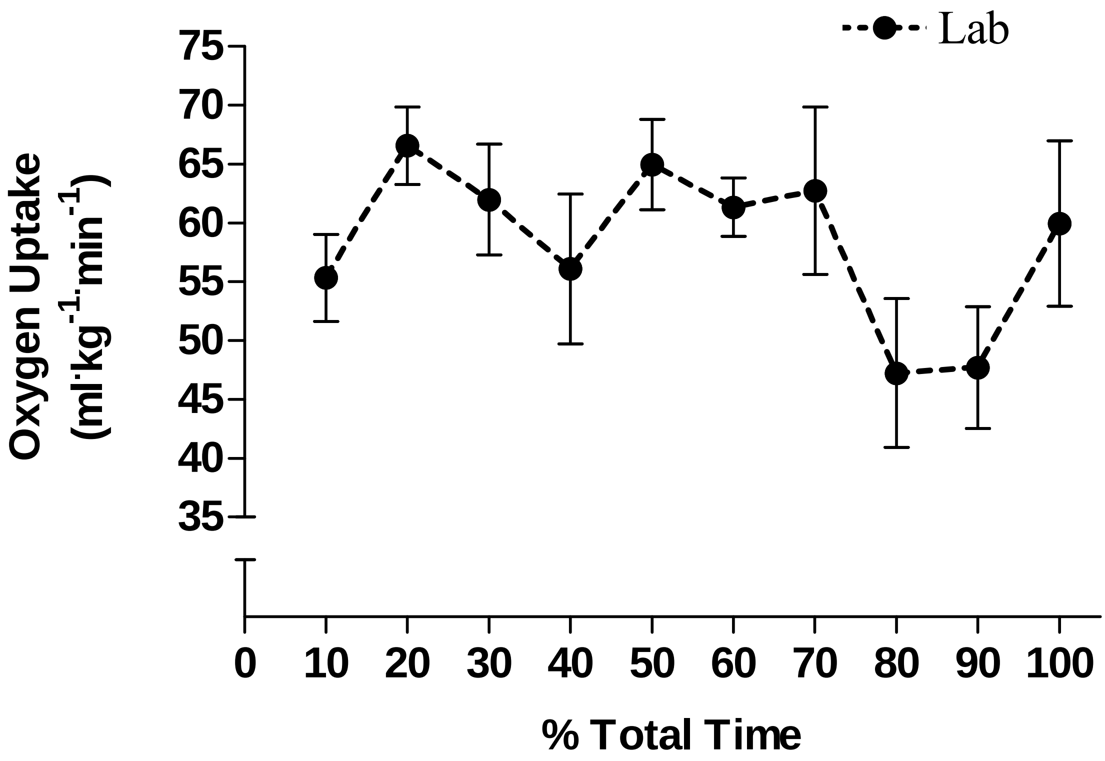

Figure 15. Oxygen uptake during the LAB test. Values are (Mean±SD).

5.4 DISCUSSION

The purpose of this study was to replicate a field MTB race and simulate the demands in the laboratory, as there are currently no well-recognised laboratory based simulations. The first process in this study was to design a MTB course in the field and simulate it in the laboratory to determine the appropriate interval rate for replication. Prior testing using MTB SRM power cranks was completed at a sample rate of 1 s but this sample rate wasn't used in the simulation because of the high intermittency of MTB riding. Pilot testing identified the 5 s average of PO to be most suitable, as with 10 s it was difficult to sustain the higher end power values for the required time without any recovery, which does occur in the field. A longer familiarisation of the laboratory test wasn't provided to the cyclists to prevent the occurrence of a learning effect. During racing the course is constantly changing due to the number of riders on the course and the lines used. Therefore, the cyclists are constantly making adjustments during the race even after they have learned the course.

The ergometer system used for the laboratory simulation allowed for rider and bike specificity during testing, but unfortunately the different types of resistance experienced in the field were unable to be replicated in the field. The computer software required the cyclist to ride their MTB with an SRM MTB power crank fitted so during the test the cyclist had visual feedback. The test utilised a visual display for the cyclist to attempt to match PO for each 5 s block of the average and peak PO. When the cyclist pedalled, an image appeared on the screen as feedback to let the cyclist know the power they had produced. A problem with the system was that when a cyclist stopped pedalling there was a delay reaching the computer because the ergometer fan was still moving. To avoid as much of this overshoot as possible, the cyclist was instructed to stop pedalling when the PO dropped below 100 W to replicate the times in the field when there was no pedalling such as on descents or through technical sections.

Two separate race laps were completed in the field to determine if one lap was representative of a lap in a normal race. When cyclists are racing consistently, there will be minimal difference between lap times (~0:20 min:s) over 4-8 laps (personal observation). There was little difference between the time for lap 1 and lap 2 in the field, 21:08 ± 0:57 and 21:13 ± 0:47 min:s, respectively. The same for lap 1 and lap 2 was found for PO (283 ± 38 and 279 ± 40 W), cadence (70 ± 10 and 60 ± 10 rpm), HR (176 ± 9 and 174 ± 8 bpm) and speed (18.5 ± 0.9 and 18.6 ± 0.6 km), respectively. It can therefore be seen that MTB cyclists are able to reproduce laps of similar quality.

The cyclists only had to attempt to replicate PO because from pilot testing it was discovered that the cadence-power output relationship found during the field test was unable to be replicated, again because of the ergometer. In the field when riding a steep climb, a high PO is required with a low cadence but in the laboratory to replicate the same power, a high cadence is needed to maintain the gear to match the power. Inertia is the most likely cause of the problem in this instance. A bicycle will accelerate when the average cycling power transferred to the pedals by the cyclist exceeds the sum of aerodynamic, rolling, grade and transmission resistances and both wheels become angularly accelerated (Broker, 2003). Bicycle wheels have a certain amount of rotational inertia or resistance to angular acceleration, which is determined by their mass and the distribution of their mass around the hubs (Broker, 2003). To improve the laboratory simulation, an ergometer that accounted for inertia would be needed because the inertia naturally occurring in the field is lost in the laboratory because the bike is stationary.

There was no difference found for average PO in the field and laboratory, although a significant difference was found for the power bands at 4-5 and 7-8 $W \cdot kg^{-1}$. There was not as much recovery time in the laboratory compared to the field for 0-1 $W \cdot kg^{-1}$ which is a result of the lag time when stopping pedalling and the ergometer wheel keeps turning. More time was spent in the 2-6 $W \cdot kg^{-1}$ in the laboratory than the field and the opposite was true for 7-10 $W \cdot kg^{-1}$, which can partly be explained by the ergometer system used and the psychological aspect at the higher workloads. If there is a climb in the field, the cyclist will select a gear and ride it but in the simulation it was difficult to sustain the higher powers, which corresponded to climbs in the field.

The significant differences found in the cadence bands of 60-69, 70-79 and 90-99 rpm relate to the ergometer system because when trying to replicate high power in the laboratory a high cadence is needed to maintain the gear but in the field a low cadence was used because is was a climbing section. Interestingly, there is no significant difference for cadence greater than 100 rpm because the range of values produced in the laboratory is large. In the field there is a cadence-power output relationship but that was unable to be replicated in this particular study.

Average HR values produced in the field and laboratory were not significantly different. As found in a study by Stapelfeldt et al. (2004) HR stays relatively constant during MTB racing although power is highly intermittent and this study supports those findings. Even though no significant differences were found, it can be seen in Figure 14 that HR in the laboratory is lower than the field during the last section. This occurred because in the field the last section of the course was a descent and as previously discussed when riding a descent the HR doesn't decrease as a result. In the laboratory because the PO was low and there was no technical aspect of environment for the cyclist and no isometric contractions of the arms and legs, the HR decreased.

The $\dot{V}O_2$ measured in the laboratory followed closely the profile of HR in the laboratory test. Similar to HR, $\dot{V}O_2$ for the last section of the test also decreased because there was less stimulus in the laboratory for the cyclists to keep the HR elevated. The average $\dot{V}O_2$ measured during the laboratory trial, 57.5 ± 3.3 ml·kg·min^{-1} was similar to the $\dot{V}O_2$ found at anaerobic threshold from the $\dot{V}O_{2max}$ test (58.7 ± 5.0 ml·kg·min^{-1}) and $\dot{V}O_{2peak}$ was 69.3 ± 4.4 ml·kg·min^{-1} which is also similar to $\dot{V}O_{2max}$ (72.0 ± 4.6 ml·kg·min^{-1}). The average %HR_{max} utilised during the field and laboratory tests was similar to the values found for road and MTB cyclists in previous literature (Palmer et al., 1994, Stapelfeldt et al., 2004) and similar to the results from study 2 of this research project for XC racing.

MacRae et al. (2000) hypothesised that $\dot{V}O_2$ would track PO or at the least $\dot{V}O_2$ would follow PO but they actually found a similar dissociation between PO and HR and additionally between PO and $\dot{V}O_2$, which was also true for this study. The usual relationship between PO, cardiovascular and metabolic responses observed in a laboratory setting appear to change when cyclist's perform in the field (MacRae et al., 2000). The BLa response was higher after the laboratory test than the field test (13.4 ± 2.2 and 8.9 ± 3.0 mmol·L^{-1}, respectively). This could also be a result of the different dynamics of the ergometer used in the laboratory compared to the bike used in the field test. Although there was no significant difference for post RPE for the FIELD and LAB trials (16.8 ± 3.7 and 17.2 ± 3.0), the cyclists found it more difficult to complete the last section of the laboratory simulation at high power outputs (personal communication). There is no comparison data for RPE during the last section of the test because RPE was unable to be obtained in the field.

5.5 SUMMARY

The power output and heart rate responses to a simulated MTB race in the laboratory are similar to the MTB field race, although in the laboratory higher cadences are selected for the higher power outputs than for the field. The sustained nature of ergometer efforts, kinetic energy of the ergometer, and gearing ratios used in the laboratory simulation may explain the differences between the field and laboratory trials.

CHAPTER SIX
CONCLUSIONS, RECOMMENDATIONS

6.1 CONCLUSIONS

Research examining different aspects of elite MTB competitors is in its infancy. Although a few papers have been published documenting different aspects of the sport there are still many issues that are not resolved. More specifically, female competitors are not well studied, anaerobic traits in MTB athletes are rarely quantified, detailed analysis of the demands of competition have only recently been explored and the ability to replicate the demands of MTB racing in the laboratory have not been addressed. The primary aims of this thesis were to improve the knowledge base in these important areas.

A detailed investigation of the physiological characteristics of male and female Australian MTB athletes revealed that power to mass performance traits are important and that both male and female MTB athletes display well developed peak power output ($W \cdot kg^{-1}$) as compared to other athletes competing in different cycling disciplines.

There is little published literature concerning female athletes, in particular MTB cyclists. Part of this study has examined the physical and physiological characteristics of elite Australian female MTB cyclists and found their results comparable to the literature. Another unique feature of this thesis was the investigation of anaerobic power and capacity characteristics of MTB cyclists, which has been found to be important when racing at the start and for hill climbs (Baron, 2001).

Both MTB coaches and athletes are interested in the specific physical demands of competition. These demands can be used as the basis for talent identification, training, progressions and pacing strategies. Unfortunately, very little is known about the cadence-power output demands of MTB competition. There are two preliminary reports that have examined different aspects of MTB competition (Impellizzeri et al., 2002, Stapelfeldt et al., 2004). However, the data presented in this thesis is the first to specifically address the cadence-power output demands of this unique cycling discipline. SRM power crank data reveal low average cadence for relatively high power in both MTB TT and XC events. This finding has training implications especially for MTB athletes participating in ergometry based interval programs. Another unique observation was the high peak power output produced in both the TT and XC events (>1200 W), despite the substantial duration of both races (approx 15-120 min).

Many advances in sport science have been achieved by replicating the demands of competition in a laboratory setting. In regards to MTB, there are currently no well-recognised laboratory based simulations. It is most likely the case that a lack of understanding of the demands of the sport has prevented the development of such protocols. Fortunately the previously discussed experiment allows for a detailed profile of both cadence and power produced during a MTB event. This information was used in conjunction with a novel visual display of target workloads to recreate MTB racing in a laboratory setting. Although our attempts at MTB simulation were adequate for reproducing the number, duration and intensity of power output surges, the specific cadence-power relationships observed in the field were difficult to replicate. It is most likely that the kinetic energy of the stationary ergometer used must be modified to allow for exact MTB replication to occur. Despite this difference in cadence, data suggests that laboratory based MTB trials can be constructed that are far more specific to the demands of MTB competition than standard $\dot{V}O_{2max}$ or time trial tests.

In summary, the male MTB cyclists in this study produced comparable aerobic power values ($\dot{V}O_{2max}$ 74.6 ± 5.6 ml·kg·min^{-1}, MPO 5.64 ± 0.52 W·kg^{-1}, HR_{max} 197 ± 9 bpm) to road cyclists and anaerobic power and capacity similar to track cyclists. The female cyclists displayed comparable anthropometric and aerobic power values to those of road and MTB female cyclists. TT MTB racing is significantly shorter in duration and distance than XC racing with significantly higher power outputs and HR. Also, more time is spent above anaerobic threshold and MPO in TT racing compared to XC racing. Mean PO and HR responses to a MTB field race are similar when replicated in the laboratory (4.18 ± 0.55 and 4.17 ± 0.15 W·kg^{-1} respectively, 175 ± 9 and 170 ± 8 bpm). Time spent below 2 W·kg^{-1} and above 6 W·kg^{-1} for the field and laboratory trials accounted for ~62% of the total time. Cyclists utilised ~77% of MPO, 91% of HR_{max} during the field and laboratory trials. There was a significant difference between mean cadence in the field and laboratory trials and cyclists were able to sustain an average of ~80% $\dot{V}O_{2max}$ during the laboratory test.

MTB competition can be characterised as a prolonged endurance event that involves numerous short high intensity surges performed at relatively lower cadences than observed in other cycling disciplines. Data presented in this thesis extends upon previous work describing the physiological characteristics of MTB athletes and presents for the first time a detailed description of the cadence-power relationships produced during MTB competition. Advances in laboratory based MTB simulations such as the one described in this thesis will be necessary in order to better understand how training environment and erogenic aids influence MTB performance.

6.2 RECOMMENDATIONS

To fully understand the nature of MTB racing, future investigations would need to involve a greater number of athletes and MTB SRM power cranks. It would be ideal to have 5 – 10 cyclists using SRM power cranks during each competition, which would also follow on to the analysis of requirements of a winner or top 5-10 compared to a rider outside of the top 10. Although there is published female MTB power data, it only consists of 2 riders. It would be ideal to involve females in the study. Also complete analysis of the race would help to extend the knowledge of the demands of MTB, such as the number of efforts, where the efforts occurred (eg. climb, sprinting off the start line), cadence-power relationship for ascents, descents and, profiled course analysis (terrain types, altitude).

The laboratory simulation of a MTB field race has the potential to be useful in profiling MTB courses around the world. It would be ideal if you could ride a MTB course, eg. Olympic course 6 months before competition and analyse the demands (ie. number of efforts, duration of efforts, power output-cadence relationship). The course could then be practised in the home of the athlete as in study 3 of this research project. Although the technical aspect of the course would be missing, the physiological loading on the athlete can be practised. It has been shown in this study that it is possible to replicate a MTB field test in the laboratory for power output but not for cadence. Therefore a different method needs to be employed or a different ergometer type is needed to accurately simulate field riding with respect to gear ratios for the athletes.

The design of a Mountain Bike Performance Test for XC cyclists would be possible from the data collected during competition. There is a need for a sport specific test protocol for these athletes as currently the test procedures for MTB athletes involve a standard $\dot{V}O_{2max}$ test and 30 min TT. Although these tests assess the physiology of the athlete they do not assess the performance demands of competition. The performance test may assist in the determination of potential athletes (ie. Talent Identification). A novel Mountain Bike Performance Test would need to be tested for its reliability and validity. It could then be used to determine the effectiveness of intervention strategies such as the use of creatine supplementation or heat acclimatisation, which will ultimately further benefit the athlete.

REFERENCES

Achten, J. (2002) In *High Performance Cycling*(Ed, Jeukendrup, A. E.) Human Kinetics, Champaign, pp. 59 - 68.

Barbeau, P., Serresse, O. and Boulay, M. R. (1993).Using maximal and submaximal aerobic variables to monitor elite cyclists during a season, *Med Sci Sports Exerc,* **25,** 1062-9.

Baron, R. (2001).Aerobic and anaerobic power characteristics of off-road cyclists, *Med Sci Sports Exerc,* **33,** 1387 - 1393.

Bar-Or, O. (1987).The Wingate anaerobic test. An update on methodology, reliability and validity, *Sports Med,* **4,** 381-94.

Bergh, U. (1987).The influence of body mass in cross-country skiing, *Med Sci Sports Exerc,* **19,** 324 - 331.

Bishop, D. (1997).Reliability of a 1-h endurance performance test in trained female cyclists, *Med Sci Sports Exerc,* **29,** 554 - 559.

Borg, G. A. V. (1970).Perceived exertion as an indicator of somatic stress., *Scand. J. Rehabil. Med.,* **2,** 92 - 98.

Bourdon, P. (2000) In *Physiological Tests for Elite Athletes*(Ed, Gore, C. J.) Human Kinetics, Champaign, IL, pp. pp. 50-65.

Broker, J. P. (2003) In *High-Tech Cycling*(Ed, Burke, E. R.) Human Kinetics, Champaign, IL, pp. 147 - 174.

Burke, E. R. (1980).Physiological Characteristics of Competitive Cyclists, *Physician and SportsMedicine,* **8,** 78 - 84.

Burke, E. R., Fleck, S. and Dickson, T. (1981).Post-competition blood lactate concentrations in competitive track cyclists, *Br J Sports Med,* **15,** 242-5.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences,* Lawrence Erlbaum, Hillsdale, NJ.

Coyle, E. F., Coggan, A. R., Hopper, M. K. and Walters, T. J. (1988).Determinants of endurance in well-trained cyclists, *J Appl Physiol,* **64,** 2622-30.

Coyle, E. F., Feltner, M. E., Kautz, S. A., Hamilton, M. T., Montain, S. J., Baylor, A. M., Abraham, L. D. and Petrek, G. W. (1991).Physiological and biomechanical factors associated with elite endurance cycling performance, *Med Sci Sports Exerc,* **23,** 93-107.

Craig, N., Walsh, C., Martin, D. T., Woolford, S., Bourdon, P., Stanef, T., Barnes, P. and Savage, B. (2000) In *Physiological Tests for Elite Athletes*(Ed, Gore, C. J.) Human Kinetics, Champaign, IL, pp. 258-277.

Craig, N. P., Norton, K. I., Bourdon, P. C., Woolford, S. M., Stanef, T., Squires, B., Olds, T. S., Conyers, R. A. and Walsh, C. B. (1993).Aerobic and anaerobic indices contributing to track endurance cycling performance, *Eur J Appl Physiol,* **67,** 150-8.

Craig, N. P., Norton, K. I., Conyers, R. A., Woolford, S. M., Bourdon, P. C., Stanef, T. and Walsh, C. B. (1995).Influence of test duration and event specificity on maximal accumulated oxygen deficit of high performance track cyclists, *Int J Sports Med,* **16,** 534-40.

Craig, N. P. and Norton, K. P. (2001).Characteristics of Track Cycling, *Sports Med,* **31,** 457 - 468.

Crowther, N. (1999). *The Ultimate Mountain Bike Book,* Carlton Books Limited.

Ellis, L., Gastin, P., Lawrence, S., Savage, B., Buckeridge, A., Stapff, A., Tumilty, D., Quinn, A., Woolford, S. and Young, W. (2000) In *Physiological Tests for Elite Athletes*(Ed, Gore, C. J.) Human Kinetics, South Australia, pp. 128-144.

Faria, I. E. (1984).Applied physiology of cycling, *Sports Med,* **1,** 187-204.

Faria, I. E., Faria, E. W., Roberts, S. and Yoshimura, D. (1989).Comparison of physical and physiological characteristics in elite young and mature cyclists, *Res Q Exerc Sport,* **60,** 388-95.

Fernandez-Garcia, B., Perez-Landaluce, J., Rodriguez-Alonso, M. and Terrados, N. (2000).Intensity of exercise during road race pro-cycling competition, *Med Sci Sports Exerc,* **32,** 1002-6.

Foley, J. P., Bird, S. R. and White, J. A. (1989).Anthropometric comparison of cyclists from different events, *Br J Sports Med,* **23,** 30-3.

Foster, C. and Daniels, J. T. (1975).Aerobic Power of Competitive Cyclists, *Australian Journal of Sports Medicine,* **7,** 111-112.

Gardner, A. S., Stephens, S., Martin, D. T., Lawton, E. W., Lee, H. and Jenkins, D. (2004).Accuracy of SRM and power tap power monitoring systems for bicycling, *Med Sci Sports Exerc,* **36,** 1252-1258.

Hagberg, J. M. and Coyle, E. F. (1983).Physiological determinants of endurance performance as studied in competitive racewalkers., *Med Sci Sports Exerc,* **15,** 287-289.

Heller, J. and Novotny, J. (1997).Aerobic and anaerobic capacity in elite mountain bikers, *Acta Universitatis Carolinae Kinanthropologica,* **33,** 61 - 68.

Hopkins, S. R. and McKenzie, D. C. (1994).The laboratory assessment of endurance performance in cyclists, *Can J Appl Physiol,* **19,** 266-74.

Impellizzeri, F., Sassi, A., Rodriguez-Alonso, M., Mognoni, P. and Marcora, S. (2002).Exercise intensity during off-road cycling competitions, *Med Sci Sports Exerc,* **34,** 1808 - 1813.

Jeukendrup, A. E. (2002a). *High-Performance Cycling,* Human Kinetics, Champaign, IL.

Jeukendrup, A. E. (2002b) In *High Performance Cycling*(Ed, Jeukendrup, A. E.) Human Kinetics, Champaign, IL, pp. 69 - 77.

Jeukendrup, A. E., Craig, N. P. and Hawley, J. A. (2000).The bioenergetics of World Class Cycling, *J Sci Med Sport,* **3,** 414-33.

Jeukendrup, A. E., Saris, H. M., Brouns, F. and Kester, A. D. M. (1996).A new validated endurance performance test, *Med Sci Sports Exerc,* **28,** 266 - 270.

Kuipers, H., Verstappen, F. T., Keizer, H. A., Geurten, P. and van Kranenburg, G. (1985).Variability of aerobic performance in the laboratory and its physiologic correlates, *Int J Sports Med,* **6,** 197-201.

Lee, H., Martin, D. T., Anson, J. M., Grundy, D. and Hahn, A. G. (2002).Physiological characteristics of successful mountain bikers and professional road cyclists, *Journal of Sports Sciences,* **20,** 1001-1008.

Liedl, M. A., Swain, D. P. and Branch, J. D. (1999).Physiological effects of constant versus variable power during endurance cycling, *Med Sci Sports Exerc,* **31,** 1472 - 1477.

Lucia, A., Hoyos, J., Carvajal, A. and Chicharro, J. L. (1999).Heart rate response to professional road cycling: the Tour de France, *Int J Sports Med,* **20,** 167-72.

Lucia, A., Hoyos, J. and Chicharro, J. L. (2003) In *High-Tech Cycling*, Vol. Second (Ed, Burke, E.) Human Kinetics, Champaign, IL, pp. 265-288.

Lucia, A., Joyos, H. and Chicharro, J. L. (2000).Physiological response to professional road cycling: climbers vs. time trialists, *Int J Sports Med,* **21,** 505-12.

Lucia, A., Pardo, J., Durantez, A., Hoyos, J. and Chicharro, J. L. (1998).Physiological differences between professional and elite road cyclists, *Int J Sports Med,* **19,** 342-8.

MacRae, H. S., Hise, K. J. and Allen, P. J. (2000).Effects of front and dual suspension system mountain bike systems on uphill cycling performance, *Med Sci Sports Exerc,* **32,** 1276 - 1280.

Martin, D. T., McLean, B., Trewin, C., Lee, H., Victor, J. and Hahn, A. G. (2001).Physiological characteristics of nationally competitive female road cyclists and demands of competition, *Sports Med,* **31,** 469-77.

McCole, S. D., Claney, K., Conte, J. C., Anderson, R. and Hagberg, J. M. (1990).Energy expenditure during bicycling, *J Appl Physiol,* **68,** 748-53.

McLean, B. D. and Parker, A. W. (1989).An anthropometric analysis of elite Australian track cyclists, *J Sports Sci,* **7,** 247-55.

Mujika, I. and Padilla, S. (2001).Physiological and performance characteristics of male professional road cyclists, *Sports Med,* **31,** 479-87.

Neumann, G. (1992) In *Endurance In Sport*(Ed, Astrand, P. O.) Blackwell, Oxford, pp. 582 - 596.

Norton, K. and Olds, T. (Eds.) (1996).*Anthropometrica*, University of New South Wales Press, Sydney.

Padilla, S., Mujika, I., Cuesta, G. and Goiriena, J. J. (1999).Level ground and uphill cycling ability in professional road cycling, *Med Sci Sports Exerc,* **31,** 878-85.

Padilla, S., Mujika, I., Cuesta, G., Polo, J. M. and Chatard, J. C. (1996).Validity of a velodrome test for competitive road cyclists, *Eur J Appl Physiol Occup Physiol,* **73,** 446-51.

Padilla, S., Mujika, I., Orbananos, J. and Angulo, F. (2000).Exercise intensity during competition time trials in professional road cycling [In Process Citation], *Med Sci Sports Exerc,* **32,** 850-6.

Padilla, S., Mujika, I., Orbananos, J., Santisteban, J., Angulo, F. and Jose Goiriena, J. (2001).Exercise intensity and load during mass-start stage races in professional road cycling, *Med Sci Sports Exerc,* **33,** 796-802.

Palmer, G. S. (2002) In *High Performance Cycling*(Ed, Jeukendrup, A. E.) Human Kinetics, Champaign, IL, pp. 91 - 100.

Palmer, G. S., Hawley, J. A., Dennis, S. C. and Noakes, T. D. (1994).Heart rate responses during a 4-d cycle stage race, *Med Sci Sports Exerc,* **26,** 1278-83.

Palmer, G. S., Noakes, T. D. and Hawley, J. A. (1997).Effects of steady-state versus stochastic exercise on subsequent cycling performance, *Med Sci Sports Exerc,* **29,** 684 - 687.

Paton, C. D. and Hopkins, W. G. (2001).Tests of Cycling Performance, *Sports Med,* **31,** 489 - 496.

Pfeiffer, R. P., Harder, B. P., Landis, D., Barber, D. and Harper, K. (1993).Correlating Indices of Aerobic Capacity With Performance in Elite Women Road Cyclists, *Journal of Strength and Conditioning Research,* **7,** 201-205.

Richards, B. and Worland, S. (1997). *The Complete Book of Mountain Biking,* HarperCollins, New York.

Schabort, E. J., Hawley, J. A., Hopkins, W. G., Mujika, I. and Noakes, T. D. (1998).A new reliable laboratory test of endurance performance for road cyclists, *Med Sci Sports Exerc,* **30,** 1744 - 1750.

Schoberer, U. (1998) SRM, Welldorf, Germany.

Schumacher, Y. O. and Mueller, P. (2002).The 4000-m team pursuit cycling world record: theoretical and practical aspects, *Med Sci Sports Exerc,* **34,** 1029 - 1036.

Seifert, J. G., Luetkemeier, M. J., Spencer, M. K., Miller, D. and Burke, E. R. (1997).The Effects of Mountain Bike Suspension Systems on Energy Expenditure, Physical

Exertion, and Time Trial Performance During Mountain Bicycling, *Int J Sports Med,* **18,** 197 - 200.

Shephard, R. J. (1992) In *Endurance In Sport*(Ed, Astrand, P. O.) Blackwell Science, Oxford, pp. 215-225.

Sjodin, B. and Jacobs, I. (1981).Onset of blood lactate accumulation and marathon running performance, *Int J Sports Med,* **1997,** 197-200.

Stapelfeldt, B., Schwirtz, A., Schumacher, Y. O. and Hillebrecht, M. (2004).Workloads Demands in Mountain Bike Racing, *Int J Sports Med,* **25,** 294 - 300.

Swain, D. P. (1994).The influence of body mass in endurance bicycling, *Med Sci Sports Exerc,* **26,** 58-63.

Tanaka, H., Bassett, D. R., Jr., Swensen, T. C. and Sampedro, R. M. (1993).Aerobic and anaerobic power characteristics of competitive cyclists in the United States Cycling Federation, *Int J Sports Med,* **14,** 334-8.

Telford, R. D., Hahn, A. G., Pyne, D. B. and Tumilty, D. M. (1990).Strength, anaerobic capacities and aerobic power of Australian track and road cyclists, *Excel,* **6,** 20-22.

Trewin, C., Martin, D. T., McLean, B. D., Lee, H., Lawton, E. W. and Victor, J. (1999).Power output demands of womens world cup road cycling, *Fifth IOC World Congress; Sydney (abstract)***,** 203.

UCI (2003b), Vol. 2003 International Cycling Union.

UCI (2004a), Vol. 2005.

UCI (2004b), Vol. 2004 http://www.vitesseonline.it/uci/mtb/ranking.

Vandewalle, H., Peres, G., Heller, J., Panel, J. and Monod, H. (1987).Force-velocity relationship and maximal power on a cycle ergometer. Correlation with the height of a vertical jump, *Eur J Appl Physiol,* **56,** 650-6.

White, J. A. and Al-Dawalibi, M. A. (1986).Assessment of the power performance of racing cyclists, *J Sports Sci,* **4,** 117-22.

White , J. A., Quinn, G., Al-Dawalibi, M. and Mulhall, J. (1982a).Seasonal changes in cyclists' performance. Part I. The British Olympic road race squad, *Br J Sports Med,* **16,** 4-12.

White, J. A., Quinn, G., Al-Dawalibi, M. and Mulhall, J. (1982b).Seasonal changes in cyclists' performance. Part II. The British Olympic track squad, *Br J Sports Med,* **16,** 13-21.

Wilber, R. L., Zawadzki, K. M., Kearney, J. T., Shannon, M. P. and Disalvo, D. (1997).Physiological profiles of elite off-road and road cyclists, *Med Sci Sports Exerc,* **29,** 1090-4.

APPENDICES

APPENDIX A.1 **Subject Information Sheet**

Project Title
Aerobic, anaerobic and muscular strength characteristics of off-road cyclists.

Investigators

Kelly Linaker
Masters of Applied Science in Sports Studies (Exercise Physiology)
Telephone 0410 485 845
Email k.linaker@student.canberra.edu.au
Centre for Sports Studies
University of Canberra ACT 2601

with assistance from Dr Alan Roberts (supervisor), Dr David Martin (supervisor).

Aims of the Study
Off-road cycling, commonly known as mountain biking has been a recreational sport until recently. Mountain biking was contested as a full medal sport at the Sydney 2000 Olympics. Despite increasing popularity and instatement as an Olympic sport, there is little reported literature from the area of sports science. The aim of this study is to determine the aerobic, anaerobic and muscular strength characteristics of male and female off-road cyclists. The second aim is to implement a sports specific performance test that will be designed to simulate a field off-road course that can be conducted in the laboratory.

Considerable research has been conducted on road and track cyclists, from novice through to sub-elite and elite/professionals for male and females. The characteristics most extensively reported in the literature are: physical parameters – age, height, weight, body fat; aerobic power; anaerobic power and capacity; and muscle fibre composition. Muscular strength is an area that is still relatively new to investigation in cycling. There does not appear to be any literature on the upper body muscular strength of cyclists.

The characteristics essential for success in elite road or track cycling have been analysed and are known. The characteristics essential to be a successful off-road cyclist are yet to be determined. However, it is likely that similar qualities are required for off-road cycling that are used in road cycling, such as the high aerobic capacity, ability to climb and sprint and the use of sprint power and endurance speed found in track cycling. All three disciplines rely on a specific knowledge of tactics, strategies and skills. During road racing, cyclists are able to recover on long descents or when riding in the bunch which conserves a great deal of energy, whereas off-road cycling is an individual event where there is little or no allowance for recovery.

This study will aid off-road cyclists in identifying the physiological characteristics essential for success in competition and allow them to be tested in a sports specific performance testing mode.

Procedures for the Study
Initial testing of the physical parameters, such as height, weight and body fat will be measured at the University of Canberra, Sports Testing Laboratory or the Australian Institute of Sport, Physiology Laboratory.
The aerobic, anaerobic and muscular strength characteristics will be tested also in the laboratory. The field performance test will be conducted in Canberra forest on an off-road course. The simulated performance test will be conducted in the laboratory with power output and heart rate downloaded from the field test.

Aerobic and anaerobic laboratory testing
Physiological testing in the laboratory will be conducted on an electrically braked cycle ergometer. The typical test duration will be approximately 30 min. The test will start at low intensity workloads and progressively increase every 4 min for 4 stages. After a 4 min rest you will be asked to complete a final workload of 4 min to determine your maximum rate of oxygen consumption ($\dot{V}O_{2max}$) and your anaerobic capacity. During this test, expired air will be collected using a mouthpiece and tubing similar to a snorkel. Blood samples and heart rate will also be measured.

Blood Lactate Sampling
Blood lactate sampling will occur during all testing sessions except for the muscular strength tests. Small drop sized samples of blood will be collected from a fingertip, using a sterile, single-use spring loaded pin, similar to the procedure for diabetics testing their blood sugar levels. The blood sample will be analysed for blood lactic acid concentration.

Heart rate
A Polar heart rate monitor will be used to measure heart rate via telemetry every 5 seconds. A strap will be placed around the chest.

Muscular Strength testing
A Cybex 340 isokinetic dynamometer will be used to measure muscular strength. This will involve a small number of strong muscle contractions, at slow, medium and fast speeds.

Field Performance test
The field test will involve fitting SRM cranks to your mountain bike for the purpose of measuring power output while cycling on a course similar to a competition course. You will complete a pre-determined number of laps according to your gender and training status.

You will be required for six testing sessions. These will be scheduled on separate days. The testing may be fatiguing, but no more strenuous than when training or in competition.

If you have an injury or illness, which prevents you from participating in normal training and competition, you should not participate in this study.

A total time commitment of approximately 10 hours is required.

APPENDIX A.2 Informed Consent Document

Project Title
Aerobic, anaerobic and muscular strength characteristics of off-road cyclists.

Researcher
Kelly Linaker
Masters of Applied Science in Sports Studies (Exercise Physiology)
Telephone 0410 485 845
Email k.linaker@student.canberra.edu.au
Centre for Sports Studies
University of Canberra ACT 2601

Supervisor
Dr Alan D Roberts
Telephone 6201 2931 Facsimile 6201 5403
aroberts@science.canberra.edu.au
Centre for Sports Studies
University of Canberra ACT 2601

This research project has been considered and approved by the University of Canberra Committee for Ethics in Human Research.

As a participant in this research project you will receive a personal performance profile of yourself. You will have the opportunity to be tested at the University of Canberra and the Australian Institute of Sport. You will be tested for aerobic, anaerobic and muscular strength characteristics. Your mountain bike will be fitted with an SRM power crank, which is normally reserved for national/international calibre athletes and you will be tested in the field on a mountain bike course. The data collected will be downloaded to a computer for simulation in the laboratory. Your total time commitment will be approximately 10 hours.

Performance testing conducted in this study will be no more fatiguing than training for or competing in this sport. All test procedures are in common use in sports science. Blood sampling from the fingertip may result in mild bruising. There is medical and first aid support available within the Australian Institute of Sport (Sports Science and Sports Medicine) and the University of Canberra.

You will receive a personal report upon completion of the study, which will include the outcomes of the study. This will assist you in further preparing your training programs. This study will assist off-road cyclists with the identification of the physiological characteristics required to be a successful off-road cyclist and furthermore to design a sports specific performance test protocol for the sport of mountain biking.

Data collected at the University of Canberra and the Australian Institute of Sport will be restricted to the investigators involved in the study and stored securely for a period of 5 years at the University of Canberra and for 7 years at the Australian Institute of Sport, Physiology Laboratory, respectively. After 7 years the data at the AIS will be destroyed or archived to the Australian Sports Commission Archives. Any data published or used for reporting, as a result of this study will be done in an anonymous form.

Your participation is entirely voluntary and you may withdraw at any stage without penalty. Please be sure to ask any questions or queries you may have concerning the project by contacting Kelly Linaker on 6201 2032 or 0410 485 845.

DECLARATION

I have read and understood the information provided about this project. I am not aware of any medical condition which would prevent my participation, and agree to take part in this research.

Signature	Date	Witness