The Physiological and Physical Determinants of Mountain Bike Cross Country Cycling

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CERTIFICATE OF AUTHORSHIP OF THESIS

I hereby certify that the thesis submitted today has no material that has been accepted by the University of Tasmania or any other institution.

For the exception of indicated references, I confirm that I am the sole author of the thesis submitted today for the fulfilment of the Master of Medical Science at the University of Tasmania.

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John Gregory

John Gregory 12/08/ 2002.

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LIST OF ABBREVIATIONS

AnT: Anaerobic threshold

ANOVA: Analysis of variance

AIS: Australian Institute of Sport

ATP: Adenosine triphosphate

ATP-PC: Adenosine triphosphate phosphate creatine

Bla: Blood lactate

BMX: Bicycle motocross

CK: Creatine kinase

CMT: Cycling maximum test

DH: Downhill

E-1 / E-4: Endurance 1 / 4 training zones

F: Female

FDH: Fast downhill

h: Hour

HR: Heart rate

Hb: Haemoglobin

Hct: Haematocrit

HCO_3^-: Bicarbonate ion concentration

Hz: Frequency

IAT: Individual anaerobic threshold

ITT: Individual time trial

Kcal: Kilocalories

kg: Kilogram

kJ: Kilojoule

$km \cdot hr^{-1}$: Kilometres per hour

km: Kilometres

l: Litre

LD: Lactate dehydrogenase

LT: Lactate threshold

P: P-value

PPO: Peak power output

Peak HR: Peak heart rate

PV: Plasma volume

M: Men / Male

Max HR.: Maximum heart rate

min: minute

mL: millilitre

$mmol.l^{-1}$: millimole per litre

mM: millimole per litre

MTB: Mountain bike

MTB XC: Mountain bike cross-country

N·m: newton-metre

OT: Open track

REC: Recovery training zone

RPE: Rating of perceived exertion

RPM: Revolutions per minute

S: Second

SD: Standard deviation

SRM: Schoberer rad mess technik

ST: Single track

TDH: Technical downhill

TT: Time trial

TTT: Team time trial

TIS: Tasmanian Institute of Sport

µl: Micro litre

UCI: International Cycling Union

$\dot{V}O_2max$: Maximal oxygen uptake

$\dot{V}O_2$: Sub maximal oxygen Consumption

W: Watts

$W \cdot kg^{-1}$: Watts per kilogram

WC: World cup

WT: World title

XC: Cross-country

%: Percentage

±: Plus or minus

°C: degree celsius

GLOSSARY

Anaerobic threshold: The point at which he metabolic demands of exercise can no longer be met by available aerobic sources and at which an increase in anaerobic metabolism occurs, reflected by an increase in blood lactate concentration.

Cadence: The frequency at which the cranks and pedals of a bicycle are rotated per minute.

Concentric muscle contraction: A contraction in which tension is developed throughout a range of movement, so that the muscle shortens and moves a body part.

Cycle ergometer: A stationary cycle with adjustable resistance, used for measuring power output and energy expenditure of a cyclist.

Economy: In human movement the relationship between the amount of work performed at a given load and the energy expended in completing the work.

Fatigue: Reduction in muscle force generating capacity during exercise, which is likely to affect performance.

Gradient: The degree of inclination of a slope, usually expressed as the rise over the run in percentage.

Individual time trial: A cycling discipline that requires the rider to complete a set distance with the winner finishing in the fastest time.

Increment: A predetermined workload interval of set resistance and duration.

Isometric muscle contraction: A contraction in which tension is developed, but there is no shortening of the muscle fibres or change in the angle of the joints.

Individual anaerobic threshold: Is defined as the workload corresponding to the steady state between diffusion of lactate into the blood compartment and maximal elimination from the blood and muscle compartments.

Lactate: Anionic form of lactic acid. A metabolic intermediate and end product of glycolysis, which is used as a substrate at aerobic and anaerobic exercise intensities.

Massed start road racing: A cycling discipline where a large number of riders start at the same time and the object is to be first over the finish line. A road race can last anywhere between 1 to 8 hours and take in a considerable number of kilometres and changes in elevation.

Maximum oxygen uptake: The quantitative measurement of the maximal rate of oxygen extracted from the atmosphere and consumed by the tissues per minute; the highest power of the aerobic system.

Model: A model is a simplified description of a system to assist in calculations and predictions. A mathematical, physical or computer representations that predict outcomes based upon relationships between variables.

Mountain bike: A sturdy bicycle with knobbly tyres and suspension that is ridden off-road.

Mountain bike cross country race: An individual endurance cycling discipline, that is ridden on off road circuits with large variations in vertical ascension and includes technical sections.

Performance: The manner or quality of carrying out a sporting activity.

Peak power output: The highest power output achieved in an incremental maximum cycle test.

Power output: In sport, power output is the ability to transform physical energy into force at a given rate. In cycling power output is measured in watts.

Power to mass: Peak power output derived from a maximum cycle test, divided by the subject's mass. Power to mass is regarded as being critical in describing performance where gravity plays a role in performance.

Sub maximal: Exercise intensities above rest to below maximum.

Terrain: The type of land and gradient of a given area. Terrain types vary considerably on XC race courses.

Training: An exercise programme designed to improve physical fitness in order to prepare the athlete for competition.

Workload: The total amount of work completed in a specified period. Graded exercise tests have multiple workloads.

ABSTRACT

Purpose: The purpose of this investigation was to establish the physical and physiological determinants of mountain bike (MTB) cross-country (XC) cycling, and to elucidate the technique adopted in riding off road. As there is minimal data outlining the sport of XC cycling, the design and results of elite races were documented and analysed. This was undertaken to summarise event information and review technical race characteristics that impact on the performer. These analyses allowed the construction of a XC time trial (TT) course, which was employed to profile the physical and physiological demands of completing it. A model was developed based on test measures, with the purpose of predicting XC performance and validating its production method. The purpose of the final section in this research was to determine if elite XC cyclists perform similarly to competitive riders.

Method: Twenty nine World Cup and Title XC races were documented and averaged for winning time, race ascension, race speed, race duration, mean gradient, % time to 20th place and % of breakdown of technical course content. This established broadly the demands of XC cycling at the highest level and allowed a representative off road course to be constructed.

Laboratory cycle maximum test (CMT) and TT measures were compared to determine which variables best described performance. Eleven experienced male XC cyclists (25.1 ± 4.9 y, 71.4 ± 6.7 kg, $\dot{V}O_2max$ 64.7 ± 8.2 mL·kg^{-1}·min^{-1}) completed CMT, followed by a XC TT (15.52 km, 624 – m elevation gain). CMT values were related to the physiological responses and ride times recorded from the TT. TT power output was measured with

the SRM™ training system, with blood lactate (Bla) and perceived exertion (RPE) taken each lap.

To construct the XC model the TT course was divided into 8 discrete terrain categories, with the relationships between category speed and % of peak power output (PPO) established. The model tested relationships established between CMT and the XC TT by comparing real performances to predicted ones.

Five elite male cyclists (28 ± 3.3 y, 68.8 ± 6.2 kg, $\dot{V}O_2max$ 75.4 ± 2.3 $mL \cdot kg^{-1} \cdot min^{-1}$) completed laboratory testing, whilst three cyclists performed XC TT's (13.8 km, 646-m elevation gain). Power output was measured by the SRM™ training system. TT values were compared to competitive cyclists, which established similar ride patterns.

Results: Race analysis revealed: a duration of 141 ± 11 min. for elite men (M) and 119 ± min. for elite women (W), a race ascension of 1942 ± 245m (M) and 1402 ± 175 (W), an average speed of 21.2 ± 1.7 $km.hr^{-1}$ (M) and 17 ± 1.7 $km.hr^{-1}$ (W) and a mean gradient of 4.11 ± 0.52%. Percentage of fast downhill (DH) (12.8 ± 6.3%), technical DH (9.1 ± 4.1%) and single track (44.9 ± 10%) was measured. Mean gradient in 1999 (4.46 ± 0.36%) was significantly higher ($P<0.05$) than in 1997 (3.99 ± 0.53%) and 1998 (3.91 ± 0.53%)

No differences ($P>0.05$) were observed between the mean XC TT and values at individual anaerobic threshold (IAT) for heart rate (174 ± 7 bpm vs 173 ± 8 bpm) and power output (315 ± 39W vs 309 ± 27W). Significantly higher ($P<0.05$) Bla concentration was observed during the XC TT than calculated at IAT (8.1 $mmol \cdot L^{-1}$ ± 2.1 vs 4.0 ± 1.0 $mmol \cdot L^{-1}$). Significant differences ($P<0.01$) were observed in power output, cadence and speed between TT laps and terrain categories. Strong relationships were established between CMT values and TT performance. Peak power output (PPO) to total mass was strongly correlated (r= -0.93) to XC TT time, whilst PPO was less strong (r= 0.64).

The difference between modelled XC TT time and actual performance time for two subjects was -2.65% and 2.27%, respectively.

Elite XC cyclists showed an ability to sustain a high power output in a lab based TT (362.8 ± 23W) and maintained a high percentage of peak HR (93.3 ± 1.5%). During XC TT's elite cyclists averaged 306.8 ± 14.5W, 68.3 ± 4.3 rpm and maintained 90.7 ± 0.80% of peak HR. For "15-20% Ascent", "10-15% Ascent" and "5-10% Ascent" categories percentage of PPO between elite and competitive cyclists was not different ($P>0.05$) (114.4 ± 8.8% vs 115.1 ± 8.2%; 100.3 ± 7.8% vs 102.2 ± 9.5%; 89.8 ± 7.7% vs 88.5 ± 2.8%). Significantly greater ($P<0.05$) speed and power output was observed between elite and competitive cyclists in seven and six of the eight terrain categories, respectively. Modelling between actual and predicted times revealed small mean differences (4.62% of mean performance time) and median absolute differences (4.67%).

Conclusion: This investigation has established with novel ways the primary determinants of off road cycling, showing that MTB XC places considerable endurance and technique demands on the performer. The nature of a XC course appears to dictate the physical responses observed and techniques adopted. Strong relationships established between test variables relative to mass and XC TT performance indicate the marked influence of gradient in off road cycling. This investigation demonstrates that MTB XC is an intermittent and high intensity cycling discipline, which despite requiring significant technical skill, is dependent on physiological measures related to mass.

LIMITATIONS

1. The subjects were selected on the basis of:
   - Being cyclists who were primarily active in mountain bike events.
   - Being able to comply to the procedures and instructions pre-testing and during the data collection period.
   - Having no injuries or illness that would hinder their performances.
   - Reducing training before and during the testing periods.
2. Blood lactate may not be a true indicator of the conditions within the muscle. It has been suggested that blood lactate reflects the balance between lactate release from the muscle and its uptake from plasma.
3. Some testing methods were undertaken outside with subsequent changes in weather conditions.
4. Lack of testing experience and familiarity with the laboratory testing procedures and equipment for some of the subjects.
5. Accuracy of all measurements was limited to the calibration and consistency of the equipment used.
6. Inability to measure compliance with the pre-test requirements, with regard to diet and training.
7. Subject's judgment in regard to the severity of upper respiratory tract infection and thus their suitability to test.
8. Unfamiliarity with RPE scales and judgment of effort.
9. Unfamiliarity of the test cycle and track.
10. Loss of rhythm due to having to stop every lap for blood lactate and RPE readings.
11. Minor problems during XC time trials (TT) resulting in some loss of time including:

- Loss of chain
- Incorrect direction

- Variation in soil moisture content between trials.

DELIMITATIONS

1. The scope of the study was limited to competitive and elite mountain bike cyclists. Limited inferences can be made with respect to other sports or the general population.
2. Blood samples taken from the fingertip were used to analyse the lactate concentration of the leg muscles.
3. All the subjects tested were male. This was due to subject availability.
4. The Quinton metabolic cart oxygen analyser sampled over a period of 30 s.
5. The YSI lactate analyser was not always calibrated exactly to the lactate standard.
6. Variations in the ambient temperature, barometric pressure, wind strength and humidity varied between field trials.
7. Consistency of the blood lactate sampling and analysis technique throughout the testing period.
8. All subjects were unpaid volunteers.

1 Chapter One – Physiological and Physical Determinants of Mountain Bike Cross–Country Cycling

1.1 Introduction

A mountain bike (MTB) is a robust fat tire bicycle designed to be ridden across rough countryside. The MTB surged into popularity in the 1980's as a recreational vehicle and by the end of the 1990's had sold thousands. Mountain bikes are ridden in competitive races, which include cross-country (XC), downhill (DH) and trials events. Of these different disciplines the XC race is considered to be the blue ribbon event and is the focus of this research.

Mountain bike XC cycling has become a popular leisure time activity and professional sport over the past 10 years. Off road racing begins with a mass starts and is contested on a circuit that is made up of a variety of terrain including forest road, narrow dirt trails and numerous hills. During a MTB XC race the surface conditions are not constant with a minimum combination of loose soil and compact ground to be expected. The XC courses often include large vertical changes, placing a reliance on controlled descending and sustained climbing.

In 1994, the International Olympic Committee included a MTB XC event for men and women as a full medal sport for the 1996 Summer Games. The length of the race at the 1996 Atlanta Olympic Games was 48.8 km for men and 30.3 km for women.

There are annual world championships, professional trade XC and DH teams and an international world cup. World Championship titles are held every year and in 1996 and 2000 the sport of MTB XC racing was included in the Atlanta and Sydney Olympic Games, respectively. The World cup MTB XC season begins typically in March and moves between 7-8 different countries over the next 7 months. Points are awarded from 1^{st} – 75^{th} position, with the best of 7 results determining the overall world cup winner. The world cup is thus a competition of the most consistent performer. European championships rank high in difficulty and much prestige is afforded to the National XC title races also.

The sport is credited to have started in the early 1970's when cyclists in Marin County, California, cycled mountain trails on modified 'cruiser' frames. Members of the Mt Tampalais velo club used heavy cycles to descend from the summit of Mt Tampalais. The need for better brakes, stronger frames and the requirement to get back up hills saw developments in the single speed cruiser. Cycles emerged with a rear deraileur, freewheel gears, thumb gear shifters, triple front chain wheels and motorcycle brake levers. From these developments this cycle was given the name 'mountain bike' (Skilbeck, 1998). From 1979 the first production MTB's emerged and the sport and leisure time activity, that is MTB today, was born.

As MTB XC racing is largely individual and lasts up to 2 hours for women and 2:30 for men it can be classified as an endurance sport. Success or failure in off road cycling can be separated by small differences in performance. In order to optimise performance, training is a year-long process that requires national level cyclists to submit themselves to regular physiological testing. Hence the role of sports science in assessing and researching XC performance is an important one.

According to Martin (1997) XC cyclists claim that greater levels of skill are required to cycle off road, whilst the training principles from road racing and techniques from cyclo-cross have guided XC cycling. The vast majority of research in cycling has concentrated on road cycling (Lucia *et al.* 1998, 1999, 2001; Fernandez-Garcia *et al.* 2000; Padilla *et al.* 1999, 2000), whilst relatively little research has been conducted on identifying the physiological and physical determinants of off road cycling. It is the aim of this research to fill this knowledge gap. This research will measure key physiological and physical measures of a heterogenous group of XC cyclists in a laboratory and field setting. From these measurements XC cycling may be profiled and the parameters that determine performance elucidated. Furthermore, the validity of the determinants of XC cycling can be tested by the construction of a model.

This investigation attempts to answer the following questions:

1. What are the broad demands of MTB XC racing and course design? This question was posed to gain an insight into distinctive demands of the off road event. If key event information such as race duration and course gradient are known, then it may be possible to better understand the physiological requirements of the off road event.

2. Which physical and physiological test measures best describe MTB XC performance? Given that MTB XC is an endurance sport this question is integral in elucidating the determinants of off road cycling. For coaches to construct optimal training programmes and/or identify talent, they must have access to

essential qualities of performance. An improved understanding of XC cycling will allow specific assessment protocols and performance analysis to be implemented.

3. What is the contribution of neuromuscular aspects such as skill to XC cycling? The contribution of skill in XC cycling is not fully understood and on casual inspection bike handling requirements are much greater than in road racing. Thus, if the importance of technique can be quantified then skill training may be better prescribed.

4. Can MTB XC performance be modelled based on laboratory test results accurately? This question will test the validity of the primary determinants of XC performance. Furthermore, modelling will determine which physiological measures contribute to the performance specialty. Whilst modelling has been applied to many sports, no research has attempted to include XC cycling.

5. Does XC cycling force a variable pattern of effort and recovery? Given the variation of terrain that is encountered in XC cycling it's of interest to determine if power output is different to road TT's. Insight into these demands could improve race tactics and may reduce time losses.

The benefits that may arise from this research are that training programmes may be more precisely applied and that improved talent identification can result. Using this information coaches should identify immerging talent and establish minimum physiological norms. It is proposed that a model of MTB XC performance may convert rider's current test results into lap times and compare those to elite cyclists with better physiology. Hence, the coach should be able to relate changes in a cyclists test results to performance in a more scientific way. Outcomes from this research may provide a greater insight in to the unique demands of MTB XC cycling and thus, optimise preparation of the athlete.

Despite its popularity as a leisure activity and its coming of age as an Olympic sport XC cycling has not been extensively profiled from a sports science perspective. Clinical reports describe injury rates of off-road cyclists (Chow *et al.* 1993; Kronisch and Rubin 1994), whilst the effect of suspension systems on performance has been established (Seifert *et al* 1997; Mac Rea *et al.* 2000). Furthermore, Wilber *et al.* (1997) documented the physiological test results of national level XC cyclists. Some data exists on XC cycling, however, very little information is available on the discipline directly. It is the intention of this research to profile the MTB XC cycling and improve the understanding of this discipline.

The following review of literature discusses research related to cycling physiology, identifies the determinants of success in road cycling, outlines the unique demands of XC cycling and discusses test measures that may relate closely to off road cycling. It is the traditional measures of physiological effort including; blood lactate response to exercise, HR response, perceived exertion, dehydration and more recently measurement of power output that forms the basis of this review. In addition, markers of muscular breakdown will be discussed, as it's important to quantify the stress and recovery associated with XC cycling. Given the considerable amount of climbing and event duration observed in off road racing it is proposed that relative physiological measures may more closely describe MTB XC performance than absolute values.

1.2 Hypothesis

Relative physiological test measures will describe MTB XC performance more accurately than absolute values currently used in road cycling and the contribution of technique will be integral to performance.

2 Chapter Two – Literature Review

2.1 History of cycling

The bicycle is a lightweight human powered vehicle consisting of a frame, two wheels, one behind the other, handles for steering, a saddle and pedals to drive the rear wheel. The modern MTB is similar to this basic design, with the exception of purpose built suspension and larger tyre diameter to deal with unpaved surfaces.

The first bicycles weighed between 30 and 50 kilograms and as a result proved to be no faster than running. In 1869 the first competitive cycling event was held as a road race in France, with the winner completing 34 kilometres at an average speed of 10.8 km.hr (Faria, 1984). It appears that the initial purpose of designing a better bicycle was to make human movement faster and more efficient and with the advent of gears and the pneumatic tyre, cycling became a low energy cost form of transport. Walking costs approximately 3.138 kilojoules (kJ) per kilometre, whereas cycling requires only 0.627 $kJ \cdot km^{-1}$ (Faria, 1984). Thus, the bicycle not only became a popular and practical means of transport, but a vehicle for athletic use also.

Following World War II motorisation swept the industrialised countries and although the bicycle was still widely used in Europe and Asia, as it is today, its widespread use declined. Interest in the bicycle has been renewed in the past two decades in western countries as the physical and ecological benefits of cycling have been recognised. According to Kyle (1996) the resurgence in the interest in cycling has been largely due to the appeal of the MTB.

The sport of cycling has grown to include MTB in the last 20 years, whilst other disciplines in competitive cycling have a longer history. Off road training programmes have been largely based on information from existing cycling disciplines.

2.2 Cycling disciplines

There are few sports that are as varied and physiologically challenging as competitive cycling, with races ranging from a 200 m match race sprint that lasts approximately 10 s, to the gruelling demands of multiple day (>20 d) tour racing.

There are 5 cycling disciplines, which include road and track racing, bicycle motocross, Cyclo-cross and MTB. Within each cycling discipline there are different formats and lengths of races that require varied technique, tactics, skills and physical fitness for success (Table 2.1). According to Kent (1994) physical fitness includes the components of cardiovascular fitness, body composition, flexibility, muscular endurance and strength, whilst skill components relate to agility, balance and reaction time.

Table 2.1. Outline of cycling disciplines in regard to event duration and energy systems.

Discipline	Format	Duration min s	Energy System
BMX	Dirt track	<2	ATP-PC - Glycolytic.
MTB XC	Dirt trail	>120	Aerobic - Glycolytic
Track racing	Track	10 s - >60	ATP-PC - Aerobic - Glycolytic
Road racing	Sealed road	>60	Aerobic - Glycolytic - ATP-PC
Cyclo-cross	Dirt track	~60	Aerobic - Glycolytic - ATP-PC

BMX, Bicycle moto-cross; MTB XC, Mountain bike cross-countryATP-PC, Adenosine triphosphate and phosphate creatine.

2.2.1 Road cycling

Road cycling is of primary interest in this review, as much research exists on this discipline, which will form the basis of comparison and reference to XC cycling. Road cycling is the oldest type of bicycle competition, requiring excellent cardiovascular fitness and tactics to be competitive (Burke, 1980). Many MTB cyclists participate in road events and make extensive use of road training to prepare for off road events (personal communication, Andi Seeli). Road training is attractive to the MTB cyclist as it is convenient, permits active recovery and allows exercise intensity to be more precisely regulated compared to off-road cycling. There are several formats in road racing, including multiple day events, one-day races, TT's and criteriums. The Tour de France is the most famous multiple day race lasting approximately 20 days, whereas one-day road races can span anywhere from 40 to 300 kilometres in a single day. Typical one-day races include the Olympic road race, the World Championships and European classics such as Paris-Roubaix; these events can have up to 220 participants.

In an ITT the rider cycles over a set distance alone, with the cyclists being ranked on the basis of their completion time; whilst TTs are conducted over all types of terrain the majority of events are conducted on relatively flat courses.

In road racing elite cyclists have excellent cardio-respiratory fitness (VO_2max), high peak power output (PPO), favourable power to mass and low body fat (Burke, 1980; Coyle *et al.* 1988, 1991; Lucia *et al.* 1998, 1999, 2001; Padilla *et al.* 1999, 2000). Off road cyclists participate in all forms of road racing, developing endurance, power and skill. The worlds top XC cyclist's portion there time approximately 70% on road and 30% off-road (personal communication, Andi Seeli). To develop the qualities needed in road racing demands large volumes of training and comprehensive planning. Both tradition and increasingly scientific research has guided road race training, which in turn influences preparation of MTB XC cyclists also. A summary of road cycling disciplines can be seen in table 2.2.

Table 2.2. Outline of road cycling disciplines.

Discipline	Length (km)	Format	Duration (min)
Road race	40 - 300	Massed start	60 - 450
Criterium	40 - 100	Massed start	50 - 130
ITT	5 - 80	Individual	6 - 105
TTT	40 - 100	Team	45 - 120
Tour racing	250 - 5000	Massed start	360 – 7000

ITT, Individual time trial; TTT, Teams time trial.

2.2.2 Cyclo-cross

Of all the cycling disciplines cyclo-cross resemble MTB XC racing closely. cyclo-cross is conducted primarily in western Europe and North America for a short winter racing period, culminating with the World titles. Cyclo-cross is raced over multiple laps of a cross-country course on modified off-road cycles, with cyclists being forced to dismount and run over man made barriers and up hills. Ground surfaces are often wet, muddy or frozen. The race duration is short at approximately 1 h. Cyclo-cross racing is performed at high relative work rates (Hansen, 1996), involves short explosive climbs, and periods of running.

Cyclo-cross races include natural pauses followed by periods of power output far above peak aerobic values that appear to be maintained for brief periods of time (<2 min)

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(Hansen *et al.*1996). Based on these results, cyclo-cross may be described as a high intensity and variable load cycling discipline that has considerable skill demands. Similar HR intensity has been reported in MTB XC racing, however, the influence of terrain on power output has not been fully established.

2.2.3 Mountain bike

The distinctive features of a MTB compared to a road cycles include wider tyres, a smaller but stronger diamond frame, greater range of gears, up to as many as 27, powerful brakes and suspension forks. Typically a MTB has suspension and wider knobbly tyres so as to negotiate rocks, water and varying unpaved surfaces.

The XC race requires the cyclist to be self sufficient in finishing the race with minimal outside assistance, although food, drinks and eyewear can be handed up to the rider during a race. In the case of a mechanical breakdown or puncture, XC cyclists have to make their own repairs. Cross-country racing is an all-round endurance test that includes bike handling skills, physical fitness and mental toughness, visual acuity, pacing and increasingly tactical decision-making. The MTB XC race begins with a start en mass, which soon sees cyclists separated into small groups of 2-3 or alone for the duration of the event. Races are conducted on closed circuits of between 3 - 15 kilometres in length and include technical sections of climbing and descending. It is not essential that mountains are included, as almost any tract of land can be used, provided it is ecologically stable to do so. Races vary between 2:00 – 3:00 h for elite men and between 1:30 – 2:00 h for elite women. The duration of MTB XC races are longer than the longest Tour de France ITT's (< 2.00 h), but are shorter than the road race classics like Paris – Roubaix (~6.5 h) by approximately two thirds.

The MTB XC event is longer (~1 h) than the traditional 40km ITT, but shorter than professional road races by approximately 50%. Thus XC events require a high effort of a largely individual and aerobic nature. Off road racing is sometimes regarded as resembling a road ITT, however the considerable skill requirements, surface variation, narrow tracks, large vertical changes and event duration, makes XC unique in cycling. Off road cyclists compete with high average heart rate (HR) values that coincide with individual anaerobic threshold (IAT) indicating the endurance nature of the event (Lee, 1998; Martin, 1997, Schoberer, 1998). The IAT is defined as the workload corresponding to the steady state between diffusion of lactate into the blood compartment and maximal elimination from the blood and muscle compartments (Stegmann and Kindermann, 1982). In simple terms a race requires completing a series of laps at the fastest possible speed. The cyclist must overcome the resistance of dirt and mud, race over large changes in elevation, handle their bike through technical sections and deal with environmental stressors. The average speed of most elite MTB XC events are approximately half that of mass start road races, however, the effort per minute is reported to be greater (Martin, 1997; Seifert *et al.* 1997; Lee, 1998; Schoberer, 1998).

To ride quickly and efficiently over varied off-road terrain places distinctive physiological and physical demands on the XC cyclist. Overall HR is high and constant during a XC race, despite substantial changes in terrain type (Lee, 1998; Seifert *et al.* 1997: Mac Crea *et al.* 2000). The XC cyclist will reduce the size of the gear to climb hills, free wheel on some descents and then engage a larger gear on the flats. This effect produces a relatively smooth and elevated HR response, as the descending portions offer relatively brief periods of relief and hence only minor decreases in HR are observed. In contrast power output fluctuates greatly in response to the variations in the course direction and profile (Schoberer, 1998). The XC event requires considerable endurance and skill, but appears to have different physical demands to a 40km road ITT, which is largely ridden at constant power output (Martin, 1999; Schoberer, 1998; Padilla *et al.* 2000).

The length of a MTB XC race is generally shorter and ridden at speeds lower than seen in a massed start road race. Martin (1997) compared the demands of a massed start road race and XC event and found that the road race was 90 minutes longer and had an average speed of 37.6 km.hr, compared to 21.2 km.hr for the off road event. More recently the 20 day 1999 Tour de France was completed by the winner at an average speed of 40.2 km.hr, whilst in comparison the 13 day 1998 MTB Tour de France returned an average speed of 20.8 km.hr (UCI, 1999). The lower event speeds are perhaps explained by the climbing demands, increased surface resistance and a minimal drafting effect and hence, sharing of the workload in XC cycling.

Despite being an Olympic sport, there is very little research on XC cycling. According to Martin (1997) anecdotal claims are that MTB cyclists have greater upper body strength and more leg power than their road cycling counterparts, however, these assumptions are yet to be proven. The purpose of this thesis is to investigate MTB XC cycling and to identify and quantify the demands of this discipline. However, firstly it's necessary to review and compare existing cycling research to MTB XC.

2.3 Road racing analysis

Road cyclists include high training volumes in their training programmes, often in excess of 35,000 km per season (Jeukendrup *et al.* 2000). The goal of endurance training is to elicit cellular and systemic adaptations to allow the body to function at a higher level of performance. However, road events are not ridden at a constant rate, requiring high overall endurance and an ability to vary effort also.

2.3.1 Variation of effort.

Massed start road cyclists generally start races at an easy pace and then plan aggressive periods to be amongst the top riders at the finish or help team-mates throughout the event. During the course of a road race rapid accelerations are frequent, which in turn places unique physiological demands on the cyclist. According to Palmer *et al.* (1994) massed start road racing produces responses to exercise that vary randomly in intensity, whereas the ITT maintains a more steady state exercise response (Martin, 1999; Padilla *et al.* 2000). Martin's (1997) comparison between a XC and road cyclist competing in off road and massed start events found greater variation of power output in the road event. From that study it appears that massed start road events produce a different pattern of power output than does a XC event. Furthermore, it seems off-road cycling may differ to the ITT event also. The following analyses of road events attempts to further develop the differences and similarities between road and MTB XC events.

Massed start road races can be regarded as a series of efforts, with variations in speed, within an overall time frame of many hours. In the course of a road event changes in terrain, wind direction, positioning and tactics causes speed to vary considerably (Fernandez-Garcia, 2000). Moreover, greater changes in power output and HR are observed in massed start road cycling than in XC events (Lee, 1998; Martin, 1997; Schoberer, 1998). In the course of a road race it is possible to recover and take advantage of sitting in a slipstream, which may see power output fall to low levels (<100W), but in turn the rider may produce very high power output (>1000W) during an all out effort (personal communication, Garry Palmer). On average massed start road racing may be regarded as being less intense and more variable in power output, HR and speed compared to a steady state sport such as distance running (Palmer *et al.* 1994; Lucia *et al.* 2000; Padilla *et al.* 2001). On inspection massed start road events appear to produce a lower overall effort than is seen in XC racing. Furthermore the amplitude of power output and HR appears to be greater in massed start road events also.

2.3.2 Heart rate variation in road events

Due to the ease of measurement HR is routinely used in many test and field settings with endurance cyclists, (Boulay, 1995; Lucia *et al.* 1999, 2000; Padilla *et al.* 1999, 2000). Astrand and Rodahl (1986) claim that HR is closely related to cardiac output and oxygen consumption and therefore quantifies the whole body effort during aerobic exercise. Given the cyclist is well hydrated, has refrained from caffeine or other stimulants and is not unduly fatigued, then HR is a reliable indicator of overall effort (Boulay, 1995). Coaches routinely use HR to prescribe and monitor exercise intensity in track, road and MTB XC cycling. According to Palmer *et al.* (1994) national level road cyclists maintained between 78.6 ± 8.9% of peak HR during a massed start event, whilst Lee reports that XC cyclists averaged 88 ± 3% of peak HR during a 2 hour XC race. From this information it is observed that the work rate demands of off road cycling are greater per minute than seen in a massed start road event.

It is without doubt that both massed start and ITT racing is both physiologically and psychologically demanding. What has been unclear until recently is how cyclists respond in different ways during these events. In research by Palmer *et al.* (1994) seven well-trained cyclists wore HR monitors for the duration of a 4-day road stage race, which included 2 mass start and 2 ITT stages. Markedly different HR responses were reported for both the ITT and massed start stages. During the ITT stages cyclists produced near maximal efforts from the start attaining 91.1 ± 2.5% and 93.2 ± 4.7% of peak HR for the 5 and 16 kilometre ITT duration, respectively.

Maintenance of a high percentage of peak HR has also been reported in longer ITT events, with observations from elite road riders during 40 to 50 kilometre ITT's (Hoogeveen *et al.* 1999; Padilla *et al* 2000). Similar mean HR values have been cited by Kinderman *et al.* (1979) for cross-country skiers, Lehman *et al.* (1983) in marathon runners and by Stegman and Kinderman (1983) in rowers. It appears that road ITT event sees a sustained and high percentage of peak HR (Table 2.3), as is the case in other steady state endurance sports.

Table 2.3. Mean percentage of peak heart rate for ITT events, ergometer trials and cyclo-cross racing. Values are means (± SD).

Research	Conditions	% HR Maximum
Coyle *et al.* (1991) n=14	60 min. Lab TT	87.2 ± 3.3
Palmer *et al.* (1994) n=7	5.5 km hill TT	91.1 ± 2.5
Palmer *et al.* (1994) n=7	16 km ITT	93.2 ± 4.7
Hansen *et al.* (1996) n=3	60 min. Cyclo-cross race	91.1 ± 2.5
Lindsay *et al.* (1996) n=8	40 km Lab TT	91.6 ± 3.1
Hoogeveen *et al.* (1999) n=14	40 km ITT	90.1 ± 2.4
Padilla *et al.* (2000) n= 18	28 ± 8.6 km ITT	85 ± 5

ITT, Individual time trial; TT, Time trial; n, Number of subjects; km, Kilometres; min, Minutes.

During mass start road events large changes in HR frequency are observed compared to the consistent values seen in ITT's. According to Palmer *et al.* (1994) the mean HR during the course of an 110km road race was 81.9 ± 9.6% of peak HR. Whereas Padilla and co-workers (2001) recently report that mean percentage of peak HR during flat (51 ± 7%) and mountainous (61 ± 5%) races in professional cyclists was lower. Despite a lower average HR in a massed start road race, a greater distribution in HR response is apparent when compared to an ITT. A cyclist may reach the top of a hill with near peak HR, or conversely negotiate a long descent where HR may fall to <100 bpm. Outside of long hills, where the task stays relative constant, massed start road events appear to have little in common with the work demands of MTB XC.

It is well documented that performing ITT's sees cyclists work at a high percentage of peak HR. The demands of the ITT mean that training is undertaken to sustain and improve power output at transition thresholds and above, whereas in road racing the cyclist is required to vary power output and HR response more markedly. Variations in power output are called for that may see very high work rates followed by relatively easy periods. On average the HR response is lower in massed start events as intensity is often influenced by factors outside of the cyclist's control, whereas the HR response is more predictable in ITT events. The average HR response to a MTB XC race shows similarities to the ITT event, in that it remains elevated at a high percentage of peak HR for the duration of the event or trial (Seifert *et al.*1997; Martin 1997; Lee, 1998; Schoberer, 1998; Mac Rea *et al.* 2000). This effect is apparent despite considerable differences encountered in terrain type in a XC race.

2.4 Heart rate response in cross-country cycling

It is established that during a MTB XC race that high average HR's are maintained. The HR response during a XC event is probably dependent on the race duration, tactics and the course profile of the event. According to Martin (1997) a single MTB XC cyclist averaged 88 ± 8.8% of peak HR during a 2 hour race, whilst Lee (1998) reports, from his investigation into the HR response of 8 national class MTB cyclists during a three day MTB Tour, a mean HR intensity of 88.6 ± 2.3% (Table 2.4). Furthermore, according to Lee (1998) the mean relative VO_2max of the group was high at 74.0 ± 2.3 $mL \cdot kg \cdot min^{-1}$, which is comparable to values obtained from US national XC cyclists (Wilber *et al.* 1997).

In national class XC cyclists a high mean HR is observed during the course of an event. This outcome is not surprising, as a XC race requires the highest possible effort paced over its duration. Further analysis of XC events reveals that although the mean HR is high, the distribution of the HR response is greater than seen in an ITT, but less varied than a massed start road race (Martin, 1997 n=1; Schoberer, 1998 n=2) (Figure 2.1). Despite the low subject numbers in these studies, it may be that DH and technical sections oblige the cyclist to reduce effort, causing HR to fall. It appears that the off road event sees a high mean HR, but the range in the HR response may be greater than more steady state events such as the ITT. Further analysis of XC events with greater subject numbers should confirm the findings of these investigations.

Table 2.4. Average percentage of peak heart rate for MTB XC events, XC time trials and a single Cyclo cross event. Values are means (± SD).

Research	Event and Duration (km)	% HR Peak
Lee (1998) n=8	30km, 39km XC, 20km XC CRT	88.6 ± 2.3
Martin (1997) n=1	39 km XC	88 ± 8.8
Seifert *et al.* (1997) n=7	10.4 km XC TT	93.1 ± 7
Hansen *et al.* (1996) n=3	32km CC	91 ± 2.5

n, number of subjects in the research; XC, Cross country; CRT, criterium; TT, Time trial; CC, Cyclo-cross; km, Kilometres.

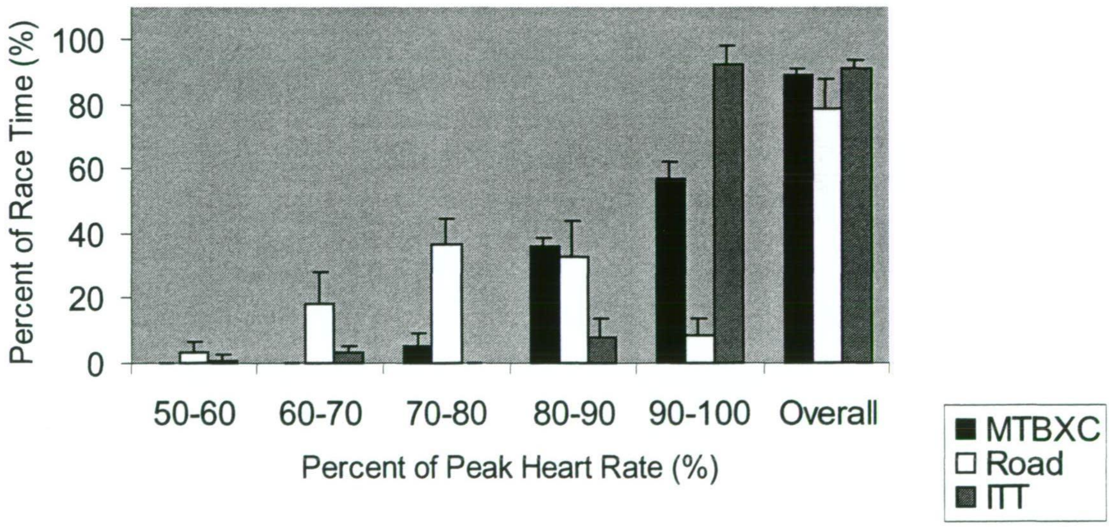

Figure 2.1. Distribution of percentage of peak HR during a 105km massed start road race, a 16km flat ITT and a 44km MTB XC race. Values are means (± SD). Redrawn from data taken from Martin (1997) and Lee (1998).

2.5 Energy systems in cross-country cycling

A fundamental relationship exists between exercise intensity and duration. As a race becomes longer exercise intensity falls and the predominant energy system is aerobic. Hence, a 2.5 h XC race would require a considerable contribution from the aerobic energy system; however the pattern of power output appears to be less steady state than traditional endurance sports such as distance running. When comparing the documentation of the energy requirements of different cycling events, some assumptions about the energy contributions in a XC race maybe possible.

It can be observed in table 2.5 that the 100 km teams time trial (TTT) requires approximately 2% energy contribution from glycolytic sources, with the remainder coming from the aerobic energy system. The TTT entails cyclists leading at the head of the pack for 150-200m at a time, returning to the back of the group to take advantage of the slipstream, before appearing at the front again. Hence, cyclists make variable efforts between working on the front and returning to the slipstream within an overall time frame of approximately 2 h. This pattern of variable loading may be similar in XC cycling (Martin 1999). Off road cycling may see a greater reliance on glycolytic energy sources, due to the highly variable loading pattern of the event, than the time/intensity relationship suggests alone. Furthermore, performing in 20-40km TT's (30min - 1 h) may utilise ~2.5% from the glycolytic sources (Table 2.5), but see significant elevation of blood lactate concentration (~7.0 mM) (Coyle *et al.* 1991; Nichols *et al.* 1997). Similarly, during the first hour of an off road event the blood lactate concentrations are expected to be above transition thresholds. Although the contribution of the energy systems to XC cycling remains to be quantified, it is postulated that a power output reserve (anaerobic capacity) may be important in the need to negotiate obstacles and climbs in the XC event. While the aerobic system will probably provide the majority of the energy needs in off road cycling, the contribution of the glycolytic energy system may be greater than Table 2.5 suggests.

Table 2.5. Summary of the cycling disciplines and approximate estimates of the percentage contribution of the energy systems to performance.

Event	Range of Event Duration	ATP-PC System (%)	Lactate System (%)	Aerobic System (%)
Road Events	hr.min.			
150km Road Race	3:55 - 4:05	-	1	99
100km Criterium	2:05 - 2:10	-	2	98
100km TTT	2:05 - 2:10	-	2	98
40km ITT	0:52 - 0:60	-	2.5	97.5
40km Criterium	0:50 - 0:60	1	3	96
Track Events	min s.			
16km Points Race	20:00 - 25:00	1	3	96
4000m Individual Pursuit	4:20 - 4:30	1	15	84
1000m Kilometre	0:59 - 1:05	5 -7	47	45
200m Match Sprints	0:06 - 0:10	55 - 30	45 - 70	-

ITT, Individual time trial; TTT, Team time trial; m, Metre; hr, Hour; min, minute; s, Second; km, Kilometre. (Data taken from Gore 2000 and Craig *et al.* 1993).

The individual nature and length of the event would appear to place the primary demand on the aerobic energy system, with an effect on the cardio-vascular system consistent with ITT events.

2.6 Physiological and physical determinants of endurance cycling

The endurance and power output demands of XC cycling requires and efficient oxygen and nutrient delivery system. Hence, it is important to identify those physical and physiological variables from existing research that may relate to off road cycling also. These variables include: maximum aerobic power ($\dot{V}O_2max$), transition thresholds, peak power output (PPO), power to mass and height, body mass and body type (anthropometry). The following sections will address the key physiological and physical parameters in the cycling literature, as they relate to the off raod cyclist. It is documented that differences in key physiological and physical measures relate closely to levels of performance (Coyle *et al.* 1991; Lucia *et al.* 1998). Thus, it's of interest not only to determine those measures that may describe XC performance, but to discuss the possible effect of changes in these measures on performance also.

2.6.1 Anthropometry

The physique of an athlete is considered to be an important determinant of success in many sports. To the observer it clear that elite XC cyclists tend to be similar in size and mass to elite road uphill specialists. According to Foley *et al.* (1989) there is in elite sport the tendency for individuals to choose events to which they are anthropometrically best suited. Anthropometry is the study of quantifying human physique status and involves measurement of body parts and dimensions (Mc Ardle *et al.* 1991). In a study of Olympic cyclists Foley *et al.* (1989) concluded that there is a decrease in muscularity and an increase in linearity as the duration of the event increases. Hence, track cyclists are generally categorised as being more muscular, whilst road cyclists tend to have a more linear body types (Foley *et al.* 1989). Body type may be an important determinant of success in XC cycling as certain types are observed at elite levels.

2.6.2 Body mass

In many sports, there is a clear advantage to individuals with a particular body size and mass. Cycling is a complex sport in which many variables affect performance, but body size and mass appears to have a significant impact. To the casual observer, it is apparent in endurance running that the successful athletes are smaller than the average person, whereas in XC skiing it has been found that elite performers are larger and heavier than the average person (Bergh *et al.* 1992). Differences in size, mass and performance have also been documented in running and rowing (Bergh *et al.* 1992; Secher and Vaage 1983), whilst trends in body size and mass are apparent within the discipline of road cycling also (Padilla *et al.* 1999). At the elite level training probably has an impact on body type. However in Tanaka and co-workers (1993) study on competitive cyclists, a low percentage of body fat was recorded (~6.6 – 7.3%) despite moderate values for $\dot{V}O_2max$ (63.5 - 65 $mL \cdot kg^{-1} \cdot min^{-1}$). It is well documented that energy expenditure is influenced by differences in body size, event duration and exercise intensity (Mc Ardle *et al.* 1991). Changes in body mass and size impact on energy expenditure and economy and thus, performance also.

2.6.2.1 Body mass and climbing

Along with air resistance gravity becomes a strong contributor to the energy cost when climbing hills whilst cycling. When a cyclist climbs uphill the force of gravity becomes the greater cost to forward movement, whereas air resistance comprises only a small portion of the forces opposing the cyclist. According to Swain (1996) gravity is directly proportional to mass, so cyclists must provide the same amount of energy relative to their own body mass plus the mass of the cycle. This puts the heavier cyclist at a disadvantage, as energy availability ($\dot{V}O_2$ expressed as $mL \cdot kg^{-1} \cdot min^{-1}$) is not proportional to body mass.

According to Stovall *et al.* (1993) cyclist who participated in the 1992 Tour du Pont were weighed and their times in different stages compared. On the hilliest stages lighter riders performed significantly ($P<0.05$) better than their heavier rivals (Stovall *et al.* 1993). Whilst according to Swain *et al.* (1994) a typical 79.5 kg cyclist might expect to finish a 40km ITT on average 4 minutes faster than a 63.6 kg cyclist. It is anticipated in elite XC racing that the smaller performer should have an advantage and explain the finding that elite male XC cyclist's mass is similar to uphill road specialists (Padilla *et al.* 1999; Lucia *et al.* 2000). This outcome is expected, as the climbing demands of XC cycling would appear to favour low body mass and high relative values such as power to mass.

2.6.2.2 Body mass of competitive cyclists

Analysis of research on competitive road cyclists reveals that body mass is on average higher than seen in elite road cyclists. It is not known if a similar trend is to be expected in XC cycling, as limited research prevents meaningful comparisons. The purpose of this analysis is to establish values for mass and size from road research and when possible predict and contrast to XC research available. Drabbs and co-workers (1997) report an average mass and height for male competitive road cyclists of 71.5 ± 8.5 kg and 179.4 ± 6.5 cm (n=9), whilst Vrijens *et al.* (1983) found similar values for mean mass and height for 5 male competitive road cyclists, with a mean of 76.3 ± 6.2 kg and 182 ± 7.6 cm. Tanaka *et al.* (1993) conducted a comprehensive study into the physiological characteristics of US competitive cyclists and reported mean values for mass and height for males of 72.9 ± 2.87 and 181.5 ± 1.78 cm (n=11). It appears that the competitive road cyclist has a mass and height that is on average greater than elite male road riders. In Mac Rea *et al.* (2000) research on the effect of suspension systems on uphill cycling, the average height and mass of XC subjects fell within the range reported for competitive road cyclists (Figure 2.2).

2.6.2.3 Body mass of elite cyclists

With regard to elite male road cyclists, considerable information exists. Generally it's observed that elite road cyclists are on average smaller and lighter than the competitive road rider. Garcia-Roves *et al* (1998) conducted a nutritional and test analysis on one of the top ranked professional cycling teams during the Vuelta a Espana. Subjects (n=10) height was 179 ± 4 cm, whereas the mean mass for the group was 66.9 ± 3.7 kg; which is clearly lower than values reported for competitive road cyclists. Furthermore, in a study that tested 25 elite professional cyclists, it was revealed that the average mass and height was 69.2 ± 5.3 kg and 177.1 ± 4.2 cm, respectively (Lucia *et al.* 1998).

Padilla *et al.* (1999) evaluated the test values of professional road cyclists according to the role that the rider specialised in. Padilla and co-workers (1999) found that uphill specialists were lighter (62.4 ± 4.4 vs 76.2 ± 3.2 kg) and less tall (175 ± 7 vs 186 ± 4 cm) than flat terrain specialist. These findings compare with Foley *et al's* (1989) anthropometrical study of cyclists from different events, whereby specialist ITT cyclists had the highest mass (76 ± 2.8 kg) and height (186.3 ± 3.0 cm) of all other categories. It appears that mass and height changes according to cyclist's ability, but may also change in regard to the role they perform also. From the literature, it is observed that elite road cyclists have lower body mass relative to height than the competitive rider (Figure 2.2). It's expected that the elite MTB XC cyclist may conform more closely to professional uphill road specialists.

2.6.2.4 Body mass of elite cross-country cyclists

There is limited information on the mass and size of elite XC cyclists. However, an exception to this is a comparative study between national road and XC cyclists by Wilber *et al.* (1997). According to Wilber *et al* (1997) a mean mass of 71.5 ± 7.8 kg and height of 176 ± 7 cm was reported for a group of 10 male XC cyclists, whilst in a study by Lee (1998) a group of national level XC cyclists returned an average mass of 67 ± 4.5 kg and height of 177.2 ± 4.2 cm. From the limited research it's difficult to compare elite XC cyclists to their road counterparts. However, an investigation by the author of the top 10 men and top 6 women at the1999 Sydney XC World Cup competition, revealed that the mean mass was 64.2 ± 7 kg for men and 52.9 ± 4.3 kg for women. This finding puts the male XC cyclists below the average mass of elite road cyclists and interestingly compares with elite uphill road specialists.

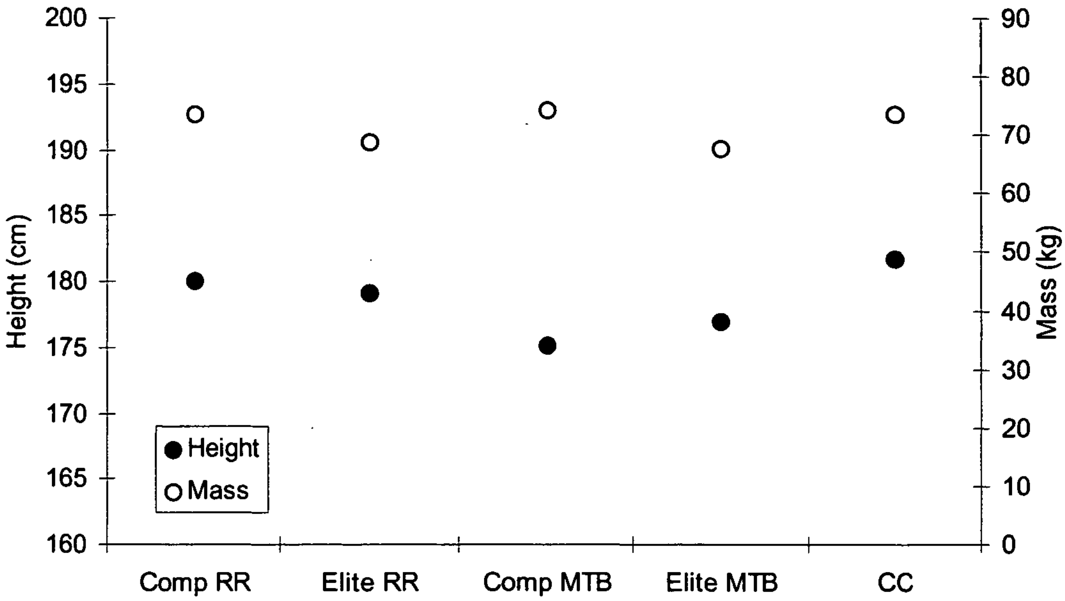

Figure 2.2. Summary of male height and mass for different cycling categories. Values are grand weighted means. Comp, Competitive; RR, Road race cyclist; MTB, Mountain bike cross-country; CC, Cyclo-cross. (Reference data is found in appendix A)

2.6.2.5 Effect of body size and $\dot{V}O_2max$ on climbing

The most common method of determining the total amount of energy an aerobic athlete can produce is via maximal oxygen uptake ($\dot{V}O_2max$). $\dot{V}O_2max$ is proportional to surface area and gives an impressive advantage to smaller endurance athletes when expressed per kilogram of body mass. The smaller cyclist has a greater amount of relative energy (O_2) and is thus favoured in hill climbing. This is seen in road and XC cycling, whereby smaller cyclists generally excel on hills. An analysis of the results of a major road tour confirms, in part, the observation that low mass is an important determinant when ascending in massed start road racing. Cyclists who participated in the 1992 Tour du Pont were weighed and their race times in different stages compared. On the hilliest stages the cyclists with a mean mass of 63.6 kg completed the race 10 minutes faster than a cyclist with a mean mass of 79.54 kg (Stovall *et al.* 1993). It is hardly surprising that the steepest XC races see the lighter cyclists place proportionately better than their heavier counterparts. Generally it can be said that the smaller cyclist will have an advantage in hill climbing and this is related to relative $\dot{V}O_2max$ and body size.

It appears that elite male MTB XC cyclists compare in size and mass to uphill professional road cyclists, reported by other authors (Padilla *et al.*1999; Lucia *et al.* 2001). Elite XC cyclists may be attracted to the discipline of XC racing in a similar way as uphill road cyclists.

2.6.3 Maximal aerobic power ($\dot{V}O_2max$)

Generally it is accepted that as $\dot{V}O_2max$ increases so too does athletic performance (Astrand and Rodahl, 1996). Furthermore, in summarising athletic populations $\dot{V}O_2max$ has been used as a standard measure of athletic level and therefore useful in categorising groups of athletes. Thus, $\dot{V}O_2max$ provides a quantitative statement about a cyclist's capacity to produce aerobic energy and influence performance also. As $\dot{V}O_2max$ is still regarded as an integral determinant of cycling success, its consideration in regard to MTB XC cyclists and performance is important.

Maximal aerobic power has been tested and used traditionally as a measure and indicator of endurance performance and is regarded as a strong determinant of performance in groups of athletes with divergent talent (Barbeau *et al.* 1993). Whereas Palmer *et al.* (1996) claims that $\dot{V}O_2max$ is the most important physiological test measure in endurance performance, as it reflects the ability of the central circulation to transport oxygen. This is assumed as $\dot{V}O_2max$ sets the limit of aerobic energy available to the athlete. Foster *et al.* (1975) supports this concept with his finding of a direct relationship between performance ability of competitive cyclists and $\dot{V}O_2max$. A cycling coach can make some conclusions as to the level and potential of a cyclist based on $\dot{V}O_2max$ and it is unlikely that a prospective elite XC cyclist will succeed without a minimum $\dot{V}O_2max$. Thus, VO_2max may be regarded as a good discriminator between population groups and explain, in part, differences in performance also.

2.6.3.1 Maximum oxygen uptake of competitive cyclists

As minimal reference data is available on XC cycling comparisons and predictions in relation to existing road cycling research is necessary. In a study on competitive road cyclists, Vrijens *et al.* (1983) reported mean absolute values for $\dot{V}O_2max$ of 4.79 $l \cdot min^{-1}$ (range 4.44 - 5.14 $l \cdot min^{-1}$) and an average relative value of 62.7 $mL \cdot kg^{-1} \cdot min^{-1}$ (55.7 - 67 $mL \cdot kg^{-1} \cdot min^{-1}$). Furthermore, in Tanaka and co-workers (1993) investigation on the physiological profile of category 3 cyclists, mean $\dot{V}O_2max$ was 64.98 $mL \cdot kg^{-1} \cdot min^{-1}$. On average, competitive road cyclist's relative aerobic power falls approximately at 60 $mL \cdot kg^{-1} \cdot min^{-1}$. With regards to competitive MTB XC, Berry *et al.* (1993) and Mac Rea *et al.* (2000) report average values for relative $\dot{V}O_2max$ of 62.8 ± 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$ and 58.4 ± 5.6 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. Research findings suggest the traditional measurement of $\dot{V}O_2max$ is a valid indicator in the assessment of athletic groups, including competitive road and XC cyclists also. Table 2.11 includes a mean value for $\dot{V}O_2max$ of competitive road and XC cyclists.

2.6.3.2 Maximum oxygen uptake of elite cyclists

Elite road cyclist's mean values for $\dot{V}O_2max$ are amongst the highest recorded for endurance athletes. According to Burke (1995) values range for male road cyclist between 75 and 88 $mL \cdot kg^{-1} \cdot min^{-1}$. In moderately and well-trained athletes, with years of continuous aerobic training, improvements in $\dot{V}O_2max$ have been found to be small compared with simultaneous increases in performance (Daniels *et al.* 1978). Aerobic power is related to cycling performance and is typically high in elite performers, but may not be considered as the most important index of fitness as it once was.

Values for $\dot{V}O_2max$ as high as 85 $mL \cdot kg^{-1} \cdot min^{-1}$ or 6.2 $l \cdot min^{-1}$ have been reported in elite road cyclists in Australia, with the average male relative vaue at 76 $mL \cdot kg^{-1} \cdot min^{-1}$ (Pyke, 1991). In Lucia *et al*'s (1999) study on 8 professional road cyclists who participated in the Tour de France, a mean relative $\dot{V}O_2max$ of 74 ± 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$ was recorded, whilst recently mean values were reported for 24 professional road cyclists of 78.8 ± 3.7 $mL \cdot kg^{-1} \cdot min^{-1}$ (Padilla *et al.* 1999). It's clear that elite road cyclists have high relative values for $\dot{V}O_2max$, which are approximately 15% and 6% greater than the competitive and sub elite road categories, respectively (Table 2.6). Clearly it can be seen that a high relative aerobic power is an important determinant in elite level road cycling.

2.6.3.3 Maximum oxygen uptake of cross-country cyclists.

It is assumed that elite level XC cyclists would possess high values for relative $\dot{V}O_2max$, however, research on elite off road performers is lacking. In a study comparing national

XC and road cyclists, it was found that the mean relative $\dot{V}O_2max$ for the off road group was 70 ± 3.7 $mL \cdot kg^{-1} \cdot min^{-1}$ (Wilber *et al.* 1997). Lee (1998) investigated the effect of an off road tour on biochemical changes in group of national XC cyclists and found in pre race tests, that $\dot{V}O_2max$ averaged 4.96 ± 0.33 $l \cdot min^{-1}$ or 74.0 ± 4.9 $mL \cdot kg^{-1} \cdot min^{-1}$. Furthermore, according to Hansen and co-workers (1996) analysis of three elite cyclo-cross cyclists, average absolute and relative values for $\dot{V}O_2max$ were high (5.61 ± 0.74 $l \cdot min^{-1}$ and 76.0 ± 2.0 $mL \cdot kg^{-1} \cdot min^{-1}$).

Laboratory data is not extensive on XC cyclists, but from the information available, it's observed that national level XC cyclists have aerobic power in the range reported for professional road cyclists (Lucia *et al.*1998, 1999, 2001; Padilla 1999, 2001). This finding is not surprising, given the endurance nature of the event and low mass of elite riders reported. According to Coyle *et al.* (1988) a relative $\dot{V}O_2max$ of 70 $mL \cdot kg^{-1} \cdot min^{-1}$ is regarded as the minimum aerobic power required for national level road cycling. However, the validity of this claim to elite XC cycling needs to be confirmed. In regard to aerobic power it appears that competitive and elite XC riders compare similarly to the values established for road cyclists.

Table 2.6. Selected mean values for $\dot{V}O_2max$ according to category and discipline. Values are means (± SD).

Categories	Research	$\dot{V}O_2max$ ($l \cdot min^{-1}$)	$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)
Competitive Road	Tanaka (*et al.* 1993) n=11	4.72 ± 0.15	
Sub elite Road	Tanaka (*et al.* 1993) n=9	4.98 ± 0.14	
Elite Road	Lucia (*et al.* 2000) n=14	5.00 ± 0.60	78.6 ± 2.0
Competitive	Mac Rae (*et al.*2000) n=6		58 ± 5.6
Elite MTB XC	Wilber (*et al.* 1997) n=10	4.99 ± 0.44	70.0 ± 3.7
Elite MTB XC	Gregory (1999) n=5	5.20 ± 0.38	75.4 ± 2.28

$\dot{V}O_2max$, Maximal aerobic power; n, Number of subjects; MTB, Mountain bike; XC, Cross country (Gregory data are self reported; see Table 2.11 for grand weighted means).

2.6.4 Blood lactate response to cycling

There is much evidence to indicate the body is always producing lactic acid, with the levels changing primarily due to exercise intensity (Jacobs, 1986). Lactic acid is one of the by-products of anaerobic glycolysis, an energy yielding system that increasingly contributes to power output as exercise intensity rises. As MTB XC races and trials are performed at high relative HR intensities (Lee, 1998; Martin, 1997; Seifert *et al.* 1997), it is important to quantify the metabolic demands of this event through the blood lactate response. Off road racing lasts more than two hours and indicates a reliance on aerobic energy production, whereas the extent of glycolytic contributions are largely unknown.

Rising levels of blood lactate due to increased work rate indicate that entry levels exceed removal rates; declining levels indicate the opposite (Billat, 1996). For a given sub maximal work rate, a well trained endurance athlete will produce less blood lactate, as well as remove it at a much faster rate than an untrained individual (Weltman, 1994;

Lucia *et al.* 1998). According to Billat (1996) several factors appear responsible for the mechanisms in lactate production and these include: muscular contraction, recruitment of fast-glycolytic fibres and blood re-distribution to lactate producing tissues.

During the initial stages of an incremental cycling test blood lactate concentration remains near resting levels (~1.0 mM). Most of the external power is produced by slow twitch muscle fibres, which produce little lactic acid and are well adapted to using fat as fuel. As the power demands increase, more intermediate and fast twitch fibres are recruited, causing blood lactate concentrations to rise. With successive workloads a greater number of fast twitch fibres are recruited and eventually a point is reached where lactate is produced at a rate greater than it can be removed. The point at which lactate elimination is equal with diffusion uses various mathematical methods to determine, whilst in this research modified D max IAT is used (Bourdon, 2000).

It has been established that the more highly trained cyclist is able to produce more power output for a lowered blood lactate response at sub maximal workloads. Given the endurance and climbing demands (Mac Rea *et al.* 2000) of XC racing it is important to determine if off road cyclists conform similarly to findings in the literature. According to Lucia *et al.* (1998) comparison between test results of professional (n=25) and amateur road cyclists (n=25), a lowered blood lactate response was noted in the professional riders. In that research amateur cyclists had a peak blood lactate concentration of 9.4 ± 3.0 $mmol \cdot l^{-1}$, whilst professional riders were able to produce 8% more power at peak with a significantly lower ($P<0.05$) blood lactate concentration (7.4 ± 1.5 $mmol \cdot l^{-1}$) (Lucia *et al.* 1998).

It may be expected that elite XC riders produce less blood lactate in a field or laboratory setting at high exercise intensities. In research comparing between physiological variables in national male road and XC cyclists it was observed that blood lactate concentrations at the lactate threshold were similar (~2.7 mM vs 3.0mM) (Wilber *et al.* 1997). However, power output at the lactate threshold was significantly higher ($P<0.05$) in the road cyclists (321 ± 17W vs 271 ± 29W), indicating a greater level of training in those athletes (Wilber *et al.* 1997). In this example the XC cyclists tested showed a lower level of conditioning, however further questions concerning the blood lactate response during off road competition remain unanswered.

One goal of endurance training is to lower the blood lactate response, so as to be able to withstand fatigue or cycle at a higher power outputs. Graded exercise testing is routinely used to determine the blood lactate response, establish the effect of training and evaluate components identified as contributing to success in cycling (Bourdon, 2000). Furthermore, lab and field based TT testing is used to assess performance. It is expected in the first hour of XC races, as the cyclists attempt to establish the highest position possible, that blood lactate values will be above 4.0 $mmol \cdot l^{-1}$ concentrations. However, as research on the blood lactate response to XC cycling is lacking, references to other investigations will be made (Table 2.7).

Table 2.7. Blood lactate data taken from field and lab based time trials. Values are means (± SD).

Research	Trial	BLC (mM)	Gender
Nichols *et al.* (1997) n= 13	13.5km ITT	7.6 ± 1.8	F
Nichols *et al.* (1997) n= 13	20km ITT	6.9 ± 2.1	F
Coyle *et al.* (1991) n= 9	60min Lab TT	7.1 ± 0.7	M
Myburgh *et al.* (2001) n= 11	60min Lab TT	7.6 ± 2.1	M

BLC, Blood lactate concentration; ITT, Individual time trial; km, kilometre; F, Female; M, Male.

2.6.4.1 Lab based blood lactate response

With regard to Table 2.7, the cyclists in Coyle and co-workers (1991) study were highly trained athletes (539 ± 63 km·wk) and competent ITT performers in the 40 km event (53.9 ± 0.5 min). This confirms the observation that elite performers complete ITT's at high blood lactate concentrations despite well-developed aerobic capacity (69.6 ± 1.2 $mL \cdot kg^{-1} \cdot min^{-1}$). The ability to cycle with high blood lactate concentrations appears to be an important response in performing ITT's and this may be the case in MTB XC races also. In the ITT the blood lactate response of different athletic groups shows the effort of riding such events are above 4.0 $mmol \cdot l^{-1}$ blood lactate concentrations (Coyle *et al.* 1991; Nichols *et al.* 1997; Myburgh *et al.* 2001). It is generally accepted that the exercise intensity regulates the blood lactate concentration (Mader and Heck, 1991). Thus, in ITT events performance is not only a function of training at a transition threshold as Faria (1986) suggests, but also of the tolerance of blood lactate above optimal removal rates.

According to Coyle *et al.* (1991), the "elite-class" ITT cyclist has superior power output and force production compared to "good-class" rider, despite similar metabolic responses and this may be facilitated by a higher percentage of slow twitch fibres and capillaries per fibre in elite performers (Coyle *et al.* 1992). It is perhaps the combination of physiology and preferred cadence that allows cyclists to maintain elevated blood lactate concentrations for extended periods (>30min). It is expected, but largely un-confirmed, that the XC cyclist will have endurance qualities similar to the ITT rider in this regard.

2.6.4.2 Cyclo-cross blood lactate response

Cyclo-cross is a tactical off-road race ridden at work rates similar to those reported in 40km ITT events (Hansen *et al.* 1996). According to Hansen *et al.* (1996) the mean HR for 3 elite cyclo-cross cyclists during an elite race was 91 ± 2.5% of peak. Given the moderate event duration and dismounting and running required, mean values for blood lactate are expected to be similar to lab and field based ITT's. Janssen (1987) confirms this assumption, finding a range of blood lactate concentration between 7.0 – 9.0 $mmol \cdot l^{-1}$ during simulated cyclo-cross racing.

2.6.5 Transition thresholds

The power output at blood lactate and ventilatory (VT) transition thresholds are regarded as strong indicators of performance in cycling as they represents the sustainable power output possible in endurance cycling events. Blood lactate transition thresholds (BLTT) are used extensively in the assessment of endurance cyclists. Many terms describe the kinetics of lactate accumulation at the aerobic – anaerobic energy transition point. Some terms refer to the exercise intensity at which a given lactate accumulation occurs, whilst others relate to the intensity that elicits a blood lactate concentration above baseline values. Despite the differences in methods that calculate transition thresholds (VT and BLTT), according to Weltman (1994) they remain highly related and describe a similar phenomenon. Although methods vary in the determination of transition thresholds in the research, consideration of this measure in the performance of XC cycling remains important. According to Noakes and co-workers (1990) in endurance running strong relationships exist between BLTT and performance (r=-0.80 - -0.92), whilst similar associations are seen in road cycling also.

According to Manfredi and Miller (1987) a strong relationship between 15km ITT performance time (r=-0.93) and anaerobic threshold (AT) was observed. In massed start road cycling a rider with a high transition threshold is able to sustain changes in pace and terrain, climb and time trial quickly, as well as disperse lactate efficiently from high power output efforts. Regardless of methodology many authors report high values for transition thresholds for road and ITT cyclists alike (Coyle *et al.* 1988; Wilber *et al.* 1997; Lucia *et al.* 1998, 1999; Hoogeveen *et al.* 1998; Padilla *et al.* 1999). It may be assumed that transition thresholds may be similarly important in XC cycling, as it represents the capacity of the aerobic system to produce the highest sustained power output without significant acidosis. However, it's not known if transition thresholds can describe performance in XC cycling with the same strength as does in the ITT.

A review by Olds *et al.* (1993) revealed that elite cyclists have recorded values for D-max IAT of between 88 – 92% of $\dot{V}O_2max$. It's observed that blood and ventilatory thresholds are high in elite road cyclists and given the duration of XC events, they are expected to be similarly important in well trained off road cyclists also.

2.6.5.1 Transition thresholds of competitive cyclists

Training at identified transition thresholds for competitive cyclists can be a potential area of performance improvement, independent of $\dot{V}O_2max$. Coyle *et al.* (1991) evaluated the physiological responses of elite and competitive cyclists during a simulated 1 h lab based TT. Elite cyclists maintained a higher percentage of $\dot{V}O_2max$ than their competitive counterparts (90 ± 1% vs 86 ± 2% $\dot{V}O_2max$). In the authors previous study on 10 male competitive road cyclists a D max IAT was observed at 85.6 % ± 5.1 of $\dot{V}O_2max$ (Gregory, 1998). It may be expected that a competitive cyclist may have lower values at IAT and this may be reflected in reduced work rates also. A similar pattern may be anticipated in competitive and elite XC cyclists, as comparable physiological profiles may describe performance in these athletes. A comparison between cycling categories for percentage of $\dot{V}O_2max$ at transition thresholds is listed in Table 2.8.

2.6.5.2 Transition thresholds of elite cyclists

Transition thresholds are an important determinant of success in the endurance cyclist with an already well-developed $\dot{V}O_2max$ (Coyle and Coggan 1988). Furthermore Jacobs (1986) claims that transition thresholds account and explains for a larger proportion of the variation in endurance exercise performance than other variables traditionally determined in the sports science laboratory, including the measurement of $\dot{V}O_2max$. Elite XC performance might be elusive without high values at identified transition thresholds. Given the event duration in off road cycling, performance may be reliant on favourable endurance physiology, including the measure of IAT. It would thus appear important to review and relate this measure to XC performance.

In a study by Lucia *et al.* (1999) on 8 professional road cyclists who underwent laboratory testing, the percentage of $\dot{V}O_2max$ at VT was high at 87.5 ± 3%. Whereas in research on 14 elite road cyclists conducted by Hoogeveen *et al.* (1998), it was found that the percentage of VT was similarly high (90 ± 2.1% of $\dot{V}O_2max$). Furthermore, this study suggests the VT calculated from laboratory based testing has strength in predicting ITT performance. With regard to elite XC cyclists, Wilber and co-workers (1997) investigation into national XC cyclists calculated lactate threshold (LT) at 77.1 ± 6.4 % of $\dot{V}O_2max$, with this result being lower than expected. The limited research on elite XC cyclists prevents concrete conclusions from being made at this stage. It appears that elite road cyclists perform at high percentages of $\dot{V}O_2max$ at blood and ventilatory transition thresholds (Table 2.8), which compares to other endurance sports. Despite fewer studies similar findings are observed in elite XC riders.

Table 2.8. Average percentage of $\dot{V}O_2max$ at transition threshold according to road and MTB XC cycling categories. Calculation parameters and methods are included. (Values are grand weighted means)

Category	Competitive Road Race	Sub Elite Road Race	Elite Road Race	Competitive MTB XC	Elite MTB XC
% VO_2max	74.8	78.7	85.6	84.2	83
Subject numbers	62	31	87	10	40
Calculation Parameter	BLC	BLC, VENT	BLC, VENT	BLC	BLC, VENT
Calculation Method	OBLA, IAT	OBLA, IAT, LT	OBLA, IAT, LT, VT	IAT	LT

$\dot{V}O_2max$, Maximal oxygen uptake; MTB, Mountain bike; XC, Cross country; BLC, Blood lactate concentration; VENT, Ventilatory threshold; OBLA, Onset of blood lactate accumulation, IAT, Individual anaerobic threshold; LT, Lactate threshold; VT, Ventlilatory equivalents. (See appendix A for listed studies.)

2.6.6 Power output

It is broadly accepted that speed and HR changes considerably during cycling events, but until recently little was known about variations in power output. However, with the recent development of the SRM™ training system, it has been possible to measure and record power output during road and MTB XC events (Martin, 1997; Schoberer, 1998; Padilla *et al.* 2000; Mac Rea *et al.* 2000). It is generally held that the measurement of power output is the most objective way to quantify training intensity in the sport of cycling. Heart rate can be influenced by heat and dehydration and blood lactate is affected by fatigue and diet, whereas power output remains accurate under all conditions. The speed that a cyclist can maintain is dependent on how much power can be applied to the pedals. It has been calculated that World hour record holder Chris Boardman averaged approximately 430W through the trial (Bassett, *et al.* 1999), whereas in comparison untrained subjects can produce 75-100W of power to ride a bicycle between 16-24 km·hr (Kyle, 1996).

Power output is defined as the rate at which work is performed over time (Kent, 1994). The SRM™ system uses a modified cycle crank which measures power output, via strain gauges that sit between the chain rings and the crank arm and relays information to a computer mounted on the handlebars (Figure 2.3). Use of these cranks has revealed that power output during massed start road events fluctuates constantly throughout the course of a race and may often be lower than 100 Watts (W) for minutes at a time (personal communication, Garry Palmer). It appears that high power outputs (>500W) are important during massed start road races.

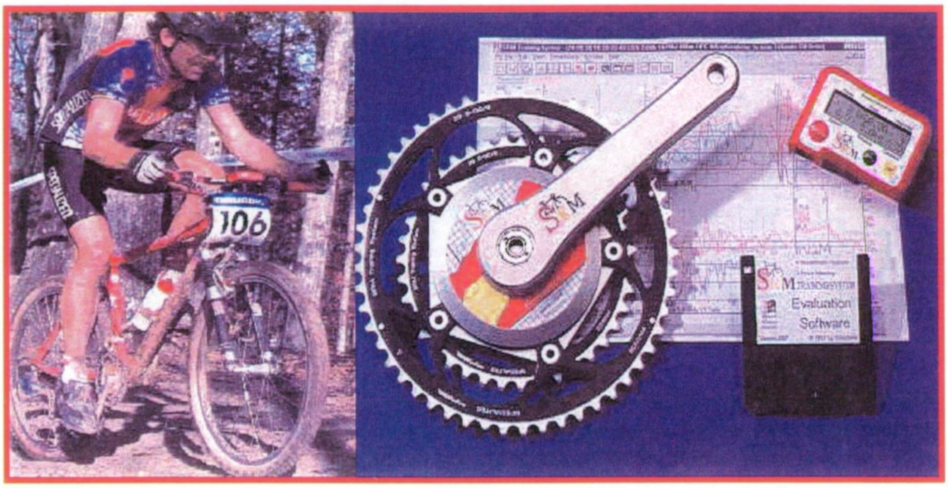

Figure 2.3. SRM™ road crank and Power meter. The XC power crank uses the same technology as the road version. Former World Champion Ned Overend races the Atlanta International with the MTB SRM™ system

This was highlighted when Bjarne Riis, winner of the 1996 Tour de France, used the SRM™ training system during a one day race to document changes in power output. In the 260km event, Riis was able to produce 530W of power on 20 occasions and make a solo break in the last 40 kilometres, averaging 390W in the last hour on his own (Mantell, 1998). Such efforts are critical for success, as the cyclist who can respond repeatedly with high power output may escape or at least finish ahead of their more fatigued counterparts. Thus, an ability to maintain high constant power output and also quickly develop high power output appears to be important in elite massed start road events. The pattern of power output appears to be much different to XC cycling, as pack riding is not a feature of an off road race and hence, periods of high power output (>500W) are not expected.

It has recently been reported in the cycle discipline during a triathlon race that was draft legal, that power output resembled the variable pattern seen in massed start road events. In Smith's (1999) unpublished study, elite Triathletes used the SRM™ training system during the 40 km draft legal cycle leg. Variations in power output between 43 to 900W were recorded, whilst mean values (238 ± 167 W) were lower than power output coincident at IAT. It appears that a draft legal cycle leg sees a power output that is variable and similar in pattern to massed start road events.

Road cyclists undertake interval, motor paced training and competition to train for the variable pattern observed. Traditionally off road cyclists have used the same training techniques of road cyclists and this approach may not have been optimal for the demands of XC cycling. Furthermore, the pattern of power output in massed start cycling appears to vary in amplitude to a greater extent than expected in MTB XC. Thus, the ability to work for extended periods of time aerobically and to produce periods of high power output are integral in road cycling. Based on these findings massed start road racing can be described as having an intermittent loading pattern (Palmer *et al.* 1994).

2.6.6.1 Time trial power output

The traditional ITT event requires a relatively steady state power output with few tactical concerns. Peak power output (PPO) and power at transition thresholds obtained from an incremental cycle test are strong predictors of ITT performance (Coyle *et al.* 1991; Hawley and Noakes 1992; Gunning *et al.* 1995; Bentley *et al.* 1998; Balmer *et al.* 2000). Coyle *et al.* (1991) evaluated the physiological responses of elite and competitive road cyclists by having them cycle a simulated 1 h laboratory based TT at their highest power output. It was found for the elite and competitive groups the mean power output was 346 ± 7 W and 311 ± 12W, respectively, which related to 89.7 ± 1.1% and 85.8 ± 1.6% of VO_2max (Coyle *et al.* 1991). Given that Padilla *et al.* (1999) and Lucia *et al.* (2000) report values for PPO ranging between 365W and 520W, it is not surprising that an elite road cyclist could maintain power outputs between 350 – 400W for an hour. Furthermore Padilla *et al.* (2000) recently showed that professional road cyclists averaged 362 ± 59W in 28 ± 8.6 km long ITT's (Figure 2.5). As the duration of an ITT increases it's expected that power output will fall, as there is an inverse relationship between intensity (% PPO) and event duration (Whitt and Wilson, 1982) (see Figure 2.4). Padilla *et al.* (2000) observed this effect in their study on professional road cyclists competing in ITT's during the Tour de France, Giro d'Italia and Vuelta a Espana. In this research it was revealed that a 7.3 km prologue ITT, 28 km and 49.3 km ITT, returned values of 89 ± 6%, 84 ± 7% and 79 ± 5% of PPO, respectively (Padilla *et al.* 2000) (Figure 2.5). According to the length and nature of the ITT, power output can be expected to range between 360 to 400W in elite road performers (Figure 2.5).

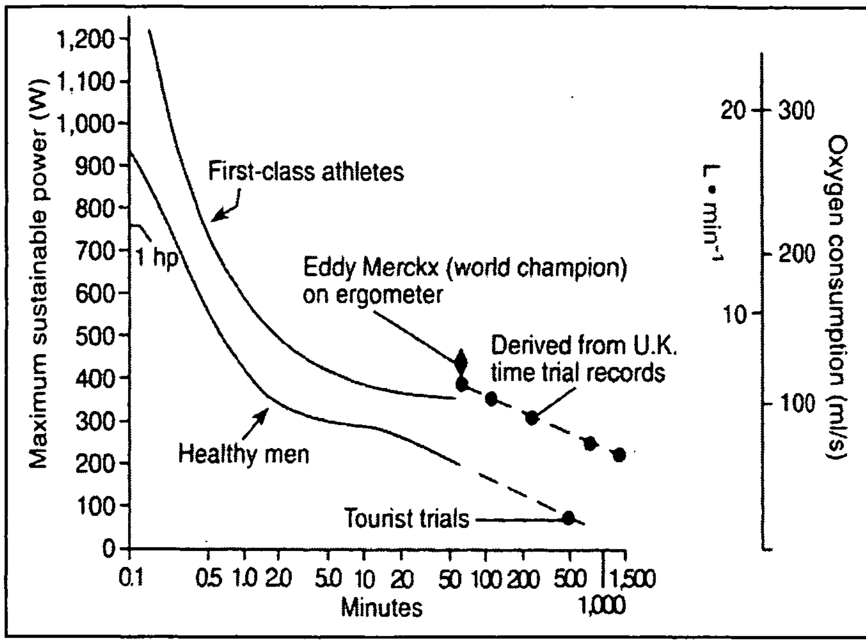

Figure 2.4. Relationship between event duration and maximum sustainable power output. (From Whitt and Wilson, 1982)

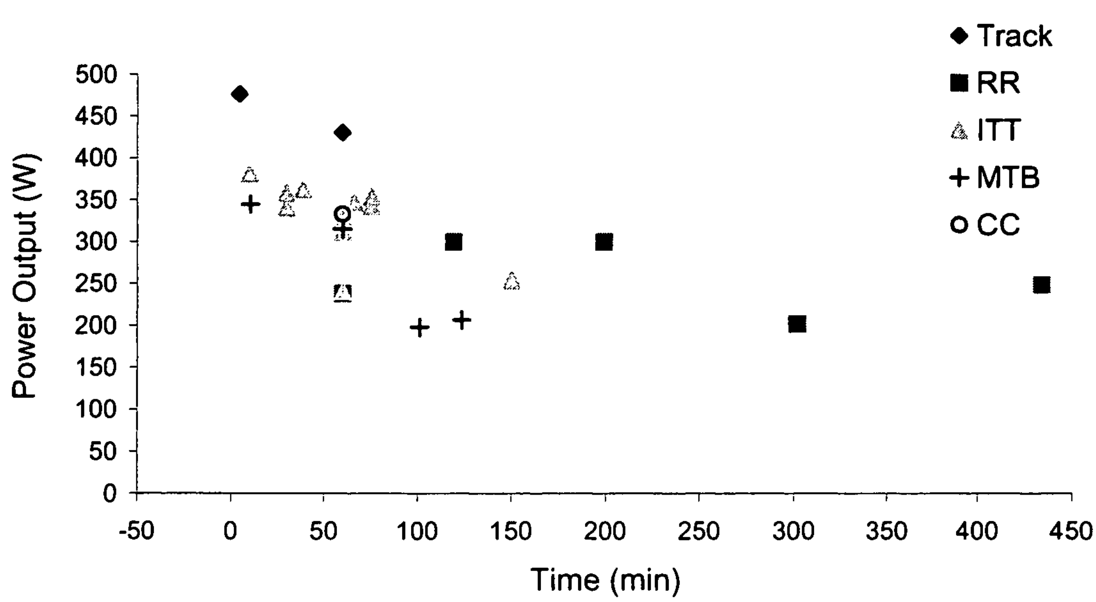

Figure 2.5. Mean power output for different cycling disciplines and event durations. All values come from published research. (Track, track racing; RR, road racing; ITT, individual time trial; MTB, mountain bike cross-country; CC, cyclo-cross)

High average HR values reported in XC events may erroneously suggest an even and high power output (Seifert *et al.* 1997; Lee 1998), whereas changes in terrain and technical demand would indicate a variable loading pattern (Martin 1997). Furthermore, due to the shorter event duration of XC cycling it's expected that average power output may be greater than that reported in a massed start road race, however, given the nature of a XC race-course, lower values are expected than a 40km ITT.

Road cycling research has primarily concentrated on massed start and ITT events. From these studies it is possible to conclude that massed road racing sees an intermittent loading pattern that in turn causes power output to be variable (Palmer *et al.* 1994; Mantell 1998; Padilla *et al.* 2001). Average road race values for HR and power output tend to be lower than seen in ITT's. The ITT is characterised by a high work rate but more even loading pattern, with a high percentage of PPO maintained during such events. In MTB XC races it's expected that the HR and blood lactate response will be similar to the ITT, whilst the pattern of power output is expected to be more variable.

2.6.6.2 Mountain bike cross-country power output

Given the relationship between intensity and duration it is expected that the average power output in a 2:30 h XC race would be higher than in a massed start road race, as an off road cyclist should produce more power output over the shorter duration. This assumption is supported, in part, by the finding that HR response is on average higher in a XC race than in a massed start road event. However, the hypothesis that power output should be higher based on duration is not supported in the literature available. According to Martin (1997) comparing between a massed start road and XC race the average power output was approximately 100W higher during the road event (300 ± 177W vs 198 ± 140W), despite the off road race being about one third shorter. Furthermore, during the Atlanta International XC race, a single male rider averaged 233W for the 2.5 hour race, whereas a professional road cyclist maintained 250W for a 7.25 hour race (Schoberer, 1998) (Figure 2.5).

On the information available mean power output is proportionately lower in a XC race, despite significantly shorter event duration. It appears that not only is average power output low during a XC race; it's also observed (Figure 2.6) that the distribution of power output is variable. According to Martin (1997) a single road racer produced 10% of his power at values greater than 500W, whereas the off-road cyclist spent only 1% of his race at that figure. This confirms, in part, the idea that XC cycling may have a variable pattern of power output, but have lower peaks than a massed start road race also. This trend was apparent for the distribution of HR response also. The low subject numbers of these investigations limits the conclusions that can be drawn. However, these outcomes cannot be completely disregarded on the criterion of subject numbers alone and further research is needed to substantiate or refute the findings.

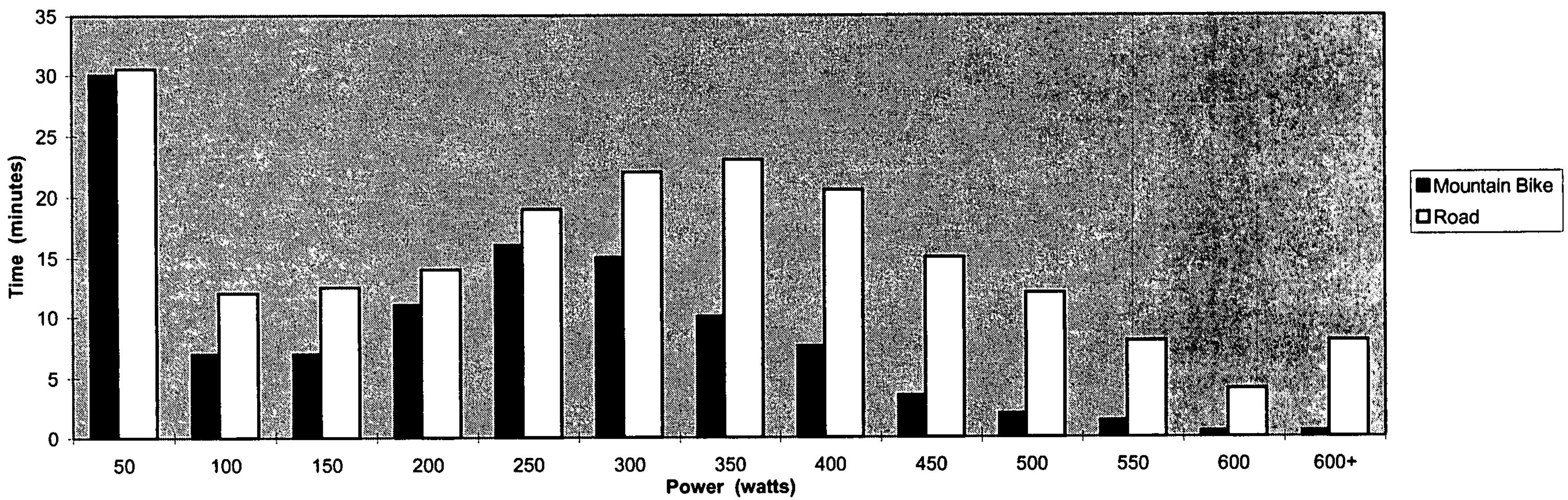

Figure 2.6. Comparison of power output distribution taken from a single mountain bike and road cyclist (Re-drawn from Martin, 1997).

Hansen *et al.* (1996) measured power output via the SRM™ system on 3 elite cyclo-cross riders during a 1 h race, with a mean value of 333 ± 36W, which corresponded to 77.6 ± 4% of VO_2max. Despite the high effort involved in cyclo-cross racing, the average power output is lower than that reported by Padilla *et al.* (2000) for ITT's of similar duration (347 ± 46W), which included cyclists of similar athletic level (Figure 2.5). The lower power output is explained by the need to dismount, run and descend causing greater periods of disruption to power output as well as contributing to fatigue. In addition, the increased muscular recruitment from the upper body may be responsible for the high HR response and moderate average power output reported. It is postulated that power output in MTB XC cycling may also be influenced in similar ways (Martin, 1997).

Furthermore, Hansen *et al.* (1996) claimed that cyclo-cross riders varied power output according to changes in the terrain encountered. It was found that over uphills of 6-8% that power output related to an average of 86 ± 7% of VO_2max, which suggests the gradient caused the cyclists to work at exceptional percentages of peak abilities (Hansen *et al.* 1996). It's unknown if a similar effect of terrain on work rate may be expected in XC cycling.

It's observed from the analysis of Martin (1997) and the Schoberer (1998), that power output traces from XC races are intermittent in nature (Figure 4.2). Former national US cycling federation coach Chris Carmichael comments on the demands of XC racing, stating "within the duration of the XC race, which can be considered overall to be aerobic, there are a series of variable efforts (Myleroie, 1998)." The variations in power output are perhaps caused by the changes in surfaces, the differences in the terrain and the demands of technical sections, subsequently causing periods of low and high power output. To negotiate a slippery forest floor, traverse a rocky section or climb a loose ascent will require the off-road cyclist to make deliberate adjustments in body position to stay upright and maintain speed and contact with the dirt. The need to maintain a dynamic position and tyre contact may contribute to greater variations in power output and also explain the lower than expected power output observed.

According to Martin (1997) where a single XC cyclist generated the highest power output, there wass a brief period of recovery before and after the 737W effort. When power output is intermittent and cycling includes recovery periods, higher power outputs are achieved than when the effort is more sustained (Martin, 1997). It is assumed that an even pace is the optimal strategy for optimising performance. However, in some sports such as middle distance running significant variations in pace are observed (Foster *et al.*1993). Similarly XC cycling may see an uneven power output, as external (terrain changes, technical demand, gradient, tactics…) and internal (pace judgement, ratings of exertion and fatigue…) factors may contribute to variances in power output.

Given the high values for $\dot{V}O_2max$ (~70 $mL \cdot kg^{-1} \cdot min^{-1}$) reported for national level XC cyclists (Wilber *et al.* 1997; Lee 1998), it could be expected that average race power output should be higher than that reported from current SRM™ data. Wilber *et al.* (1997) and Lee (1998) report similar mean data for absolute VO_2max (4.99 ± 0.44 $l \cdot min^{-1}$ and 4.96 ± 0.33 $l \cdot min^{-1}$), whilst Recently Martin (1999) tested a single male XC cyclist with a relative $\dot{V}O_2max$ of 85 $mL \cdot kg^{-1} \cdot min^{-1}$. Given the assumption that elite XC cyclists could work between 80%-90% of $\dot{V}O_2max$ during a race, the power / $\dot{V}O_2max$ regression equation developed by Hawley and Noakes (1992) calculates a power output between 310W to

350W. From the data available, off-road cyclists perform with lower values than those calculated. This maybe explained by the greater O_2 demands of the upper body and increased sympathetic HR response, but is more likely to be caused by the nature of the XC race-course.

A further explanation for the moderate power output seen in the XC races maybe due to the time spent negotiating technical sections. Off road race-courses rarely include smooth and straight sections where power output can be continuously applied, as the rider has to spend time freewheeling and picking the way with care, which equates to a fall in mean power output as a result. Dobbins (1997) confirms this idea with data from national XC cyclists using the SRM™ power cranks, finding that between 20 and 25% of XC events were cycled with power output below 100W. Furthermore, in Martin's (1997) analysis, 27% of a XC race was spent at values less than 50W. These power outputs are below the easiest level of training intensity and reflect, perhaps, the emphasis on technique during such periods. Dobbins (1997) claims these periods of low power output coincide with the technical/downhill sections, where power output is still required but is produced periodically as a result of bike handling taking precedence over smooth pedalling. It appears that a substantial percentage of a XC race is performed at minimal power outputs and this may explain the low mean power output recorded during a race.

During a MTB XC race a rider is largely self-reliant and must ensure that the pace is high, but sustainable. Thus, the lower power output in a XC event may also be due to the pacing demands of such long individual efforts. In research that simulated a road race in a laboratory, which was greater than 2 h in duration, similar mean power outputs to those recorded by XC cyclists are observed (Schabort *et al.* 1998). In this study cyclists had to cover a 100 km distance as fast as possible with 4 x 1 km and 4 x 4 km sprints included. Schabort *et al.* (1998) found that cyclists completed the distance in an average time of ~147 and a mean power output of 260 ± 40W. Despite participants being considered to be competitive cyclists (~65 $mL \cdot kg^{-1} \cdot min^{-1}$) the power output observed appears to be caused by the task duration (Schabort *et al.* 1998). Hence, the need to pace the effort for the duration of a 2.5 h off road event may further explain the lower power outputs reported in the literature.

In a XC race cyclists need to pace their efforts overall, but must measure their efforts up steep hills and through technical sections and these dual needs may influence average power output. Elite XC cyclists tend to start races very hard to get a position at the head of the pack and thereafter will attempt to maintain the highest work rate they can maintain throughout the event. The energy demands of negotiating varying obstacles, dealing with environmental stressors and completing the distance in the fastest time are considerable. Thus, a too aggressive start will cause fatigue and see a drop in speed, whilst a conservative approach will create positioning disadvantages and slow lap times early.

The XC race requires considerable emphasis on pacing of effort, which is also the case in road ITT's. After the start phase the XC cyclist will avoid very high power outputs (>500W) and attempt to maintain the highest power output they can for the remainder of the event. In massed start road races a cyclist is forced to produce high power outputs (>700W) in response to attacks and positioning in the pack, or they may have to help a team-mate also (Mantell, 1998; Schoberer, 1998). In addition road cyclists have the opportunity to draft, recover and repeat such efforts, whereas the XC cyclist has very few rest opportunities, as they must concentrate intently to maintain speed and negotiate technical sections. Although descending is required in road racing it is much different to an off road race. The need to remain standing, resist gravity and anticipate obstacles forces the XC cyclist to recruit muscles isometrically throughout the descents, which requires energy that is not measured by the SRM™ system. Often the off-road cyclist cannot pedal on DH sections, as opposed to their road counterparts, which may further explain the differences in power output between the disciplines. Thus, the XC cyclist is constantly required to expend considerable energy during descents, which is not recorded, but contributes to overall rider fatigue.

2.6.6.3 Peak power output of competitive cyclists

To gain an insight into the power output expected during XC cycling an understanding of the range of PPO that can be generated in the lab must be reviewed. In addition, the increased use of SRM™ cranks during road and XC competition, allows lab based PPO to be related to the field setting (Figure 2.5). This is of particular interest in off road cycling, as a clear understanding of power output in this sport is lacking. Peak power output is obtained from either a continuous or discontinuous incremental cycling test. With the aid of ventilatory parameters or a blood lactate transition curve, modified IAT can be calculated (Bourdon 2000; Hoogeveen *et al.* 1998). Peak power output appears to be a strong determinant in ITT performance and thus, an important parameter to review. According to Coyle *et al.* 1991 the relationship between one hour lab based TT power output and 40 km ITT performance is strong (r= -0.88), whereas Gunning *et al.* (1995) found that PPO is a strong predictor (r= -0.98) of 21 km ITT performance in elite cyclists also.

There is limited information on PPO in competitive cyclists, with only a few studies indicating the range expected. However, Hawley and Noakes (1992) found an average PPO of 296 ± 76.5W in their study on 19 competitive cyclists, whilst Bentley *et al.* (1998) reported 352 ± 47.3W for PPO in a group (n=10) of well-trained triathletes. In the authors previous research a mean value of 348.8 ± 16.2W was obtained for PPO in 10 active road cyclists (Gregory, 1998). These values are approximately 120W less than the average PPO reported for elite cyclists by other authors (Lucia *et al.* 1998, 1999, 2000; Hoogeveen *et al.*, 1998; Padilla *et al.*, 1999, 2000). Peak power output is highly related to performance and may represents a considerable limit to performance of the competitive cyclist.

The relationship between XC performance and PPO is not known, however, it's hypothesised that it may be an important determinant in off-road cycling. According to Hawley and Noakes (1992) PPO of a cyclist is dependant on the amount of muscle mass, percentage of slow twitch muscle fibres, body mass and $\dot{V}O_2max$. It appears that PPO requires many key physiological parameters to be optimised in a cyclist and thus can be considered as a central determinant in the sport of cycling. Furthermore the measurement of PPO may reveal a broad insight into XC cyclists physical abilities, which could then relate closely to performance.

2.6.6.4 Peak power output of elite cyclists

According to Hawley and Noakes (1992) the relationship between $\dot{V}O_2max$ and PPO is strong (r=0.97) and as elite performers have superior values for $\dot{V}O_2max$ (>70 $mL \cdot kg^{-1} \cdot min^{-1}$) (Table 2.11) high values for PPO are expected in these cyclists. The elite cyclist is characterised by a high maximum aerobic power and PPO (Lucia *et al.* 2000; Padilla *et* *al.*2000). Methodological differences in test protocols make it difficult to compare between PPO obtained from different research; however despite this limitation the PPO values for elite cyclists remain high.

Lucia *et al.* (1998, 1999) used a 25W increment test protocol to determine $\dot{V}O_2max$, VT and PPO in professional road cyclists. In the first study on 8 cyclists who competed in the Tour de France, a mean PPO of 501.1 ± 24.8W was recorded, whilst the second study on 25 professional road cyclists saw an average value of 466 ± 30.8W (Lucia *et al.* 1998, 1999). Wilber and co-workers (1997) employed a 25W per minute protocol also, with a PPO of 470 ± 35W recorded. Furthermore, utilising a similar test protocol Hoogeveen *et al.* (1999) report that 14 elite road cyclists had a PPO of 440 ± 33W.

In Australia the national lab standards protocol used to assess male endurance cyclists employs of a longer work period of 5 min that increases 50W at each workload. The longer duration of this method may create more force fatigue and hyperthermia in turn lowering PPO (Davis *et al.* 1982). Nonetheless, Craig and co-workers (1995) report a high mean PPO for elite Australian endurance cyclists of 459 ± 27W, using this protocol.

Recently Padilla and co-workers (2001) recorded a mean PPO of 430 ± 11.4W for a group of 16 professional road cyclists using a 35W per 4 min protocol. It appears in spite of the test protocol utilised, the PPO of elite road cyclists is high and often in excess of 430W (Table 2.9). With regards to national level XC cyclists, Wilber *et al.* (1997) reports a PPO of 420 ± 42W, whilst Lee (1998) found a PPO of 391.3 ± 11.4W. Lack of research on "elite"

XC cyclists leads to the speculation they may have PPO that is similar to professional road cyclists (~430W). However, current investigations on elite off road cyclists shows a lower PPO (~396W) than that reported for their road counterparts (Table 2.9). Research indicates PPO is important in ITT performance, however, given the climbing demands of XC racing it may be a combination of power to mass that better describes off road cycling performance. A summary of road and XC research in Table 2.9 outlines the average PPO determined for each cycling ability category.

Table 2.9. Average research values for peak power output according to cycling category. Values are grand weighted means.

Category	Competitive RR	Sub Elite RR	Elite RR	Competitive MTB XC	Elite MTB XC
PPO (W)	332.8	391.5	438.5	375.5	395.4
Subject numbers	94	58	181	16	40

PPO; Peak power output; W, Watts; MTB, Mountain bike; XC, cross country; RR, Road race. (See appendix A for listed studies.)

2.6.7 Power to mass

Power to mass is simply the power at PPO divided by the body mass of an athlete and is considered to be more indicative of climbing ability, as mass is taken into consideration. When climbing a cyclist mainly overcomes the force of gravity and smaller cyclists are favoured climbing due to their higher surface to body mass ratios (Swain *et al.* 1987; Swain, 1994). Aerobic power is proportional to surface area and gives the smaller cyclists an impressive advantage when expressed in relative terms (Swain, 1994). Hawley and Noakes (1992) found PPO to mass values for competitive road cyclists of 4.26 ± 0.78 $W \cdot kg^{-1}$. It has been suggested that a power to watts ratio of 5.5 $W \cdot kg^{-1}$ is necessary for top-level cycling performance (Palmer *et al.* 1994). However, in research conducted by Lucia *et al.*

(2000) and Padilla *et al.* (1999) on elite road "climbers" values for power to weight of 7.5 $\pm$ 0.2 $W \cdot kg^{-1}$ and 6.5 $\pm$ 0.3 $W \cdot kg^{-1}$ were recorded for each group. Wilber *et al.* (1997) found a mean value for power to mass of 5.9 $\pm$ 0.3 $W \cdot kg^{-1}$ in a group of national level XC cyclists, whilst Lee's (1998) study on XC riders revealed 5.84 $\pm$ 0.17 $W \cdot kg^{-1}$. The values reported for elite road "climbers" confirms the importance of power to mass in professional road events and it is speculated by the author that power to mass of elite XC cyclists may be similarly high. Again research on "elite" MTB XC cyclists is sparse, which may cause current mean power to mass to be underestimated in this group (Table 2.10).

It is seen in individual elite performers that values for power to mass are high. The 1998 Tour de France winner Marco Pantani recorded a power to weight of 7.3 $W \cdot kg^{-1}$ (Mantell, 1998), whilst it is claimed that Lance Armstrong can maintain 6.0 $W \cdot kg^{-1}$ on climbs (personal communication, Edmund Burke). Despite a moderate average power to mass of 5.70 $W \cdot kg^{-1}$ (Table 2.10), recently Martin (1999) reported that a two times World Cup XC winner, had a comparably high PPO to mass of 7.3 $W \cdot kg^{-1}$. It is no surprise that these three cyclists are noted climbers and are considered to be amongst the World's best in their fields. It appears that high power to mass is a feature of elite road cycling "climbers" and it's expected that this parameter will be a key determinant in XC performance also.

Table 2.10. Average research values for peak power output to body mass according to cycling category. Values are grand weighted means.

Category	Competitive RR	Sub Elite RR	Elite RR	Competitive MTB XC	Elite MTB XC
Po/Mass ($W \cdot kg^{-1}$)	4.79	5.38	6.22	5.10	5.70
Subject numbers	62	58	181	16	40

Po:Mass, Power to mass; $W \cdot kg^{-1}$, Watts per kilogram; MTB, mountain bike; XC, cross country RR, Road race. (See appendix A for table of studies used.)

2.6.8 Body composition

It is generally believed that the elite athlete will have a lower percentage body fat than a competitive performer, as the elite athlete has a high level of competition and increased training volumes (Jeukendrup *et al.* 2000). In Lindsay *et al's* (1996) investigation on competitive road cyclists the group reported a mean percentage body fat of 13.2 ± 2.5%, whilst Hoogeveen *et al.* (1999) and Lucia *et al.* (1999) reported 8.3 ± 4.2% and 8.3 ± 0.2%, respectively, for percentage body fat in elite road cyclists. Percentage body fat may explain some differences between the elite and sub elite performer and values are expected to be lower in elite cyclists, however, this may not always be the case. This was observed in Tanaka *et al.* (1993) research on category 2 road cyclists, who had moderate values for $\dot{V}O_2max$ of 65 ± 1.7 $mL \cdot kg^{-1} \cdot min^{-1}$, whilst mean body fat was low at ~6.6%. In regard to national level XC cyclists Wilber *et al.* (1997) research revealed a low value of 5.8 ± 1.1% for body fat. Limited research makes it difficult to report definitively for off road cyclists in regard to percentage body fat. However, due to the training and competition demands of XC cycling, similar values for percentage body fat are expected to their road counterparts.

2.6.9 Conclusion

It can be seen from the literature that differences in indices of fitness exist in both road and MTB XC cyclists. Research on road cycling presents a profile of the physiological test measures and physical characteristics that discriminates between athletic groups. Research on XC performers appears to fall between the elite and sub elite categories. Overall it has been possible to categorise cyclists by using values obtained from laboratory testing that include; $\dot{V}O_2max$, PPO, transition thresholds and power to mass. Descriptive data such as height and mass appears to be less reliable in the categorisation of cyclists, although specialist road hill climbers and elite XC cyclists seem smaller and weigh less than 65 kg. It may be possible to categorise cyclists on the basis of physiological test measures obtained and broadly expect variances in performance due to these differences (Table 2.11). The values outlined in Table 2.11 are important as they may be used to guide coaches and scientists in predicting off road performances.

Table 2.11. Average combined values for road and MTB XC research for peak power output, maximal aerobic power and power to mass according to cycling category. Values are grand weighted means.

	Physiological and Physical Test Measures			
Category	**$\dot{V}O_2max$** ($L^{-1}{\cdot}min^{-1}$)	**$\dot{V}O_2max$** ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	**PPO** (Watts)	**Power to Mass** ($W{\cdot}kg^{-1}$)
Competitive	4.38	58.9	339	4.89
	(n=156)	(n=99)	(n=110)	(n=49)
Sub Elite	5.06	70.4	391.5	5.38
	(n=52)	(n=50)	(n=58)	(n=58)
Elite	5.06	72.8	430.8	6.11
	(n=226)	(n=231)	(n=221)	(n=221)

$\dot{V}O_2max$, Maximal aerobic power; PPO, Peak power output; $W{\cdot}kg^{-1}$, Watts per kilogram; n=Subject numbers. (See appendix A for table of studies used.)

From the review of MTB XC and cycling research, it is evident that off road cycling has characteristic energy and technique demands. The highly variable loading pattern in road racing is different to XC cycling. Hence, massed start road cycling has the least in common with off road cycling. Consequently research and training schemes based on these events may be of limited value to the XC cyclist.

In contrast the ITT resembles the HR and blood lactate response expected in XC cycling. Simulated 40km ITT events see blood lactate concentrations in excess of values at 4.0 $mmol \cdot l^{-1}$ and suggests a notable glycolytic contribution to performance. These two aspects of the ITT appear to resemble the effort required in XC cycling. Despite these similarities, power output in the ITT is performed at high percentages of peak (~90%) and is highly stable, both of which are not reported in XC cycling. Selective use of the findings and practices seen in ITT's may be of value in elucidating the demands of XC cycling. The sport of cyclo-cross has strong links to MTB XC, as both are performed under similar conditions, but limited research is available on this branch of cycling. Useful relationships between the traditional cycling disciplines and XC cycling exist, but a specific investigation into the unique determinants of MTB XC is warranted.

2.7 Cadence

Despite the evolution of training methods and the refinement of equipment in cycling, one aspect has remained unchanged, that is the freely chosen cadence of cyclists during training and racing. Cadence is the rate that the pedals turn over and it is expressed as revolutions per minute (rpm). It is of interest in this investigation to relate cycling research findings to the cadences expected when climbing or on the flat during off-road cycling. In addition it is important to compare and contrast between cadence observed during road and lab based and XC cycling.

Variations in cadence occur according to the energy demands of the task and the cycling discipline. Cadences above 120 rpm are seen in short efforts such as sprinting, whilst lower cadences 60 - 80 rpm are reported during ITT's and climbing (Schoberer, 1998; Lucia *at al.* 2001). There is considerable research on cadence and central to this are what constitutes the most economical pedalling rate and how does this relate to off road cycling.

The use of ratings of perceived exertion (RPE) associated with cadence might provide insights into preferred pedal frequency. Coast *et al.* (1986) reports a lower RPE, HR and blood lactate concentration during a 20 and 60-min ITT at the cadence of 80 rpm, as opposed to the cadences of 40 and 60 rpm. Cadence tends to be maintained at higher (~90 rpm) rates in aerobically well trained riders during long races (>300 min) and this may be linked to athletes RPE (Lucia *et al.* 2001).

2.7.1 Hemodynamic response to cadence

The increased muscle pump activity and venous return associated with 90-100 rpm, may explain the preference of higher cadences of road cyclists. Gotshall *et al.* (1995) conducted a study on cyclists that had them pedal at 70, 90 and 110 rpm at a constant load of 200W, whilst HR, cardiac output (Q), blood pressure and oxygen uptake were measured. It was found that with higher cadence that HR, stroke volume, Q and $\dot{V}O_2$ all increased (Gotshall *et al.* 1995) (Figure 2.7). It is thought that with increasing cadence that the skeletal muscle pump mechanism is improved, which may explain the increased Q and muscle blood perfusion. This effect may be linked to preferred cadence at 90 – 100 rpm, as increased blood flow may be advantageous to performance, muscle fibre recruitment and reduced RPE.

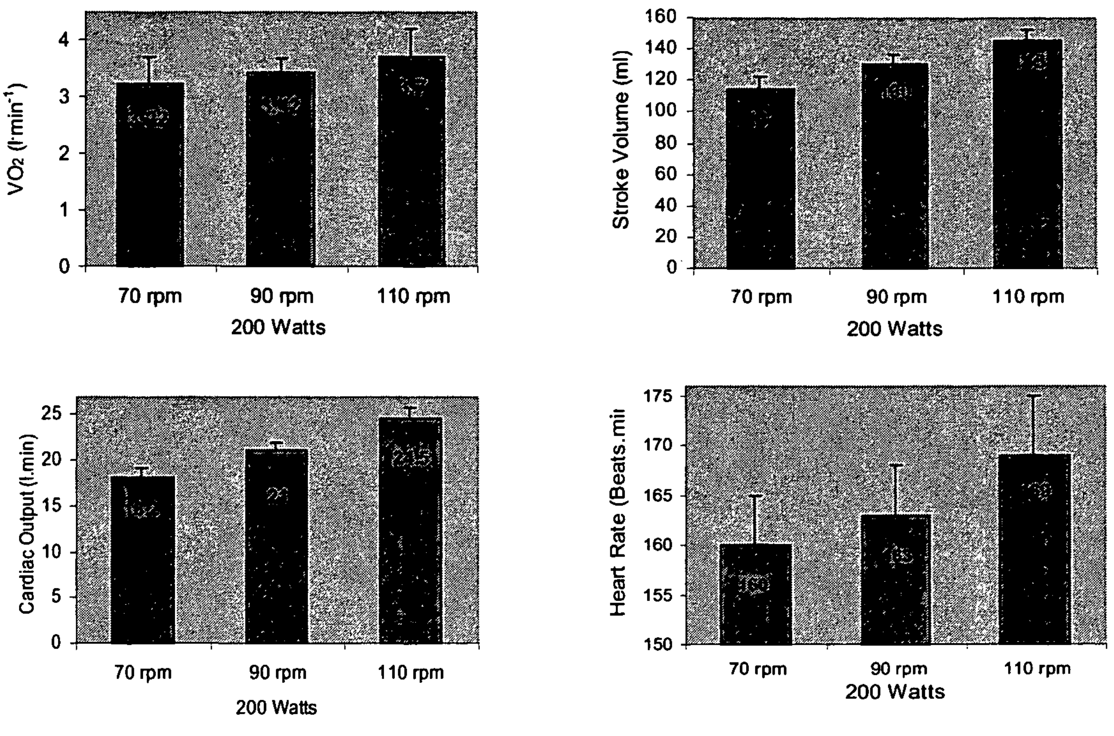

Figure 2.7. The effect of different pedal cadence on $\dot{V}O_2$, stroke volume, cardiac output and heart rate during cycle ergometry at 200 watts. Values are means (± SD) Adapted from Gotshall *et al.* 1995.

2.7.2 Muscle fibre recruitment and force development

It is thought by some researchers that muscle fibre type may have a strong influence on the higher preferred cadences selected by highly-trained road cyclists. Muscles consist of many thousands of muscle fibres and they are termed slow (ST), fast (ST) and intermediate twitch (IT). A single neuron running to the leg may control 500 – 1000 fibres, the neuron innervating a group of ST, FT or IT fibres only. The single neuron and the group of fibres it controls are called a motor unit. In the course of movement the body activates motor units to produce force. For tasks requiring low forces, such as cycling at 20 km.hr, a slow to moderate number of ST motor units are selected and this process is termed muscle fibre recruitment. As the force requirements increase (e.g. riding uphill or sprinting) the FT and IT fibres, along with most of the ST fibres, are recruited. With regard to higher pedal cadences, laboratory studies indicate a decline in peak pedal forces as cadence increases (Patterson and Moreno, 1990; Coyle *et al.* 1991).

Several studies have used force sensing devices mounted in the pedal to determine the pedal forces as the cadence or power output is changed. Patterson and Moreno (1990) measured the effects of cadence on the total force applied to the crank and the component of the force perpendicular to the crank. It was found that the resultant pedal force, averaged across a complete crank cycle, was minimised at 90 and 100 rpm at 100 and 200W (Patterson and Moreno, 1990). Thus, average pedal force decreases inversely with pedalling rate. Ahlquist *et al.* (1993) measured glycogen depletion in ST and FT muscle fibres of riders cycling at 50 and 100rpm at 85% of $\dot{V}O_2max$ and the results showed that at 50 and 100 rpm a similar number of ST fibres were recruited, whilst fewer FT fibres were recruited at 100rpm (Ahlquist *et al.* 1992). These findings support the idea that the force demands of the task play a part in preferred cadence.

It appears that higher cadences (>90 rpm) reduce the reliance on FT fibres, which may attenuate the rise in blood lactate and RPE. This observation fits in with the findings of lower perceived effort at higher cadences and hence, it's not surprising in road racing that cadences of around 90-100 rpm are observed when the cyclist is not making individual efforts.

As a MTB XC race is essentially a TT and involves repeated periods of climbing, were force development is critical, it's doubtful that a XC cyclist would use cadence (~90 rpm) similar to road cyclists. In XC racing there is not the pack riding that is found in road cycling, which would prevent riders from selecting cadences at approximately 90 rpm. In addition, the need to maximise force and prevent the rear wheel from slipping on dirt whilst climbing would indicate a lower frequency than 90 rpm. It may be difficult, in off road cycling, for the rider to reduce the loading on their legs with higher frequencies and maintain power output at optimal levels at the same time. Thus, it expected that XC cadence might be on average closer to the values reported in road riders when climbing (~70 rpm) (Lucia *et al.* 2001).

2.7.3 Climbing cadence

Competition cyclists are observed to climb steep hills at reduced cadences, whether they are competing off or on road. Often the road cyclist will shift their weight out of the saddle and over the pedals to increase power output and relieve fatigue. On short road climbs that can be topped in <4 min, the standing position and lower cadences are sometimes used to maximise climbing velocity, whilst longer climbs (>10 min) may see cadence rise closer to 80 rpm. In Coyle *et al's* (1991) research on competitive and elite ITT cyclists, it was reported that the elite performer was able to produce more power by increasing peak vertical forces. According to La fortune *et al.* (1980) resultant crank force and force applied perpendicular to the crank rises significantly at a cadence of 50 rpm, as opposed to 100 rpm. It is observed that cadence falls when climbing and this is perhaps due to the need to develop more force to overcome gravity.

It remains difficult to maintain high force and cadence simultaneously whilst climbing and hence XC and road cyclists broadly select lower frequencies when climbing. Given the individual nature and amount of climbing in XC events, average cadence is expected to be significantly lower than seen in massed start road races. Unlike cadences reported during flat road races (~90 rpm) (Lucia *et al.* 2001) XC cyclists may select different cadences due to changes in terrain and the potential time losses involved. It would not be feasible to cycle off road at a constant or most economical cadence due to the extreme external conditions encountered. In addition the use of high cadences may not maximise force and speed on steep climbs. Results from Martin (1997) and Schöberer (1998) appear to confirm that XC cyclists use low pedal frequency, with mean values ranging between 58 and 67 rpm, respectively. It is the purpose of this research to determine the preferred cadence of XC cyclists.

Cycling cadence appears to vary according to the cycling discipline and the specific demands encountered during the event. In road racing there is high variation in cadence, whilst during off-road cycling it is expected that cadence will be significantly lower than 90 rpm due to the amount of climbing and nature of the event. Field investigations performed in this study are designed to reveal if the assumption of low cadence in XC cycling is correct.

2.8 Markers of muscular damage

It has been established that there is an increase in plasma concentrations of various intracellular enzymes after endurance exercise (Noakes, 1987). Off road cyclists report anecdotally that XC races require more time to recover than massed start road events and this may be related to the degree of biochemical disturbance caused by the demands of the event. Hence, it is of interest to test this idea by quantifying the activity of key blood borne enzymes to a field based TT.

There are differences in the degree to which plasma enzymes increase according to exercise mode, intensity, and duration and individual variability also. There are several blood enzymes that are regularly measured in endurance athletes to indicate the level of muscle breakdown and stress with the most widely used enzymes include creatine kinase (CK), lactate de-hydrogenase (LDH) and aminotransferase (AST).

Creatine kinase is a key enzyme involved in muscle cell metabolism. In healthy rested muscle, CK is contained within the plasma membrane and blood borne levels are low. The amount of CK release between pre and post race samples has been associated with the size and severity of muscular damage. Creatine kinase release results primarily from eccentric muscle contractions and structural damage to cellular membranes (Schwane *et al.* 1983), with Clarkson *et al.* (1982) finding that isometric exercise was responsible for considerable CK activity also.

Research has implicated mechanical factors and or tension to be responsible for the release of CK with evidence showing elevated serum CK levels after whole body massage, strenuous exercise and impact with hard objects (Clarkson *et al.* 1982). It is thought that impact and tension causes sarcolemma damage with resultant leakage into the bloodstream of cellular enzymes (Hansen *et al.* 1982). Other factors such as amount of lean body tissue and fibre distribution are thought also to be related to CK release, as FT fibres have a higher CK activity levels (Novak and Tillery, 1977). Although the exact mechanisms of CK release are not fully understood, it is accepted that CK activity is a good indicator of muscle damage after exercise (Apple and Rhodes, 1988).

According to Karamizrak (1994) CK activity is closely related to duration of exercise. Hansen *et al.* (1982) lends support to this contention with high values for CK activity immediately and 24 hours post 15 km and 30 km running events (Table 2.12.) Furthermore, according to Mena *et al.* (1996) significant increases ($P<0.05$) in plasma aspartate aminotransferase (AST), alanine aminotramsferase (ALT) and lactate dehydrogenase (LDH) were observed in 15 professional cyclist who rode the Tour of Spain (2700 km, 20 d) compared to competing in the Tour of Valencia (800 km, 5 d). It appears to be a relationship between the level of blood enzyme activity and event duration, which may have implications in XC cycling.

Table 2.12 Serum creatine kinase catalytic activity of different running events and according to sampling period. Values are means (± SD).

Event	Immediate Post Race CK (µl)	24 Hours Post Race CK (µl)
15 km Road Race	300 ± 121.6	313.7 ± 167
30 km Road Race	494.6 ± 112.6	758.8 ± 337.2

km, Kilometre; CK, Creatine kinase.

Concentric muscle contractions are primarily involved during cycling. However, in XC cycling isometric contractions are used extensively for shock absorption during descents. In Seifert *et al.* (1997) study on the effects of different MTB suspension systems on physical exertion a significant change ($P<0.05$) in CK was reported for a rigid MTB (without suspension) as opposed to a front suspension bike (91.9 ± 79.5 vs 8.6 ± 17.5%). In that research cyclists maintained a constant speed of 16.1 km·hr for a duration of 63 minutes, which was at an intensity and duration considerably lower than a typical XC race. According to Lee (1998) who conducted a study into biochemical responses of 8 national level XC cyclists during a 3-day off road Tour, large increases in CK activity (125 ± 25 v's 350 ± 50 Iµ/L; $P<0.05$) post event were revealed. These rises were relatively higher in the XC performers for the shorter event duration compared to road cyclists (Personal communication Dr Martin, AIS). Increased blood enzyme activity in XC cyclists may indicate increased trauma and that off road cyclists require greater recovery time following races than their road counterparts.

The amount of blood borne enzymes found in the bloodstream such as CK and LDH may indicate the amount of physical trauma that an event places on a competitor. This has implications for recovery periods, as elevated blood enzyme activity may point to the need for increased recovery time. According to the literature event duration and amount of isometric exercise can have a significant influence on blood borne activity of certain enzymes. This is significant in regard to XC racing, as both precursors to increased mechanical trauma are present. The effect of elevated blood enzyme activity on recovery and training in XC cycling are not well understood. It is the purpose of this research to attempt to answer these questions.

2.9 Fluid shifts

Loss of body water can adversely affect performance and health of an athlete. Light exercise under thermo-neutral conditions can increase the rate of water loss by approximately 0.5 to 0.7 L·h, resulting in dehydration (Grucza *et al.* 1987). Dehydration is defined as the depletion of fluids from the body, which can lead to, impaired thermo-regulation and increases in core temperature (Kent, 1994). Off road races held in hot conditions can lead to significant dehydration, which may in turn affect performance.

Water provides the medium for biochemical reactions and is essential for maintaining blood volume and therefore the integrity of the cardiovascular system. Maintenance of blood volume is important for optimal arterial blood pressure and regulation of body temperature during exercise, with reductions in blood volume resulting in a fall in cardiac filling pressure, stroke volume and Q (Nose *et al.* 1988). Fluid loss is dependent on environmental conditions (temperature, humidity, radiant load and air velocity), clothing and exercise intensity.

According to Nose *et al.* (1988) fluid is mobilised from the intracellular to the extracellular space to enable the defence of blood (plasma) volume in dehydrated subjects. In humans the extracellular fluid has two components: the interstitial fluid and blood plasma. Blood plasma constitutes about 5% of body mass and losses of 10-20% have been reported after endurance events (Costill and Fink 1974). If exercise intensity and environmental conditions cause sweating, plasma volume (PV) may fall as a result. In endurance events where heat loss is a problem, such as encountered during XC events, blood flow to the active muscles is reduced to allow more blood to be diverted to the skin and increase the rate of heat loss via sweating.

It is apparent in endurance events that PV can decline; however, there is evidence that PV can be defended despite the onset of dehydration. For example Sawka *et al.* (1980) showed that during 100 min of treadmill running the PV remained stable despite a 4% reduction in body mass. Furthermore, Kolka *et al.* (1982) reported during a marathon race the PV remained static, whilst body mass decreased by ~7%. Explanations for a stable PV include the release of water from glycogen breakdown, metabolic water and the redistribution of water from inactive skeletal muscle (Sawka and Pandolf, 1990). According to Sawka and Pandolf (1990) in neutral environments a 4-8% loss of aerobic power occurs after dehydration of ~ 3% body mass, whereas in hot conditions a much smaller level of dehydration (~2% of body mass) may cause a more substantial decrease in $\dot{V}O_2max$ of around 10%. Therefore even in thermo-neutral conditions a MTB XC cyclist may not prevent dehydration and subsequent losses in performance.

Fluid losses in MTB XC events are to be expected and appear to be caused by a combination of low average speed (<20 km hr), high mean percentage of peak HR and sometimes-high humidity and ambient temperatures. Strategies to replace fluid can offset the performance decrements associated with dehydration; however, they cannot be completely eliminated. Off road riding is a high intensity cycling discipline with considerable energy expenditure, which coupled with environmental heat load may place additional demands on the rider.

2.10 Statement of the problem

Mountain bike XC is a popular and professional sport that has an international World Cup, annual World Titles and recently was included in the 1996 and 2000 Summer Olympic games in Atlanta and Sydney. Despite coming of age as an international sport, off road cycling has not been comprehensively studied from a scientific perspective. Training and preparation of off road cyclists has drawn extensively on the cycling disciplines of cyclo-cross and road racing for guidance. Techniques and practices have emerged through participants and coaches' own impressions and experiences, whilst others have been refined by trial and error. As little research exists in off road cycling coaches have had to rely on there own judgments, based on other cycling disciplines, in identifying talent and making training and racing recommendations.

Traditionally in order to more accurately identify talent and maximise performance of cyclists, profiling of a sport has been conducted and this has not been done in the sport of MTB XC, despite the obvious advantages of doing so. The existing research documents the effect of suspension systems (Seifert *et al.* 1997; Mac Rea *et al.* 2000), lists the injury rates of XC riders (Kronisch *et al.* 1992) and has established some test results of national

XC cyclists also (Wilber *et al* 1997; Lee 1998). However, research pertaining to the determinants of MTB XC performance does not exist in the literature.

2.11 Purpose of the research

It is the purpose of this research to elucidate the physical and physiological determinants of the sport MTB XC cycling by field and laboratory based investigations, which are designed to include and measure the unique demands of off road cycling.

3 Chapter Three - Analysis of World Cup and World Title Cross-Country Race-Courses

Introduction

From the review of literature it is apparent that little research information exists on MTB XC cycling. The purpose of this chapter is to gain a broad understanding of the unique demands of XC cycling, which should support the idea that relative physiological measures may best describe this cycling discipline. This chapter will attempt this task by the analysis of elite XC race-courses and events. From these analyses it should be possible to gain insights into the contribution that physiology plays in MTB XC performance. These observations should help quantify the endurance; technique and climbing requirements of elite level off road cycling.

Off road competition is conducted at regional, national and international levels. The World Cup, World Title and Olympic Games XC races are considered to represent the highest level of competitive mountain biking in the world. The World cup has developed into a major, global cycling series during the last 10 years, whilst the first MTB World championships was conducted under the auspices of the International Cycling Union (UCI) in Durango, USA in 1990. Cross-country racing was included as a full medal sport in the 1996 Summer Program in Atlanta, USA and again at the Sydney 2000 Olympic Games, Australia. World Title and Olympic Games XC races are conducted on a single day, whereas the World Cup is contested over a series of races with the most consistent cyclist being the winner.

In 1990, the international MTB XC circuit was called the Grundig Challenge and the level of competition was relatively low compared with other cycling events being held at the time. A year later the world circuit became the UCI / Grundig World Cup and immediately the standard of competition increased. The UCI introduced tighter racing rules and laid down course design guidelines. The number of races in the series increased from six to ten rounds in 1992 and this led to an influx of road and cyclo-cross riders into the competition. The mid nineties had established the international calendar with familiar race venues in North America and Europe. At the same time Europeans were winning at the traditional races at altitude in the USA, proving the home ground advantage enjoyed by the North Americans up until then had been eroded. Europeans continued to dominate the results of men's international XC events during the next 5 years with only a few minor exceptions. From the mid nineties onwards MTB XC had gone through its period of development and from that point on could be considered a truly professional sport.

In the past three years World Cup MTB XC race-courses have become increasingly standardised with the lap distance being around 8-9 km in length, which is significantly shorter than the original races. However, this shorter lap distance has made the sport more accessible to the public and television. The UCI have worked to standardise races on the World Cup XC circuit by implementing a range of course design rules and criteria. The course must be 100% ride-able regardless of the terrain and weather conditions; however, brief and unavoidable dismounts may be approved in some circumstances. World Cup and World Title XC race-courses should be free of significant obstacles that have not been planned or notified to the riders, whilst extended sections of single track must have periodic passing sections included. Each race kilometre must be clearly marked and technical sections denoted before hand, with between one and three downward pointing arrows indicating the level of technical difficulty for the section. The downhill sections are also marked in this manner.

During a XC race the cyclist must complete the entire distance and is not permitted to take any short cuts. The mountain cycle must be equipped with 26 inch wheels front and rear and during the course of an event a cyclist cannot receive any outside assistance, including, help from fellow team members. This rule has meant that the basic diamond frame and suspension fork design has remained largely unchanged over the past 10 years. The provision of no outside assistance during races has kept construction materials and weight of components within reach of the normal consumer. Thus, the current rules of XC racing ensure that the physical and technical demands of a race are more consistent between events and each race is ridden with a high level of self-sufficiency, which is in keeping with the original ethos of MTB XC racing.

The world cycling governing body, the UCI, recommends optimum race duration based on age and gender categories (Table 3.1), whilst road events have traditionally relied on a set number of kilometres to standardise races. The UCI guidelines on race duration and field sizes in international XC events have further standardised the overall effort of off-road racing. Table 3.1 outlines the recommended range of winning times for a MTB XC circuit race at World Cup and World Title level. Time is used for each given race category, as lap distance, amount of ascension, weather conditions and technical demands affect average speed from one course to another.

Table 3.1. UCI recommended MTB XC race duration.

	Race Duration (h min)		
Race Category	**Minimum**	**Optimum**	**Maximum**
Junior Men	1.45	2.00	2.15
Junior Women	1.15	1.30	1.45
Under 23 Elite Men	2.00	2.15	2.30
Elite Women	1.45	2.00	2.15
Elite Men	1.45	2.15	2.30

At the World Cup and World Title level the maximum field of 130 male cyclists is allowed, with up to 80-90 competitors in the Women's competition. When entries exceed 130 riders a shorter qualifying race is held on the Friday of race week. Recently at World cup races cyclists perform a single maximal lap the day before the race proper, which then seeds them on the grid. It is a considerable advantage to have a top 20 qualified start, as this puts a cyclist further forward in the starting line up, which means less overtaking and time losses once the race commences. A cyclist with a forward position is able to see clearly, follow the pace line and stay ahead of those behind, whereas the riders from 20th start position and back have to cope with dust, crashes and limited vision into technical sections. Thus, tactically the start is very fast and is regarded as being important in a high overall race result. These factors often cause XC riders to start aggressively and enable them to maximise any start position advantage. Off road cyclists include practice starts and interval training in their programmes to optimise the start phase (personal communication, Damian Grundy).

The technical and course details remain similar for both the men and women at the highest level of MTB XC competition. The nature of a XC event places considerably higher technical demands on the XC competitor as compared to their road counterparts. In road events, the race distance and amount of climbing are the most important overall considerations, whilst technical course details play a smaller role in the final outcome of a race. Thus, a road competitor may require less thorough course information to prepare for a specific event, whilst a MTB XC cyclist will benefit from receiving more detailed information.

Anecdotal evidence tends to suggest that some cyclists are able to peak and be successful at certain times of the season, whilst other cyclists are consistent performers throughout the entire year. Given that cyclists have different strengths and weaknesses, information such as the amount of technical single track or climbing at a given race venue may help the cyclist to prepare optimally.

Several investigations have studied the work demands of cycling in the field setting (Mc Cole *et al.* 1990; Craig *et al.* 1993; Palmer *et al.* 1994; Hansen *et al.*1996; Lucia *et al.* 1999, 2000; Padilla 2000), whilst authors claim that 70% or more of race time on North American XC race courses is spent climbing (Mac Crae *et al.* 2000). However, until now no study has analysed the race results and course characteristics first hand to verify this claim.

The aim of this chapter is to outline event information and review technical race characteristics that may impact on the off road cyclist. It is hoped from these analyses that the demands of MTB XC racing will be elucidated, and that ideas will emerge that can be tested in later sections of this investigation. In addition this chapter should allow the construction of a "test" XC TT circuit that approximates the content of international race-courses. This test circuit will allow central questions regarding energy expenditure and power to mass to be answered.

The precise aims of this chapter are:

- To document the international course characteristics and race results over three separate seasons.
- To determine the technical course details over this period.
- To determine any differences between the male and female race-course results and technical details.
- To compare the average race results for men and women XC cyclists between North American and European race-courses.
- To provide specific race venue information.

Methods

Race Analyses

The average characteristics of 20 World Cup (WC) and 3 World Title (WT) race-courses and 29 race results were determined from 1997 to 1999, for both male and female competitors (See appendix B). This was performed by analysing the official course descriptions available to riders and teams from UCI and race organisers internet sites and season guides. Information was collected for each race on the winning time, average speed, metres ascended, race duration, race distance, race lap distance, time between races and the % of time between 1st and 20th placing. The mean race gradient was determined by dividing the total race ascension by the race distance. The 29 WC races were conducted over ten different international race-courses (WC1 – WC10).

The technical descriptions of each of the WC and WT race-courses were broken down into 4 categories and expressed as a percentage of the total race-course lap distance, these included; the percentage of fast and slow downhill (DH), percentage of single track and open track. These categories were chosen as they include and describe the technical breakdown of a XC race-course. The descriptive categories were taken from the official UCI categorisation of course terrain.

Single track (ST) is described as a narrow path 500 to 1000 mm wide, uneven, rough, twisting and strewn with numerous obstacles such as rocks and logs. The higher the percentage of ST the higher the overall technical difficulty of a race-course. Open track (OT) refers to wider fire road trails or sealed road, where passing opportunities are more numerous than on ST. The technical demand of OT is generally low and therefore may allow for higher sustained power output or speed than ST. The start loop and first kilometre of each race-course comprise OT to allow the large field to negotiate the early parts of the course safely. Open track is not restricted to the start, however, and is often found dispersed throughout a XC race-course. Fast downhill (FDH) refers to usually open and straight sections of ST and OT that have a slope > 15%. Slow technical downhill (TDH) includes single track descents, which includes turns; drop offs, obstacles and narrow traverses. Both slow and fast descents require high levels of concentration and bike balance, with power output usually low during these periods. Any given WC or WT race-course combines all of the technical categories listed above.

Statistical analyses

Descriptive statistics are expressed as means and ± SD. Repeated measure ANOVA was used to examine the differences between the race seasons for gradient, time to 20th place, race speed, race duration, amount of race ascension and number of days before races, whilst the *post-hoc* Bonferroni test was applied. Student's t-tests were used to compare the differences between North American and European race values for gradient, time to 20th place, race speed, race duration, amount of race ascension and number of weeks before races. Pearson's product moment analysis was used to generate correlation coefficients between race duration, race speed and race ascension and distance. Student's t-tests were used to compare the differences between the men' s and women's average results from the 1997, 1998 and 1999 seasons for mean race gradient, speed, duration, ascension, time to 20th place and the number of weeks between races. Significance for the ANOVA, t-tests and Pearson's correlation analysis was determined at $P<0.05$.

Results

Overall race-course characteristics and results

Table 3.2 outlines the MTB XC race-course characteristics and results for males, whilst Table 3.3 shows the same information for female cyclists competing in the World Cup (WC) and World Title (WT) races from 1997 to 1999. Male cyclists covered significantly greater distances (47.4 ± 4.7 km vs 33.7 ± 4 km, $P<0.01$) and performed for longer periods of time (141.33 ± 11.14 min. vs 119.54 ± 15 min., $P< 0.01$) than the women.

As expected males had significantly faster mean race speed compared to the women (21.2 ± 1.7 km.hr vs 17 ± 1.7 km.hr; $P< 0.01$). Male cyclists completed significantly more ascension than the women on average (1942 ± 245m vs 1402 ± 174m, $P<0.01$). Furthermore, the male cyclists had a significantly lower percentage of time between the 1st and 20th place compared to the women (7.1 ± 2.1 % vs 12.24 ± 3.81 %, $P< 0.01$).

Table 3.2. Men's overall World Cup and World Title cross country course characteristics and race results, for the seasons 1997, 1998 and 1999.

	World Cup and World Title Values (n=29)			
Race and Course Details	**Mean**	**Minimum**	**Maximum**	**± SD**
Race speed (km·hr)	21.2	15	24	1.7
Winner's race time (min)	141	114	162	11
Weeks between races	2	1	6	1
Mean race gradient (%)	4.11	3.24	5.09	0.52
Lap distance (km)	9.2	6.2	15.8	1.9
Lap ascension (m)	345	225	410	68
Total race distance (km)	47.4	32	53.9	4.7
Time between 1st to 20th (%)	7.1	3.8	11.7	2.1
Total race ascension (m)	1942	1520	2416	245

km.hr, Kilometres per hour; min, Minute; % Percentage; km, Kilometres; m, Metres; SD, Standard deviation.

Table 3.3. Women's overall World Cup and World Title cross country course characteristics and race results, for the seasons 1997, 1998 and 1999.

	World Cup and World Title Race Values (n=29)			
Race and Course Details	**Mean**	**Minimum**	**Maximum**	**± SD**
Race speed ($km \cdot hr^{-1}$)	17 *	14.1	20.1	1.7
Winner's race Time (min)	119*	97	154	15
Mean race gradient (%)	4.10	3.4	5.98	0.64
Total race distance (km)	33.7*	28	40.1	4
Time between 1st to 20th (%)	12.2*	20	6.3	3.8
Total race ascension (m)	1402*	1100	1900	175

km.hr, Kilometres per hour; min, Minute; % Percentage; km, Kilometres; m, Metres.

*Denotes a significant difference ($P<0.05$) between genders.

Table 3.4 summarises the overall and yearly percentage make up of the various different technical race-course categories of the WC and WT races from 1997 to 1999. The average percentage of FDH and TDH was similar at 12.8 ± 6.3% and 9.1 ± 3%, respectively.

Table 3.5 outlines and compares between the average North American and European WC and WT race-course characteristics and results. Out of 29 races surveyed between 1997 and 1999, 12 of the race venues were conducted in North America, 15 were based in Western Europe and 2 races were conducted in the Oceania region.

A significantly greater ($P<0.05$) mean gradient was observed for the female cyclists North American events (4.40 ± 0.73%), compared to their European races (3.86 ± 0.53%). Analysis of the women's events revealed that the North American races tended to be longer than the European races (35 ± 3.4 km vs 32.2 ± 4.6 km, $P<0.07$).

Furthermore, consistent differences were observed between North American and European events for men's race speed (19.8 ± 2 km·hr vs 21.7 ± 2.2 km·hr, $P<0.10$), race distance (45.5 ± 5.2 km vs 48.5 ± 4.2 km, $P<0.10$) and mean race gradient (4.28 ± 0.54% vs 3.94 ± 0.51%, $P<0.10$). These findings indicate that the European races tend to be longer, but also less steep than North American events.

Table 3.4. Overall and yearly World Cup and World Title cross country course details 1997 - 1999. Values are means (± SD).

World Cup and World Title Technical Course Details (n=29)				
Technical Parameters	**1997**	**1998**	**1999**	**Overall**
Fast Downhill (%)	11.6 ± 6	12.6 ± 5.8	14.5 ± 7.5	12.8 ± 6.3
Technical Downhill (%)	8 ± 2.8	8.5 ± 3.2	10.8 ± 6	9.1 ± 4.1
Single Track (%)	47.5 ± 9.7	45 ± 10.3	41.4 ± 10.7	44.9 ± 10
Open Track (%)	53.5 ± 9.5	55 ± 10.3	58.6 ± 10.7	55.1 ± 10

%, Percentage; SD, Standard deviation.

Table 3.5. Comparison between the average North American and European World Cup and World Title course characteristics and race results, for the period1997 to 1999.

World Cup and World Title Values for North American and European Courses (n=27)				
Event and Course Details	**Men (± SD)**		**Women (± SD)**	
	North America	Europe	North America	Europe
Speed ($km \cdot hr^{-1}$)	19.8 ± 2	21.7 ± 2.2	16.4 ± 1.8	17.40 ± 1.5
Race time (min)	139 ± 13	142 ± 11	119 ± 16	122 ± 15
Days between races	15 ± 14	15 ± 12	15 ± 9	15 ± 9
Mean gradient (%)	4.28 ± 0.54**	3.94 ± 0.51	4.40 ± 0.73*	3.86 ± 0.53
Lap distance (km)	8.6 ± 1.6	9.4 ± 2.2	8.6 ± 1.6	9.4 ± 2.2
Lap ascension (m)	360 ± 52	353 ± 80	360 ± 52	353 ± 80
Race distance (km)	45.5 ± 5.2	48.5 ± 4.2	32.2 ± 4.6†	35 ± 3.4
Time to 20th (%)	7.3 ± 1.6	6.9 ± 2.2	13.3 ± 3	12 ± 3.1
Race ascension (m)	1944 ± 232	1911 ± 200	1400 ± 220	1331 ± 146

km.hr, Kilometres per hour; min, Minute; % Percentage; km, Kilometres; m, Metres.

* Denotes a significant difference ($P<0.05$) between the European and North American mean race gradient.
** Denotes a significant difference ($P<0.10$) between the European and North American mean race gradient.

† Denotes a significant difference ($P<0.10$) between the European and North American race distance.

Table 3.6 summarises the technical course details of both the North American and European race-courses. A greater difference was observed between North American and European races for the average amount of ST (47.6 ± 12% vs 42.7 ± 8.8%), although this did not reach a level of significance ($P>0.05$).

Table 3.7 summarises the men's and women's average WC and WT race characteristics and results for the separate seasons 1997, 1998 and 1999. As seen in table 3.7, the men's mean race gradient was highest for the 1999 season (4.26 ± 0.36%) and was significantly greater than reported for the 1997 ($P< 0.05$) and 1998 ($P< 0.05$) seasons.

Table 3.7 shows the women's overall season averages for average gradient from 1997 to 1999. The mean values for the 1997, 1998 and 1999 seasons were 3.96 ± 0.49 %, 3.95 ± 0.55 % and 4.46 0.82 ± %, respectively. As seen in Table 3.7, the women's 1999 international season recorded the lowest mean percentage of time to 20th place (10.6 ± 2.9%) and this was found to be significantly lower to the 1997 (13.6 ± 3.9%, $P< 0.05$) and 1998 (14.4 ± 2.7%, $P< 0.05$) race seasons.

Table 3.6. Comparison between the North American and European World Cup and World Title cross country technical course details. Values are mean (± SD).

World Cup and World Title Values for North American and European Courses (n=27)				
Technical Course Details	**North America**		**Europe**	
	Mean	± SD	Mean	± SD
Fast downhill (%)	12.8	4.4	11.9	7.3
Technical downhill (%)	9.3	3.4	8.2	3.5
Single track (%)	46.7	12	42.7	8.8
Open track (%)	53.3	11.8	57.3	8.8

Table 3.7. Overall World Cup and World Title cross country course characteristics and race results, for the individual seasons 1997, 1998 and 1999. Values are mean (± SD).

Event and Course Parameters	**World Cup and World Title Values (n=29)**					
	Men			**Women**		
	1997	**1998**	**1999**	**1997**	**1998**	**1999**
Speed ($km \cdot hr^{-1}$)	20.6 ± 1.8	21.4 ± 1.5	19.7 ± 2.8	17.5 ± 1.5	17.1 ± 1.5	17 ± 1.7
Race time (min^{-1})	144 ± 14.6	139 ± 9	137 ± 9	114 ± 11	126 ± 18	119 ± 15
Days between races	13 ± 11	13 ± 9	18 ± 17	13 ± 11	13 ± 9	18 ± 17
Mean gradient (%)	3.99 ± 0.53	3.91 ± 0.53	4.46 ± 0.36*	3.96 ± 0.49	3.95 ± 0.55	4.46 ± 0.82
Lap distance (km)	9.4 ± 2.6	9 ± 1.5	8.3 ± 1.2	9.4 ± 2.6	9 ± 1.5	8.3 ± 1.2
Lap ascension (m)	368 ± 81	331 ± 60	361 ± 50	368 ± 81	331 ± 60	361 ± 50
Race distance (km)	47.9 ± 4.1	49.6 ± 2.6	44.6 ± 6	33 ± 3.2	35.5 ± 2.9	33.7 ± 4
Time to 20th (%)	7.1 ± 1.7	7.3 ± 2.4	6.87 ± 2	13.6 ± 3.3	14.4 ± 2.7	10.6 ± 2.9**
Race ascension (m)	1919 ± 179	1936 ± 230	1985 ± 276	1282 ± 110	1396 ± 205	1442 ± 179

km.hr, Kilometres per hour; min, Minute; % Percentage; km, Kilometres; m, Metres; SD, Standard deviation.

* Denotes a significantly higher ($P<0.05$) for mean gradient for the1999 season compared to 1997 and 1998.

** Denotes a significantly lower ($P<0.05$) % time from 1st to 20th position for the 1999 season compared to1997 and 1998.

Table 3.8 lists the World Cup and World Title race numbers venues, country locations and venues (Individual race information is detailed in appendix B).

Table 3.8. World Cup and World Title race number and location.

	Race Location and Country		
Race	**1997**	**1998**	**1999**
WC1	Nappa Valley, USA.	Nappa Valley, USA.	Nappa Valley, USA.
WC2	Wellington, New	Silves, Portugal.	Sydney, Australia.
WC3	St Wendel, Germany.	Budapest, Hungary.	Madrid, Spain.
WC4	Budapest, Hungary.	St Wendel, Germany.	St Wendel, Germany.
WC5	Spinderluv, Czech	Plymouth, England.	Plymouth, England.
WC6	Mt Snow, USA.	Canmore, Canada	Big Bear, USA.
WC7	Mt St Anne, Canada.	Conyers, USA.	Canmore, Canada.
WC8	Vail, USA.	Bromont, Canada.	Houffalize, Belgium.
WC9	Houffalize, Belgium.		
WC10	Annecy, France.		
WT	Chateau doex,	Mt St Anne, Canada.	Are, Sweden.

WC, World cup; WT, World Titles.

Correlation analyses revealed the relationship between race duration and race distance (r= 0.62) and total race ascension (r= 0.69) to be moderately strong. Further analysis showed a similar relationship between race speed and percentage time to 20th place (r= -0.63).

Race venue characteristics

Figure 3.1 shows average percentage of FDH for the individual World Cup and World Title race venues for the period 1997 to 1999. The greatest amount of FDH at 26% was reported for World Cup (WC2) venue in Sydney, 1999, whilst the least amount of FDH of 4% was recorded for the WT venue at Mt St Anne in 1998.

Figure 3.2 depicts the overall percentage of TDH for the individual WC and WT race venues from 1997 to 1999. The Sydney WC venue had the greatest percentage of TDH at 26%, whilst the WC race at Big Bear had the lowest amount at 4%.

The percentage of ST for each of the WC and WT venues for the period from 1997 to 1999 are depicted in figure 3.3. The % ST was significantly greater ($P<0.01$) than TDH. The values for percentage ST per race venue varied considerably. The highest amount of ST reported was 61% for the WT venue at Mt St Anne and 60% for both the WC races in Nappa Valley and ex Olympic venue at Conyers, Atlanta. Recently, the least amount of ST of 25% was reported for the Big Bear XC race venue.

The average amount of OT per World Cup and World Title venue is displayed in figure 3.4. There is an inverse relationship between percentage of OT and ST, with the greatest amount of OT at 75% was reported for the WC venue at Big Bear.

Figure 3.5 outlines the men's and women's individual mean race venue and overall average percentage values for gradient. The highest mean gradient was seen at the WT race at Mt St Anne race with an average of 5.09%. The WC race in St Wendel has had consistently the lowest mean gradient for each year studied; although these values were not significantly lower ($P<0.112$) than the mean gradient for each of seasons, respectively (1997, 3.24%; 1998, 3.43% and 1999 3.98%).

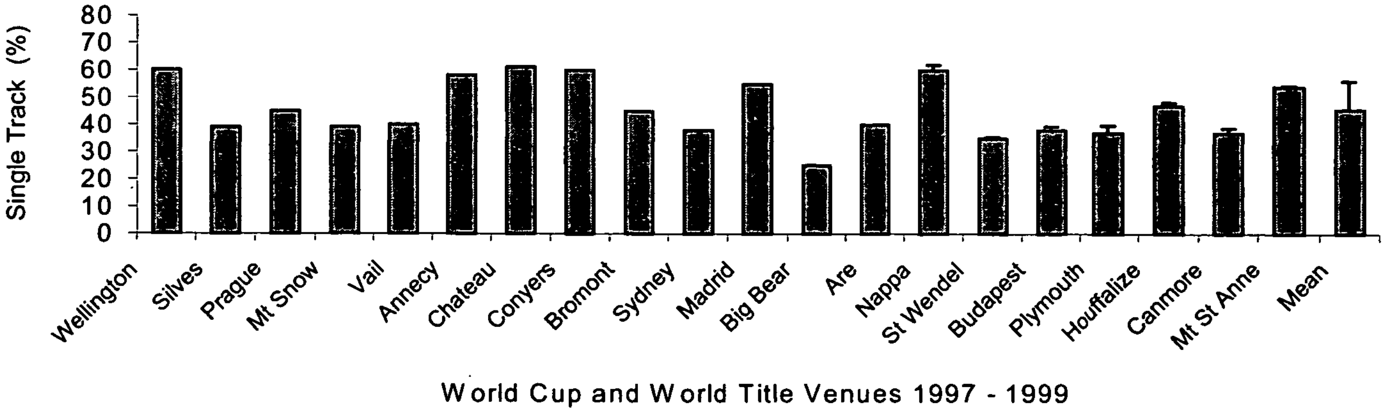

Figure 3.1. The individual race mean (± SD) and overall average percentage values for the amount of fast downhill, for World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

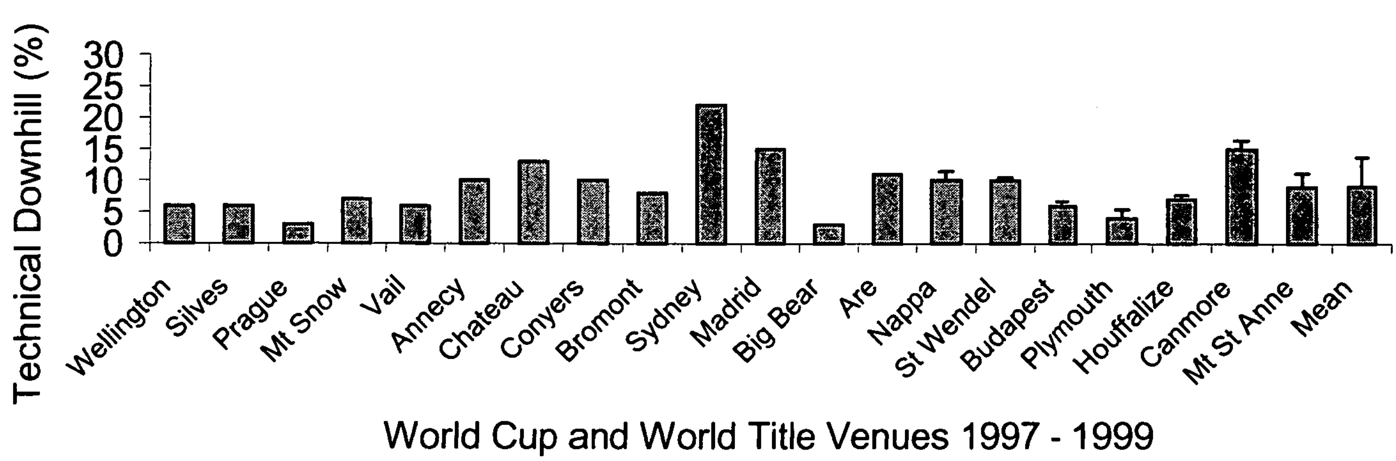

Figure 3.2. The individual race mean (± SD) and overall average percentage values for the amount of technical downhill, for World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

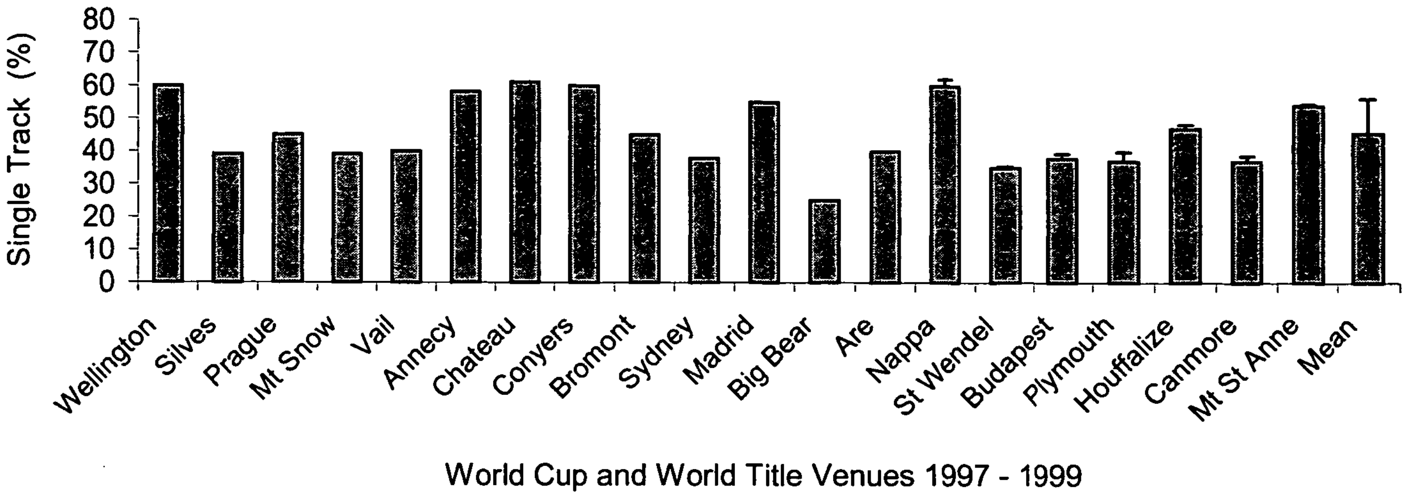

Figure 3.3. The individual race mean (± SD) and overall average percentage values for the amount of single track, for World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

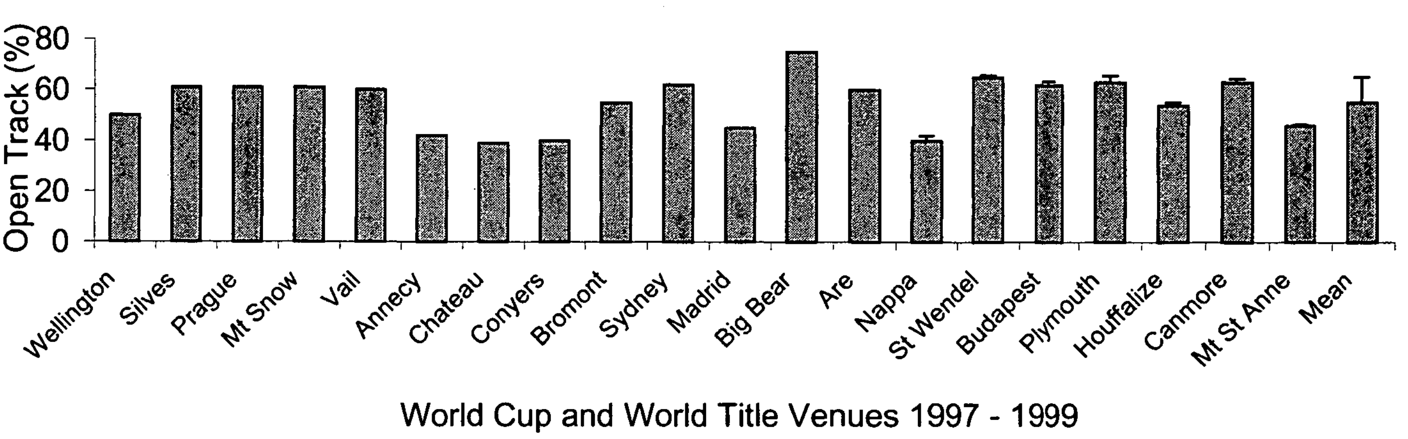

Figure 3.4. The individual race mean (± SD) and overall average percentage values for the amount of single track, for World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

Elite international race results

Figure 3.6 outlines the men's individual race venues and overall average % of time between 1st and 20th place for the 1997, 1998 and 1999 seasons. The greatest difference between 1st and 20th place was seen at the WT race in Are at 11.7% in 1999, whereas the smallest percentage difference was recorded for the WC venue at Bromont at 4.6% in 1998.

Figures 3.7 shows the men's separate mean race venues and overall winning speed for the period 1997 to 1999. The 1999 edition of the Canmore WC race returned the lowest winning race speed at 15 $km{\cdot}hr^{-1}$, whilst the 1997 WC3 race in St Wendel, had the fastest race speed for the 3 year period at 24 km·hr. The mean race speed for St Wendel over the past 3 years was found to be significantly higher ($P<0.05$) than the overall speed for all WC and WT races (23.2 km·hr vs 20.6 km·hr).

Figure 3.8 outlines the men's separate race venues and overall averages for race duration. The race venue in Chateau doex had the longest winning race duration of 162 min., whilst the venues at Bromont, Big Bear and Conyers shared the shortest winning duration at 131 min.

The individual men's races values for total and average race ascension for the period from 1997 to 1999 is depicted in figure 3.9. The race venue at Madrid had the greatest amount of vertical ascension at 2310 metres, whilst the St Wendel race-course recorded a significantly lower ($P< 0.01$) amount of cumulative ascension 1662 ± 37 m compared to the overall average of 1966 ± 197 m.

Figure 3.10 shows the men's and women's individual race venues and overall season averages for the number of days between races. On average there are significantly ($P < 0.05$) fewer days between the races in the first half of the season (5 races per 51 ± 8 days) as opposed to the second half of the season (5 races per 96 ± 22).

Figure 3.11 shows the women's individual race venues and overall values for the percentage time between 1st and 20th place. The greatest difference was reported for the race in New Zealand at 20% between 1st and 20th place, whilst the WC race in St Wendel had consistently the least amount of time as a percentage to 20th place at 8.9 ± 2.5%.

The women's average and individual race venues for race speed are outlined in figure 3.12. Less variation is seen between the race venues for speed, compared to the other categories. The Mt Snow race recorded the lowest average winning speed at 14.1 $km.hr^{-1}$, whilst again St Wendel had the highest average speed for elite women MTB XC cyslist at 18.4 ± 0.54.

Figure 3.13 depicts the women's individual race venues and overall values for race duration. From the race venues studied the women's WT race in Are (152 min) and the race in Budapest (148 min) exceeded the recommended maximum race duration of 2.15 min set by the UCI guidelines. The shortest women's international MTB XC race was 99 min in Conyers.

Figure 3.14 shows the women's individual race venues and overall values for total race ascension. The greatest amount of total race ascension was observed for the Big Bear race venue at 1620 metres, whilst the Budapest venue recorded the lowest amount of total race ascension with 1216 ± 129 metres.

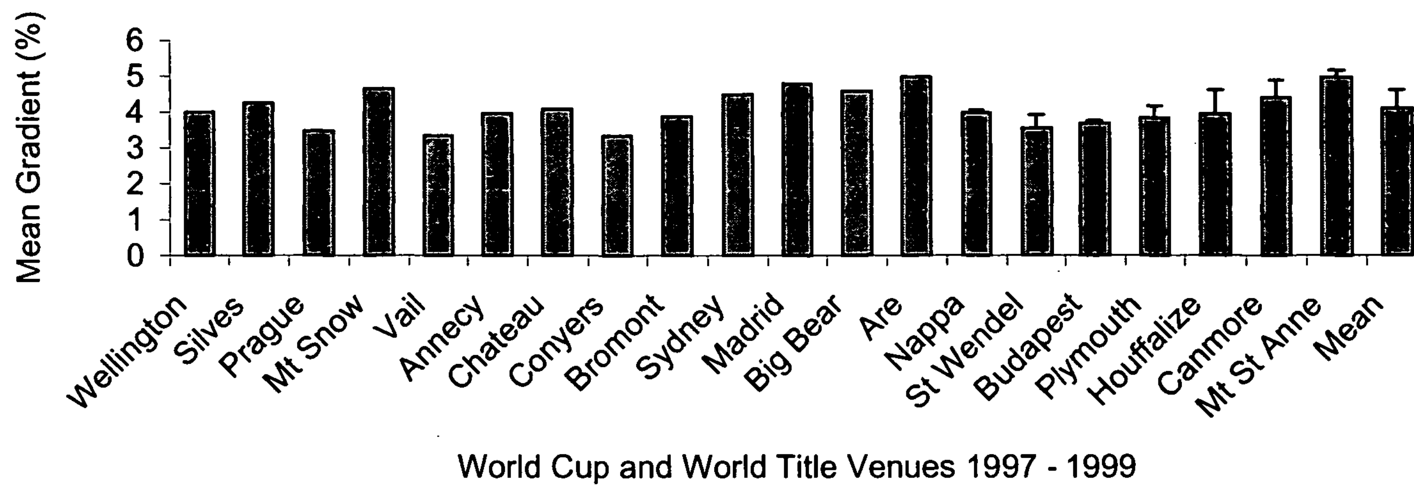

Figure 3.5. The men's and women's individual race mean (± SD) and overall average percentage values for race gradient, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

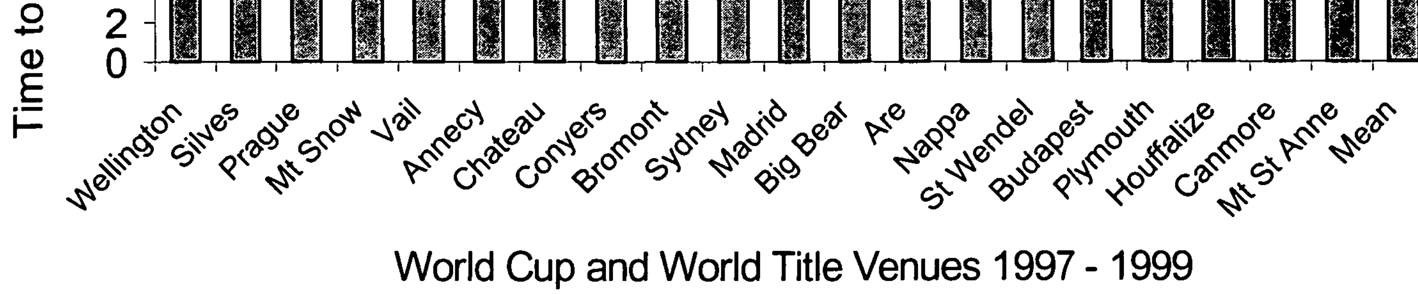

Figure 3.6. The men's individual race mean (± SD) and overall average percentage values for time to 20[th] place, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

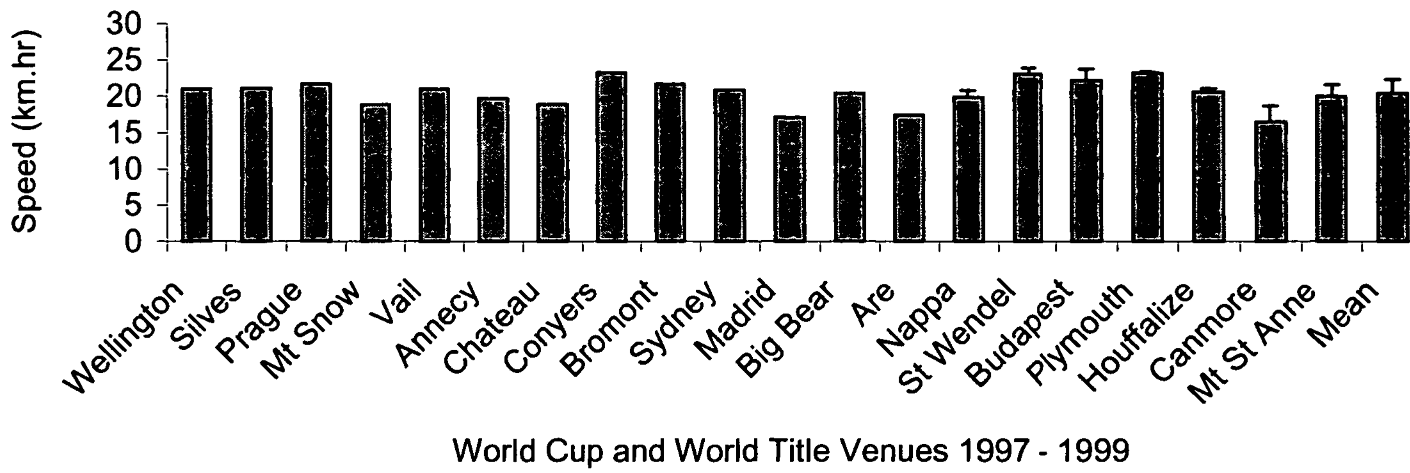

Figure 3.7. The men's individual race mean (± SD) and overall average values for the winner's race speed, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

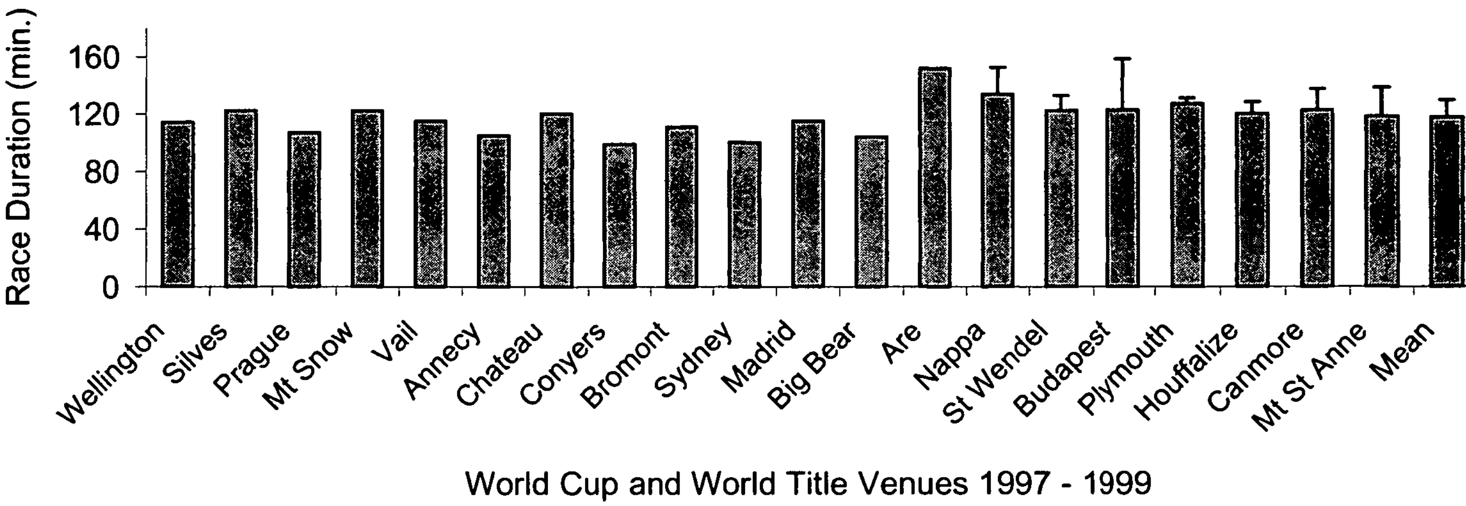

Figure 3.8. The men's individual race mean (± SD) and overall average values for the winner's race duration, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

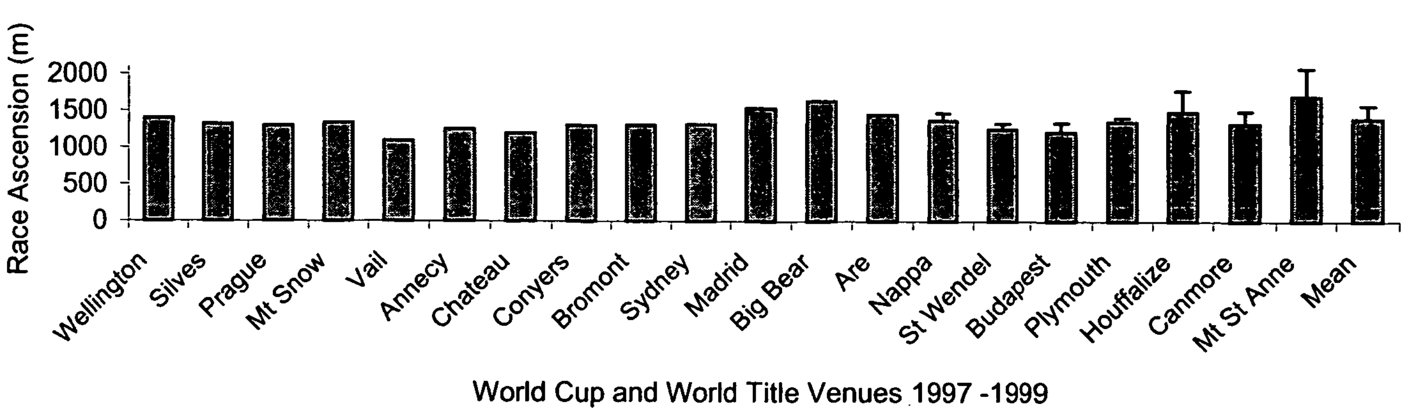

Figure 3.9. The men's individual race mean (± SD) and overall average values for the total race ascension, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

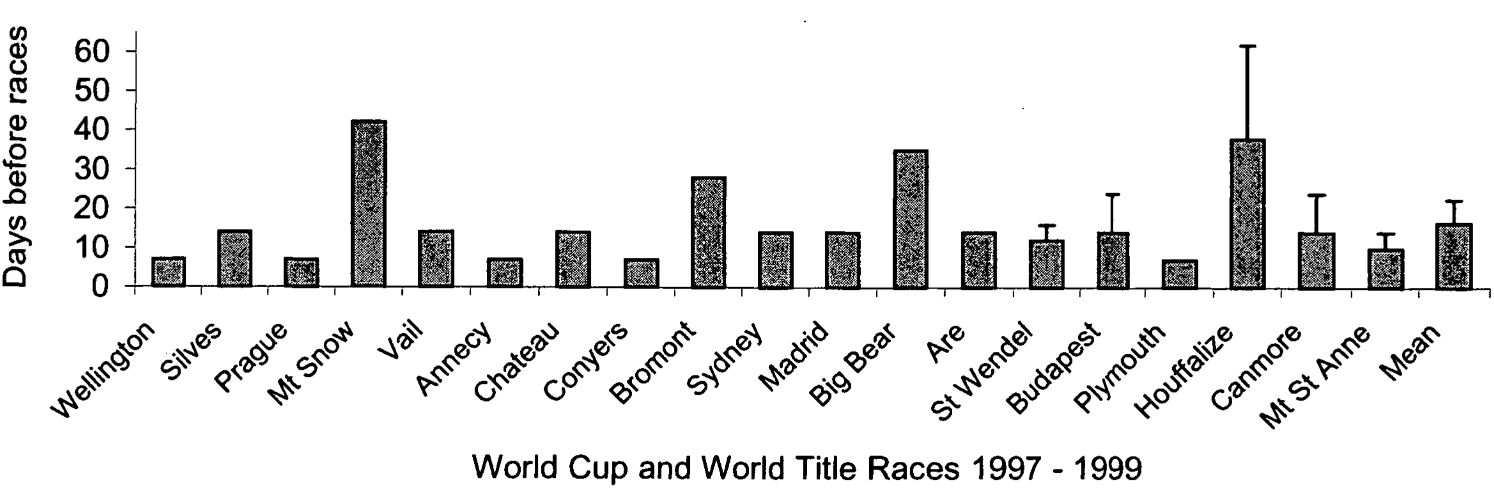

Figure 3.10. The men's and women's individual race mean (± SD) and overall average number of days between the races, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999. Nappa Valley World Cup is omitted due to it being the first race of the season.

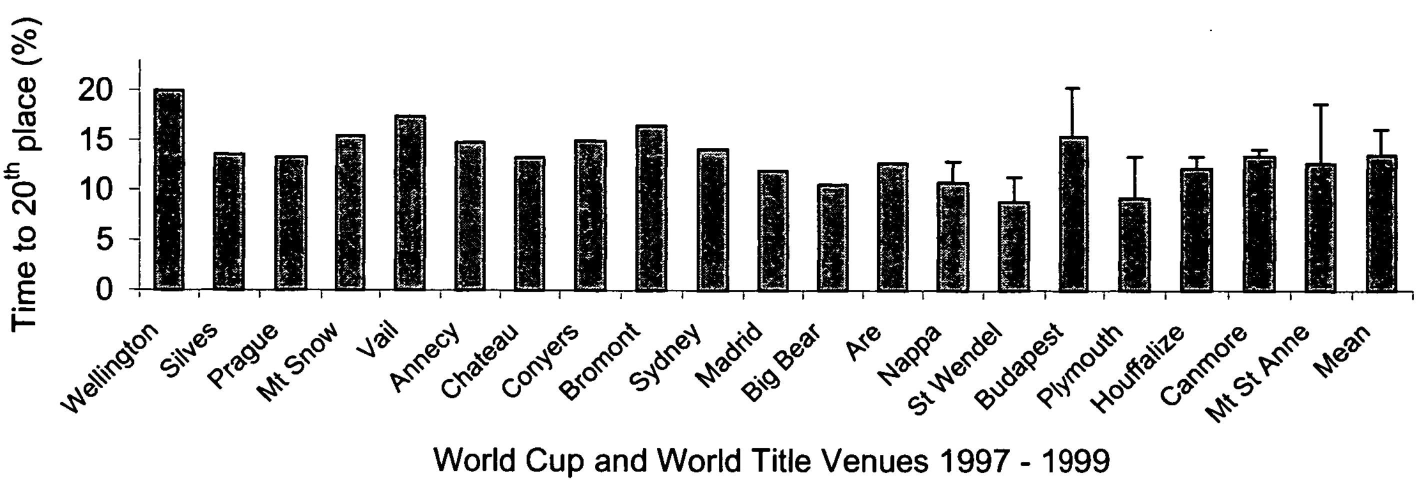

Figure 3.11. The women's individual race mean (± SD) and overall average percentages for time from 1st to 20th place, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

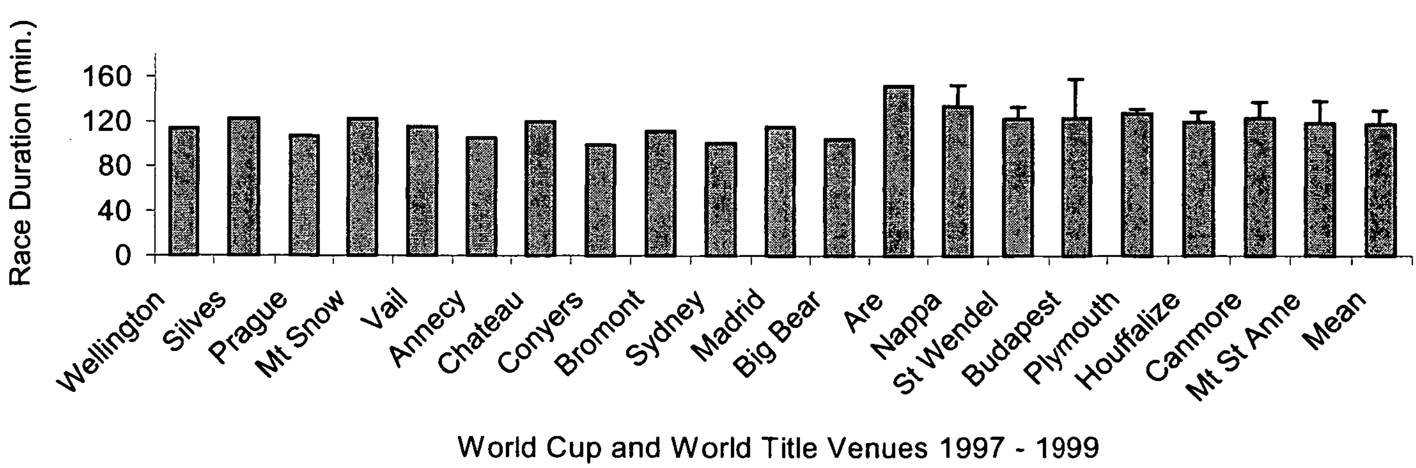

Figure 3.12. The women's individual race mean (± SD) and overall average winner's race speed, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

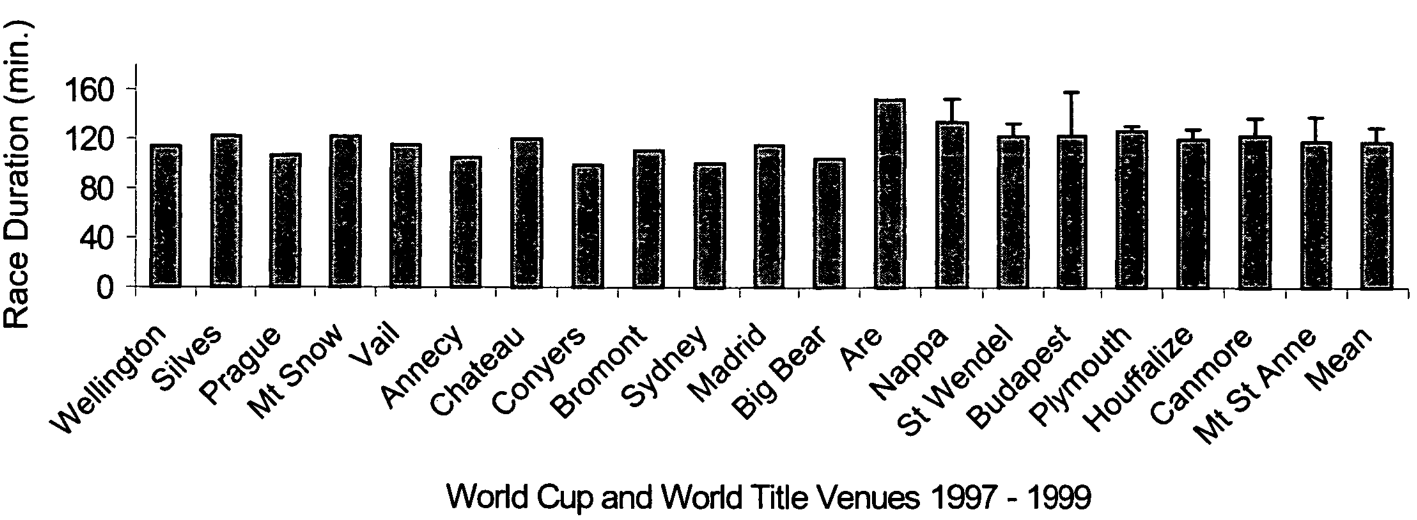

Figure 3.13. The women's individual race mean (± SD) and overall average winner's race duration, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

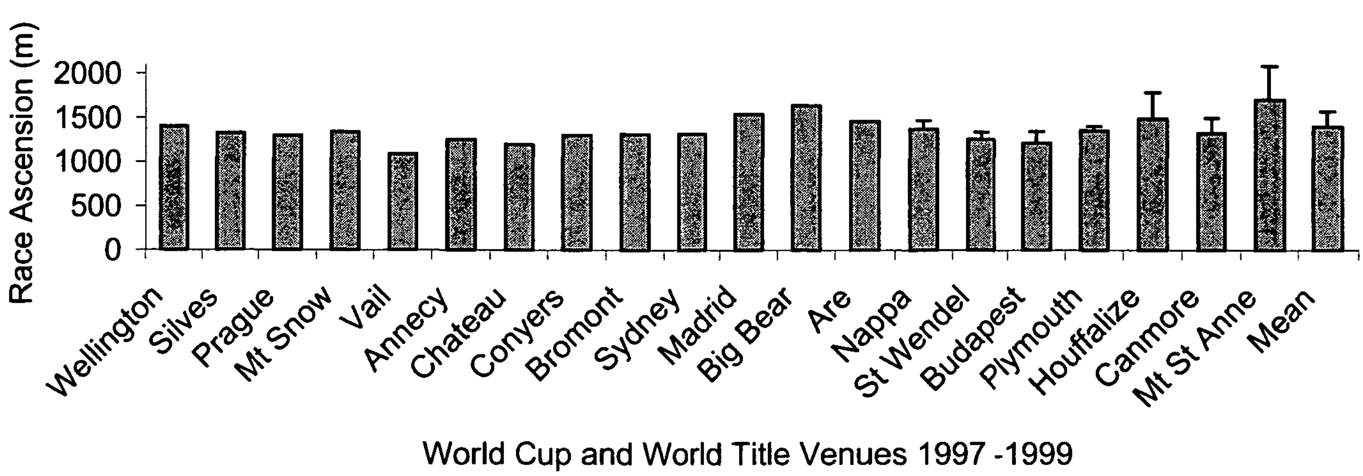

Figure 3.14. The women's individual race mean (± SD) and overall average race ascension, for the World Cup and World Title races during the mountain bike cross country seasons 1997, 1998 and 1999.

Discussion

To the best of the author's knowledge, this analysis is the first attempt to evaluate World Cup (WC) MTB XC race performance results, establish individual technical race-course characteristics and summarise the yearly and overall averages for three seasons of International races. This chapter verifies that elite XC race-courses have considerable volumes of climbing and furthermore, off road climbs are steeper and technically more difficult to ride than in road events. In addition to the climbing demands, it was observed that XC events are performed principally alone and span durations greater than 2 h. The race-course and event information suggests that low body mass may favour XC performance. Furthermore relative physiological test measures could therefore better explain XC performance than measures currently used in time trial (TT) research. It is therefore of interest to examine the line of thought that MTB XC may be reliant on relative physiological measures.

Physical race-course demands

It is generally held in a road race that climbing sections are more physiologically demanding than other parts of the race and may therefore be pivotal to the overall race outcome. It is expected that the climbing demands in an elite level XC race will be also an important consideration in success. The overall mean race gradient of ~4.1% for elite men's and women's races is high compared with the average gradient found in road races. In road events that include steep climbing sections (>7%), it is apparent that exercise intensity is maintained at high levels (Lucia *et al.* 1999). In Palmer *et al's.* (1994) investigation on massed start and ITT events on the road, it was observed that in a 5.5 km uphill TT that the average heart rate (HR) intensity was equivalent to 89% of $\dot{V}O_2$max. Furthermore, in Lucia *et al.* (1999) study of the HR response to riding the 3 week long Tour de France, it was reported that cyclists worked at an intensity >90% of $\dot{V}O_2max$ over the steepest category climbs such as the "Col du Tourmalet," which has a mean gradient of 7.4%. According to Lucia *et al.* (1999) such a high exercise intensity was maintained for periods of 30-40 min and often determined the final outcome of the 3 week long race. In road events uphill sections are critical in determining race outcome.

The average MTB XC race-course is approximately divided between climbing and descending demands per lap, the mean values for gradient can therefore be doubled for both the ascension and downhill segments. This equates on average to 4.6 km of uphill and downhill at an average percentage of 8.2%. However, it must be remembered that a XC races include many sections that are between 10-20%. According to Seifert and co-workers (1997) analysis of competitive MTB cyclists, a mean value of 92% of peak HR was reported whilst riding a XC uphill TT at a gradient of 8%. It may be assumed that the average WC and WT climbs elicits a similarly high percentage of peak HR. Such a HR response indicates that MTB XC events demand a high resistance to fatigue of type I muscle fibres and an ability to work near identified transition thresholds for extended periods of time. The mean race gradient is high in the MTB XC races studied and this would be expected to cause periods of high exercise intensity, which are physiologically demanding and thus, important in the race outcome.

In road individual time trial (ITT) events there appears to be an advantage to individuals who are taller and larger, whilst smaller riders tend to be more successful on long mountain passes (Stovall *et al.* 1993; Padilla *et al.* 1999; Lucia *et al.* 2001). An important consideration in climbing, in which body mass makes up a large part of the resistance, is how much power a cyclist can produce relative to his or her own mass. In cycling events that have a large amount of cumulative steep climbing, such considerations are essential for success in the event. International XC events have considerable climbing demands as seen by the high average race ascension of ~1942 m for elite men and ~1402 m for elite women. Although mountain Tour de France road stages may have greater aggregates of climbing (>4000 m) (Fernandez *et al.* 2000), elite XC cyclists are required to compete over a shorter race distance and thus climb proportionately more per race minute than road cyclists (13.8 m/min vs 8.75 m/min).

International XC competition places considerable climbing demands on the cyclist, requiring excellent cardio-vascular fitness, low body mass and high power to mass values. According to Swain (1994) a smaller cyclist excels on climbs because their advantage of a high relative $\dot{V}O_2max$ is greater than their overall energy cost. This concept is evident from Padilla *et al's* (1999) and Lucia *et al's.* (2000) investigations on professional road cyclists, whereby specialist uphill cyclists had the highest values for relative $\dot{V}O_2max$ (~81 $mL \cdot kg^{-1} \cdot min^{-1}$) and power to mass (~7.5 $W \cdot kg^{-1}$) compared to specialist flat riders. Given the substantial and consistent climbing demands that elite XC competition places on riders, similar relative $\dot{V}O_2max$ maybe expected at this level. Limited physiological test data exists on elite XC cyclists, however, according to Martin (1999) the relative $\dot{V}O_2max$ of a World Cup male winner is high at 86 $mL \cdot kg^{-1} \cdot min^{-1}$.

In regard to body mass some confirmation of the observation that elite MTB XC cyclists are small is apparent. In an analysis of the top 10 men and top 6 women for the 1999 XC WC standings, a mean body mass of ~64 kg and ~54 kg was recorded, respectively. These values are lower than reported for professional road riders at 68.9 ± 5.2 kg and are similar to the mass of uphill specialist road cyclists (62 ± 2.3 kg) (Padilla *et al.* 1999). Elite women's mass is lower to the values reported by Wilber *et al.* (1997) for 10 national female XC riders at 57.5 ± 4.7 kg. The 1999 number one and two male ranked World Cup XC cyclists have exceptionally low body mass of 59 and 51 kg, respectively. It is apparent that the climbing demands in elite XC races are considerable. Thus, body mass of <65 kg for elite men would appear advantageous in light of the climbing demands outlined. It's expected that elite XC riders will possess high relative physiological test values; however, further research is needed to confirm this assumption.

Event duration

It appears that MTB XC cycling requires considerable physical endurance and the capacity to resist the effects of fatigue. Whereas road cycling is conducted over considerably longer distances than international off road events (~2.5 h), XC races are approximately half the duration of a 200 km road race, but twice as long as a 40 km ITT. The duration of a XC race is substantial given the individual nature and amount of climbing encountered. The average elite XC race duration for men was ~141min and ~119 min for women, whilst the race distance for elite men was ~47 km and ~34 km for women, respectively. Thus, it appears that the average WC and WT race places substantial endurance demands on the XC cyclist by the length of the event alone. Furthermore, the average XC race intensity remains high, as according to Lee (1998) between 86 - 92% of HR peak is reported during XC racing. It must be also considered that the average race results are those of the winning athletes and that many XC competitors perform longer and therefore at slower speeds than their winning counterparts. For the 20th placed competitor this represents on average, an extra race time of 12 min for men and 20 min for women.

With regard to the women's race duration, the 2nd longest race was for the WC race in Budapest at 148 min in 1998. This race length was much longer than recommended by the UCI guidelines, despite the fact that the Budapest race had a moderate amount of climbing compared to the season average (~1216m vs 1402m). The long duration and subsequently low mean race speed at 14.9 km.hr was caused by wet weather and heavy ground conditions. Thus on some courses, wet conditions will increase the physical and technical demands of the event substantially and cyclist's pacing strategies may need to take this fact into account.

Race-course technical demands

Anecdotal reports claim that single track (ST) and technical downhill (TDH) place increased physical and technique demands upon cyclists, as compared to flat terrain cycling. It is also observed that some cyclists excel on courses that have a higher technical demand than those that require primarily climbing ability. The amount of ST and TDH constitutes a work demand unique to XC racing and should be taken into account in training or planning for an event. On average it was observed that the average amount of ST (~45%) and TDH (~9%) is considerable in WC and WT races. It is also claimed that cycling over obstacles and negotiating downhill sections causes increased upper body muscle recruitment, elevation of HR and increased energy expenditure (Berry *et al.* 1993; Seifert *et al.* 1997). Therefore, it's expected that a high percentages of ST and TDH would add to the moment by moment physical demands of the XC event. The overall amount of technical demand of an off road event must be considered as a significant stressor to the XC cyclist.

Continental comparisons

Traditionally international XC venues have been shared between Europe and North America and thus, it is of interest to analyse the differences and document trends between the continents. A significantly higher ($P<0.05$) mean gradient was observed for the women's North American XC events (~4.4%) compared to the European races (~3.9%). Similarly the men's mean race gradient was observed to be steeper for the North American races (~4.3% vs 3.9%, $P<0.102$). Further analysis of the races revealed that the North American races tended to be shorter than the European races, for both the men's (~45km vs 48 km; $P<0.10$) and the women's events (~35km vs 32km; $P<0.01$). In some cases North American venues tended to have more climbing and a shorter race distance than European events.

With regard to the technical differences between the WC and WT courses on the two continents, it was observed that there was 5% more ST for the North American courses (~48 vs 43%) compared to European race venues. It was observed for the study period, that North American races generally have steeper climbs, have slightly shorter race distances and have more ST than the European events, for both men and women. Although these differences may appear to be small, subtle variations between the continental races may need to be taken into consideration by athletes and coaches.

Seasonal comparisons

An overall 'average' race-course profile was determined over the 3 year study period, and further changes in the mean yearly course-profiles were observed also. The elite men's races during the 1999 season were significantly steeper ($P< 0.05$) on average than races held during the previous two years and also greater than the overall mean gradient.

Although a high mean race gradient was also reported in 1999 (~4.5%) for elite women, this increase was not significantly different to the previous two years. The higher mean gradient in 1999 for men was caused by the increase in total race ascension during that season (~1985 m). For the 1999 season a 6% decrease for the average race distance was observed, compared to the overall mean race duration (~137 vs 141 min). This finding suggests that although the race distance had decreased, the amount of climbing had remained high and male cyclists not only performed a large amount of climbing, but did so over proportionately steeper courses.

For elite women the average metres climbed per season increased between1997 to 1999 (~1282m vs 1442m), whilst 1999 race duration remained similar to the 3 year average (~119 min vs 120 min). The course profile for elite women has included a greater amount of ascension during a similar race time and hence, increased the gradient of the events. It appears that both the men and women are required to climb considerable aggregates and over steeper gradients during the 1999 WC and WT season. This change would suggest an increase in the physiological demands of racing at the international level.

Further trends are apparent when comparing the 1999 international XC season with the previous two. During the 1999 women's international XC season, the lowest average percentage of time to 20th place (~10.6%) was found to be significantly lower ($P<0.05$) to the 1998 (~14.4%) and 1997 (~13.6%) seasons. One explanation may be that the overall depth of the women's fields has improved, resulting in less time lost to the leading cyclists. This may be a reflection of improved training and performance despite a trend to more demanding races.

The percentage of time to 20th place for males is relatively low at 7.1% and this may be a reflection of the depth of talent in the men's races over the 3 year study period. This represents on average one race position every 30 seconds and underlines the closeness of racing at the elite level for men, despite event duration. It may be that only slight improvements in pacing strategy, technical skill and physical abilities can lead to improvements in race results.

The WC 1999 race in Canmore had the lowest average race speed at 15 $km.hr^{-1}$. However, this maybe explained by low temperatures and heavy rain leading up to the race causing slower speeds through the greater rolling resistance and more care needed through slippery sections. It was observed the percentage time to 20th place was negatively related to race speed ($r=-0.63$). This suggests that as a race becomes harder it takes more time to complete for all competitors. Races that are rain affected and or have high amounts of ascension probably slow the speed for all competitors.

Race venues

It is apparent for the race characteristics and cyclists results that considerable technical skill and physical fitness is required from the rider who aspires to compete at World Cup or World Title level. However, it is not only the overall, average seasonal or continental variations that the rider has to accommodate, but the substantial variations between race venues also.

The technical demands of the Olympic race venue in Sydney are much higher than those frequently encountered in World Cup races. The Sydney 2000 race-course has 26% of both FDH and TDH, which were the highest values reported for races surveyed. Other race venues, such as Mt St Anne and Big Bear, have as little as 4% FDH and TDH, respectively. The Mt St Anne venue has the highest amount of ST at 61%, whilst the Big Bear XC course has the lowest at only 25%. The Mt St Anne course is a tighter and technically a slower speed course than at Big Bear, which has much more open, flowing and fast descending sections. It can be seen that the technical demands vary greatly between race venues and therefore cyclists probably adjust their riding style and preparation accordingly.

The highest mean gradient for a race venue was reported for the Mt St Anne WT course at 5.09%. Along with a high percentage of ST, the Mt St Anne race-course can be regarded as a climbing and slow speed technical XC course. Whereas the St Wendel WC course with the lowest mean gradient of 3.5%, may be considered as a faster power XC race. Thus, consideration to the mean course gradient is important in the specific race preparation and overall race pacing strategies that the cyclist chooses.

The WC St Wendel XC race was consistently completed at the highest race speed of 23.2 km.hr, which was significantly faster ($P<0.05$) than the overall average speed. This is not surprising as the St Wendel WC course has the lowest average amount of vertical ascension of all the WC and WT race venues. This has implications for race preparation, as venues such as St Wendel place an emphasis on greater speed, less on steep climbing and more on tactical racing.

The greatest amount of climbing for the men and women was observed in the WC races at Madrid (2310m) and Big Bear (1620m), respectively. The lowest amount of climbing reported for men was at the WC race in Conyers (1710m), whilst for women it was recorded in the WC race in Vail (1090m). The amount of vertical ascension for individual races should be clearly taken into account in the pacing and training strategies employed by XC cyclists prior to the event.

Race calendar

Not only is the international race season run over two continents, but also the race calendar appears to be grouped into two periods of the year. In an analysis of the season layout, the first half of the season saw significantly fewer days ($P<0.05$) between races (5 per 51 d), compared to the second half of the season (5 per 96 d). The first half of the season demands faster recovery between events, whereas the second half of the season allows increased recovery time between races and more lead up time to prepare. Some cyclists choose to race for the highest overall WC position, whilst others peak for one or two events in the course of the year. Close consideration to the number of days between races and the time of the year will be important in optimising race results for both strategies.

Conclusion

World Cup and World Title events represent the highest level of MTB XC competition. This study was the first to analyse the MTB XC race-courses and events. Each season consists of between 9-11 races over approximately a 21 week period and involves extensive travelling. This chapter concludes that World Cup and World Title XC race-courses have a considerable amounts of climbing, a high mean percentage gradient and a long race distance. Furthermore international XC events have large percentages of single track, which probably contributes to the overall fatigue of the off road cyclist. Purpose built off road race-courses are subject to changes due to weather and field numbers. The technical requirements of elite level XC races probably place greater demands on the skill of a rider than their road ITT counterparts. The overall physical and technical demands of elite XC races are substantial. From this investigation it is possible to design a XC TT course that approximates the demands of elite off road cycling, and furthermore determine the effect of power to mass on performance.

4 Chapter Four - Physiological and Physical Responses of Riding a Simulated Mountain Bike Cross-Country Race-Course

Introduction

Mountain bike cross country (MTB XC) cycling has become a popular leisure activity and professional sport over a relatively short period of time. At the highest level, an eight-round World Cup competition exists, which runs over a seven-month period. A World Championship event is also held each year, and in 1996 and 2000 the sport of MTB XC racing was included in the Atlanta and Sydney Olympic Games, respectively. Research specific to MTB XC cycling is sparse and studies profiling the physiological and physical characteristics is lacking.

Successful sporting performance in off road cycling is determined not only by physiological parameters, but as well as one's technical skill level. It is important to measure the cyclist's physiological and physical responses during a XC time trial (TT) as well as determine the technique adopted when riding the course. Whilst individual time trial (ITT) and massed start road racing has been profiled and the determinants of success studied (Balmer *et al.* 2000, Coyle *et al.* 1990, Fernandez-Garcia *et al.* 2000, Lucia *et al.* 1999, 2001, Padilla *et al.* 1999, 2000), scarce research has been conducted into the sport of MTB XC.

Off road racing may be thought of as being similar to road ITT events, as racing is individual and does not have the element of pack riding that is found in massed start road cycling. Hawley and Noakes have shown a strong relationship (r= - 0.91) between peak power output (PPO) obtained from an incremental cycle test and 20km ITT time. Whereas the idea that body mass is less important in flat ITT performance is observed by

Coyle *et al.* who report a weak correlation between mean 40 km ITT and relative $\dot{V}O_2max$ (r = – 0.39). As XC events are largely ridden individually and have large amounts of time spent climbing (Mac Crae *et al.* 2000), it's expected that physiological measures relative to body mass will relate to XC performance more strongly than PPO currently reported in ITT research.

Variances during competition in power output, percent of peak heart rate (HR) and cadence have been extensively investigated in the more traditional forms of cycling such as TT's, massed start road and cyclo-cross races (Lucia *et al.* 1998, 1999; Palmer *et al.* 1994, Hansen *et al* 1996). According to Padilla *et al.* (2000) research on professional cyclists (n=18) in flat ITT events (28.0 ± 8.6 km), riders performed with a low variation in power output (± 7%). In comparison, studies by Martin (1997) and Schoberer (1998) of single XC cyclists suggest that power output during XC events is more highly variable.

The marked influence of terrain type and gradient on the work demands of an off-road cyclist is illustrated by a study by Hansen and co-workers. (1996). In an analysis of elite cyclo-cross riders (n=3), measured power output related to 86% of $\dot{V}O_2max$ after riding steep gradients (5-8%) and power output increased to 800-900W following dismount sections. These values are higher than the mean power output of 362 ± 59W in professional road cyclists performing ITT's (28.0 ± 8.6 km) (Padilla *et al.* 2000). As a MTB XC race-course has a range of different terrains, it's also expected that a cyclist's power output will be influenced by the rise and fall of the terrain.

The effect of suspension systems on performance has been investigated (Berry *et al.* 1993, Seifert *et al.* 1997, Mac Crae *et al.* 2000) and laboratory test comparisons between national level XC and road cyclists have been published (Wilber *et al.* 1997). Despite XC racing coming of age as an Olympic sport, it has not been as extensively investigated as other cycling disciplines. This may have been due to the youthfulness of the sport and /or the technical difficulty of measuring power output in the field. The aim of this chapter is to profile the physiological responses and physical demands of completing an off road TT, and to document the technique adopted in accomplishing that task. An additional aim is to elucidate whether selected physiological variables are indicative, or predictive of overall performance.

The specific purposes of the research in this chapter include:

- Establishing the physiological responses of a group of riders racing over a simulated MTB XC course.
- Document the physical responses of riding over a simulated MTB XC course.
- Ascertain the technical way a trial course is ridden.
- Determine the relationships between physiological measures established during lab testing and performance over the XC TT course.
- Outline the differences in physiological and physical responses according to lap position and terrain gradient.

Methods

Subjects

Eleven subjects, of regional and national level participated in this research. Prior to testing subjects were briefed and the following physical characteristics measured: age 25 ± 5 y, height 180.2 ± 3.5 cm, body mass 71.6 ± 6.3 kg and sum of 7 skinfolds (biceps, triceps, subscapular, supraspinale, abdomen, thigh and calf) 51 ± 14.8 mm (TEM%, 2.1) (Harpenden, Burgess Hill, England) (Norton *et al.* 2000). The mean percentage body fat was 9.2 ± 2.8%, calculated from the sum of seven sites and converted to a population specific percentage value (Withers *et al.* 1987). All testing procedures were explained to each cyclist, and their written informed consent was obtained before participation. The Human Ethics Committee of the University of Tasmania approved all testing procedures, which conformed to ASCM standards. All subjects had been engaged in at least 12 weeks of continuous endurance training prior to the field and laboratory assessments. The subjects completed a progressive cycling maximum test (CMT) on day one. Following a 48 h recovery period, subjects then completed a 15.5 km XC TT on a circuit that included elements of a world class XC course.

Cycle maximum testing (CMT)

The CMT was conducted on an electrically braked cycle ergometer (Lode Excalibur Sport v 1.5, Groningen, Netherlands), modified with clip-less pedals and drop handlebars, interfaced to a Lode B Work load Programmer. Before the CMT commenced the saddle height and handlebar position of the bicycle ergometer were adjusted to each of the subject's personal measurements. Immediately prior to the commencement of the CMT a warm up was conducted on the ergometer for 10 min at a power output of 75W. CMT consisted of five-min stages commencing at 100W and increasing by 50W until either cadence fell below 75 rpm, or volitional exhaustion. Expired gas was collected continuously during CMT and analysed with a Quinton Metabolic Cart (QMC, Seattle, USA). Maximal aerobic uptake was defined as the highest oxygen consumption (VO_2) obtained during two consecutive 30-s periods. At the completion of each 5 min interval, two blood samples were taken from the finger via capillary tubes (approx 2 x 30 μL) and analysed for blood lactate in duplicate with a lab (YSI 2300, YSI Incorporated, Yellow Springs, USA) and portable lactate analyser (Accusport, Boehringer-Mannheim, Mannheim, Germany). At the completion of each 5 min stage ratings of perceived exertion (RPE; 6-20) were taken (Borg and Noble 1974). Heart rate was recorded by telemetry (Polar Advantage, Kempele, Finland) during the last 15 seconds of each 5 min interval and the peak HR was also recorded. Peak blood lactate concentration was determined by taking consecutive samples immediately post test at 1 min intervals.

From these data, PPO was calculated using the following formula from Kuipers *et al.* (1985).

$$P@\dot{V}O_2max = P_P + (t_f \times (V_f - P_p/5\ min))$$

Where P_P was the power output of the previous stage, V_f is the power output of the final stage and t_F is the time (min) at final power.

In addition, a correction factor was devised for the Accusport:

$$Y\ (YSI) = -1.574 + 1.155 * X\ (Accusport)\ (r = 0.98)$$

Cross country time trial course

Course elevation and terrain profile

Field-testing consisted of 6 laps of a 2.58 km XC course with a total elevation gain of 104 m per lap. This course included characteristics similar to the average of 29 World Cup (WC) MTB XC courses surveyed prior to the study (Figure 4.1). An 'average' WC course profile could not be constructed logistically and in addition WC technical content varies significantly between events (ST ± 23.5%). This research is the first to quantify and include WC technical components in a trial, with previous authors concentrating on laboratory trials (Berry *et al.* 1993), uphill only trials (Mac Rae *et al.* 2000) or un-quantified outdoor trials (Seifert et al. 1997). The TT course contains some differences to the mean WC courses surveyed (ST – 62.3 vs 44.6%; OT – 38.7 vs 55.4%), however it's expected the physiological responses of completing the trial (~1 h) will not be adversely affected by these differences.

Prior to the XC TT's, the entire race-course was measured and categorised as follows. The slope and category were determined for every 10m of the XC TT course, with 258 measurements made on this basis. The overall lap and 10m segments were measured with a calibrated surveyors wheel, whilst the slope was calculated with an inclinometer. For a given terrain category the course slope, distance and location was matched to the SRM™ data downloaded from the XC TT. Power output, speed, cadence and speed was then related to the given terrain category based on gradient.

Table 4.1. Summary of the world cup MTB XC course characteristics.

Course Details	World Cup Mean (n=29)	World Cup Minimum	World Cup Maximum	± SD
Lap distance (km)	8.90	6.2	15.7	1.94
Race duration (min)	140:23	114:53	158:58	11:32
Lap ascension (m)	353.8	250	545	66.9
Total race ascension (m)	1935.8	1520	2416	220.2
Total distance (km)	48.04	32	56	4.80
Mean gradient (%)	4.13	3.38	5.50	0.61
Single track (%)	44.6	27	61	10.50
Open track (%)	55.40	39	73	10.50
Technical DH (%)	8.1	4	15	3.3
Fast DH (%)	12.4	5	25	5.6

DH, Downhill.

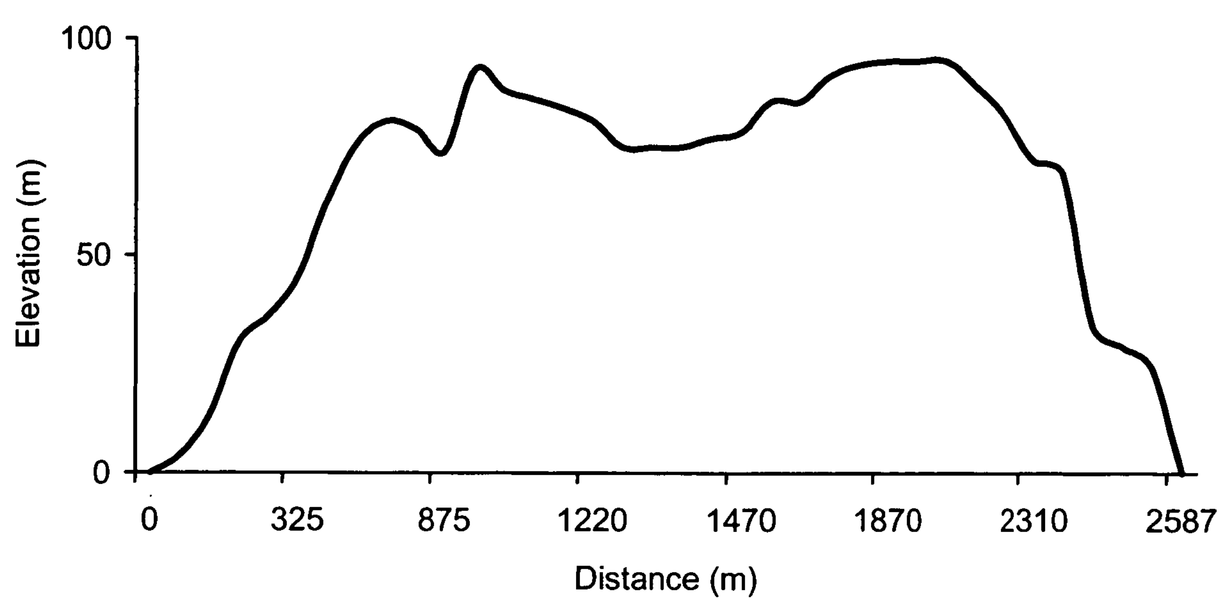

Figure 4.1. Cross country TT profile and lap distance. The XC TT course was constructed to include the approximate characteristics of the summary of World Cup and Title race-courses.

The XC TT was conducted on an 18 inch carbon fibre MTB (Giant, MCM1, Taiwan), which was fitted with SRM™ power cranks (Schoberer, Welldorf, Germany) and front suspension forks (Rock Shox, San Jose, USA). The front wheel circumference was measured and the value was entered into the SRM™ Powermeter™ prior to the start of the TT. Each subject completed the XC TT on the same bicycle and wheels with a constant tire pressure (front 40 psi, rear 45 psi). The saddle and stem lengths were adjusted to accommodate each cyclist's height and reach, and the SRM™ crank was set to zero before the start of each XC TT. Cyclists completed a full lap of the XC TT course at a moderate pace as a warm up, followed by six laps at race pace. Power output, HR, cadence and speed were recorded continuously at one-second intervals on the SRM™ system for the duration of the TT.

At the completion of each lap, cyclists paused for approximately 30 s, whereupon a blood sample was taken from the finger via capillary tubes and pipetted (20 μL) onto a test strip for blood lactate analysis (Accusport, Boerhinger–Mannheim, Mannheim, Germany). These values were later corrected with the regression equation established from CMT. At the same time RPE (6-20 scale) (Borg and Noble, 1974) and lap times were recorded. Temperature and relative humidity were also measured and recorded for each lap from a portable probe (Mini-mitter, Oregon, USA). Following completion of the XC TT, the set position of the SRM™ was recorded and the subject warmed-down over the next 10 min on the MTB cycle.

Course analysis

The XC TT course was divided up into eight discrete terrain categories in order to determine if a cyclist's technique or physiological response varied between the terrain types encountered during the XC TT. The terrain types were grouped into three ascent, two flat and three descent categories. Thus the categories include "15-20% Ascent", "10-15% Ascent", "5-10% Ascent, "5-10% Descent", "10-15% Descent", "15-20% Descent" and "Post Hill Flat" and "Post Tech Flat."

SRM™ calibration

Prior to the XC TT the SRM™ power cranks were calibrated. The SRM™ system uses a modified cycle crank which measures power output via strain gauges that sit between the chain rings and the crank arm (175 – mm) and relays information to a computer mounted on the handlebars. The SRM™ cranks were mounted on a fan braked Hays ergometer (South Australian Institute of Sport, Adelaide, Australia) in place of the normal cycle cranks. One month prior to the SRM™ calibration trial the Hays ergometer was tested via the procedure outline by Woods *et al.* (1994) on a dynamic calibrator located at the South Australian Institute of Sport and was found to have an accuracy of ± 2% for measured power output.

The SRM™ was zeroed and set to record at a frequency of 1 hz. A subject then pedaled the ergometer for 5 min at constant power output of 50W, rested for 1 min and then repeated the procedure increasing the power output by 50W to a peak of 450W. After a 5 min break the subject pedaled the ergometer for a further 2 min period at 550W and 650W. Following testing, the power outputs from the SRM™ crank and Hays ergometer were downloaded and saved to a portable computer.

A correction factor was determined from the regression equation between the SRM™ crank and Hays ergometer power reading and found to be:

Y (Hays power) = 10.546 + 1.04 * X (SRM power)

Sweat rate, blood sample collection and analysis.

Prior to the start and at the completion of the XC TT, subjects body and water bottle mass were recorded. Along with ride time and change in total mass, sweat rate was calculated at litres per hour. Twenty min before the field trial a 10 ml resting venous blood sample was taken, spun down and frozen for later enzymatic assay (Technicron RA 1000, New York, USA) for catalytic activity of lactate dehydrogenase (LDH) and creatine kinase (CK). Thirty min and 24 h after the completion of the XC TT a further 10 ml venous blood sample was taken, spun down and also frozen for later analysis of LDH and CK catalytic activity. Prior to and at the conclusion of the XC TT haematocrit and haemoglobin values were determined by the cyanmethaemoglobin auto analysis method (Sysmex K 1000, Kobe, Japan) from which change in plasma volume was calculated according to the formula by Costill and Fink (1974).

Lap analysis

Four lap categories were determined for analysis and comparison. As the riders completed six laps of the XC TT course, results from laps one and two and three and four where averaged and termed the first lap and mid lap. These combined laps where compared to the second last lap and the last lap of the XC TT. The average power output, cadence, HR and speed for each of the terrain types were also calculated for each individual 'lap' and over the entire XC TT.

Statistical analyses

Descriptive statistics are expressed as means and standard deviation (± SD). The SRM™ Power Meter™ data was downloaded, saved and graphed on a PC (Figure 4.2). Using the SRM™ graphing software (V 6.00e) individual laps and terrain types were analysed and categorised. Power, $\dot{V}O_2$, HR and blood lactate concentration at modified IAT (Bourdon, 2000) were determined using the log-log transformation method (Beaver *et al.* 1985) from CMT data. To examine the relationship between CMT physiological measures and XC TT performance, Pearson's product moment correlations were performed (Sigma Stat, version 2.03, USA). Significance level was set at $P<0.05$. Repeated measures ANOVA was used to investigate the physical and physiological differences between the terrain categories; the *post-hoc* Bonferroni test was applied. Paired t-tests were employed to determine the differences in the physical and physiological values between the XC TT and CMT and to compare the change in CK, LDH and PV pre and post TT. Significance for ANOVA and paired t-tests was set at $P<0.05$.

Results

Subject characteristics and CMT results

The results of the laboratory CMT are outlined in Table 4.2. Relative $\dot{V}O_2max$ was measured at 67.1 ± 3.6 mL kg^{-1} min^{-1} and at PPO 367 ± 35W.

Off Road TT conditions and selected physiological responses.

Post XC TT blood enzyme catalytic activity showed significant increases (P<0.05) between rest and 24 hours post values for CK and LDH, respectively (Table 4.3). Mean XC TT blood lactate concentration was significantly (P>0.05) higher than calculated at IAT (8.1 mmol·L^{-1} ± 2.1 vs 4.0 ± 1.0 mmol·L^{-1}).

Off road TT performance.

When subjects performed the off road TT significant differences (P<0.05) were found between the CMT for cadence and blood lactate concentration at IAT (Table 4.4).

Table 4.2. Selected data from the cycle maximum test (CMT). Values are means (± SD).

Variables	**Mean**	**± SD**
Peak power output (W)	367.5	32.0
Peak power:mass ($W \cdot kg^{-1}$)	5.1	0.4
$\dot{V}O_2max$ ($L \cdot min^{-1}$)	4.5	0.5
$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	64.7	8.2
Peak HR (bpm)	191	7
Peak lactate concentration (mM)	12.3	1.8
Peak RPE (6-20)	19	1
Power:mass @ IAT ($W \cdot kg^{-1}$)	4.3	0.3
Power at IAT (W)	309.5	27.8
HR at IAT (bpm)	173	8
Blood lactate at IAT (mM)	3.9	1.0
RPE at IAT workload (6-20)	17	1
Cadence (rpm)	89 †	4

$\dot{V}O_2max$, Maximal oxygen uptake; HR, Heart rate; IAT, Individual anaerobic threshold; RPE, Ratings of perceived exertion; Cadence, Pedal revolutions per minute.

† Mean cadence determined from all CMT workloads completed.

Table 4.3. Off road TT conditions and physiological responses. Values are means (± SD)

Variables	Mean	± SD
Temperature (°C)	13.5	2.4
Relative humidity (%)	70.7	11.2
Heat rate (bpm)	174	7
Blood lactate concentration (mM)	8.2 *	2.85
Sweat rate (L˙h)	1.387	0.491
Pre CK (μl)	136.9	83.9
20 h post CK (μl)	219.8 **	120.9
Pre LDH (μl)	161.2	45.4
20 h post LDH (μl)	206.6 **	59.1
Change in plasma volume (%)	2.34	.03
RPE (6-20)	17	1

CK, creatine kinase; LDH, lactate dehydrogenase; RPE, ratings of perceived exertion.

* Denotes a significant difference between field trial blood lactate concentration and CMT peak lactate concentration and at IAT ($P<0.05$).

** Denotes significant differences between pre test resting and 20 hours post blood enzyme activity of CK and LDH ($P<0.05$).

Table 4.4 Selected physical responses from the off road TT and course characteristics. Values are means were shown (± SD)

Variables	**Mean**	**± SD**
Trial duration (min s)	61:33	6:12
Speed (km·hr)	15.3	1.5
Trial power (W)	315.4 †	39.5
Time freewheeling (%)	17.4	3.9
Cadence (rpm)	53.2 *	3.7
Cadence (rpm)	62.8 * †	4.8
Lap distance (km)	2.58	
Lap ascension (m)	104	
TT ascension (m)	624	
TT distance (km)	15.5	
Mean lap gradient (%)	4.0	
Single track (%)	62.3	
Open track (%)	38.7	
Technical DH (%)	9.4	
Fast DH (%)	16.2	

DH, Downhill; TT, Time trial.

* Denotes a significant difference to CMT mean cadence ($P < 0.05$).

† Denotes XC TT power output and cadence calculated with descending portion omitted

Correlations between CMT and XC TT results.

Physiological measures related to mass were strongly correlated to off road TT performance (Table 4.5). Significant relationships ($P<0.01$) were observed between PPO to total mass (body, cycle, helmet, SRM™, shoe mass....) ($r= -0.93$; $P<0.01$), PPO to body mass ($r= -0.86$; $P<0.01$), relative VO_2max ($r= -0.81$; $P<0.01$) and power to mass at IAT ($r= -0.78$; $P<0.01$) and XC TT time. The relationship between absolute VO_2max, PPO and absolute VO_2max, were less strongly related to XC TT time.

Off road TT terrain categories.

ANOVA showed a global effect of terrain category (based on gradient) on TT power output, cadence and speed with significantly different ($P<0.01$) values recorded between all terrain categories (Table 4.6). The highest mean HR was reported for "15-20% Ascent" category which was significantly greater ($P<0.01$) than "10-15% Ascent", "Post tech flat", "Post hill flat " and "15-20% Descent" categories.

Furthermore, the mean "Post tech flat" category was significantly greater ($P<0.01$) than the average HR reported for "10-15% Ascent", "5-10% Descent", "10-15% Descent" and "15-20% Descent" categories, whilst the "Post hill flat" category HR was also greater ($P<0.01$) than "10-15% Ascent", "5-10% Descent", "10-15% Descent" and "15-20% Descent" categories.

Table 4.5 Cycle maximum test (CMT) physiological measures and their relationship to off road TT performance.

Variables	PPO:Total Mass ($W \cdot kg^{-1}$)	PPO:Mass ($W \cdot kg^{-1}$)	$\dot{V}O_2max$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	PO: Mass	$\dot{V}O_2$@ IAT	$\dot{V}O_2max$ ($L \cdot min^{-1}$)	PPO (W)	Sum of 7 Skinfolds (mm)
TT Time	-0.93 *	-0.86 *	-0.81 *	-0.76 *	-0.75 **	-0.66 **	-0.64 **	0.632 *
TT Speed	0.93 *	0.85 *	0.80 *	0.78 *	0.76 *	0.66 **	0.64 **	-0.63 **
Ascending TT Time	-0.87 *	-0.83 *	-0.72 **	-0.73 **	-0.61 **	-0.67 **	-0.61 **	0.65 **

* Denotes significance level ($P<0.01$)
** Denotes significance level ($P<0.05$)

PPO : Peak power output; PO : Power output; Total mass, Body, bike, helmet, shoes and SRM™ mass; PO:mass, Power output to body mass; IAT, Individual anaerobic threshold; $\dot{V}O_2max$, Maximum oxygen uptake.

Table 4.6. Terrain category comparison for selected response taken from the XC TT. Values are means (± SD).

Variables	Speed (km·h)	PPO (W)	% PPO (%)	HR (bpm)	% Peak HR (%)	Cadence (rpm)
15-20% Ascent	**7.6 ± 0.91**	**419.8 ± 39.7**	**115.1 ± 8.2**	179 ± 8 *	93.8 ± 2.6 *	**57.7 ± 5.6**
10-15% Ascent	**9.9 ± 1.2**	**372.6 ± 48**	**102.2 ± 9.5**	173 ± 8	90.6 ± 3.4	**61.8 ± 7**
5-10% Ascent	**11.6 ± 2.2**	**326.8 ± 44.8**	**89.2 ± 7.6**	178 ± 7 +	93 ± 2.2 +	**67.9 ± 6.3**
Post Hill Flat	**10.9 ± 1.1**	**306.6 ± 39.8**	**85 ± 7.2**	178 ± 7†	93.4 ± 2 †	**71.8 ± 6.9**
Post Tech. Flat	**18.4 ± 2**	**257.4 ± 31.4**	**71.7 ± 7.8**	177 ± 7 **	92.4 ± 3 **	**74.3 ± 5.6**
5-10% Descent	**20.7 ± 2.3**	**64.7 ± 27**	**18.2 ± 13.6**	168 ± 9	87.8 ± 3.6	**49 ± 13.6**
10-15% Descent	**22.7 ± 2.6**	**33.1 ± 14.9**	**10.6 ± 10.8**	152 ± 9	79.6 ± 4.5	**27.6 ± 9.2**
15-20% Descent	**19.4 ± 2.8**	**19.4 ± 2.8**	**17.6 ± 22.9**	150 ± 9	78 ± 4.4	**6.4 ± 12.1**

PPO, Peak power output; HR, Heart rate; % PPO percentage of peak power output (obtained from category PO / CMT PPO).

old values represent significant differences between all terrain categories (P=< 0.01)

Significant differences (P<0.01) between 15-20% Ascent and 10-15% Ascent, 5-10% Ascent, 10-15%, 10-15% Descent and 15-20% Descent.

Denotes significant differences (P<0.01) between 5-10% Ascent and 10-15% Ascent, 5-10% Descent, 10-15% Descent and 15-20% Descent.

Denotes significant differences (P<0.01) between Post hill flat and 10-15% Ascent, 5-10% Descent, 10-15% Descent and 15-20% Descent.

Denotes significant differences (P<0.01) between Post tech flat and 10-15% Ascent, 5-10% Descent, 10-15% Descent and 15-20% Descent.

Cross-country TT Lap Analysis.

1st lap mean blood lactate concentration (8.8 ± 2.3 $mmol \cdot L^{-1}$) was significantly higher than 2nd last (6.9 ± 2.5 $mmol \cdot l^{-1}$; P<0.05) and last laps (7.2 ± 2.6 $mmol \cdot L^{-1}$; P<0.05) (Figure 4.3).

There was no significant variation (P>0.05) in average HR from one lap to another. The perceived exertion recorded during the last lap was significantly higher (18 ± 1) than the RPE measured during the 1st (15 ± 2; P<0.01), mid (15 ± 1; P<0.01) and 2nd last laps (17 ± 1; P<0.05) (Figure 4.5).

Figure 4.6 shows lap one cadence was significantly higher (66 ± 5 rpm) than mid lap (62 ± 4 rpm; P<0.01), 2nd last lap (62 ± 4 rpm; P<0.01) and last laps (61 ± 5 rpm; P<0.01).

Figure 4.7 outlines that the 1st lap was ridden at a significantly faster speed than the mid (14.7 ± 1.5 km hr; P<0.01) and 2nd last laps (14.6 ± 1.5 km hr; P<0.01).

As shown in figure 4.8, mean lap power output recorded during the 1st (337.1 ± 38W) and mid laps (331.1 ± 39W) was significantly higher to the power output measured during the 2nd last (306 ± 41W; p<0.01) and last laps (315 ± 37W; p<0.01).

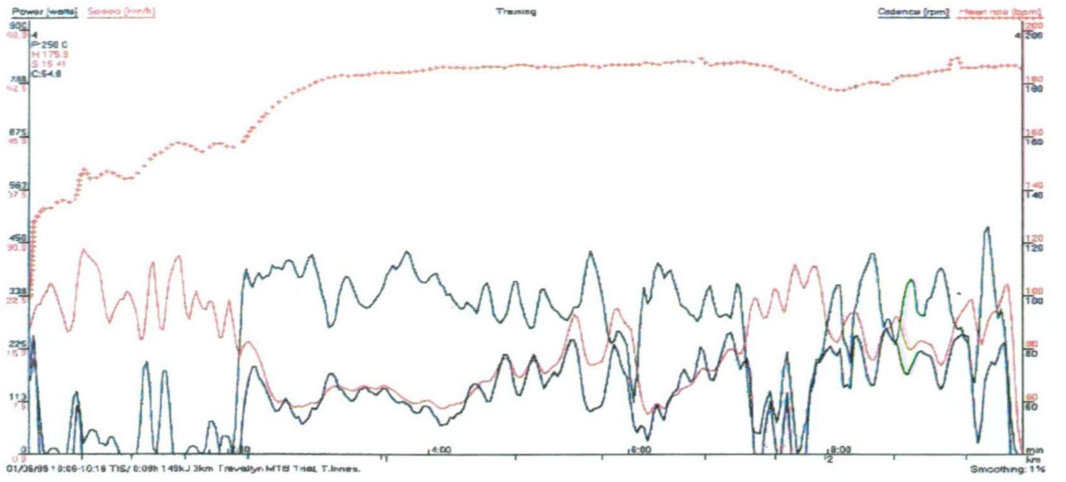

Figure 4.2 SRM graph of power (green line), speed (pink line), cadence (blue line) and HR (red line) taken from a single lap of the MTB XC trial course.

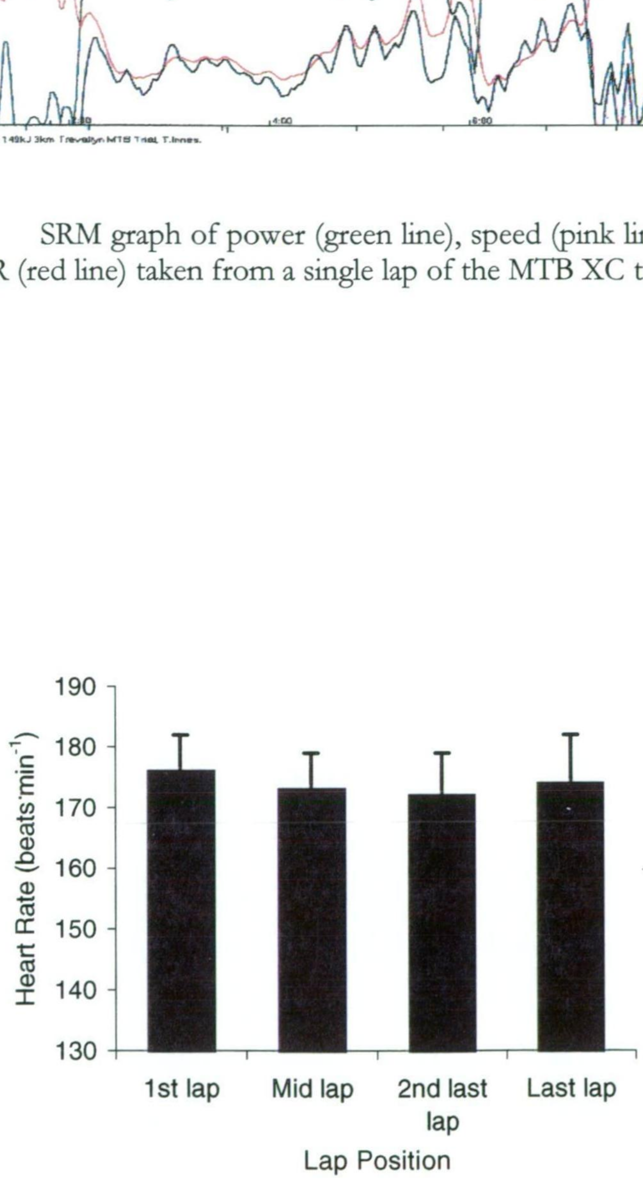

Figure 4.3 Values are means (± SD). Blood lactate values taken from the XC TT for each lap position.

* Denotes a significant difference (P<0.01) between 1st lap, 2nd last lap and last lap.

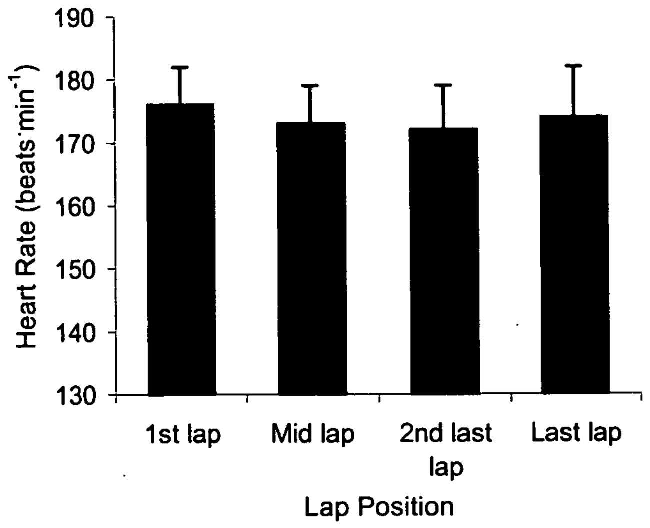

Figure 4.4 Values are means (± SD). Mean heart rate values taken from the MTB XC TT for each lap position.

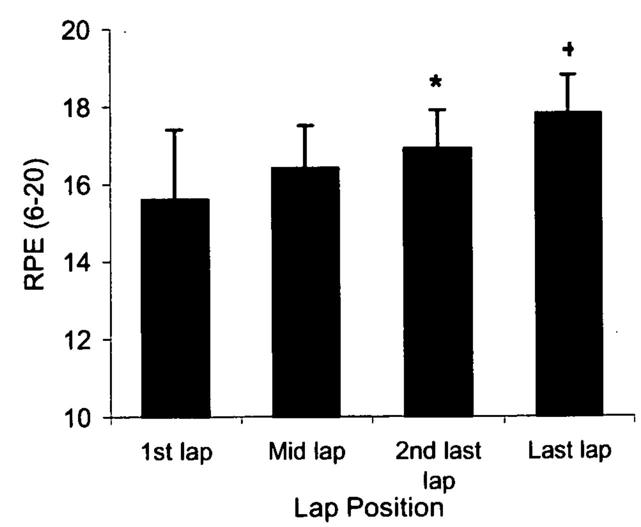

Figure 4.5 Values are means (± SD). Ratings of perceived exertion for each lap category.

* Denotes a significant difference ($P<0.01$) between the 2nd last lap and last lap.

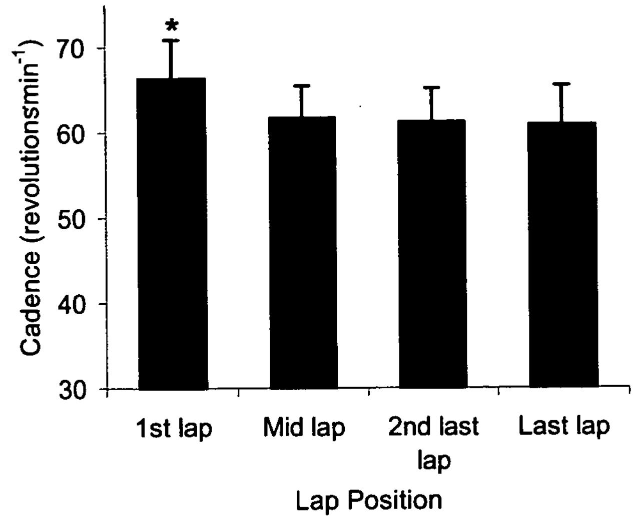

Figure 4.6 Values are means (± SD). Average values for pedal cadence during the MTB XC TT for each lap category.

+ Denotes a significant difference (P<0.01) between the last lap, 1st lap, Mid lap and the 2nd last lap.

* Denotes a significant difference (P<0.01) between the 1st lap, the Mid, 2nd last and last laps.

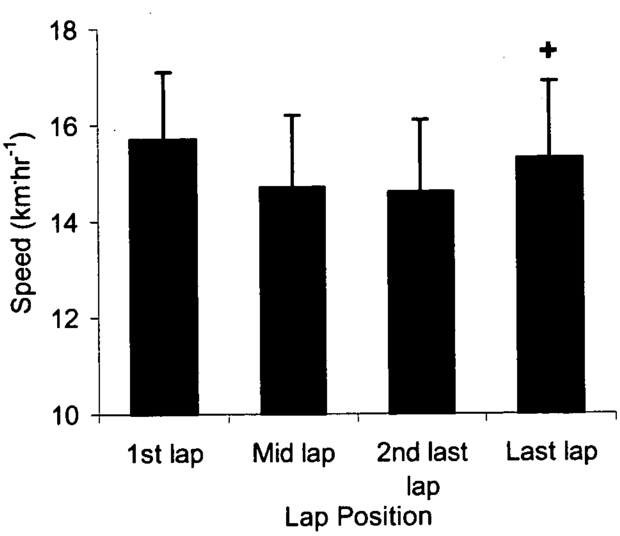

Figure 4.7 Values are mean (± SD). Average values for lap speed from the MTB XC trial.

* Denotes a significant difference (P<0.01) between the 1st lap, mid and 2nd last laps.

+ Denotes a significant difference (P<0.01) between the last lap, mid lap and 2nd last laps.

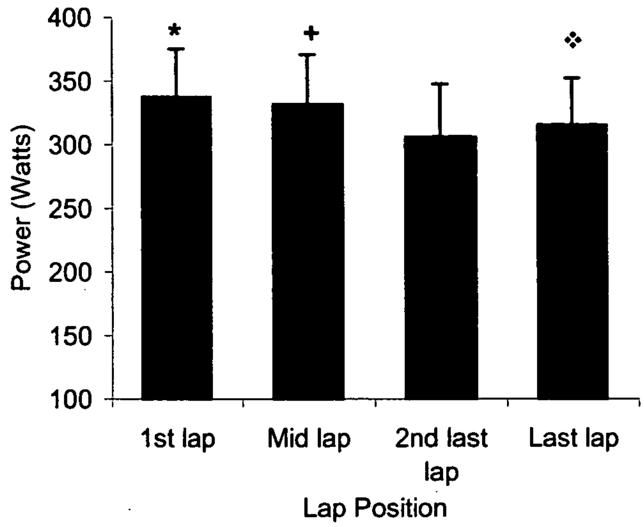

Figure 4.8 Values for average power output for each lap category. Values were determined from the XC TT. Values are Mean (± SD).

* Denotes a significant differences ($P<0.05$) between the 1st lap, 2nd last lap and last lap.

\+ Denotes a significant difference ($P<0.05$) between the mid lap, 2nd last lap and last lap.

❖ Denotes a significant difference ($P<0.05$) between the last lap and 2nd last lap.

Discussion

This study established strong relationships between CMT variables relative to mass and XC TT performance. An apparent finding of this investigation is that on average, an off road TT of approximately 60 min duration elicits high exercise intensity, coincident with measures at IAT. Furthermore it was observed that selected physical and physiological measures varied considerably according the marked influence of gradient during the off road TT.

Cycling maximum test and TT relationships

A major finding of this research was the strong relationship between relative physiological measures determined from CMT and XC TT performance measured by the SRM™ system. The strongest relationship was observed between TT time and PPO to total mass (r= -0.93). This outcome may be due to the amount of climbing and the variable power output caused by the steep gradients encountered in the XC TT, and is contrary to current road ITT research. In a study by Balmer *et al.* (2000), trained cyclists (n=16) underwent a 16.1 km ITT and CMT, with a strong relationship between PPO and ITT power output (r=0.99) established. In the current examination however, a weaker relationship was observed between PPO and XC TT speed (r= 0.64). It is of note that Hawley and Noakes (1992) report a weaker relationship (r= -0.68; P<0.01) between 20km ITT time and PPO expressed as watts per kilogram. These differences indicate that whilst absolute values are a good basis for predicting road ITT performance, relative measures provide inadequate performance estimates, contrary to the results of the road TT's. The difference between these results may be explained by the considerable climbing demands of the XC TT that were largely absent in the ITT research reviewed. Thus, the relative measure of power to mass appears to be an important determinant in describing overall XC TT performance. Theoretically a high power to mass ratio of an XC cyclist would indicate an ability to produce fast lap times.

A strong relationship was found to exist between relative $\dot{V}O_2max$ and XC TT time (r= -0.81; P<0.01). This outcome contrasts against findings reported for highly trained cyclists (n=15) for the relationship between relative $\dot{V}O_2max$ and a 60 min laboratory based TT performance (r= -0.39) (coyle *et al.* 1991), whilst Bentley *et al.* (1998) report a similarly weak relationship (r= 0.58) between relative $\dot{V}O_2max$ and a 40 km ITT performance in trained male triathletes (n=10). The correlation between relative VO_2max and TT time was -0.81 and the likely range was -0.41 to -0.89. Whereas relative VO_2max does not seem to predict road ITT performance well, it appears to have been a stronger determinant in the XC TT examined. This finding reinforces the importance of relative physiological measures in describing XC TT performance.

Overall effect

It appears that completing the off road TT elicited both steady state and intermittent responses. Measures such as HR indicate the global demand of the trial, whilst analysis of power output reveals the variable loading pattern during the XC TT.

Variable power output

During flat road ITT's the power output can be considered to be largely steady state. According to Foster *et al.* (1992), variation in velocity during a flat ITT results in the slower completion time compared to maintaining a constant power output. During the

XC TT's cyclists were observed to increase power output on ascents and reduce effort on descents. This was caused by technical and gradient changes that caused cyclists to vary power output to a greater extent than seen in road ITT's. Hansen and co-workers (1996) report similar increases in power output due to alterations in gradient and technical demand. Large differences ($P<0.05$) in percentage of PPO were observed between the flat (~72%) and steepest (~115%) uphill terrain categories in this investigation. This outcome appears to agree with Swain's (1997) ITT modeling, which claims for undulating events that performance time is decreased when a strategy of greater power output on uphill sections is employed. It appears that the cyclists in this study responded with variable power output, producing high values on the steepest sections and reducing effort during technical and descent portions of the course.

Blood lactate response

The XC TT elicited a high mean blood lactate concentration (~8.2 mM), which was significantly greater ($P<0.05$) than the blood lactate concentration calculated at IAT (~4.0 mM). It was apparent during the XC TT that a work rate above IAT blood lactate concentration was maintained. This finding agrees with the blood lactate response observed in 60 min ergometer trials and 20km ITT performances (Coyle *et al.* 1991, Nichols *et al.* 1997, Myburgh *et al.*2001,). The high overall blood lactate response found in this research is due largely to the high exercise intensity of the XC TT, but other mechanisms may have also contributed.

Concentric muscle contractions are primarily involved whilst riding, however in XC cycling, isometric contractions are used extensively for shock absorption and during descents. Hence, the clearance of blood lactate may have been impaired by increased isometric contractions required in both the technical and descending portions of the XC TT. Thus, despite the existence of descending and natural pauses within the course design, significant clearance of blood lactate was probably not possible.

Heart rate response

Average HR response during the XC TT as a percentage of peak HR was similar to HR at IAT, determined from CMT (~174 bpm and ~ 91% peak HR). The HR values reported are comparable to other studies involving professional cyclists in massed start (Lucia *et al.* 2001) and ITT events (Padilla *et al.* 1999). The average TT HR in this research falls within those reported by Lee (1998) and Seifert *et al.* (1997) who observed mean values of 87 and 93% of peak HR during 40 km and 10.4 km off-road events, respectively. According to Seifert *et al.* (1997) greater isometric contractions during off road cycling may raise sympathetic activity and in turn cause HR response to be elevated. In off road cycling exercise intensity may be slightly overestimated when calculated on the basis of HR data, but nevertheless remains high for such exertions.

Power output

The average XC TT power output was determined after omitting the descending sections of the trial. This was done to obtain representative data of the working sections of the XC TT course, as power output during the descents was low compared to flat and uphill sections. Hence, a high mean percentage of PPO (~86%) was maintained during the XC TT; with the mean power output of ~315W, which was not significantly different ($P>0.05$) to the value determined at IAT (~310W). This finding is similar to Coyle's *et al.* (1991) evaluation of the physiological responses of competitive road cyclists completing a simulated 1 h ergometer TT with a mean power output of 311 ± 12W, which related to 86 ± 4% of PPO. The power output and percentage of PPO confirms the high relative exercise intensity of the XC TT. In addition, it appears that off road TT's sees a power output coincident with power at IAT.

Cadence

A significant difference (P>0.05) was observed for self-selected cadence between CMT and the XC TT (~89 and ~63 rpm); average XC TT cadence was determined after omitting the descending sections of the trial. This finding confirms the contention that cyclists vary their cadence according to the demands of the task. This concept is supported by Lucia *et al.* (2001) observations of professional road cyclists who averaged 90rpm during flat massed start road events, compared to 70rpm during mountain ascents. It appears that the cyclists in this study used a lower cadence than reported for professional road cyclists and it remains unknown the cadence elite XC cyclists would employ. In order to negotiate rocky sections and prevent tyres from slipping on loose ground, the XC cyclist is often required to remain in the saddle and adjust their body in order to sustain contact with the ground. On steep sections the need to maintain tyre contact, sustain high power output and increase motor unit rate coding may result in greater muscle fibre recruitment (particularly Type IIa) and explain the lower cadence observed during the TT.

According Nagata *et al.* (1981) additional recruitment of Type IIa fibres occurs due to fatigue of previously recruited motor units. Furthermore a significant increase is seen in the resultant crank force and force applied perpendicular to the crank at low cadence (50 rpm), as opposed to higher frequencies (100 rpm) (La fortune *et al.* 1980). Thus, the cyclists in this study appear to ride with a low cadence, which may be to increase force and offset losses of momentum caused by the steep terrain encountered during the XC TT.

Effect of terrain type on measured responses

Both physiological and physical responses were strongly influenced by the type of terrain encountered.

Heart rate

It was discovered that HR altered considerably and according to the terrain type being ridden, affirming the observation of the intermittent nature of the off road TT. Significantly lower ($P<0.05$) HR values were observed between the ascending and descending terrain categories of each lap (Table 4.6), as well as between the flat and descending terrain categories. The fall in HR in the 5-10%, 10-15% and 15-20% "Descent" categories is explained in part by the low power output during such sections, where cyclists essentially freewheeled. However, values did not on average fall below 79% of peak HR, which suggests that despite low power output, cyclists were forced to maintain relatively high levels of energy expenditure. It is possible that isometric contractions, which are used extensively for shock absorption during descents, were responsible for increased sympathetic activation, causing HR to remain elevated.

According to Seifert's *et al.* (1997) HR remained higher when riding a non-suspension MTB, which required greater isometric activation than a suspension MTB. Furthermore, during descents cyclists may be required to jump or lift the front wheel over obstacles, which may contribute to HR elevation. In a study of trained off road cyclists (n=6) Berry *et al.* (1993) gained HR information on the effects of riding a MTB on a treadmill with or without an obstacle attached to the belt. A significantly higher ($P<0.05$) HR response (~142 vs 117 bpm) was observed in the trial featuring an obstacle than the non-obstacle trial (Berry *et al.* 1993). Therefore, although descending portions of the MTB XC course saw a reduction of HR, which may suggest recovery, the possible combination of isometric demands of descending and negotiating objects may explain minor recovery of HR.

Power output

Large variations in power output were observed with changes in gradient (Figure 4.2). Power output clearly increased in response to steeper terrain categories, with an accompanying decrease in cadence. Whereas, due to the relatively short length of the "Post tech flat" category and its position in relation to the other terrain types, the mean power output their was significantly lower ($P>0.05$) than the average power output at IAT (~257 vs 310W). It appears that the cyclists increased power above IAT on steep terrain sections ("15-10% Ascent" and "10-15% Ascent"), whereas in the subsequent terrain sections ("Post hill flat" and "Post tech flat") power output was reduced. These findings indicate that riding the XC TT course produced a more variable power output than a road ITT.

Speed

A significant difference ($P<0.05$) in speed occurred with changes in terrain type. Although speed generally increased as the gradient fell, it was found that in "15-20% Descent" category the mean speed was lower than in the less steep "5-10 and 10-15%

Descent" categories. In the descending sections of the course it may have been necessary for the cyclist to reduce speed whilst descending in order to overcome rocky, steep or technical sections. The XC cyclist was forced to a speed that was commensurate with their bike handling skills and the technical demands of the course. This suggests the technical demands of riding the XC course were a factor in overall TT time.

Analyses of the terrain sections illustrate that whilst cyclists maintained the highest power output on the steeper uphill sections of the course, power output fell below values at IAT on flat sections. Speed was generally higher during the descents, but was dependent on the cyclist's skill, the technical nature of the terrain and the gradient of a given section. These outcomes support the idea that cyclists in this study varied power output and speed markedly according to the terrain type encountered.

Effect of lap position on responses

One of the purposes of this research was to analyse the variation of physical and physiological responses between the individual laps ridden on the XC TT course.

Blood lactate response

Significant differences ($P<0.05$) were reported in blood lactate concentration between the first lap (8.2 ± 2.5 mmol·L^{-1}) and all subsequent laps (Figure 4.4). It appears that subjects were able to tolerate the highest blood lactate concentrations during the first laps, but recorded the lowest RPE values (Table 4.5).

Interestingly, cadence was significantly higher ($P<0.05$) in the first lap compared to subsequent laps, where it appears that the subjects either chose or were forced to select a lower cadence. In the first lap, subjects' ability to tolerate higher work rates and cadences indicates that fatigue and pacing considerations changed the way that they completed the subsequent laps. This is reinforced by significant increases ($p<0.05$) in RPE values between the first and last halves of the XC TT and corresponding decreases in mean blood lactate concentration over the same period. Glycogen depletion, dehydration and the accompanied feeling of heaviness perhaps explain this observation. The additive effects of the TT duration, pacing considerations, glycogen depletion, sensations of fatigue and exercise intensity may explain the reductions in lactate concentration and cadence and increases in RPE.

Power output and lap speed

A significant decrease ($P<0.05$) in average lap speed occurred between the first and last laps and this may be explained by pacing patterns. In some examples, such as between the first and mid laps, power output was found to be similar (~337W vs 332W), whilst speed was significantly lower (~15.7 $km{\cdot}hr^{-1}$ vs 14.7 $km{\cdot}hr^{-1}$; $P<0.05$). In other instances, such as between the first and the last lap, power output was significantly lower ($P<0.05$), whereas little variation in lap speed was observed (~15.7 km·hr vs. 15.3 km·hr; $P>0.05$). These findings indicate that technique, pacing and course familiarisation play important roles in determining lap speed rather than power output alone. This suggests cyclists descended quicker and chose smoother, faster lines over the entire XC TT, despite declining power output. Furthermore, a strategy appeared to be employed in the second last lap to reduce physical effort, as seen by significantly lower ($P<0.05$) power output and speed compared to the last lap. It appears that technique is an important component of XC TT performance, as cyclist's skill would seem to maintain lap times to some degree, despite decreases in power output.

Conclusion

Performing a XC TT maybe described as an intermittent and high intensity cycling discipline. This research demonstrated that the work demands of an off road TT elicit physiological and physical responses at and above IAT. The nature of a XC course appears to dictate the physical responses observed and techniques adopted. This finding supports the idea that competitive MTB XC cyclists vary power output according to the terrain gradient and technical demand. The strong relationships observed between physiological variables relative to mass and XC TT performance indicates the influence of gradient in off road cycling. It appears from this trial, that relative test measures are strong determinants in off road cycling. Given the cyclists in this study were of regional and national level, it is thought that elite riders with greater physiological and technical abilities would produce faster off road performances.

5 Chapter Five – Development of a Mountain Bike Cross Country Performance Model

Introduction

Given the outcome that relative physiological measures describe mountain bike (MTB) cross-country (XC) time trial (TT) performance, it's of interest in this chapter to test these findings with the development of a predictive model. The purposes of developing a XC model are to compare performances with changes in physiology, speculate about limits of the possible and predict performance from standard laboratory measures.

Analyses of elite races has revealed the high prevalence of climbing in XC events, whilst the significance of power to mass and terrain specific power output was confirmed during XC TT's. On the strength of the relationship between power to mass and XC TT performance (r=0.93), it is of interest to determine if a model could be based on these outcomes. Specifically such a model could then predict performance, confirm the importance of power to mass in XC performance and determine which sections of a course are skill or physiology based. In addition, it is hoped that a model could integrate these findings into a practical and useable form, so that athlete and coach could access them readily.

A model is a simplified description of a system to assist in calculations and predictions. Models typically use mathematical, pictorial or computer representations to predict outcomes, based upon relationships between variables. Hence, without having to travel to a XC race-course, it may be possible to calculate how a group of cyclists could potentially perform. Historically cycling modelling has sought to: evaluate the different pacing techniques utilised during individual time trials (ITT) and when breaking away from a field of riders (Swain, 1997), quantify the effect of alterations in physiology to performance (Di Prampero, 1979; Kyle, 1988; Olds *et al.* 1993, 1995), optimise MTB suspension systems (Olsen, 1996), measure the effect of equipment changes (tyres, time trial bars, aero-dynamic wheels) on performance (Kyle, 1990), predict times for ITT events (Olds *et al.* 1993, 1995) and evaluate the effects of using smaller wheels, increasing mass, drafting and decreasing drag (Kyle, 1991; Mc Cole, 1990).

Traditional cycling models have relied on determining the external factors that impede motion of the rider/bicycle system, whilst the limits of input factors have focused on the physiological systems of the human body. External factors include: aerodynamic drag, rolling resistance, friction at the bearings, drive train and suspension system/s and changes in kinetic and potential energy. Aerodynamic drag relates to air density, frontal area, and air velocity, whilst rolling resistance is concerned with the rider and cycle mass, tyre pressure, gradient and surface resistance. Finally changes in potential energy relate to mass and gravity, whilst changes in kinetic energy are concerned with mass, inertia and velocity. According to Di Prampero *et al.* (1979) these factors can be termed the equations of motion in cycling. Predictive models have been based historically on physiological and anthropometrical parameters and have concentrated on predicting road ITT performance by calculating the influence of changes in model inputs on performance time (Olds *et al.*1995).

The most common method of developing cycling models measures ranges of physiological variables and then applies statistical analyses to determine which parameters best predict recorded performances (Craig *et al.* 1993). This approach makes a prediction first and then trials are conducted to validate the model's predictions of performance by direct comparison between the two values obtained. The modelling outlined in this chapter is based upon the method outlined above, which consisted of establishing laboratory test measures and relating those to performance parameters measured in a XC TT.

Both road and track cycling (Olds *et al.* 1993, 1995; Craig *et al.* 1993) have been modelled extensively, as has running performance also (Leger *et al.* 1986). However, to the best of the author's knowledge the sport of MTB XC cycling has not been modelled before. With the recent advent of the SRM™ training system (Schoberer, 1998) it is now possible to measure the power output generated during a XC TT or race. This device is capable of measuring and storing power output accurately in the field, which can be related to physiological test measures determined during laboratory testing.

If MTB XC performance is dictated by physiology then relative laboratory test measures will be able to predict off road performance closely. The principle aim of this chapter is to test the findings from chapter 4, which indicate that relative physiological test measures describe MTB XC performance strongly. Developing a MTB XC performance model based on physiology will test this hypothesis. The validity of such a model will be established by comparing modelled performance to actual ride times, with the aim of producing a model with an accuracy of less than ± 5%. In addition the development of a successful MTB XC performance model seeks to:

- Predict performance of cyclists on a variety of XC race courses.

- Determine which parts of a MTB XC race course are dependant on physiology and which are more skill orientated.
- Ascertain strengths and weaknesses of riders.
- Development of a valuable pacing tool from which to plan races from.

Methods

Outline

Subjects completed field (XC TT) and cycling maximal testing (CMT) firstly. These data were then used to develop a MTB XC model, which was then employed to predict theoretical off road performance. The final stage of this chapter was to compare between modelled and actual field performance.

Data collection

Subjects, cycle maximum test and XC time trial

Eleven (n=11) experienced male MTB XC riders participated in this research, which included a performance field XC time trial (TT) (15.52 km, 624m – elevation gain) and a lab based cycle maximum test (CMT). The subject's physical characteristics, CMT results and XC TT methodology is fully outlined in chapter 4.

Course analysis and terrain types

The performance XC TT course was measured and categorised according to terrain gradient and also divided into eight discrete terrain categories as per the method outlined in chapter 4.

Modelling and prediction

The modelling is based upon the premise that cyclists power output at any time on a XC TT course will primarily be determined by the riders physiology and the type of terrain being ridden over. A given XC course is made up from differing terrain types and the model was based on the percentage gradient uphill and downhill or flat encountered. In order to develop the XC performance model a series of steps were necessary in its construction. The steps involved in producing the MTB XC model are outlined below.

Laboratory test results

1. The first step in developing the model was to determine the individual CMT results of each of the subjects (outlined in previous section and chapter 4). This was done to establish the standard physiological test measures that have been used in road cycling models to determine strength of relationships to performance.

Terrain category power output

2. The next phase involved determining the mean power output for each of the terrain categories "15-20% Ascent" to "Post Tech Flat" during the XC TT. The mean power output that each terrain category was ridden was related to cyclists PPO determined from CMT (1). There was a remarkably low standard deviation for the categories "15-20% Ascent" to "Post Tech Flat", derived from the XC TT power output (PO) and expressed as a percentage of PPO (Table 5.5). This indicated despite a heterogeneous subject group, cyclists approached the different terrain categories with similar percentages of PPO. By knowing PPO from CMT, the PO that a cyclist can deliver to the pedals for the given terrain category could be predicted. The terrain power was determined from the SRM™ downloads such as displayed in Figure 5.2.

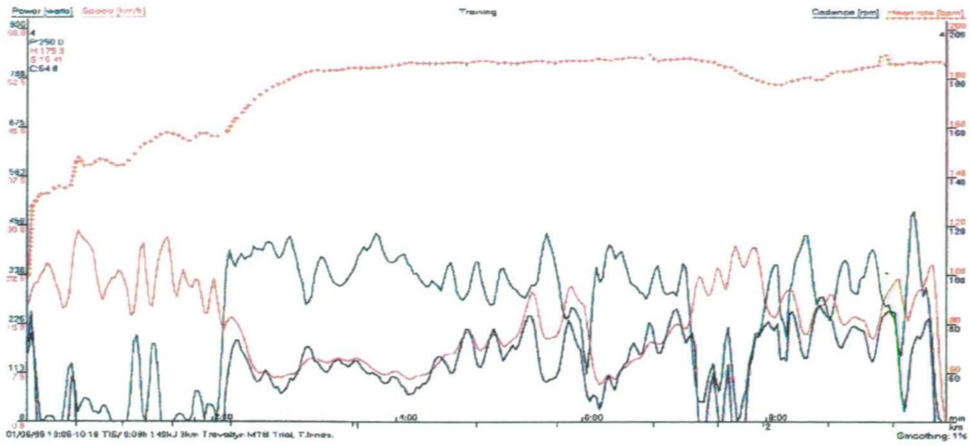

Figure 5.1 SRM^{TM} graph of power output (green line), speed (pink line), cadence (blue line) and HR (red line) taken from a single lap of the MTB XC trial course.

Prediction of terrain power from CMT values

3. The next step in the model was to predict the power output for each of the terrain types "15-20% Ascent" to "Post Tech Flat" for the individual rider to be modelled. Obtaining a rider's PPO from a progressive maximum test and utilising the calculations shown in Table 5.1 allowed this.

Table 5.1. Example calculation of terrain category power for a male ride with a PPO of 370W.

Terrain Categories	% of Peak Power Output	Power Prediction (Watts)
"15-20% Ascent"	115.1	115.1 x 370 = 425.8
"10-15% Ascent"	102.2	102.2 x 370 = 378.1
"5-10% Ascent"	89.3	89.3 x 370 = 330.4
"Post hill flat"	85	85 x 370 = 314.5
"Post tech flat"	71.7	71.7 x 370 = 265.3

Prediction of terrain speed

4. The next step was to determine the terrain speed from the already predicted terrain power output. Regression analyses were performed on the test data to establish relationships between power to mass and speed for each terrain type (See Figure 5.2). Terrain category speed was calculated from the regression

equations established for each terrain category. This was achieved by simply determining the power to mass of each terrain category, by dividing terrain power by rider and bicycle mass. Peak power output to total mass was chosen as the best measure to predict terrain category speed, as analyses between PPO and total mass revealed the strongest relationships of any other CMT value (r=0.68 - 0.93) (Figure 5.2 and Table 5.4).

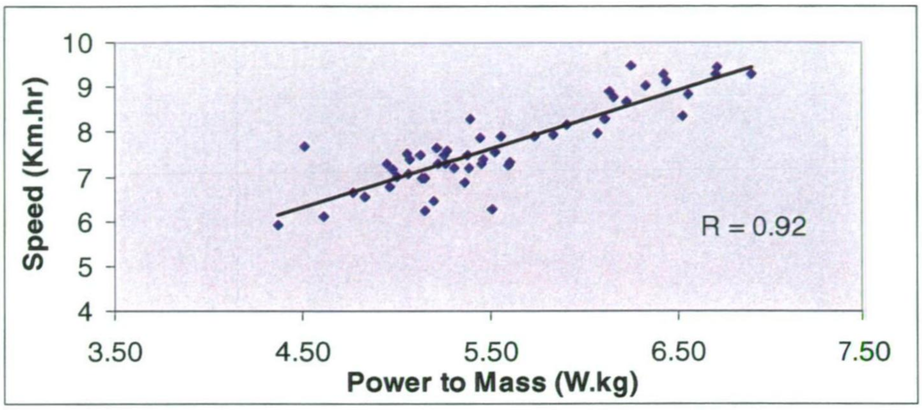

Figure 5.2. Relationship between power to total mass and trial speed for "5-10% Ascent", taken from all subjects.

Downhill speed prediction

5. For the descent terrain categories "5-10% Descent", "10-15% Descent" and "15-20% Descent" the speed for each of the subject's XC TT categories was recorded, averaged and then matched to the cyclists PPO to total mass. Again, regression analysis revealed the strongest relationship existed between downhill category speed and PPO to total mass (Table 5.5). Thus, as PPO to total mass increases so too does downhill speed.

Course profile input, speed output and lap times

6. The next stage in the model construction was to predict average speed and lap times using the speed in each section and the specific course profile. A XC course profile is required as an input at this stage, with the accurate measurement of the lap distance, slope and terrain category necessary.

7. The lap distance of the validation XC TT was measured with a calibrated surveyors wheel, whilst the slope was calculated with an inclinometer. The slope was determined every 10 metres f the validation trial, which meant there was 351 measurements of slope. An example section is shown in Table 5.2. Whilst, the overall scheme of the model is depicted in figure 5.3.

Table 5.2. Course profile measurement sheet (section only).

Slope Categorisation	Distance (m)	Slope
"Post hill flat"	10	0
"15-20% Ascent"	10	0.16
"15-20% Ascent"	10	0.17
"10-15% Ascent"	10	0.13
"10-15% Ascent"	10	0.14
"5-10% Ascent"	10	0.07

m, Metre.

The completed model will therefore predict:

- Speed in each terrain category based on PPO.
- Performance XC TT course average speed and completion time.

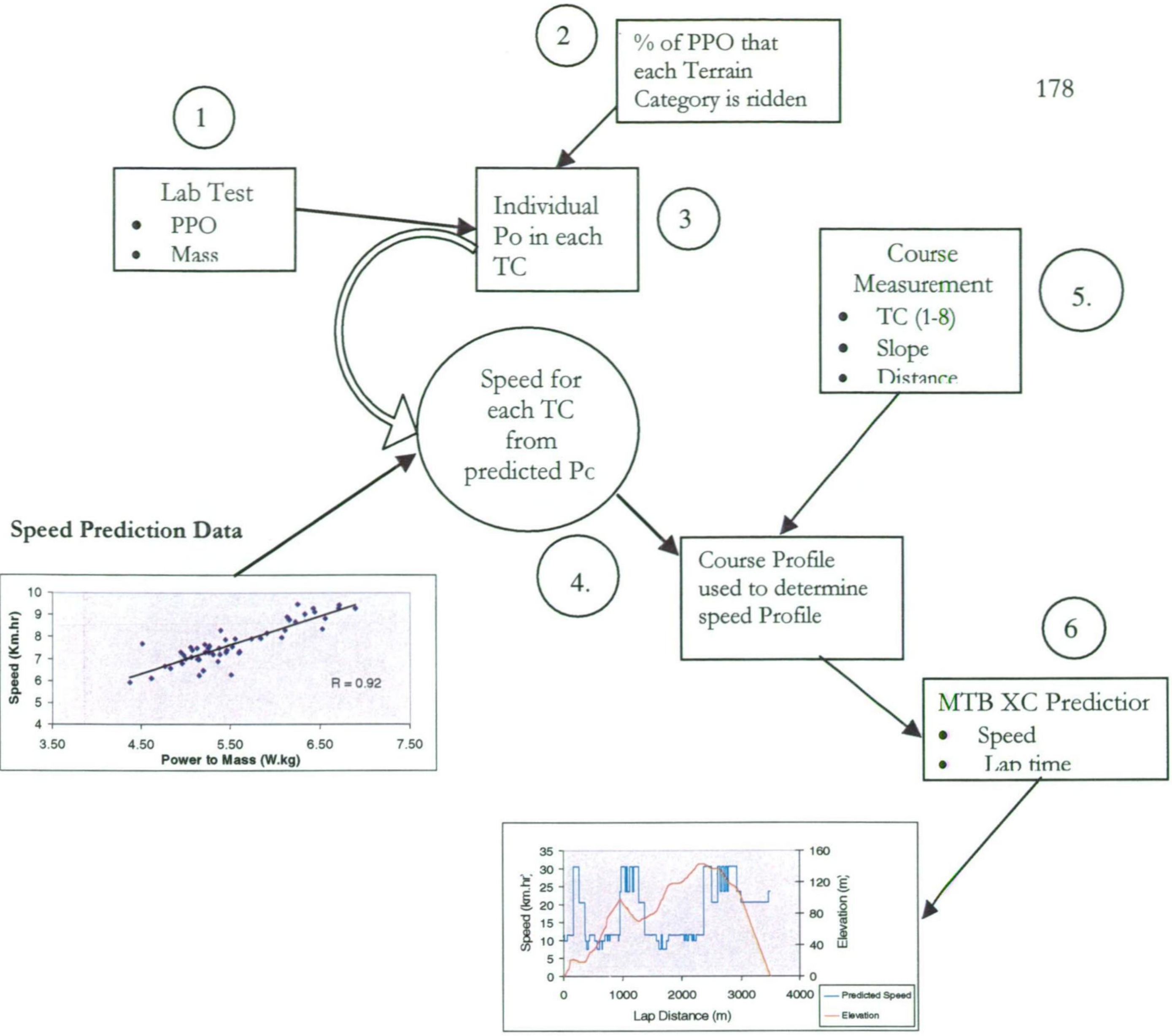

Figure 5.3 shows the overall input scheme and required components for the mountain bike cross-country performance model to generate lap speed and duration. (PPO, Peak power output; Po, Power output; MTB XC, Mountain Bike Cross-Country; TC, Terrain Category.)

Model validation

After conducting the performance and validation XC TT's, some comparative modeling was performed based on the average power to mass values obtained from selected research, values taken from the Australian Olympic MTB XC squad and the test results taken from the subjects from the XC TT. This process theoretically compared the differences between different rider categories for power to mass and modeled performance.

The second part of the validation process compared actual XC TT lap times of two well-trained XC cyclists and modeled times taken from the same subjects CMT data. The physical characteristics and laboratory test results for subject 1 and 2 include: 26.2 and 19.6 y, 184.6 and 178.1cm, 83.2 and 62.1 kg, 57.8 and 36.1 mm skinfold sum, VO_2max 58 and 67.2 $mL \cdot kg^{-1} \cdot min^{-1}$, PPO of 430 and 350W and a power to mass 5.16 and 5.64 $W \cdot kg^{-1}$, respectively. The XC validation TT's were conducted over 3 laps of a 3.5km off-road course, with the details and profile of the course outlined in Table 5.4 and Figure 5.5. Subjects underwent the same field and laboratory testing procedures outlined previously, with 2 days separating the CMT and the XC TT. In the 48 hours between the tests the laboratory values were entered into the model and a single lap time predicted for each subject. The subjects then completed the XC TT's and the actual times were compared to the modeled values.

Table 5.3. Validation, Performance and average World cup and Title race-course characteristics.

Course Details	Performance Trial Course	Validation Trial Course	World Cup Mean (n=29)	World Cup ± SD
Lap distance (km)	2.58	3.5	8.90	1.94
Lap ascension (m)	104	160	353.8	66.9
Distance (km)	15.5	10.5	48.0	4.80
Mean gradient (%)	4.02	4.56	4.06	0.59
Single track (%)	62	54	44.6	10.50
Open track (%)	38	46	55.40	10.50
Technical DH (%)	9	20	8.1	3.3
Fast DH (%)	16	11	12.4	5.6

%, Percentage; DH, Down hill; km, Kilometres; m, Metres; SD, Standard deviation.

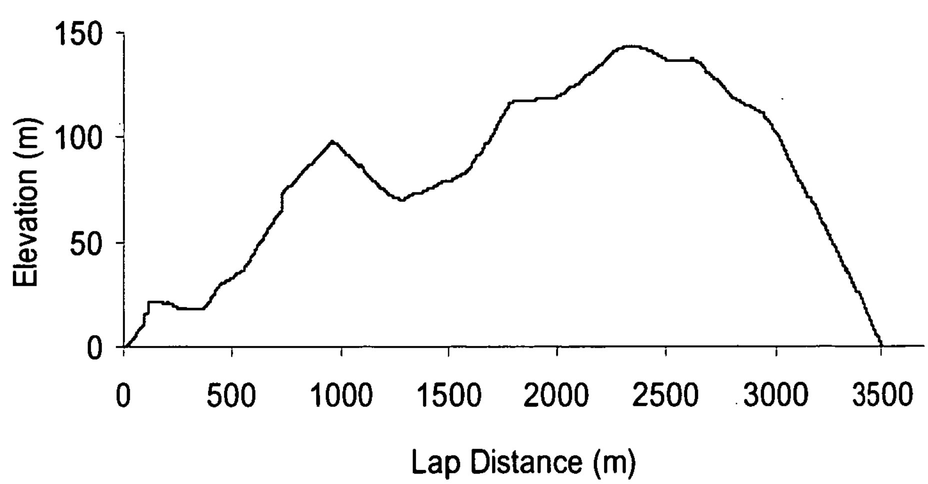

Figure 5.4. Mountain bike cross-country validation TT lap profile and distance.

Statistical analyses

Descriptive statistics are expressed as means and ± SD. Pearson's product moment correlations were used to calculate correlation coefficients between the independent variables (laboratory measures) and the dependent variables (performance XC TT). Spearman's rank order correlation was used to compare the XC TT rankings to the predicted rankings (Sigma Stat, version 2.03.0). Least squares linear regression analysis was used to calculate the correlation coefficients between power to mass and riding speed over each of the terrain categories. The power output from the performance XC TT's were corrected with the regression equation obtained from the calibration tests. Significance for Pearson's correlations and linear regression was set at $P<0.05$.

Results

Model Prediction Data

Power Output

Table 5.4 summarises the mean and SD± for percentage of PPO recorded from the XC performance TT. Given the heterogeneous nature of the subject group the standard deviation for percentage of PPO was low. As the terrain gradient increases, so too does the percentage of PPO. On average the riders worked above PPO on the steepest terrain types ("15-20% Ascent", 115.1% of PPO and "10-15% Ascent", 102.2% of PPO), whilst the Flat terrain categories saw power output well below PPO ("Post hill flat", 85% of PPO and "Post Tech Flat" 71.7% of PPO). Category means and SD were calculated from the power output per rider and for each lap (n=66).

Table 5.4. Percentage of peak power output and power at individual anaerobic threshold for the ascending and flat terrain types. Values are means (± SD).

Terrain Categories	% of PPO (W)	% of Power at IAT (W)
"15-20% Ascent"	115.1 ± 8.2	128.1 ± 10.1
"10-15% Ascent"	102.2 ± 9.5	113.4 ± 12.6
"5-10% Ascent"	89.3 ± 7.6	98.9 ± 10.6
"Post hill flat"	85 ± 7.2	93.9 ± 9.7
"Post tech flat"	71.7 ± 7.7	78.4 ± 10.3

W, Watts; PPO, Peak power output; IAT, Individual anaerobic threshold.

Cross-country time trial terrain analysis.

Table 5.5 depicts the regression values obtained for each of the 8 terrain categories determined from the XC TT. The relationship between power to total mass and speed revealed strong relationships for "15-20% Ascent" (r= 0.93), "10-15% Ascent" (r= 0.86) and "5-10% Ascent" (r= 0.93). Analysis of the flat terrain categories showed less strong relationships for "Post hill flat" (r= 0.78) and "Post tech flat" (r= 0.68), whilst strong relationships for the descent terrain categories of "5-10% Descent" (r= 0.90), "10-15% Descent" (r= 0.88) and "15-20% Descent" (r= 0.90) were observed.

Table 5.5. Regression values obtained between peak power output to total mass and XC TT speed for each of the terrain types.

Terrain Category	"15-20% Ascent"	"10-15% Ascent"	"5-10% Ascent"	"Post hill flat"	"Post tech flat"	"5-10% Descent"	"10-15% Descent"	"15-20% Descent"
PPO: Mass ($W \cdot kg^{-1}$)	0.93	0.86	0.83	0.61	0.66	0.79	0.73	0.34
PO: Mass @ IAT ($W \cdot kg^{-1}$)	0.79	0.62	0.84	0.44	0.72	0.77	0.82	0.48
PPO: Total Mass ($W \cdot kg^{-1}$)	0.93	0.86	0.93	0.78	0.68	0.90	0.88	0.90

PPO, Peak power output; PO, Power output; IAT, D max individual anaerobic threshold; $W \cdot kg^{-1}$, Watts per kilogram,

Figure 5.5 shows the strong relationship (r= 0.93) between power to total mass and XC TT speed for the "15-20% Ascent" category. Given that the greatest time losses and gains are made on the climbs during off road cycling, the relationships seen in the ascent terrain categories gives the model increased predictive power.

Figure 5.6 shows the moderately strong relationship (r= 0.78) between power to total mass and speed for the "Post hill flat" category. It appears weaker relationship for the flat terrain categories implies that the riders approach such sections with lower power output and speed and thus may not be as dependent on the measure of power to mass, as seen for the ascent categories. The "Post hill flat" category may allow the cyclist to vary power output, whilst the steeper categories probably demands a higher work rate.

Figure 5.9 outlines the strong relationship (r=0.90) between PPO to total mass obtained from the CMT and speed for the descent category "5-10% Descent".

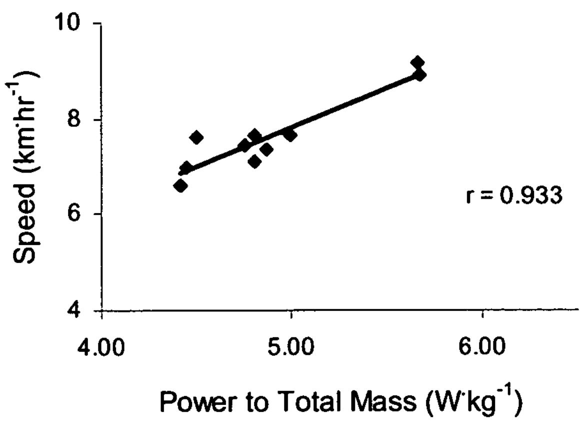

Figure 5.5. The relationship between the power to total mass and speed obtained for the ascent terrain category of "15-20% Ascent" taken during the performance XC TT.

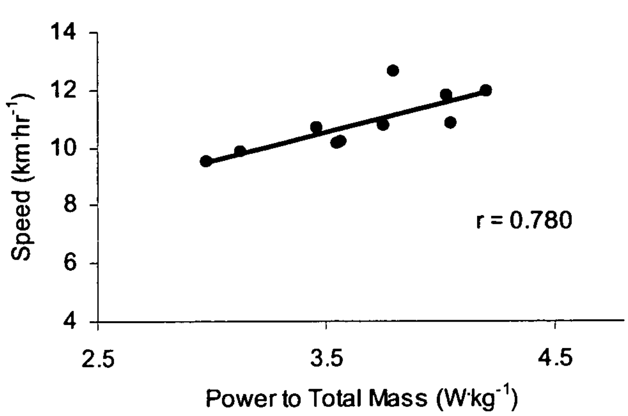

Figure 5.6. The relationship between the power to total mass and speed obtained for the flat terrain category of "Post hill flat" established from the performance XC TT.

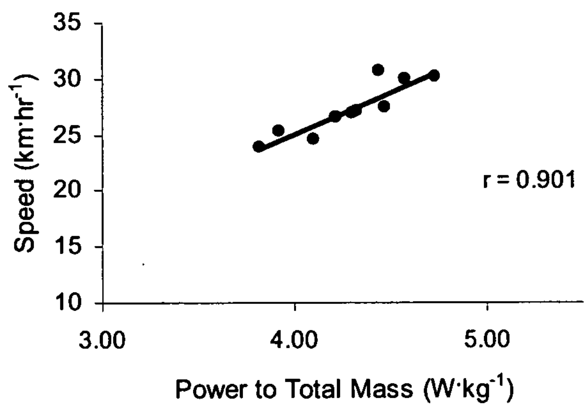

Figure 5.7. The relationship between the power to total mass and speed obtained for the descent terrain category of "5-10% Descent" determined from the performance XC TT.

Validation results

Table 5.6 outlines the comparison between the actual performance XC TT ranking and the models subsequent ranking. The model rankings were generated from each of the individual cyclist's CMT results and then applied to the validation XC TT race-course. In seven out of the eleven subjects the same ranking was achieved, with a strong overall correlation ($r= 0.93$; $P<0.01$) between predicted and actual performances.

Table 5.6. Comparison between the actual XC TT ranking and the modelled ranking on a separate off road race-course. Modelled ranking was generated from the individual rider's laboratory test results and applied to the validation XC TT course.

Subject (n=11)	MTB XC TT Rank	Modelled MTB XC TT Rank
A	1	1
B	2	2
C	3	3
D	4	6
E	5	5
F	6	4
G	7	7
H	8	8
I	9	11
J	10	10
K	11	9

A-K, Subject letter; n, Subject number; MTB, Mountain bike; XC, Cross-country; TT, Time trial.

Figure 5.8 displays the validation XC TT course profile and actual generated riding speed for the modelled validation XC TT for subject L. Overlayed on the course profile is subject L's actual XC TT lap mean speed taken from the SRM™ training system. The difference between the actual average XC TT lap time (865 s) and the modelled XC TT lap time (842 s) to complete one lap was –2.65%.

Figure 5.9 outlines the same XC TT course elevation and subject M's actual average speed for his validation XC TT. Overlayed on the course profile is the actual mean XC TT speed taken from the SRM™ system and the predicted model speed also. The difference between the rider's actual XC TT mean lap time (792 s) and modelled lap time (810 s) was 2.27%.

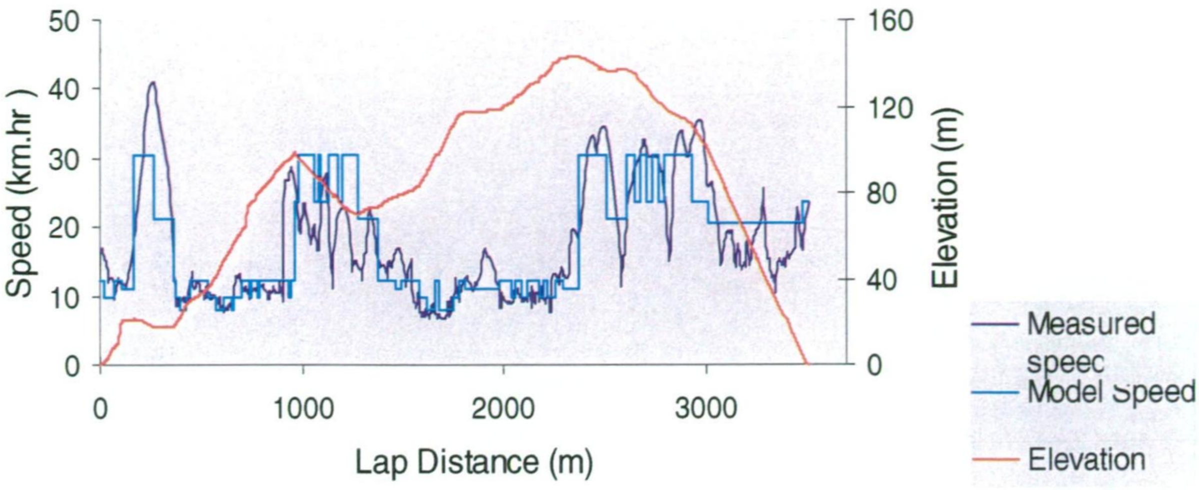

Figure 5.8. The validation MTB XC trial course elevation, actual trial speed and modelled trial speed for subject L.

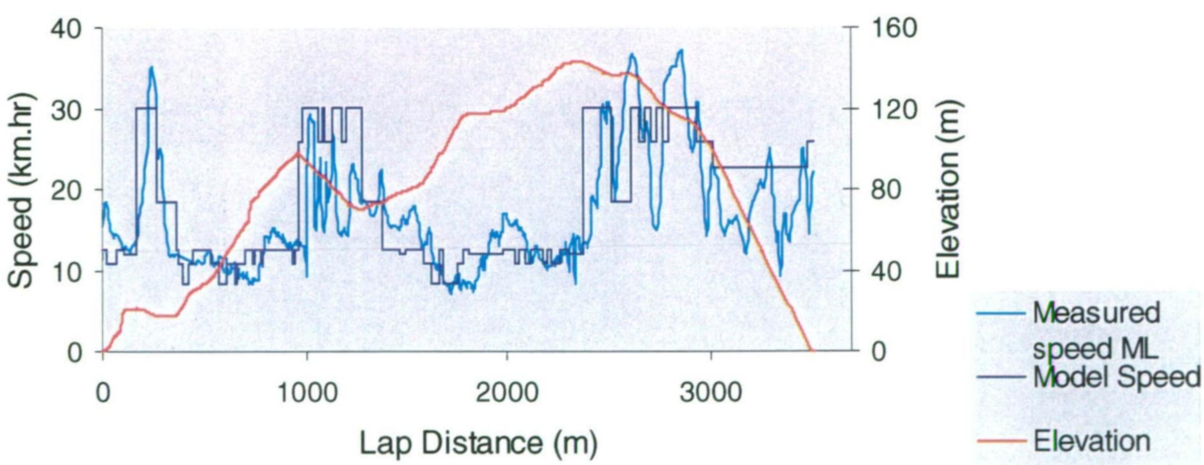

Figure 5.9. The validation XC TT course elevation, actual trial lap speed and modelled trial speed for subject M.

Table 5.7 depicts the actual mean values for peak power output, mass and power to mass obtained from the current study and other MTB XC research, as well as results from a group of elite uphill road cyclists. For each of the terrain categories the model was used to generate an average lap time, which was then compared to the mean power to mass values. The relationship between power to mass and the generated lap time for the four rider categories was very strong ($r = -0.99$, $P < 0.01$).

Table 5.7. Average physiological test values taken from MTB XC and road cycling research and power to mass used to generate lap times on the validation XC TT course. The differences (%) between power to mass and modelled XC TT lap times (%) are compared. Values are means (± SD).

	Physiological Test Measures, Performance Times and Differences					
Research/Category	Peak Power (Watts)	Mass (kg)	Power to Mass ($W \cdot kg^{-1}$)	Difference (%)	Modelled Lap time (s)	Difference (%)
Competitive MTB XC (Gregory, 1999) n=11	367 ± 32.1	71.6 ± 6.3	5.15 ± 0.42	-	877.6	-
Sub Elite MTB XC (Lee, 1998) n=8	391 ± 35	67 ± 4.5	5.84 ± 0.17	11.8	766.6	12.6
Elite MTB XC (Gregory, 1999) n=5	420 ± 28.6	68.4 ± 6.5	6.04 ± 0.19	14.7	724.9	17.4
Elite Uphill Road (Padilla *et al* 1999) n=9	404 ± 34	62.4 ± 4.4	6.47 ± 0.33	20.4	677.3	22.8

MTB, Mountain bike; XC, Cross-country; %, Percentage; s, Seconds; kg, kilogram; $W \cdot kg^{-1}$, Watts per kilogram. (Gregory data is self reported)

Discussion

Relative measures predict XC performance

The model in this chapter is based on the assumptions that off road cyclists perform over a cross-country (XC) time trial (TT) course relative to their physiological capacity. The model was constructed from the cyclist's field XC TT power output and when expressed as a percentage of their peak power output (PPO), showed remarkable consistency for all cyclists over the eight terrain categories. From these strong relationships it was possible to develop a model that predicted speed and lap times.

Despite individual variations in physiology, cycling events such as individual road time trials (ITT) and XC races require the rider to pace their effort throughout the event in order to record the fastest time. It can be seen from the laboratory test results of the 11 subjects that completed the performance XC TT, that they were heterogeneous in nature. Values for relative $\dot{V}O_2max$ ranged from 59 to 73 $mL \cdot kg^{-1} \cdot min^{-1}$, whilst PPO varied between 330 to 430 watts (W). Regardless of the variation of physiological test values reported for the group, when field power output was related to each cyclist's PPO, percentage of power output measured in the field was exceptionally constant. The model is reliant on this finding and suggests that performance can be predicted based on the terrain demands that caused cyclist's to select similar relative power outputs.

The development of the MTB XC performance model was based on two principles; the low variability (standard deviation) observed for percentage of PPO for each terrain category relative to lab test PPO, and the strong relationships established between power to total mass and speed for each of the terrain categories.

Pacing pattern

According to Foster *et al.* (1993) relatively even pacing strategies are observed in middle distance events, with negative consequences for even small variations in this strategy. However, Kyle (1988) was the first to demonstrate that the time added to a cyclist's performance when going uphill is greater than the time saved when descending. Given the high frictional losses riding off road and the substantial amounts time spent climbing (Mac Rea *et al.* 2000), a reduction in power output whilst ascending would lead to a large decline in speed and subsequent time losses. Furthermore, according to Swain's (1997) modelling of ITT road performance over an undulating course, a cyclist who deliberately increases power output on the hilly sections (± 5%) was able to increase average speed and reduce overall time losses. In this study much greater variations from mean power output on flat and uphill sections (+31% and –13%) were recorded than those suggested by Swain (1997). It was observed that the XC cyclists not only increased power output over hills generally, but also performed consistently and according to the steepness of the gradient (~"15-20% Ascent", 115.1 ± 8.2%; "10-15% Ascent", 102.2 ± 9.5% PPO). Thus, XC cyclists in this study appear to either use a variable pacing strategy or respond markedly to the demands of gradient, which is contrary to flat ITT's. It is perhaps not only the need to maximise time gains over steep gradients during a XC climb, but the requirement to maintain balance and forward momentum, as the minimum speed on steep sections probably calls for considerable power output.

The consistency of the idea of a variable pacing strategy for the subject group is further seen in the low average percentage of PPO reported over the flat terrain categories also ("Post hill flat", ~85%; "Post tech flat" ~72% PPO). It appears the variable pacing strategy saw cyclists reduce effort to recover on the flat sections, without losing significant speed and therefore time.

According to Liedl *et al.* (1999) a pattern of variable power output may cause greater physiological stress versus a constant effort. In simulated cycling trials of 1-h by Liedl and co-workers (1999) varying power output (± 5%) did not result in measurably greater physiological stress compared to constant power. In XC cycling it seems impossible to maintain either a constant or slightly variable (± 5%) power output. The XC cyclist may respond to changes in terrain and their sensations of fatigue by adjusting their pacing strategy. External factors (terrain, technical demand, gradient...) may impose a variable loading pattern, but riders may also adjust their efforts to maximise speed and attenuate physiological stress whilst competing.

It is difficult to determine if the cyclists employed a conscious pacing strategy or if the terrain forced such a marked response. However, it remains apparent the consistent manner in which the XC cyclists approached the climb and flat sections and indicates an effort and recovery pattern, which is perhaps ultimately physiology dependant. It appears from the performance XC TT that cyclists followed a variable loading pattern and overall this may be the optimal method in off road events.

Power to mass

It appears that MTB XC cyclists pace their efforts similarly when viewed in relative physiological terms, but it was also observed that changes in power to mass describe differences in individual XC performances also. This finding is not surprising given the importance of relative measures in events that have considerable climbing, including XC racing at the elite level (Mac Rea *et al.* 2000). Hence, the performance model was able to use PPO and total mass as important inputs in determining differences in modelled times. It is generally concluded that cyclists with high power to mass values excel in events where there is considerable climbing included in the course (Stovall *et al.* 1992; Padilla *et al.* 1999; Lucia *et al.* 2001).

It's observed in Table 5.2 that although strong relationships exist between PPO to body mass and for all of the terrain categories, PPO to total mass revealed a stronger relationship. This was especially apparent for the climbing categories ("15-20% Ascent" r=0.93; "10-15% Ascent" r=0.93) and suggests that the speed over steep terrain is closely regulated by not only the power output, but more importantly the power divided by the total mass (bicycle, bidon, shoes….) that the cyclist has to carry up the gradient. This finding may be explained by Swain's (1994) contention that when the mass exponent for energy cost differs to the mass exponent for energy supply, there will be a body mass influence on performance. It is not surprising that specialist uphill road cyclists tend to be significantly lighter than level ground specialists (~62 kg vs 76 kg) and climbers have higher watts per kilogram compared to flat ground specialists (~6.5 vs 6.0 $W \cdot kg^{-1}$) (Padilla *et al.* 1999). In chapter 6 it was observed that elite male MTB XC cyclists have similar values for body mass at ~64 kg to elite uphill road cyclists and this coupled to a high PPO, may largely explain their performances. Thus, it can be seen that MTB XC performance modelling can be based on physiological measures, which specifically include mass.

Flat and descent categories

Given the finding in this research that XC cyclists maximise or increase power output over steeper terrain categories, it is not surprising that the relationships between PPO to total mass and speed for the flat categories is lower ("Post hill flat" r=0.78; "Post tech flat", r=0.68). This further supports the idea that cyclists varied power output according to the terrain demands. The length of any given flat section was relatively short and was preceded or followed by a climb or descent. As a typical MTB XC race does not have long flat sections, the cyclist will usually ease back the effort (power output) to recover and may replenish energy and fluid stores during such sections, especially if there is a hill to come. If flat sections were 1-3 kilometres in length, then it may be expected that the cyclist's work rate would more closely match power output at IAT.

Despite XC cyclists in this study free-wheeling throughout the majority of the descent categories, strong relationships were observed between laboratory PPO to total mass and terrain descent speed ("5-10% Descent" r=0.90; "15-20% Descent" r=0.90). The strength of these results was unexpected and is perhaps explained by the observation that well-trained cyclists (higher $W \cdot kg^{-1}$) develop greater skill and hence descend faster, by spending more time off-road training and generally improving descending skills. This finding is noteworthy given that during the steep descents (15-20%) that physiology probably plays a secondary part to skill.

Model validation

The idea that during a XC TT cyclists vary power output according to the terrain category and their physiology has been supported by the high accuracy (< ± 3%) of the validation XC TT's. It is a generally thought that the major difference between MTB XC and road cycling lies with the technical demands of the off road event. However, it was possible in this research to develop an XC model based exclusively on physiological measures alone. This was supported by the strong correlation ($r=0.93$; $P<0.01$) between the actual XC TT ranking and the modelled ranking (Table 5.6) and suggests that the complex and skill-full task of off road cycling can be predicted from lab test measures. This result was achieved in the current model without directly taking into account the bike control and balance required during XC cycling, as a model input.

The validation XC TT's conducted on two different subjects and on a separate race course to the performance XC TT showed a difference of –2.65% and 2.27% between actual trial time and modelled time, respectively. These results reinforce the relationships established between PPO to total mass and terrain specific speed and overall XC TT speed. However, it must be remembered that only two validation subjects were used in this investigation. The model operates on breaking down a race-course into 8 terrain categories and assuming that a given percentage of PPO will be maintained for a given section. The accuracy of the validation XC TT's suggests that the cyclists in this investigation produced power output according to the terrain type being ridden and thus, confirms the models construction method. The validation XC TT's further affirms the concept that similar pacing strategies are consistently employed by XC cyclists and this approach appears to be primarily caused by terrain changes.

Limitations

On the basis of the validation XC TT's the model appears to accurately predict off road performance. However, in some terrain sections the model had weaknesses. The model appears to predict speed less accurately when; descent terrain sections exceed 15%, extreme direction changes are encountered, when sudden changes in speed are apparent and when the technical demands are high. Despite a strong relationship observed between PPO to total mass and speed in "15-20% Descent" it was difficult to predict the speed precisely, as the cyclist's skill and psycho-motor abilities probably played a greater part during steep descents and these were not factored into the model.

Skill probably determines the speed a cyclist negotiates rough and tight single-track sections and as these were not directly measured, the model could not take account of them. Hence, the model had limitations in predicting parts of a MTB XC course that are predominantly skill based and further work is needed to integrate this parameter into the model.

The input parameters of the model (terrain type, mass and PPO) were measured over dry ground conditions and at sea level. The stable trial conditions may make the application of the model over courses affected by wet weather and altitude less accurate. The model does not fully take into account the possibility of change in biophysical parameters such as anaerobic capacity either. Furthermore, the model assumes the same lap times will be performed independent of fatigue, pacing and tactics.

The model did not address the influence of terrain type on energy demand and supply. The scaling of power demand and supply is useful in considering ascents, flat riding and descents. Scaling can be used to examine how certain aspects (body mass & VO_2max) of geometrically similar objects (human body) differ (Swain, 1994). The energy cost of cycling on the flat scales with mass raised to the power 0.67, which is approximately the same as energy supply. According to Swain and co-workers (1987) larger cyclists excel on flat TT's because the energy cost scales at a factor less than VO_2max, whilst smaller cyclists excel on ascents because energy cost scales at a factor higher than VO_2max. Furthermore, during descents the accelerating force of gravity increases proportionally to body mass, which scales at 0.79, whereas air resistance scales at only 0.32, meaning the heavier cyclist is favoured. Hence, it might be expected that scaling differences may influence terrain category speed more closely than the model predicts, as scaling was not included in the model.

The model had limitations in predicting speed through relatively open and fast descent sections, as the low technical difficulty of these sections allowed for rapid acceleration and higher top speeds than the model could predict. When performing over flat sections the relationship between $W \cdot kg^{-1}$ and speed may not always be linear, as power output demand on the flat increases with the cube of speed. Furthermore the model assumes that a cyclist will cycle at their highest speed unhindered throughout a XC TT. In a World Cup event this is not always possible due to the rider numbers and possible tactics during a race, and again the model does not account for this influence on lap times. Given the limitations outlined above, the model was able to generate accurate speed profiles.

Comparative modelling

Further confirmation of the models predictive power is seen in the overall strong relationship established between the modelled lap times and power to mass for the four ability categories modelled based on $W \cdot kg^{-1}$ ($r = -0.99$; $P<0.05$). Comparative modelling between ability categories showed that improvements in physiology were directly related to performance. This finding suggests that as an off road cyclist increases power to mass, then performance time will decrease proportionately also. This indicates, at least theoretically, that even small changes in PPO to mass will influence performance time in an off road TT or race. The result of the modelling between ability categories indicates approximately for every 0.2 improvement in $W \cdot kg^{-1}$ that a 3.6% reduction in lap time is predicted. Given the average World Cup XC race duration for males (~141 min), a 3.6% reduction in race time could mean a cumulative saving of 304 s and more significantly an improvement of 8-9 places. Of course this prediction is theoretical and remains to be proven in the real competition. However, provided the cyclist is technically competent, it appears that improvements in performance may be achieved through minimal increases in $W \cdot kg^{-1}$.

According to AIS physiologist Dr Martin, improvements in power to mass and World Cup performance have been steadily achieved in elite XC cyclists under his care (personal communication). Therefore for this reason it is of value to the coach and cyclist to establish such test values and when appropriate attempt to improve power to mass ratios. This finding supports the use of ability categories in XC cycling based on laboratory test results, including the measure of power to mass. Such categories appear to be valid and should be of value in guiding the coach as to the performance potential of an off-road athlete.

The benefits of the model are that:

- Accurate lap times can be determined and used as a guide to pacing on unseen MTB XC race-courses.

- Modelling changes in physiology and determining the percentage improvement in lap times on local, interstate and international MTB XC courses is possible.

- The limits of MTB XC performance maybe analysed.

- The identification of individual strengths and weaknesses can be achieved. The overall modelled times and terrain section speed can be compared to actual terrain speed and lap times. As the model suggests an average speed expected overall and specifically for terrain, a coach can determine exactly were the cyclist rides above, under or according to the model. Thus, the model serves as a reference point from which the rider bases his/her progress upon.

Conclusion

To the best of the authors knowledge, this investigation was the first to successfully model XC TT performance and has done so with an accuracy of <± 3%. It appears that accurate speed profiles and XC lap times can be predicted from PPO and body mass determined from standard laboratory tests. It has been shown that XC cyclists increase power output as the gradient becomes steeper and reduce power output on flatter sections of a course. It appears that certain terrain categories see changes in the pace a XC cyclist performs at, which may be reliant on PPO to mass. Physiological parameters are able to describe and predict MTB XC performance closely, despite the importance of skill during XC cycling. This suggests that elite off road cyclists require minimum test results, although exact values are to be determined. Comparative modelling indicates that ability categories based on power to mass predict the magnitude of performance differences closely. With further validation it may be possible to use the current model to predict MTB XC lap times and assist in pacing strategies for race courses never before ridden by a rider. Relative physiological test measures may be used to good effect in predicting off road performance with the model developed in this chapter.

6 Chapter Six - Comparison of The Physiological Responses and Techniques Employed by Elite and Competitive Mountain Bike Cross Country Cyclists.

Introduction

It has been observed that mountain bike (MTB) cross country (XC) cycling is an endurance sport, has considerable skill demands and that relative test measures predict XC performance strongly. It is the focus of this chapter to determine if the findings established for competitive XC cyclists can be expected in elite MTB athletes also. This chapter may establish the part measurable (physiology/physical) and unmeasurable (technique) variables play in determining elite XC performance. Furthermore, this investigation seeks to establish the key differences between elite and competitive cyclists.

Mac Rae and co-workers (2000) claim that approximately 70% of North American XC events are spent climbing; suggesting race performance is strongly related to a cyclist's physiology. However, field data verifying these observations is sparse (Martin, 1997; Schoberer, 1998). Considerable laboratory test information exists on elite level track and road cyclists, with regard to peak power output (PPO), peak oxygen uptake (VO_2max) and body composition (Craig *et al.* 1993; Palmer *et al.* 1996; Lucia *et al.* 1998, 1999, 2001; Fernandez-Garcia *et al.* 2000). Road race research has shown that strong correlations exist between individual time trial (ITT) performance and PPO (Hawley and Noakes, 1992; Gunning, *et al.* 1998; Balmer *et al.* 2000). Laboratory test data is available on national XC cyclist's laboratory results (Wilber *et al.* 1997; Lee, 1998) and some power output profiles exist (Martin, 1997; Schoberer, 1998), however, limited information in regard to elite XC field or race performance is available.

Wilber *et al.* (1997) revealed a mean peak power output (PPO) of 420 ± 27W in US national MTB XC cyclists, whilst Lee (1998) found high relative values for power to mass (5.84 ± 0.17 $W \cdot kg^{-1}$) and $\dot{V}O_2max$ (74 ± 3.4 $mL \cdot kg^{-1} \cdot min^{-1}$) in a group (n=8) of national level off road cyclists. Recently Martin (1999) reported high values for power to mass (7.3 $W \cdot kg^{-1}$) and $\dot{V}O_2max$ (86 $mL \cdot kg^{-1} \cdot min^{-1}$) in a single male XC cyclist. This suggests XC cyclists tested possess physiology that is comparable to that of elite uphill road cyclists (Padilla *et al.* 1999; Lucia *et al.* 2000). Whilst Mac Rae *et al.* (2000) and Berry and co-workers (1993) report relative $\dot{V}O_2max$ values of 58 ± 5.6 and 62.8 ± 5.9 $mL \cdot kg^{-1} \cdot min^{-1}$, in trained mountain cyclists respectively. These findings are also similar to the test results of competitive road cyclists in the literature (Vrijens *et al.* 1983; Drabbs and Maud, 1997). The exact extent to which differences in physiology and technique may determine XC TT or race performance is however, not well understood.

As early as 1995 the SRM™ training system was employed in national and International XC events (Schoberer, 1998; Martin 1997, Dobbins, 1997), whilst Hansen *et al.* (1996) measured power output in 3 elite level cyclo-cross cyclists with the same system. The conclusions from these investigations have been limited and furthermore the reliability of the measurements remains unclear. With the recent advent of the independent calibration rig (Woods *et al.* 1994) external verification of the SRM™ system, along with improved sensor technology, has increased the reliability of SRM™ data in the field setting.

There is a paucity of research on MTB XC cyclists in general. Given that XC performance is described by relative physiology, then these test measures may predict elite off road performance also. The overall aim of this chapter is to test the findings from chapter 5, which indicate that competitive MTB XC performance may be predicted from laboratory test results. In addition, this chapter seeks to compare between the way elite and competitive cyclists approach the same terrain categories. Thus, with the improvement in the calibration of the SRM™ system and the need to gain more data on the Australian Olympic MTB XC squad prior to the 2000 games, an investigation into the physiological and physical demands of elite and competitive XC cyclists was undertaken.

The specific purposes this chapter are to:

- Ascertain the key physiological test measures of elite MTB XC cyclists.
- Confirm the influence of physiological and physical test values on terrain type ridden.
- Determine the way elite XC cyclists approach terrain categories during a XC trial.
- Compare between the way elite and competitive XC riders approach the same terrain categories.
- To further test the accuracy of the predictive MTB XC model by comparing between predicted and actual race speeds and times of the elite cyclists.
- Establish the contribution of physiology and skill to elite level MTB XC trial performance.

Methods

Subjects

Five elite male MTB XC cyclists participated in this research, with the following physical characteristics: age 28 ± 3.3 y, height 178.7 ± 6.6 cm, body mass 68.8 ± 6.2 kg and sum of 7 skinfolds (Harpenden, Burgess Hill, England) of 43.3 ± 7 mm (TEM% <2.0). The percentage of body fat was 7.8 ± 1.2%, estimated using the sum of seven sites and converted to a percentage value according to Withers *et al.* 1987. The elite subject group included athletes that had won national titles, world cup races, topped world cup overall standings and placed at world title race level (Table 6.1). The Human Ethics Committee of the University of Tasmania and the Australian Institute of Sport (AIS) approved all testing procedures and the cyclists written informed consent was obtained before participation. Testing was conducted early in the Australian MTB XC season. All subjects had been engaged in six weeks of continuous endurance training (~70% VO_2max) prior to the field and laboratory assessments.

Table 6.1. Summary of the National titles, World Title placings and World Cup overall position achieved by participating subjects.

MTB XC Event	Victories and Placings
World title placings	6
World cup overall 1st	2
World cup victories	3
National championships	6

Experimental design

All subjects undertook two testing sessions at the AIS. In addition, three subjects undertook multiple field trials on the Fairfield City, Sydney 2000 Olympic XC course (6.9km – 323-m elevation gain). All testing procedures where conducted within a 14 d period. Subjects were asked to refrain from training strenuously (~60% of HR peak) 24 hours prior to the progressive cycling maximum test (CMT) and during the 24 h between CMT and the 30-min TT test (30min TT). Subjects trained lightly (60% of HR peak) 24 h prior to the XC TT's.

Cycle maximum testing (CMT)

Physiological assessment was conducted on an electrically braked cycle ergometer (Lode Excalibur, Groeningen, Netherlands) equipped with a racing saddle, drop handle bars and the cyclist's own clip-in pedal system. Subjects've had the cycle ergometer adjusted to their own dimensions taken from there racing cycles. Immediately prior to the commencement of the CMT a warm up was conducted on the ergometer for ten min at a power output of 75W. The Lode Excalibur ergometer can be peddled at a constant workload within the range of 80 to 120 rpm and thus cadence is freely chosen during testing. External calibration procedures indicate that power output values produced by the test ergometer are accurate to within ± 1% (Woods *et al* 1994). Subject's self-selected cadences between 85-95 rpm. The CMT commenced at 100 watts (W) and increased resistance by 50W every 5 min. Subjects continued the test until cadence dropped below 75 rpm or volitional exhaustion terminated the test.

Peak power output was determined by the formula according to Kuipers *et al.* (1985).

$$P@\dot{V}O_2max = P_p + (t_f \times (V_f - P_p/5\ min))$$

Where P_P was the power output of the previous stage, V_f is the power output of the final stage and t_F is the time (in minutes) at final power.

Expired $\dot{V}O_2$ $\dot{V}CO_2$, minute ventilation (BTPS), and respiratory exchange ratio were determined every 30 s during the test via an open circuit indirect calorimetry system (Gore *et al.* 1997) (Australian Institute of Sport, Canberra, Australia). Maximal aerobic power was defined as the highest O_2 uptake ($\dot{V}O_2$) obtained during two consecutive 30-s periods. At the completion of each workload interval, 30 μL capillary blood sample was taken from the finger-tip and analysed for blood lactate concentration (Radiometer, Copenhagen, Denmark). At the completion of each workload stage ratings of perceived exertion (RPE) were taken via the 6-20 Borg scale (Borg and Noble, 1974) and heart rate (HR) was recorded by telemetry (Polar Advantage, Kempele, Finland) during the last 15 s of each workload interval and the peak HR reached by each subject was also recorded.

Thirty minute time trial (30minTT)

The 30minTT performance was assessed by measuring the second by second power output (W) and work completed (kj), with mean power output calculated at the completion of the 30minTT. The 30 minTT test was conducted on the same Lode Excalibur ergometer (Lode Excalibur, Groeningen, Netherlands) used for the CMT, which had been adjusted to the cyclist's own cycles dimensions. A linear factor was chosen for each subject based on a constant cadence of 90 rpm and the power output determined at D-max modified individual anaerobic threshold (IAT) (Bourdon, 2000). Cyclists were instructed to produce the highest possible power output for the duration of 30minTT, with power output adjusted by both cadence and force, with the linear factor increased or decreased at the subjects request. This was achieved by having a PC interfaced with the Lode B Work load Programmer. Subjects were continually supplied with visual feedback of cadence, power output, HR and elapsed time as well as receiving encouragement throughout 30minTT.

Subject's ratings of perceived exertion (RPE) were recorded according to the Borg scale (6-20) at each 5 min period. Heart rate was recorded every 5 min (Polar Advantage, Kempele, Finland) and at the same time a blood sample (50 μl) was drawn from the finger-tip and assessed for blood lactate concentration, bicarbonate concentration and blood glucose (Radiometer, Copenhagen, Denmark). Expired $\dot{V}O_2$ CO_2 production, minute ventilation (BTPS), and respiratory exchange ratio were recorded every 30 s for a total of 5 min at the 5, 20 and 25 min periods of the 30minTT. Power output, cadence and work rate was continuously recorded and averaged throughout the test for each subject.

Mountain bike cross-country time trials

One week following the completion of the physiological testing, three subjects completed trial laps of the Sydney Olympic 2000 MTB XC race-course (XC TT); a total of 8 trial laps were completed. Subjects were familiar with the XC race-course from practice laps and World cup and national events conducted at the venue in the previous 6 months. Cyclists performed the laps on their own cycles with the SRM™ power cranks fitted. The front wheel diameter was measured and entered into the SRM™ software before the commencement of each trial lap. Subjects completed a self paced (approx. 20 min) warm up before completing two laps at a maximal pace (~ 13.8 km, 646 m - elevation gain). The maximal lap data was analysed (Table 6.5) and compared to the competitive cyclists (Table 6.6). The SRM™ power meter was set and zeroed before the start of each lap. Following completion of the XC laps, the set position of the SRM™ was recorded and the subject warmed-down over the next 10 min on their MTB cycle. During the course of XC TT temperature and relative humidity was recorded every 15 min.

Cross-country race.

Subjects (n=5) completed 6 laps (41km 1938 m – elevation gain) of the Oceania MTB XC race, whilst on a separate occasion two cyclists completed 6 laps of the same race-course during the Sydney World Cup event. Data from both races was modelled and compared to race performance. Cyclists prepared for the event in their usual way. The individual lap times, temperature, humidity and solar radiation were recorded during the events.

SRM™ calibration

An hour before the start of the XC TT's and Oceania race, SRM™ power cranks were calibrated on a stationary dynamic calibration rig (South Australian Institute of Sport, Adelaide, Australia) according to the method outlined by Woods *et al* (1994). After the SRM™ power cranks, Power Meter™ lead kit and sensors were mounted securely according to the SRM™ manual (Schoberer, Juelich, Germany), the cycle was then placed in an upright wind braked home trainer (RX 5, Blackburn, Sydney, Australia). The cycle's left drive crank arm was removed and a drive arm from the calibrator engine firmly affixed to the cycles axle spindle and locked in place. The Power Meter™ was zeroed and set according to the manufacturers recommended procedure and set to measure at a one second interval (Schoberer, 1998). The calibrator engine, controlled by an independent PC, was started at 100W of resistance and at a speed of 100 rpm and maintained for duration of 5 min. At the completion of each 5 min period the actual power output was read and recorded from the SRM™ system against the calibrator's independent power output. This procedure was repeated for each successive power output in 50W increments to a maximum of 1000W. This method enabled the accuracy and reliability of the SRM™ power cranks to be established and in some cases, the slope of the Power Meter™ to be re-programmed.

Race-course analysis

The entire race-course was measured and categorised. The slope and category was determined for every 10 m of the Sydney 2000 MTB XC course, with 691 measurements made on this basis. The overall lap and 10 m segments were measured with a calibrated surveyors wheel, whilst the slope was calculated with an inclinometer. Each terrain category was matched to the SRM™ data downloaded from the XC TT laps for category slope, distance and location. The exact power output, speed and cadence was then related to the given terrain category based on gradient.

Race-course categorisation

The Sydney race course was divided up into eight discrete terrain categories in order to determine if a cyclist's technique or physiological response varied between the terrain types encountered during the XC TT. The terrain types were grouped into three ascent, two flat and three descent categories. Thus, the categories include "15-20% Ascent", "10-15% Ascent", "5-10% Ascent, "5-10% Descent", "10-15% Descent", "15-20% Descent" and "Post Hill Flat" and "Post Tech Flat." The Sydney race-course profile is shown in figure 6.1.

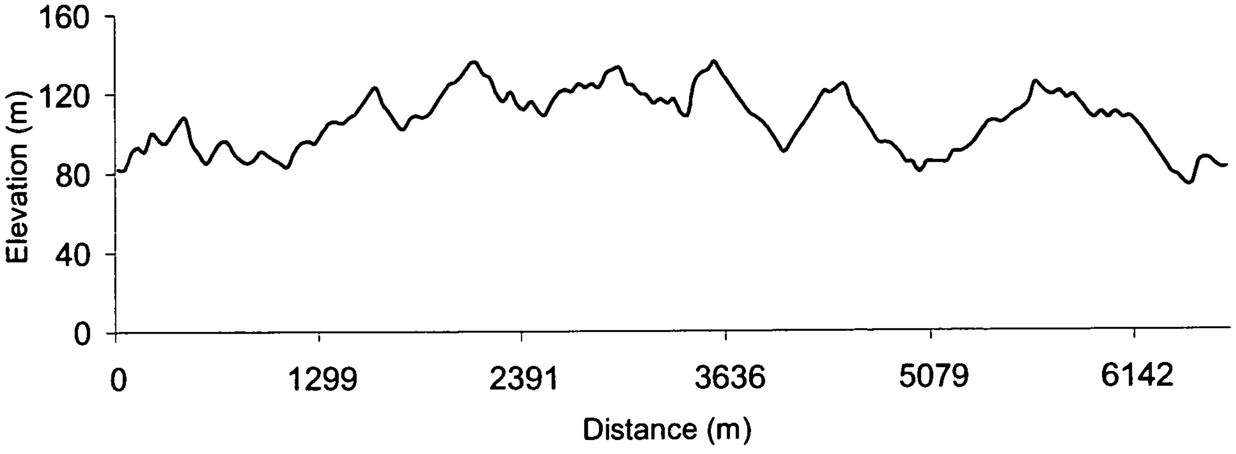

Figure 6.1. Sydney Olympic 2000 MTB XC race course profile and lap distance.

Modelling and prediction

The MTB XC model is based upon the premise that cyclists power output at any time on a race-course will primarily be determined by the riders physiology and the type of terrain being ridden over. A XC course is made up from different terrain types and the model assumes a given power output and hence speed based on a rider's mass and CMT test results. Thus, as in the procedure outlined in chapter three, the individual cyclist's CMT values and the complete Sydney 2000 course terrain categories were loaded into the XC predictive model. Lap times for each cyclist were then generated with the MTB XC model and compared to their average lap times taken from the Oceania Games race, whilst for one rider the same procedure was repeated for the 1999 Sydney World Cup race. For that event the same course was used and CMT results obtained by the same method.

Comparison to competitive XC cyclists

The same procedures for terrain analysis and subsequent XC TT (15.52 km, 624 – m elevation gain) were conducted by the author on a group (n=11) of competitive MTB XC cyclists (chapter 4), which allowed comparisons to be made for the same terrain categories for power output, speed, cadence and speed, despite neither group having cycled on the same courses.

Statistical analyses

Descriptive statistics are expressed as means (± SD). Using the SRM™ graphing software (V 6.00e), the individual laps and terrain types were analysed and categorised. Power output, $\dot{V}O_2$, heart rate and blood lactate concentration at modified individual anaerobic threshold was determined using the D-max method, as per the ADAPT procedure (Bourdon, 2000). Repeated measures ANOVA was used to investigate the differences between terrain categories for the physical and physiological values obtained during the XC TT (Sigma Stat, version 2.03, USA); the *post-hoc* Bonferroni test was applied. Significance for the ANOVA was set at $P<0.05$. Student's t-tests were used to compare the differences between the 30minTT and D-max values reported for power output, % of PPO, % of peak HR and blood lactate concentration; significance was set at $P<0.05$. Normality and equal variance tests showed that the data for t-test analysis passed. Independent T-tests were used to compare physiological and physical characteristics between the elite and competitive groups. Adjusting the alpha level via the Bonferroni method held significance at 0.05. Analysis of the t-test data, comparing between elite and competitive riders, was normally distributed.

Results

Cycling maximum test and 30 min TT results

The results of the laboratory CMT are shown in Table 6.2. Relative $\dot{V}O_2max$ was measured at 75.4 ± 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$ and at PPO 415 ± 25W.

Table 6.3 outlines the laboratory 30minTT results, with 30min TT blood lactate concentration (9.6 $mmol \cdot L^{-1}$ ± 1.7 vs 3.9 ± 0.6 $mmol \cdot L^{-1}$) and power output (362 ± 22.9W vs 323.8 ± 20.1) being significantly ($P>0.05$) higher than calculated at D-max threshold.

Off road TT performance.

Table 6.4 summarises the XC TT data. Significant differences ($P<0.05$) were found between the mean XC TT and 30minTT values for power output (306.8 ± 14.5W vs 362.6 ± 22.9W) and percentage of PPO (71.6% vs 88.1%; $P<0.05$), respectively.

Table 6.2. Cycling maximum test results of the elite mountain bike cross-country cyclists (n=5). Values are means (± SD).

Parameter	Mean	± SD	Range
Peak power output (Watts)	415	25	380 – 450
Absolute $\dot{V}O_2max$ ($l\cdot min^{-1}$)	5.20	0.38	4.78 – 5.78
Relative $\dot{V}O_2max$ ($mL\cdot kg^{-1}\cdot min^{-1}$)	75.4	2.28	73.3 – 78.9
Power to mass ($W\cdot kg^{-1}$)	6.0	0.20	5.8 – 6.27
Peak heart rate (bpm)	188	8	180 – 200
Peak Bla concentration ($mmol\cdot l^{-1}$)	15.98	1.89	13.9 – 18
D Max power output (Watts)	322 8	20.1	300 – 345
D Max power / % PPO (%)	77.6	4.2	74 – 83.1
D Max $\dot{V}O_2max$ ($mL\cdot kg^{-1}\cdot min^{-1}$)	62.7	3.6	57.9 – 67.4
D Max $\dot{V}O_2$/% VO_2max (%)	83.3	5.2	79 – 91
D Max heart rate (bpm)	159	12	161 – 178
D Max HR / % of peak HR (%)	86.1	4.9	80.7 – 91.1
D Max Bla concentration ($mmol\cdot l^{-1}$)	3.96	0.61	3.1 – 4.8

D Max, log transformation for calculating individual anaerobic threshold; Bla, Blood lactate; BPM, Beats per minute; $\dot{V}O_2max$, maximal aerobic power; $\dot{V}O_2$; Sub-maximal oxygen uptake HR, Heart rate; PPO, Peak power output.

Table 6.3. Summary of the 30 min time trial results of the elite mountain bike cross-country riders (n=5). Values are means (± SD).

Parameter	Mean	± SD	Range
Power output (Watts)	362.6*	22.9	340.4 – 393
30minTT power/% PPO (%)	87.1*	2	84 – 89
Power to mass ($W \cdot kg^{-1}$)	5.28	0.23	5.05 – 5.62
Absolute $\dot{V}O_2$ ($l \cdot min^{-1}$)	4.6	0.4	4.28 – 5.14
Relative $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	67.2	2.8	65.1 – 71.3
Economy ($W \cdot l \cdot min^{-1}$)	78.4	1.3	76 – 80
Percentage of $\dot{V}O_2max$ (%)	89.8	0.7	88.9 – 90.3
Heart rate (bpm)	172	5	166 – 179
Percentage of peak HR (%)	93.3*	1.5	91.2 – 94.4
Bla concentration (mM)	9.57*	1.74	7.5 – 11.3

$\dot{V}O_2$; Sub-maximal oxygen uptake; PPO, Peak power output; Bla, Blood lactate; 30minTT, bpm, beats per minute; Thirty-minute time trial; HR, Heart rate; $W \cdot l \cdot min^{-1}$, Watts per litre of oxygen.

* Denotes a significant difference to D-max threshold values. (P<0.05)

Table 6.4. Descriptive statistics taken from the mountain bike cross-country SRM™ trial laps (n=3). Values are means (± SD).

Parameter	**Mean**	**± SD**
Speed (km hr)	20.3	1.2
Power output (Watts)	306.8 *	14.5
Power output % PPO (%)	71.6 *	7.6
Heart rate (bpm)	176	7
Percentage of Peak HR (%)	90.7	0.80
Cadence (rpm)	68.3	4.3
Temperature (°C)	28.3	1.3
Relative Humidity (%)	41.9	4.5
Radiation (Watts)	546	189.3

HR, Heart rate; Cadence, number of pedal revolutions per minute; PPO, Peak power output; bpm, Beats per minute; km hr, kilometres per hour; °C, Degree Celsius.

* Denotes a significant difference to 30min TT values ($P<0.05$).

Off road TT terrain analysis.

Table 6.5 shows the physical and physiological values obtained for the different terrain categories. Significant differences ($P<0.05$) were observed for the elite cyclists between the terrain categories for power output, speed, power to mass and cadence.

Terrain comparison: elite vs competitive cyclists.

Elite XC cyclists performed in 7 of the terrain categories with significantly greater ($P <0.05$) speed and in 6 of the categories with greater ($P<0.05$) power output and power to mass than competitive riders (Table 6.6).

Furthermore, the elite cyclists produced significantly more power ($P <0.05$) and at a higher Watts per kilogram ($P <0.01$) for "15-20% Ascent", "10-15% Ascent", "5-10% Ascent categories. Interestingly performing over "5-10% Ascents", "10-15% and 15-20% Ascents" percentage of peak power output was not different ($P>0.05$) between elite and competitive groups (89.8 ± 7.7 vs 88.5 ± 2.8%; 100.3 ± 7.8% vs 102.2 ± 9.5%; 114.4 ± 8.8% vs 115.1 ± 8.2%).

Elite modelling.

Table 6.7 outlines the average lap times taken from the Oceania and Sydney World Cup XC events and the predicted lap times determined from CMT results for each rider. In addition, Table 6.7 outlines the individual and overall differences between the actual and predicted lap times. Modelling between actual and predicted times revealed small mean differences (4.62% of mean performance time) and median absolute differences (4.67%).

Table 6.5. Descriptive statistics for the physical and physiological responses of the elite mountain bike cross-country riders to the terrain categories (n=3). Values are means (± SD).

Parameters	15-20% Ascent	10-15% Ascent	5-10% Ascent	Post Hill Flat	Post Tech. Flat	5-10% Descent	10-15% Descent	15-20% Descent
Speed (km·hr)	**12.19 ♣**	**13.61 ♣**	**14.32 ♣**	23.15 *†♣	22.85 *†♣	30.3 *†♣	27.4 *†♣	31.4 *†♣
	(1.84)	**(1.90)**	**(1.79)**	(2.34)	(2.9)	(5.4)	(2.2)	(1.59)
Power output (Watts)	**473.3**	**420.9** *	**407.3** *	322.6 *†♣	319.9 *†♣	93.2 *†♣φ	80 *†♣φ	83.5 *†♣φ
	(35.1)	**(28.3)**	**(34.9)**	(25.5)	(43.4)	(41.1)	(18.2)	(20.8)
% Peak power output (%)	**114.4**	**100.3** *	**89.8** *†	84.9 *†	76.0 *†♣	21.6 *†♣φ	21.6 *†♣φ	44.4 *†♣φ
	(8.8)	**(7.8)**	**(9.2)**	(5.25)	(10.2)	(8.4)	(5)	(5)
Heart rate (bpm)	179	178	176	179	176	174	174	179
	(4)	(5)	(1)	(3)	(3)	(6)	(6)	(5)
% Peak HR (%)	90.8	90.6	89.7	91.3	89.5	86.8	86.8	90.0
	(2)	(2.57)	(2.76)	(2.33)	(4)	(4.9)	(2.5)	(2.4)
Power:Total mass ($W \cdot kg^{-1}$)	**5.90**	5.25 *	4.95 *	3.93 *†♣	3.86 *†♣	5.10 *	5.10 *	5.10 *
	(0.50)	(0.40)	(0.48)	(0.24)	(1)	(0.11)	(0.11)	(0.11)
Cadence (rpm)	69.4	74.4	73.5	80.1 *	79.6 *	45.5 *†♣φ	43.2 *†♣φ	43.94 *†♣φ
	(3.21)	(4.9)	(6.3)	(4.6)	(5.7)	(15.8)	(4.9)	(16.5)

* Denotes a significant difference to terrain category one (P< 0.05).
† Denotes a significant difference to terrain category two (P< 0.05).
♣ Represents a significant difference to category three (P< 0.05).
Bold values represent significant differences to terrain categories four, five, six, seven and eight (P< 0.05).
φ Denotes a significant difference to terrain categories four and five(P<0.05).

Parameters	Speed (km·hr)		Power Output (Watts)		% Peak Power (%)		Heart Rate (bpm)		% Peak HR (%)		Power :Total Mass ($W \cdot kg^{-1}$)		Cadence (revolutions·min)	
Category	Comp	Elite	Comp	Elite	Comp	Elite	Comp	Elite	Comp	Elite	Comp	Elite	Comp	Elite
15-20% Ascent	7.64	**12.19**	419.6	**473.3**	115.13	114.37	179	179	93.76	90.79	4.9	**5.90**	57.88	**69.37**
	(0.76)	**(1.84)**	(30.9)	**(35.1)**	(8.25)	(8.83)	(8)	(4)	(2.63)	(2)	(0.42)	**(0.50)**	(3.39)	**(3.32)**
10-15% Ascent	9.92	**13.61**	374.3	420.9	102.21	100.29	173	178	90.62	90.65	4.40	**5.25**	61.78	**74.45**
	(0.83)	**(1.90)**	(41.0)	(29.0)	(9.53)	(7.88)	(8)	(5)	(3.44)	(2.57)	(0.33)	**(0.33)**	(5.45)	**(4.91)**
5-10% Ascent	11.72	14.32	329.4	**407.3**	88.55	89.78	178	176	**93.0**	89.7	3.82	**4.98**	67.62	73.47
	(1.83)	(1.79)	(43.4)	**(34.9)**	(2.85)	(7.70)	(8)	(1)	**(1.72)**	(2.85)	(0.48)	**(0.48)**	(6.29)	(6.29)
Post hill flat	10.80	**23.15**	311.1	322.6	**84.89**	91.62	178	179	93.42	91.33	3.56	3.93	71.18	**80.08**
	(0.93)	**(2.34)**	39.3	(25.5)	**(5.25)**	(2.30)	(7)	(3)	(2)	(2.33)	(0.47)	(0.24)	(5.66)	**(4.58)**
Post tech. flat	18.63	**22.85**	256.6	**319.9**	71.73	76.06	177	176	92.44	89.55	**4.17**	3.86	75.01	79.63
	(2.17)	**(2.93)**	(27.3)	**(43.4)**	(7.75)	(10.16)	(7)	(3)	(3)	(4)	**(0.7)**	(1)	(3.37)	(5.66)
5-10% Descent	22.37	**30.27**	64.7	**93.2**	18.23	21.65	168	174	87.88	89.49	4.29	**5.10**	58.84	45.5
	(2.33)	**(5.38)**	(27)	**(41.1)**	(13.63)	(8.40)	(9)	(6)	(3.66)	(1.83)	(0.28)	**(0.11)**	(13.24)	(15.78)
10-15% Descent	22.24	**27.40**	33.1	**80**	27.72	21.92	152	**174**	79.63	**86.81**	4.29	**5.10**	34.17	43.20
	(2.52)	**(2.2)**	(14.9)	**(18.2)**	(6.80)	(3.88)	(8)	**(6)**	(4.55)	**(2.47)**	(0.28)	**(0.11)**	(12.77)	(4.9)
15-20% Descent	27.22	**31.39**	19.4	**83.5**	19.07	**44.40**	149	**179**	78	**90.01**	4.29	**5.10**	6.38	**43.94**
	(2.39)	**(1.59)**	(2.8)	**(20.8)**	(9.58)	**(16.28)**	(8)	**(5)**	(4.37)	**(2.37)**	(0.28)	**(0.11)**	(12.1)	**(16.52)**

Peak Power, Peak power output; Comp, competitive mountain bike cross-country rider; Elite, elite mountain bike cross-country rider; bpm, beats per minute.

Bold values represent significant differences ($P < 0.05$)

Table 6.7. Comparison of predicted and actual mean lap times ridden on the Sydney Olympic mountain bike cross-country course (n=6).

Cyclist	Mean Actual Lap (min s)	Predicted Lap (min s)	Time Difference (min s)	Percentage Difference (%)
A	19:51	21:23	1:32	7.72
B	19:54	21:12	1:18	6.53
C	20:19	20:33	0:14	1.14
D	20:04	20:38	0:34	2.82
Ei	20:45	21:18	0:27	2.16
Eii	19:50	18:24	1:28	7.39
Mean Lap ± SD	20:07 (00:21)	20:34 (01:07)	00:56 (00:34)	4.62 (2.90)
Median Lap	19:59	20:55	00:56	4.67

A, B, C, D, Ei, Cyclists who participated in the Oceania MTB XC race and testing; Eii, Cyclist who participated in the Sydney World cup XC race and testing; min, Minute; s, Second.

Table 6.8. Comparison between each predicted and actual lap times ridden on the Sydney Olympic mountain bike cross-country course (n=6).

Cyclist	Predicted Lap/s (min s)	Lap 1 (min s)	Lap 2 (min s)	Lap 3 (min s)	Lap 4 (min s)	Lap 5 (min s)	Lap 6 (min s)
A	21:23	19:11	19:29	19:59	19:55	20:20	19:47
B	21:12	19:10	19:42	19:44	19:53	20:18	20:24
C	20:33	19:09	19:35	20:19	20:16	20:17	20:07
D	20:38	19:52	20:08	20:30	20:12	20:50	20:28
E (i)	21:18	19:40	20:40	20:58	21:00	20:21	21:35
E (ii)	18:24	20:24	19:53	19:54	20:20	20:03	19:35
Mean Lap (± SD)	20:34 (01.07)	19:34 (00:30)	19:53 (00:26)	20:14 (00:27)	20:16 (00:24)	20:21 (00:15)	20:19 (00:42)
Median Lap	20:55	19:25	19:44	20:09	20:14	20:19	20:15
Mean Lap Difference (min s) / (%)		01:00 / 5.11	00:41 / 3.44	00:20 / 1.65	00:18 / 1.48	00:13 / 1.06	00:15 / 1.23
Median Lap Difference (min s) / (%)		00:26 / 2.56	00:09 / 0.75	00:14 / 1.15	00:19 / 1.56	00:24 / 1.97	00:20 / 1.64

A, B, C, D, Ei, Cyclists who participated in the Oceania MTB XC race and testing; Eii, Cyclist who participated in the Sydney World cup XC race and testing; min, Minute; s, Second.

Discussion

Elite test results

This chapter was the first to include data on world class off road cyclists. The elite XC cyclists in this study showed a high aerobic power, as indicated by their mean relative $\dot{V}O_2max$ of 75 $mL \cdot kg^{-1} \cdot min^{-1}$ and a power to mass of 6.0 $W \cdot kg^{-1}$. These values are comparable to those reported by Wilber *et al.* (1997) and Lee (1998) for groups of national level XC cyclists, whilst Hansen *et al.* (1996) found similar results in 3 elite level cyclo-cross cyclists also. As is the case with endurance athletes, these cyclists reported low values for sum of 7 skinfolds and percentage body fat at 7.6%. These findings compare similarly with the low body fat values from authors investigating elite road cyclists ranging between 6.2 - 7.8% (Lucia *et al.* 1999; Hoogeveen *et al.* 1998 and Padilla *et al.* 1999). However, it must be remembered that many physiological test and anthropometrical indices can vary according to the time of the year the measurement was undertaken. The cyclists in this investigation had on average 5-6 weeks of training before the test and XC TT period and this suggests that the values obtained may not have been at peak.

Despite the reduced training period before testing, a high mean power output (~363W), percentage of $\dot{V}O_2max$ and percentage of peak heart rate was observed during the 30minTT. These results compare similarly with the findings of Padilla *et al.* (2000) for professional cyclists who completed TT's in ~38 min, with a mean power output of ~362W. Further analysis of the 30minTT data revealed not only a high power output, but favourable $W \cdot L \cdot min^{-1}$, which was similar to the findings of Coyle *et al.* (1991) for a group of 9 elite cyclists who performed a 60 min lab based TT (~76.3 $W \cdot L \cdot min^{-1}$). The 30minTT values were significantly higher ($P < 0.05$) than those calculated at D-max individual anaerobic threshold for mean power output (~362 vs 322W), blood lactate concentration (~9.6 vs 4.0 $mmol \cdot l^{-1}$), percentage of $\dot{V}O_2max$ (~92 vs 83%) and peak heart rate (~90 vs 86%). The 30 minTT findings indicate that the elite cyclists under investigation had the ability to work above IAT for extended periods, despite considerable metabolic acidosis. Thus, elite XC cyclists were able to produce power output during a lab based TT with significant contributions from both aerobic and glycolytic sources.

Overall effect of the XC TT

Heart rate

Elite XC TT results show that a high mean percentage of peak HR was maintained (~91%) and confirms the cyclist's capacity to sustain high relative work rates. These findings are comparable to research by Lee (1998) who found that national class XC cyclists maintained a high percentage of peak HR (~87%) during a 39km off-road race, whilst Seifert and co-workers (1997) report that trained XC cyclists completing a 10.4 km off-road TT averaged ~93% of peak HR. It appears that both elite and competitive XC cyclists maintain a high relative HR's during off road TT's or races, confirming the high work rates maintained in such events.

Power output

Despite the apparent high heart rate sustained during an off road race or XC TT, the maintenance of power output is important in off road cycling. The average XC TT power output at ~307W was found to be lower than both D-max IAT power output and significantly lower ($P<0.05$) than 30minTT power output. Despite moderate power output during the elite XC TT's, these values are not dissimilar to the average power output (~333W) recorded by 3 elite cyclo-cross cyclists during a 60 min off road race (Hansen *et al.* 1993). The power output from the cyclo-cross cyclists was corrected, without including the natural pauses caused by freewheeling and running, suggesting the cyclo-cross values may be higher than found in elite XC cyclists. The moderate power output observed during the elite XC TT's may be explained by the numerous periods of freewheeling, caused by technical sections that saw cyclists stop pedalling, with average power output falling as a result.

Descending portions of the elite off road TT's could not be excluded from the data, as was the case in chapter four, due to the greater dispersion and number of descents throughout the race course (see figure 6.1). Although a moderate overall power output was recorded, periods of high power output on some sections of the course were noted. This outcome is similar to the findings of the competitive XC cyclists in chapter four. Comparing an elite road and XC cyclist, Martin (1997) found the average power output to be approximately 100W greater in a massed start road race as compared to the off road event, despite a higher mean percentage of peak HR maintained during the XC race (~88% vs 82%). Thus, despite an average XC TT power output at only 71.6% of peak power output (PPO), the high HR response would indicate the physiological stress of performing the TT was nonetheless high. Average power output recorded during the elite XC TT is therefore not an accurate reflection of the second by second work demands XC cycling.

Cadence

Given the large variations in gradient in the Sydney 2000 XC race-course, it was no surprise to observe large fluctuations in cadence of between 0 and 120 rpm throughout the XC TT laps. Cadence varied considerably, however, it was seen that it stabilised during the longer flat and uphill terrain sections of the elite XC TT's. The mean lap cadence at 68 rpm is considerably lower than the road TT cadence calculated by Lucia *et al.* (2001) of professional road cyclists performing on the flat (~90 rpm), but is higher than the cadence (~62 rpm) of the competitive XC cyclists reported in chapter four. The low cadence observed for the elite and competitive XC cyclists is perhaps explained by the periods of negligible power input, the considerable climbing demands and the need for traction and bike control made easier with a lower pedal frequency. Furthermore, Lucia *et al.* (2001) report that a group of professional road riders averaged 70 rpm during competitive uphill cycling, indicating the influence of gradient on cadence in XC and uphill riding. Given the rough and uneven nature of the terrain encountered in a XC race, it seems plausible that a higher cadence would not be realistically possible, as this may result in a loss of traction and also velocity on dirt.

Physiological and physical effect of terrain types

Apart from overall lap data, measures were analysed within a lap at specific points of the course. This was achieved by splitting the XC TT laps into discrete terrain categories based on gradient and then comparing them against each other.

Heart rate

With regard to HR response no differences were reported between the mean ascension and flat terrain categories, whereas significantly lower ($P<0.05$) HR values were reported between the "5-10%" and "10-15% Descent" categories and all other categories. It was observed that for "5-10%" ascent category that power output related to an average of ~94% of $\dot{V}O_2max$, whilst in comparison Hansen *et al.* (1996) reports that Cyclo-cross riders worked at 86% of $\dot{V}O_2max$ over similar gradients. Despite an apparent relationship between gradient and high work rate, the elite XC cyclist's values may be higher due to short nature of the climbs.

The "15-20% Descent" category showed a mean HR of ~178bpm, despite being the steepest category, where power output was very low (~84W). This effect may be partly explained by a preceding ascending category, which would cause HR to be high at the beginning of the descent, but may also reflect the cost of isometric effort.

The HR values observed for "5-10%" (~171 bpm) and "10-15% Descent" (172 bpm) categories were significantly lower ($P< 0.05$) than overall HR, indicating some recovery in less physically taxing sections. This finding suggests that the elite XC cyclists maintain a high work rate during all terrain categories, even if the effort is invested in bike control. Although it may be assumed that the physical effort should be lower during a descent phase of the elite XC TT, the amount of recovery in HR was less than expected and maybe dependant on the length of the descent, the cyclist's skill level and the technical demand of the passage. It appears the elite XC cyclist maintain a high speed and overall physical effort throughout all of the terrain categories, which is probably a requirement of maintaining the highest average speed throughout an entire XC TT or race.

Cadence

Mean cadence maintained over the flat and ascent categories was not significantly different, with a slight tendency for higher cadences during the flat terrain categories (~79 and 74 rpm). Cadence maintained during the ascent categories was similar to the mean XC TT cadence of 68 rpm. Elite MTB XC cyclists maintain cadence within a fairly tight limits (± 10 rpm) over highly variable terrain, with a tendency to bring frequency up over flat sections.

Power output

With regard to power output the "15-20% Ascent" category revealed the highest value for all the terrain categories at ~473W. It is of note that only relatively small variations in power output were apparent between "10-15% Ascent" and "5-10% Ascent" (~415W vs 400W) and similarly between "Post hill flat" and "Post tech flat" categories (~321W vs 314W). These observations suggest despite considerable differences in gradient, power output varied moderately, with the exception of "15-20% Ascent" category that saw the elite cyclists produce much higher values. Overall there is variation between the terrain categories for speed and power output alike, however, on close inspection the inter-terrain differences appear to be slightly less pronounced in the elite XC cyclists compared to competitive cyclists tested in chapter four. This effect may be attributed to pacing, whereby the elite performer may have regulated the rise and fall of speed due to terrain changes, by adjusting power output less markedly than their competitive counterparts.

With regard to power output and the descent categories, low values were observed, which is not unexpected given the primary concern of the rider is to maintain controlled descending. During the XC TT laps elite cyclist maintained a high percentage of maximum HR despite changes in gradient, whilst cadence, speed and power output varied more distinctly. Elite XC cyclists vary effort according to gradient, which is similar to the findings in competitive riders in chapter 4.

Comparison between competitive and elite cyclists

Power to mass and power output

One of the main purposes of this investigation was to compare the way elite and competitive MTB XC cyclists ride the same terrain categories. This was done to gain an insight into the strategies used by both groups and establish how these influence performance. Clearly, elite level XC cyclists are able to maintain significantly higher (P<0.01) speeds in 7 out of 8 terrain categories compared to competitive riders. In addition, elite cyclists produced greater power output (P<0.05) in 6 out of the 8 terrain categories, but did so with remarkably less variation in percentage of PPO. These findings agree with the outcomes in chapter 4, which proposed that a greater power to mass ratio in XC cyclists relates to greater terrain power output and speed. The mean power to mass of the 3 elite cyclists was higher than that reported for the 11 competitive cyclists (~6.0 $W{\cdot}kg^{-1}$ vs 5.1 $W{\cdot}kg^{-1}$) and this outcome confirms the observation that XC TT performance, including technical aspects, maybe primarily reliant on power to mass. This is further seen in the comparison for the power to total mass during the ascent categories, with the elite cyclists performing with significantly higher (P<0.05) values than their competitive counterparts. Elite XC cyclists profit from a higher power to mass ratio, but may enhance their physiological advantage with greater skill levels.

Heart rate

It appears elite off road cyclists maintained a more even work rate during the XC TT, as seen by a smaller variation in percentage of peak HR across all terrain categories (~90 ± 1.3 vs 89 ± 6.3%). Overall elite and competitive cyclists perform with similarly high HR values for all terrain categories and this confirms the high work rate maintained during XC trials for both groups.

It appears that the elite XC cyclists maintained a relatively constant HR across all terrain categories, which may be explained by a more even pacing strategy employed by these riders. According to the Swiss national XC coach Andy Seeli (personal communication), any advantage in time gained at the top of a hill must then be maximised in the following downhill section at the elite level. It appears the elite XC cyclist in this study did precisely this, in order to further any advantage made during the preceding ascent with the consequence of maintaining higher average HR values throughout the XC TT.

Cadence

Elite XC cyclists in this chapter have the tendency to perform with higher cadence than competitive riders, with significantly higher ($P<0.05$) mean cadence in 5 out of the 8 terrain categories. Despite low cadence seen in the elite cyclists compared to massed start road racing (Lucia *et al.* 2001), it appears that elite off road cyclists prefer a frequency closer to 70 rpm, which is higher than average cadence of 62 rpm observed for competitive riders.

Percentage of peak power output

Of significant note performing over "5-10% Ascents", "10-15% and 15-20% Ascents" percentage of peak power output was not different ($P>0.05$) between elite and competitive groups (89 vs 88%; 100% vs 102%; 114% vs 115.1%). A remarkably low standard deviation and similarity in mean percentage of PPO for the ascent categories was observed for elite and competitive cyclists alike. This outcome confirms the findings from chapter 5 that XC cyclists regulate speed on uphill sections according to PPO in similar ways. This indicates despite large differences between subject groups, off road cyclists approach ascent terrain categories with comparable percentages of PPO and confirms the construction methods for the XC model in chapter 5.

Elite mountain bike cross-country modelling

Given the finding that power to mass appears to be a strong indicator of XC TT performance and the outcomes from chapter 5, it was decided to test these findings with the elite cyclists with the MTB XC model. As per the method in chapter 5, the cyclists test results and mass was entered into the MTB XC model for the Sydney 2000 Olympic race-course. Despite some of the models limitations, consistent trends where revealed. Modelling between 6 sets of test and race performances, actual and predicted times revealed small mean differences (4.62% of mean performance time) and median absolute differences (4.67%). These results confirm the assumptions underlying the model in chapter 5.

The model consistently underestimated the elite cyclists actual race performance. Elite cyclists were able to produce greater velocity than the power to mass derived from the lab based testing would indicate, suggesting a greater contribution of technique and pacing to performance in these cyclists. This difference may be further explained by the effect of comparing the model with a race performance, which formed a part of the rider's Olympic preparation, as compared to a non-race XC TT that the competitive riders completed. The higher race speeds displayed by the elite cyclists may be explained by their experience in taking economical lines, carrying more momentum between terrain categories and negotiating technical sections with greater speed. This suggests elite cyclists were able to maintain their lap times with greater skill and pacing from the outset.

In comparison competitive riders were able to perform similar lap times with technique, but it appears could not increase TT performances above modelled parameters. Hence, it can be assumed that elite cyclists in this investigation were able to perform above the assumptions made by the model and this indicates the considerable importance of non-measurable inputs (technique/pacing) at this level of the sport. Despite the models under prediction of race performances in elite cyclists, the outcome is nevertheless supportive of the finding that relative physiological measures are vital determinants of MTB XC cycling.

Conclusion

This investigation was the first to include elite level MTB XC cyclists. The results of this study show that the off road cyclists had exceptional aerobic power (~75mL·kg^{-1}·min^{-1}) and laboratory TT power output (~363W), which was comparable to values obtained from professional road cyclists. A major finding from this study was that elite MTB XC cyclists convert superior relative physiology into fast lap times, which may be enhanced by greater neuromuscular factors such as technique. Elite cyclists in this study were able to perform over most terrain categories with greater speed than competitive riders, which was probably due to superior physiology and skill levels. Globally elite cyclists respond to terrain categories in similar ways to competitive cyclists, despite large differences in physiology. The findings from this chapter verify the importance of relative physiological measures in predicting elite MTB XC performance, with elite MTB XC modelling revealing an error of less than ± 5%.

Based on these results, this chapter confirms the discontinuous and high intensity nature of performing XC TT's. This investigation further demonstrates that riding a XC TT is an intermittent and high intensity cycling discipline, which has considerable skill demands and a strong reliance on physiological measures related to mass for both competitive and elite riders alike.

7 Chapter Seven - Summary and Conclusion

Cycle racing has been described as a 'physiology' sport, which has historically utilised the application of scientific principles to assess and improve performance. Many coaches and cyclists realise the benefits of obtaining basic scientific information in the pursuit of sporting excellence. The sport of MTB XC is relatively young and despite being a professional sport it was clear that relevant and useful research was lacking in this discipline.

In order to make a contribution to the sport of XC cycling it was necessary to identify the critical physiological and physical measures that best predict XC TT performance. This research was designed to give insight into the unique demands of riding an off road TT and to relate XC TT performance to standard laboratory test measurements. Given the claims from cyclists that MTB XC requires more leg strength and considerably higher bike handling skill than road cycling, it was of interest to investigate these claims. It was the primary intention of this research to ascertain to what extent XC performance is reliant on physical ability and once this was established to determine by inference the importance of the contribution of skill.

The first stage of this investigation involved analysing the MTB XC World Cup and World Title race-courses over a three year period. This was undertaken to gain an insight into the broad demands of the MTB XC event from existing race-course design and event results. In addition, this chapter attempted to relate those findings to current cycling research. This phase of the study revealed that elite XC events have considerable climbing demands. Cyclists climb substantial aggregates of climbing and at gradients that are on average significantly steeper than seen in road events (>10%). It was also revealed, given the largely individual nature of a MTB XC event, that race duration for men (141 min) and women (119 min) is considerable. Furthermore, international level XC courses require exceptional technical skills. Hence, the third finding was that MTB XC race-venues have considerable technical demands, which assumes the XC cyclist must possess a range of unique abilities that road cyclists may not require. Thus, from this analysis it could be assumed that elite level XC racing may demand endurance physiology similar to the values observed in elite level road cyclists. To be a successful XC cyclist requires not only skill and physiology in isolation, but also an ability to combine these requirements in order to perform.

The XC event requires the cyclist to; possess unique technical skills, maintain a high work rate, pace their efforts, apply race tactics, remain mentally alert and resist the affects of fatigue, de-hydration and hyperthermia. The interaction between physical and psychomotor abilities appears to be important during a MTB XC race, with some sections of a race-course demanding greater physical or technique input. For example riding uphill sections requires considerably more physical effort than skill and this is approximately reversed during rapid and technical downhill descents, whilst the physical effort required to descend is probably much higher than on similar gradients on a road bike.

Investigating the endurance and climbing demands of XC racing and comparing these to other cycling research, made it possible to hypothesise which physical and physiological parameters that may be important in MTB XC performance. These parameters included; body mass, maximum aerobic power ($\dot{V}O_2$max), peak power output (PPO), power at individual anaerobic threshold (IAT) and power to mass at PPO and IAT. In addition, from this section it was possible to construct an off road TT course that included the approximate technical components of a World Cup XC event, so as the essential elements in a 'test' XC course were included.

In order to test the assumption that key laboratory test parameters may be central to XC performance, the next step involved designing a XC course and measuring the physiological and physical responses of riding such a course and relating those performances to standard physiological measures. This step attempted to determine, which physical and physiological test measures best-described XC TT performance. The results from this phase revealed that measures related to body mass described XC TT performance strongly, with the traditional measures of cycling individual time trial (ITT) performance being weaker in this study. The strongest relationship was PPO to total mass, whilst the second strongest parameter was relative $\dot{V}O_2max$. It was predicted in the first phase of the study that absolute $\dot{V}O_2max$ may have been an important determinant of XC TT performance, however, it was somewhat unexpected that such a strong relationship was revealed for relative $\dot{V}O_2max$. Furthermore, it was not expected that power output at IAT was found to be weaker in describing XC TT performance, as it was hypothesised that MTB XC performance may have been similarly reliant on measures coincident at transition thresholds, as is the case in road ITT's. However, it is apparent from this investigation that XC TT performance is dependent upon measures related to mass and this outcome was different to ITT research findings.

Road ITT performance principally requires a high, but even power output. This is in contrast to the analyses of XC TT SRM™ data that showed a highly intermittent pattern of power output. The considerable climbing and technical demands and the change in terrain types explain the variable loading pattern observed in during the XC TT's. Thus, it was found that test measures taken from a standard laboratory test and related to body mass could strongly indicate and predict XC TT performance also. The standard physiological test measures, such as absolute $\dot{V}O_2max$ and PPO were thought to be important in an endurance sport like off road cycling, however, physiological measures related to body mass described XC TT performances more closely.

Given the outcomes from the laboratory and field trials, the next step in this investigation was to validate and integrate these findings through modelling. This approach was unique in XC cycling. This part of the investigation sought to answer if MTB XC performance could be modelled based on laboratory test results accurately. Furthermore, it has been the intention of this research to provide a tool that coaches and ultimately athletes can make practical use of and the construction of the model attempts to fulfil this role.

Traditionally XC coaches and cyclists have used their own observations and judgments to improve the quality and content of their training programmes and racing performances. In order to go forward in the pursuit of excellence in sport, coaches need to base training on information that is practical, useful and relevant. By profiling the race and physical demands of XC cycling, and incorporating the findings into a working model, it was hoped that training may become more empirically based.

The model was based entirely on physiology as the primary input, but more tellingly physiology relative to mass indices. The model was shown to be very accurate overall in predicting lap times in two separate validation trials and in other trials with elite riders. The model was able to predict uphill speed strongly, but was less than ideal during very fast and technical downhill sections.

Comparative or theoretical modelling was conducted to determine the relationship between $W \cdot kg^{-1}$ and XC TT time, which was found to be very strong ($r = -0.995$; $P<0.05$). The outcome of the comparative trials revealed that for approximately every 0.3 increase in $W \cdot kg^{-1}$ that a 2% reduction in lap times may be expected. Although these results were encouraging, the accuracy of the model had to be tested. This was achieved by getting two-experienced and well-trained XC cyclists to complete a lactate transition and test and ride a MTB XC course. The model was then utilised to predict lap times for a separate XC course. Soon after the prediction, the same XC cyclists completed three laps of the profiled and modelled course. It was found that there was less than a 3% difference between the predicted lap time and the lap time actually ridden by the two cyclists. The preliminary modelling results are encouraging and appear to confirm the XC TT findings, which claim a strong relationship between PPO to mass and off road speed. The next stage requires this information to be comprehensively validated with greater subject numbers as well as further field trials to improve prediction of downhill sections also.

The benefits of the XC model include that; accurate lap times can be determined and used as a guide to pacing on unseen MTB XC race-courses, changes in physiology and determining the improvement in lap times on local, interstate and international MTB XC courses may be possible, the limits of off road performance maybe analysed and the identification of individual strengths and weaknesses may be achieved. As the model suggests an average speed expected specifically for each terrain type compared to actual performance, coaches may be able to determine if a rider performs above, under or according to the model. Thus, the model may serve as a reference point to which the rider bases their progress upon.

The results from the modelling confirm the overall findings that physiological measure related to mass are important determinants of MTB XC performance. This outcome verifies that physiology is central in describing and predicting off road performance. A deeper analysis of the relationships between different terrain types revealed that XC performance is complex, however, the simple measure of PPO to total mass described and predicted XC performance strongly.

It was found that the strength of the relationship between power to mass and specific terrain speed was, however, variable. That is to say, that the relationships were weaker ($r = 0.68 - 0.78$) over flat and downhill terrain sections and stronger on steep uphill climbs. This finding reinforces the observation that some XC cyclists excel or struggle on race-courses depending upon the amount of climbing present. Larger riders (>75kg) may be able cycle with a greater absolute power output and ride more quickly on a course with less climbing, compared to a smaller rider (<65kg) with a higher power to mass, who may be faster performing on a hilly race-course. Clearly both riders develop strategies to offset there losses on there non-preferred XC race-courses, however, it is the assertion of this author that power to mass probably plays a significant part in the success of a XC cyclist, regardless of course type or level of competition. It is not coincidental that heavier riders dominate the front placings in World Cup races that are more technical and have less climbing, whilst the smaller riders excel in the steeper races, but more tellingly in the year long classifications.

There is an excellent overall agreement between the modelled and actual MTB XC performances, with even stronger conformity for uphill sections. This is logical as a rider can only ride at a speed that is a result of the power and mass that they have.

In recent talks at the 1999 Sydney World Cup MTB XC race, the vast majority of elite coaches and cyclists did not use sports science support to help in planning or monitoring of performance. Some of the cyclists had been tested, however, it seemed that these were one off experiences and the riders could not relate any benefits from this process to the author. Thus, as a professional sport with an extensive series of international races, not only has there been a lack of relevant scientific research to guide training practices, but few embrace or seem to understand this process even when available to them. Elite off road cyclists appear to currently use an eclectic approach of road and trail riding in their training. Off-road coaches use a variety of methods and approaches, with some more practical and useful than others, whilst it is doubtful that demands of XC racing are fully understood. For example, all of the riders and coaches at the Sydney World Cup placed a high importance on keeping body mass low and the majority of riders commented that they tried to be at there leanest for races targeted as peak events. Given that elite XC cyclists training and race schedules may see their skinfolds at already low levels it may take other strategies, such as improved pacing, use of specific interval and resistance training to gain further performance edges. Although riders and coaches attempt to improve sporting performance their efforts may be aided with the findings revealed in this investigation.

The next stage of the investigation involved again laboratory and field-assessments and the application of the XC model to a group of elite level XC cyclists. This was undertaken to add to the sparse information on elite ff road riders, to compare the way elite athletes perform over the same terrain categories as competitive cyclists and to further test the accuracy of the XC model. The physiological test results indicated that the body composition and test values were similar to elite XC and road cyclists reported by other authors (Wilber *et al.* 1997; Lee, 1998 and Padilla *et al.*1999, 2000). High relative values for $\dot{V}O_2max$ and power to mass were noted (~75mL·kg^{-1}·min^{-1} and ~6.0 W·kg^{-1}) despite limited training pre-test. Elite XC cyclists showed ability to sustain a high power output in a lab based TT (~363W) and revealed high economy during the test (~78 W·l·min^{-1}) also. These values indicate a strong physiological capacity to work at steady state, which was not unexpected given the individual nature of the XC event.

Throughout XC TT's elite cyclists performed at ~91% of HR peak, which confirmed their abilities observed in the laboratory. Average XC TT power output was lower than calculated at D-max anaerobic threshold (~307W vs ~323W). This was expected as the variable loading pattern and built in pauses in XC cycling probably caused mean power output to be below values expected from laboratory-derived values.

Interestingly terrain comparisons between elite and competitive cyclists revealed that elite athletes maintained a HR that was less variable throughout their trials (90 ± 1.3% vs 89 ± 6.3%). Specifically there was significantly less recovery ($P<0.05$) of HR during descent categories for elite performers. Mean percentage of PPO for the climbing terrain categories showed that elite cyclists performed remarkably similarly to their competitive counterparts, reinforcing the reliance upon relative physiology in this sport. Overall the elite rider is forced to respond to changes in steep gradients similarly to competitive cyclists and this was clearly seen in the "Aescent" categories. However, on closer inspection it was revealed that elite riders vary power output slightly less for the flat and moderately steep terrain categories, than competitive athletes. It is speculated by this author that such an approach contributes to their greater overall velocity, as maintenance of higher speed and better management of fatigue may be achieved by this approach. This contention is supported, in part, by the finding that elite XC cyclists maintained a significantly higher ($P<0.05$) cadence for most terrain categories, as it is widely held that a higher cadence attenuates fatigue.

Comparisons between the modelled and actual race performance revealed a difference of -4.6 ± 2.6%. The consistent underestimation from their laboratory results reinforces elite cyclist's ability to perform faster than their physiology would suggest. The ability to ride faster than the model predicts may be explained by a combination of improved pacing and technical skill. In some cases elite cyclists put this into effect and improve speed despite lower values for power to mass, whilst other elite performers, with superior power to mass, lost ground through technical sections.

Elite cyclists appear to conserve more speed between sections and also maintain high speed out of corners and after obstacles without necessarily a significant contribution to energy output. This phenomenon has generically been termed free-speed and is probably a very important ability to develop in MTB XC, given the intermittent loading pattern imposed by the variable terrain demands of the event. Furthermore, superior conservation of momentum and power to mass suggests that elite cyclists may gain more from a lighter and better-equipped cycle than their competitive counterparts.

It appears skill and physiology is inter-dependant and remains inseparable in contributing to elite XC performances. Despite more refined pacing and superior technique inferred in elite cyclists, nevertheless, the use of power to mass appears to be highly reliable in predicting elite XC performance. This finding is pleasing, given the model was based entirely on competitive cyclists results and power to mass. These outcomes suggest that skill, pacing and physiology need to be developed at similar rates in order to maximise performances in the aspiring off road cyclist.

Overall it is the finding of this research that both skill and physiology are important determinants in MTB XC performance. This investigation demonstrates that competitive XC performance is primarily dependent on physiological measures related to mass. With regard to elite riders it appears that relative physiology is similarly important in determining performance, however, "skills" such as pacing and handling may contribute to performance more than in competitive cyclists. It is the contention of the author that these "skills" play pivotal and discriminating roles in describing elite MTB XC performance when physiology is similar, whereas, physiology perhaps explains differences in competitive riders performance potential more closely.

Mountain bike cross country cycling be described as an intermittent and high intensity cycling discipline, requiring high skill inputs, favourable relative physiology, an ability to pace effort according to technical demand and gradient and capacity to resist fatigue caused by event duration and environmental factors. Improvements in both skill and measurable physiology may benefit any MTB XC cyclist.

The tough nature of the MTB XC event is simply illustrated in the words of the 1999, 2000 and 2001 Tour de France winner, Lance Armstrong, after recently completing a national level MTB XC race:

"This is a real hard sport, nothing in the Tour de France compares to this. It was a much harder race than I expected. It's only a two-hour race, but it was the hardest two hours of my life. I have a lot of respect for these guys."

Appendix A

Summary tables of research used for grand weighted means.

Height and mass of elite MTB XC cyclists

Research	n	Height (cm)	Mass (kg)
Wilber *et al.* (1997)	10	176	71.5
Lee (1998)	8	177.2	67
Gregory (1999)	10		64.2
Gregory (1999)	5	178.7	68.8

Height and mass of elite road cyclists.

Research	n	Height (cm)	Mass (kg)
Burke (1980)	6		67.1
Sjogaard (1984)	16	178.2	71.1
Coyle *et al.* (1988)	7	180.1	71.1
Lucia *et al.* (1998)	25	177.1	69.2
Hoogeveen *et al.* (1998)	14	181	69.2
Garcia-Roves *et al.* (1998)	10	179	66.9
Lucia *et al.* (1999)	8	180.1	68.9
Lucia *et al.* (2000)	8	176	63.6
Lucia *et al.* (2000)	6	181.6	72.3
Padilla *et al.* (1999)	24	180	68.2

Height and mass of competitive MTB XC riders.

Research	n	Height (cm)	Mass (kg)
Gregory (1999)	10	176	71.5
Mac Rea (2001)	6	174.2	76.9

Height and mass of competitive road cyclists.

Research	n	Height (cm)	Mass (kg)
Drabbs (1997)	9	179.4	71.5
Vrijens *et al.* (1983)	5	182.2	76.3
Tanaka *et al.* (1993)	11	181.5	72.9
Coyle *et al.* (1991)	6	176.3	70.7
Mac Rea *et al.* (2000)	6	174.2	76.9
Palmer *et al.* (1994)	9	184	74.5

Peak power output, power to mass and % of transition threshold (TT) to $\dot{V}O_2$max of sub elite cyclists.

Research	n	PPO	W.kg	TT % $\dot{V}O_2$max
Craig *et al.* (1993)	18	373	4.95	78.6
Coyle *et al* (1991)	6	405	5.57	75.3
Tanaka (1993)	9	398	5.55	
Palmer *et al.* (1994)	7	398	5.39	
Hopkins & McKenzie (1987)	6	405	5.39	
Gore (2000)	12	397	5.82	
Gore (2000)	7			81.9

Peak power output, power to mass and % of transition threshold (TT) to VO_2max of competitive MTB XC cyclists.

Research	n	PPO	W.kg	TT % $\dot{V}O_2$max
Gregory (1999)	10	367.5	5.1	84.2
Mac Rae *et al.* (2000)	6	389	5.1	

Peak power output, power to mass and % of transition threshold (TT) to VO_2max of elite MTB XC cyclists.

Research	n	PPO	W.kg	TT % $\dot{V}O_2$max
Wilber *et al.* (1997)	10	420	5.9	77.1
Gregory (1999)	5	415	6	83.3
Baron (2001)	25	381.7	5.5	85.4

Peak power output, power to mass and % of transition threshold (TT) to VO_2max of competitive road cyclists.

Research	n	PPO	W.kg	TT % $\dot{V}O_2$max
Hawley & Noakes (93)	54	312.80		
Heil *et al.* (2001)	8	366	4.88	82.2
Heil *et al.* (2001)	8	369	4.8	74.5
Tanaka *et al.* (1993)	12			
Jeukendrup *et al.* (1992)	7	336		69.6
Vrijens *et al* (1983)	8			
Liedl *et al.* (1999)	8	378	5.08	70.4
Gregory (1998)	9	348.8	5.01	85.5
Miller & Manfredi (1987)	22			71.1

Peak power output, power to mass and % of transition threshold (TT) to $\dot{V}O_2max$ of competitive road cyclists.

Research	n	PPO	W.kg	TT % $\dot{V}O_2max$
Lucia *et al.* (2000)	13			90
Lucia *et al.* (2000)	8			85.6
Lucia *et al.* (1998)	25	428.6	6.4	80.4
Lucia *et al.* (1998)	25	466	6.7	87.0
Lucia *et al.*(1999)	6			87.5
Padilla *et al.* (1999)	24	432	6.34	90
Lindsay *et al.* (1996)	8	415.8	5.25	
Wilber *et al* (1997)	10	470	6.5	80.1
Sjogaard (1984)	16	397	5.58	
Hoogeveen *et al* (1999)	14	440	6.35	90
Padilla *et al.* (2000)	18	439	6.4	87.7
Coyle *et al.* (1991)	9	406	5.58	79.2
Palmer *et al* (1996)	8	443	5.71	
Gore (2000)	10	419	5.81	85.1
Gore (2000)	14	487	6.59	81.2
Gore (2000)	11			85

Maximal oxygen uptake ($\dot{V}O_2max$) of sub elite road cyclists.

Research	n	Ab. $\dot{V}O_2max$ ($L.min^{-1}$)	Rel. $\dot{V}O_2max$ ($mL.kg^{-1}$ min^{-1})
Craig *et al.* (1993)	18	5.13	68.5
Gotshall *et al.* (1995)	7		70.5
Palmer *et al.* (1994)	7	4.97	66.7
Coyle *et al.* (1991)	6	4.88	69.3
Tanaka *et al.* (1993)	9	4.98	

Maximal oxygen uptake ($\dot{V}O_2max$) of competitive MTB XC cyclists.

Research	n	Ab. $\dot{V}O_2max$ ($L.min^{-1}$)	Rel. $\dot{V}O_2max$ ($mL.kg^{-1}$ min^{-1})
Mac Rae *et al.* (2000)	6	4.50	58.4
Gregory (1999)	10	4.5	64.7
Berry *et al.* (1993)	6		62.8

Maximal oxygen uptake ($\dot{V}O_2max$) of elite MTB XC cyclists.

Research	n	Ab. $\dot{V}O_2max$ ($L.min^{-1}$)	Rel. $\dot{V}O_2max$ ($mL.kg^{-1}$ min^{-1})
Wilber (*et al.* 1997)	10	4.99	70
Gregory (1999)	5	5.2	75.4
Lee (1998)	6	4.96	74.0
Hansen (1996)	3	5.61	76.0
Baron (2001)	25	4.767	68.4

Maximal oxygen uptake ($\dot{V}O_2max$) of competitive road cyclists.

Research	n	Ab. $\dot{V}O_2max$ (L.min^{-1})	Rel. $\dot{V}O_2max$ (mL.kg^{-1} min^{-1})
Hawley & Noakes (1993)	54	4.00	
Heil *et al.* (2001)	8	4.90	65.4
Heil *et al.* (2001)	8	4.51	59.0
Tanaka *et al.* (1993)	12	4.54	
Vrijens *et al* (1983)	8	4.79	62.7
Liedl *et al.* (1999)	8	4.24	57.1
Gregory (1998)	9	4.22	61.3
Miller & Manfredi (1987)	22	4.43	59.7
Tanaka *et al.* (1993)	11	4.72	

Maximal oxygen uptake ($\dot{V}O_2max$) of elite road cyclists.

Research	n	Ab. $\dot{V}O_2max$ (L.min^{-1})	Rel. $\dot{V}O_2max$ (mL.kg^{-1} min^{-1})
Lucia *et al.* (2000)	8	5	78.6
Lucia *et al.* (2000)	13		74.4
Lucia *et al.* (1998)	25	4.9	72.9
Lucia *et al.* (1998)	25	5.1	73.9
Lucia *et al.* (2000)	6	5.2	72.0
Lucia *et al.* (1999)	8	5.1	74.0
Padilla *et al.* (1999)	24	5.36	78.8
Lindsay *et al.* (1996)	8	5.2	
Wilber *et al.* (1997)	10	5.09	70.3
Sjogaard (1984)	16	4.96	71
Hoogeveen *et al* (1999)	14	4.77	69
Coyle *et al.* (1991)	9	5.07	69.6
Gore (2000)	10	5.1	70.8
Gore (2000)	14	5.5	74.5

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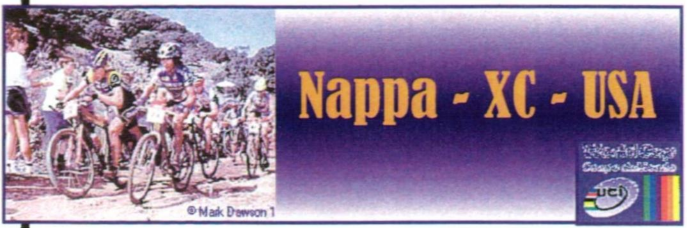
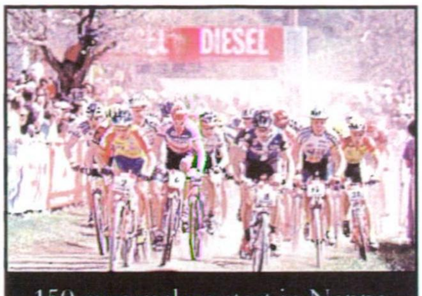
Supplement

World cup and world title race-course characteristics and details, 1997, 1998 and 1999.

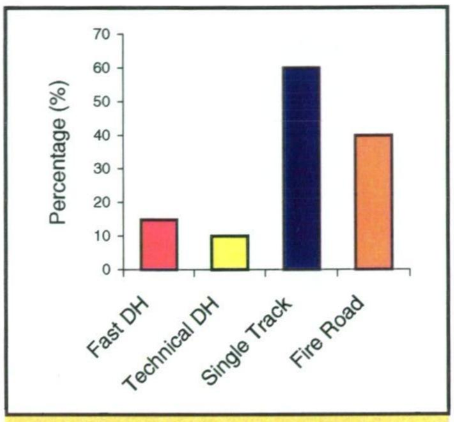




150 men make a start in Nappa

Course Description

The Nappa Valley XC race-course has a generous mix of single track and technical downhill that is mostly flowing and ridden at speed. The race-course has a large amount of climbing and being the season's opening race, it is ridden at high average speeds. The 4.1 km Calistoga climb is decisive in thinning out the field. The Nappa race venue is famous for the 2km long Manzanita single track which some claim is one of the most demanding single track sections in the world. This section has many changes in direction as well as small undulations and has a high speed roller coaster section to conclude with.



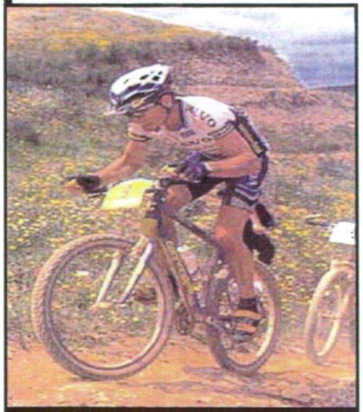
Technical course details

Soil conditions are mostly sandstone and a granite rock base on all trails. The Nappa Valley XC course is completely rideable in wet conditions, although it can be slippery under trees when wet. Open sections tend to be dry or slightly tacky when wet.

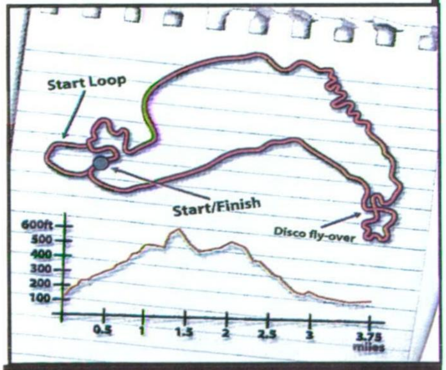
The Nappa Valley course favours a competent climber and skilled descender who is capable of riding at the front with sustained speed.

Race Facts

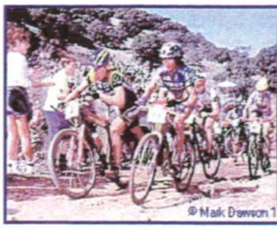
- Race distance: M. 50km, W. 33km.
- Laps: M. 6 x 8km; W. 4 x 8km, plus 1 x 1km start loop.
- Lap ascension: 324m.
- Race ascension: M. 1973m, W. 1373m.
- Weather conditions 19-24°c.
- Winners speed: M. 19.9 km.hr., W. 17.4 km.hr.
- Race duration: M. 149 min., W. 133 min.
- Average gradient: 4.0%
- Percentage time to 20th: M. 6.2%, W. 10.9%.
- Field size: M.>130, W. >80.
- Course type: Fast, technical and climbing course.



Cadel is always a favourite



Race course profile and layout



Silves - XC - POR

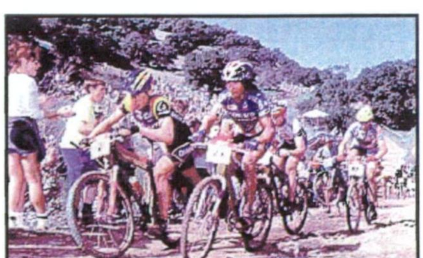
Course Description

The silves XC course has a good balance between climbing and single track. After the obligatory open fired start the course has a hard middle ring climb to the high point of the course. The mid sections of the course have a series of fast technical single track descents, quickly followed by climbs. After completing these the riders return to the start/finish and commence the main climb again.

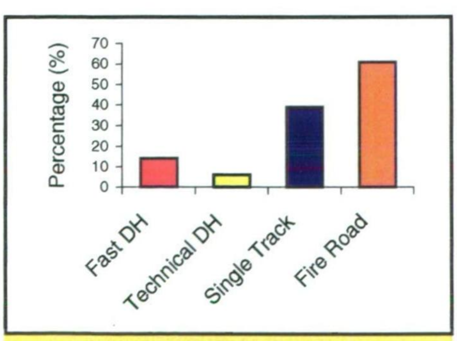
The surface is loose and dusty in some places, with some rocky off cambered single track sections also.

The course requires a good blend of climbing and single track descending skills.

Picturesque Portuguese course



Familiar faces battle it out

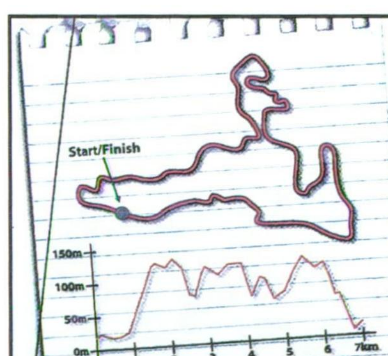


Technical course details

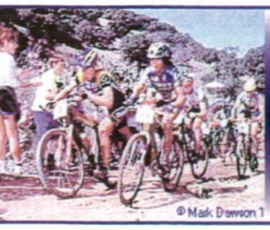
Race Facts

- Race distance: M. 50km, W. 36.4km.
- Laps: M. 7 x 7km; W. 5 x 7km, plus 1 x 1km start loop.
- Lap ascension: 225m.
- Race ascension: M. 2125m, W. 1326m.
- Weather conditions 19-22°c.
- Winners speed: M. 21.1 km. hr., W. 17.8 km.hr.
- Race duration: M. 143 min., W. 122 min.
- Average gradient: 4.2%
- Percentage time to 20th: M. 10.7%, W. 13.6%.
- Field size: M.>100, W. >70.

Course type: Fast, power and technical course.



Race-course lap and profile



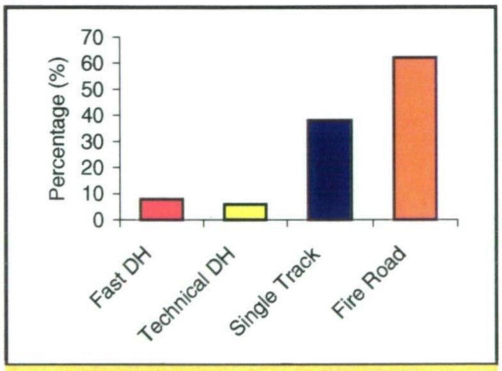
Budapest - XC - HUN

Course Description

The Budapest XC race course has a moderate amount of climbing and some tricky single track sections. The lap distance has been shortened to 7km and the number of slow technical sections has also been reduced from past years. Usually a high speed track if dry, but prone to be very slick, slippery and heavy when wet, giving Ex Cyclo-cross riders an advantage. Not always the easiest of courses to pass on. A race that changes complexion according to the weather. Be prepared for all conditions in Northern Europe.

Fast and flowing European MTB XC track with plenty of big and middle ring sections.

Heavy conditions



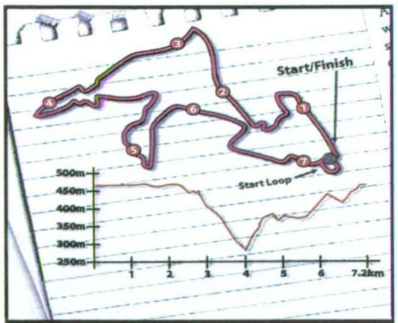
Technical course details

Race Facts

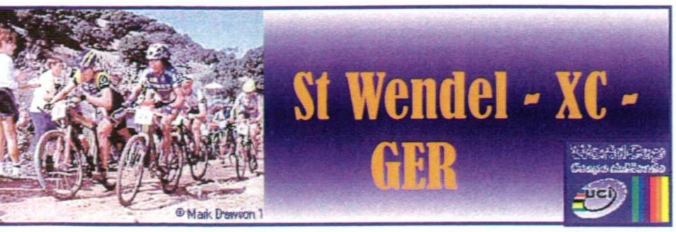
- Race distance: M. 50.4km, W. 37km.
- Laps: M. 7 x 7km; W. 5 x 7km, plus 1 x .900km start loop.
- Lap ascension: 260m.
- Race ascension: M. 1855m, W. 1216m.
- Weather conditions 16-22°c.
- Winners speed: M. 22.2 km. hr., W. 17.5 km.hr.
- Race duration: M. 141 min., W. 123 min.
- Average gradient: 3.7%
- Percentage time to 20th: M. 6.2%, W. 15.5%.
- Field size: M.>130, W. >80.

Course type: Fast, flowing and power course.

The dust flys in another mad start



Race-course lap and profile

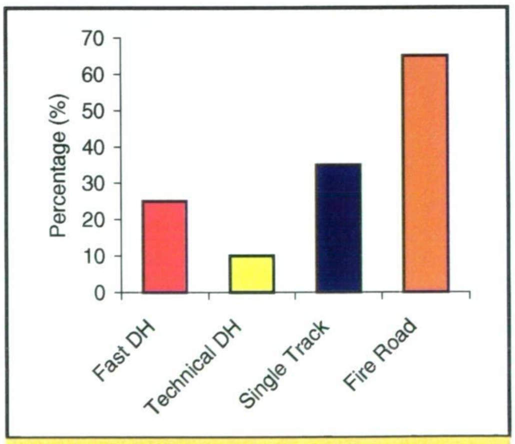


Course Description

St Wendel has a reputation for exciting finishes that sees the leading riders stay together for the most part of the race. One of the few courses to see a sprint finish of more than two riders. St Wendel has the least amount of climbing on the circuit and is known for high average speeds and tactical battles. Single track sections are not overly difficult, but when wet the race takes on a whole new dimension being slow, slippery and heavy going when wet.

A fast pace and limited passing opportunities places a premium on getting as far forward as possible at St Wendel. The only trouble is everyone tries this tactic, which makes for spectacular starts. The track requires greater levels of power with the 70kg riders often doing well here.

St Wendel starts on an athletic track



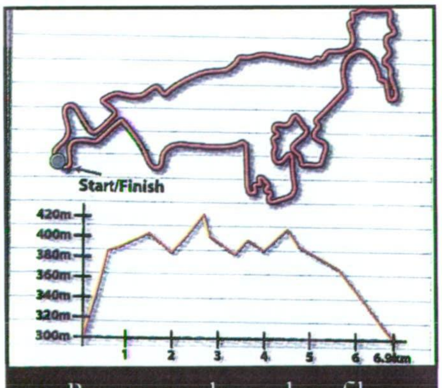
Technical course details

Race Facts

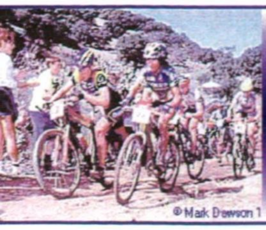
- Race distance: M. 49.2km, W. 34km.
- Laps: M. 7 x 7km; W. 5 x 7km,.
- Lap ascension: 265m.
- Race ascension: M. 1662m, W. 1260m.
- Weather conditions 16-20°c.
- Winners speed: M. 23.1 km.hr., W. 18.4 km.hr.
- Race duration: M. 149 min., W. 122 min.
- Average gradient: 3.5%
- Percentage time to 20th: M. 5.8%, W. 8.9%.
- Field size: M.>130, W. >90.

Course type: Fast, power and tactical course.

Pushing is required when wet



Race-course lap and profile



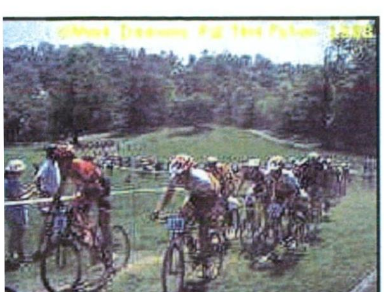
Plymouth - XC - GB

Course Description

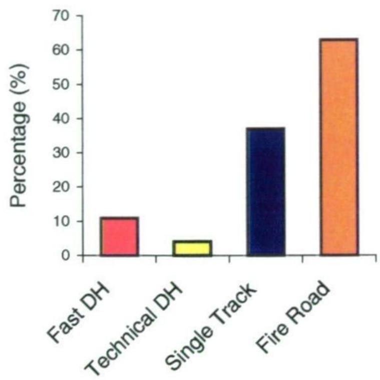
The Plymouth course is famous for its numerous water crossings and visit out to Dartmoor National park. Plymouth has a longer lap at over 11 km, which winds its way back to the start/finish area several times. The pipeline descent and bomb holes are to be expected, as well as off cambered forest traverses which when wet can cause trouble for the riders. The Plymouth track has a moderate amount of climbing overall, a long race duration and high average race speeds. Single track is plentiful but must be ridden at high speeds to avoid being passed.

Passing opportunities are frequent. Smaller riders have traditionally struggled to win on this course, as it calls for high power output.

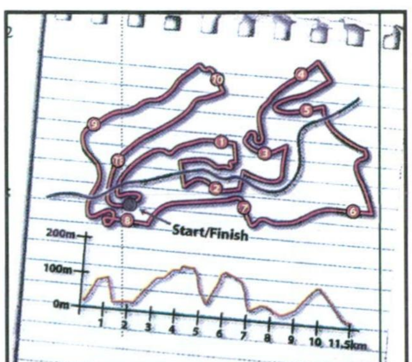
A tactical, long and fast race, requiring attention to pacing.



Full power after the start



Technical course details

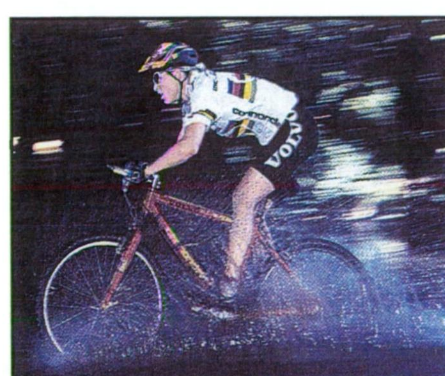


Race-course lap and profile

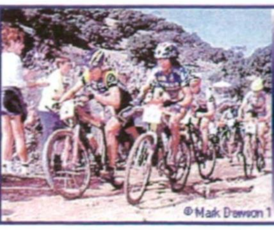
Race Facts

- Race distance: M. 54km, W. 37km.
- Laps: M. 5 x 11.5km; W. 3 x 11.5km,.
- Lap ascension: 375m.
- Race ascension: M. 1975m, W. 1356m.
- Weather conditions 16-20°c.
- Winners speed: M. 23.2 km.hr., W. 17.5 km.hr.
- Race duration: M. 142 min., W. 127 min.
- Average gradient: 3.8%
- Percentage time to 20th: M. 5.2%, W. 9.3%.
- Field size: M.>130, W. >90.

Course type: Fast, power and tactical course.



Sydor flys through a water crossing



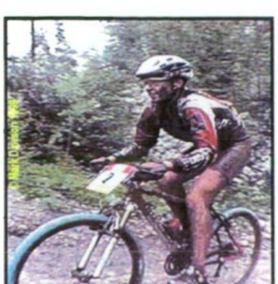
Canmore - XC - CAN

Course Description

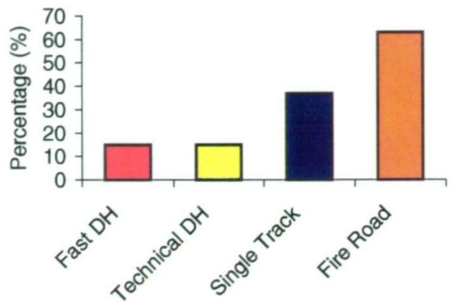
'he Canmore XC race has been ın twice before, once in ideal onditions and once in wet and eezing rain and like Northern urope the difficulty changes ac-ordingly. The course is a figure f eight with several crossover oints.

'he race starts with the Rundle op at a short 2.6km in length , ut has the majority of fire road nd middle ring climbing on it. fter crossing a bridge the 5.6km ieorgetown loop begins and is ere most of the technical and ngle track sections are located. 'he soil is mostly loam, silt and ravel and makes for fast riding in ry conditions. However, under et conditions the soil turn uickly to mud and the steep and oot strewn sections will chal-nge the best technical riders.

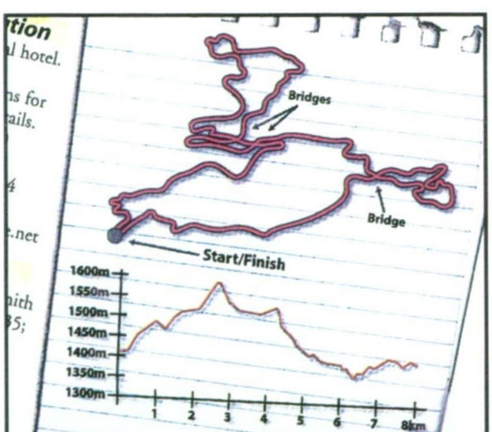
here are plenty of passing op-ortunities built into the course. he nature of the course changes ccording to the weather condi-ons, but the Canmore XC ourse is described as a fast and chnical, with moderate to sig-ficant climbing demands.



Gunn-Rita excels



Technical course details



Race-course lap and profile

Race Facts

- Race distance: M. 48km, W. 32km.
- Laps: M. 6 x 8km; W. 4 x 8km,.
- Lap ascension: 375m.
- Race ascension: M. 1950m, W. 1356m.
- Weather conditions 5-24°c.
- Winners speed: M. 16.5 km.hr., W. 13.6 km.hr.
- Race duration: M. 143 min., W. 123 min.
- Average gradient: 4.4%
- Percentage time to 20th: M. 8.2%, W. 13.5%.
- Field size: M.>120, W. >70.

Course type: Fast, climbing and technical course.

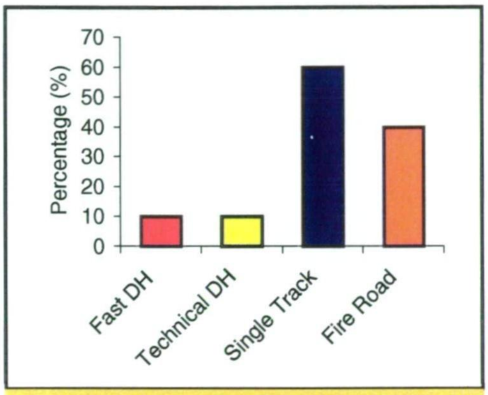
Wet weather suits Thomas

Course Description

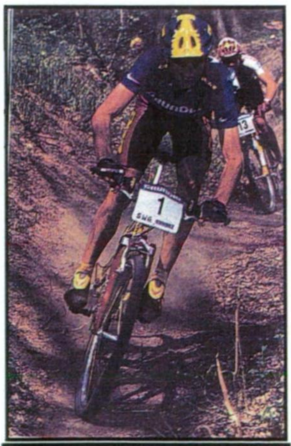
The Conyers MTB XC race-course will be remembered as the site where the first Olympic medals were decided in the sport. Some venues are famous for their epic scale and technical demands, whilst Conyers is preserved by that single event and not by the qualities of its terrain.

Conyers is a fast, entirely ride-able course that takes in many direction changes and small hills. The course wends its way through a light woodland as opposed to a large mountain side.

There are no super technical sections, although poor concentration can lead to punctures on some of the rocky sections. None of the hills measure more than 30m in elevation, but the unending undulations and single track also offers very little recovery time. As with most MTB XC courses, there is a need to maintain effort, but at a sustainable pace. These features and the notorious hot and humid southern weather, usually sees racers riding mostly on their own. Although fast, moderately technical and not vertically challenging, the Conyers course is not to be underestimated.



Technical course details


Front running

Race Facts

Race Facts

- Race distance: M. 51km, W. 38.4km.
- Laps: M. 5 x 11.5 km; W. 3 x 11.5km,.
- Lap ascension: 270m.
- Race ascension: M. 1710m, W. 1302m.
- Weather conditions 30-35°c.
- Winners speed: M. 23.3 km. hr., W. 18.1 km.hr.
- Race duration: M. 131 min., W. 99 min.
- Average gradient: 3.3%
- Percentage time to 20th: M. 7.2%, W. 15%.
- Field size: M.>120, W. >70.

Course type: Fast, power and front rider's course.

Race-course lap and profile

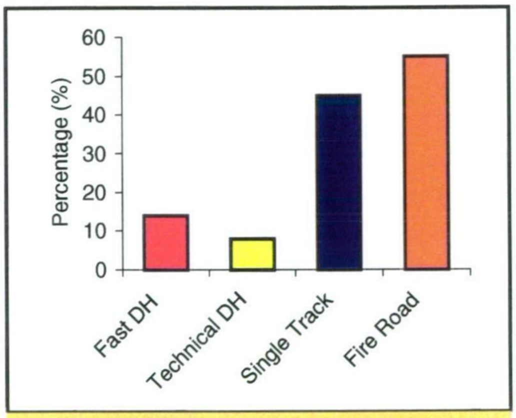
Bromont - XC - CAN

Dry conditions

Course Description

The 8km course in Bromont, in the Canadian mountains, has hard packed and mix of rooty single- and open double-track which makes for a strenuous rollercoaster ride. The track changes quickly from fast straights to extremely steep climbs, then over the top and straight down again.

With it's considerable climbing this course favours the climber and strong technical riders. With plenty of climbing and a high percentage of single track, the Bromont course is one of the toughest to win.



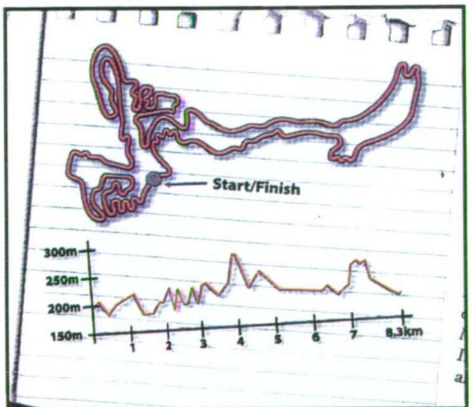
Technical course details

Race Facts

- Race distance: M. 45km, W. 32km.
- Laps: M. 6 x 8.2km; W. 5 x 7km,.
- Lap ascension: 350m.
- Race ascension: M. 2100m, W. 1650m.
- Weather conditions 17-24°c.
- Winners speed: M. 21.7 km. hr., W. 17.3 km.hr.
- Race duration: M. 131 min., W. 111 min.
- Average gradient: 4.6%
- Percentage time to 20th: M. 4.6%, W. 16.5%.
- Field size: M.>130, W. >80.

Course type: Climbing, technical and tactical course.

Sydor performs strongly at home



Race-course lap and profile

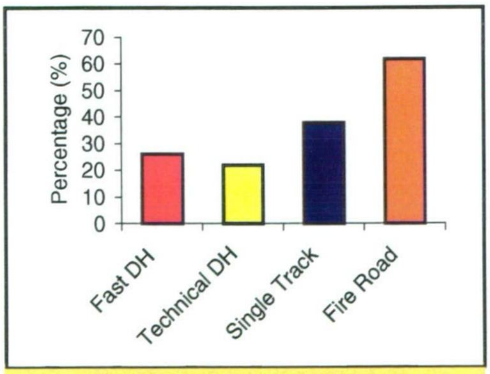
Course Description

The 8.4km course in Wellington, on the slopes of Mt Victoria, is dry and hard packed, with a mix of loamy single- and double-track which makes for a hard race through the pine trees. Somewhat similar to eastern-U.S. conditions, the track's landscape changes quickly from fire road climbs to extremely steep single track descents. The start loop is on an old outdoor velodrome and then proceeds straight up 15% gradient and continues on up for another 3km in the middle and even big rings.

The course has passing opportunities built into its single track sections, which when not going uphill flow well. The NZ course requires good climbing and descending skills, which becomes deceptively wearing on riders as the race progresses. This race rewards strong riders who set out off the front on their own and maintain momentum.

A course requiring technical and climbing ability, with little opportunity to ease back the pressure on the pedals.

The top riders apply power



Technical course details

Race Facts

- Race distance: M. 50.4km, W. 33.6km.
- Laps: M. 6 x 8.4km; W. 4 x 8.4km,.
- Lap ascension: 350m.
- Race ascension: M. 2100m, W. 1400m.
- Weather conditions 17-22°c.
- Winners speed: M. 21.3 km. hr., W. 18.7 km.hr.
- Race duration: M. 157 min., W. 114 min.
- Average gradient: 4%
- Percentage time to 20th: M. 5.3%, W. 20%.
- Field size: M.>120, W. >20.

Course type: Climbing and technical course.

Climbing in Wellington

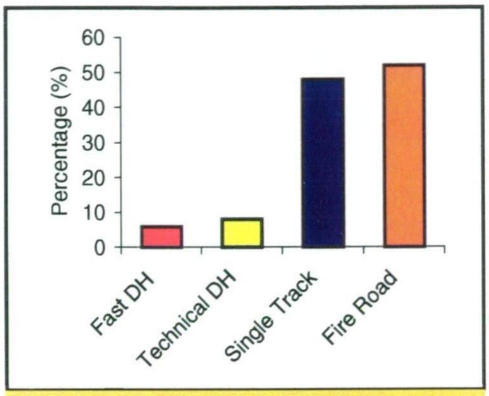
Houffalise - XC - BEL

Course Description

The now famous MTB XC Houffalize course begins in the town centre. The race lap has traditionally been long at about 11km in the past, however, it has been reduced to now 9km now. There is approximately 425m of climbing per lap, which is evenly distributed throughout the lap. This fact wears on the legs, but gives an impression of a flatter course than it really is. The technical single track amounts to about 1km in total, which is again dispersed throughout the course.

Houffalize is famous for its winding through the fir trees on smooth hardpacked singletrack, although this can quickly turn to mud when wet.

The course is either undulating or descends moderately on single track trails. Often a fast and tactical race at the front.

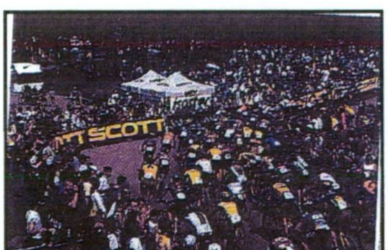


Technical course details

Race Facts

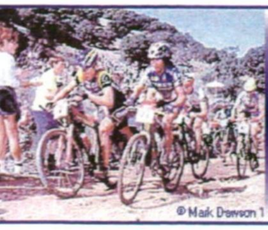
- Race distance: M. 51.8km, W. 37km.
- Laps: M. 6 x 9.1km; W. 4 x 9.1km,.
- Lap ascension: 425m.
- Race ascension: M. 1912m, W. 1487m.
- Weather conditions 18-24°c.
- Winners speed: M. 20.6 km.hr., W. 17.7 km.hr.
- Race duration: M. 133 min., W. 120 min.
- Average gradient: 3.9%
- Percentage time to 20th: M. 7.7%, W. 12.2%.
- Field size: M.>130, W. >90.

Course type: Fast, power and tactical course.



Hectic conditions at the start

Riders race through the streets



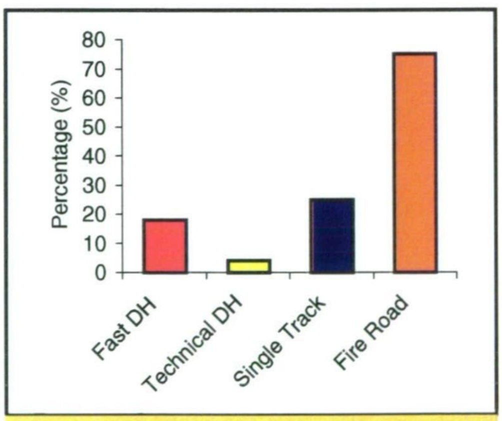
Big Bear - XC - USA

Course Description

The Big Bear course, situated in the mountains west of Los Angeles, is dry, and sometimes hard packed and at other times dusty and loose. One of the few altitude XC races still on the World Cup circuit. The track's desert landscape changes from long and often steep climbs to fast and open descents frequently strewn with rocks. The fragile sandy soil is susceptible to braking bumps and general deterioration, which makes for puncture and run off opportunities for the unwary rider.

The Big Bear course is a series of two straight-forward climbs and descents, with not much flat riding to be seen. Once a North American riders paradise, but now suited to the lithe European climbers.

Elation on the victory dias

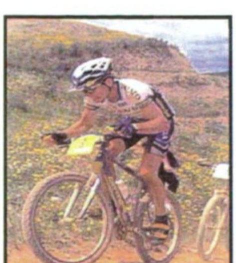


Technical course details

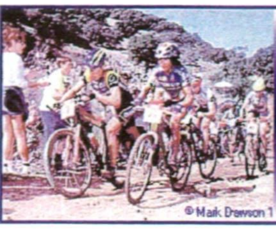
Race Facts

- Race distance: M. 44.7km, W. 27.4km.
- Laps: M. 5 x 8.7km; W. 3 x 8.7km,.
- Lap ascension: 375m.
- Race ascension: M. 2050m, W. 1640m.
- Weather conditions 23-32°c.
- Winners speed: M. 20.4 km.hr., W. 15.7 km.hr.
- Race duration: M. 131 min., W. 104 min.
- Average gradient: 4.6%
- Percentage time to 20th: M. 6.5%, W. 10.6%.
- Field size: M >120, W. >80.

Long line of starters work uphill



Big Bear climbing

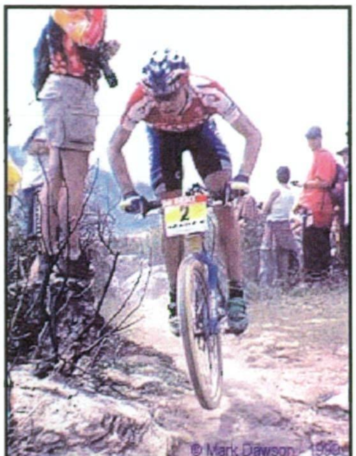


Madrid - XC - ESP

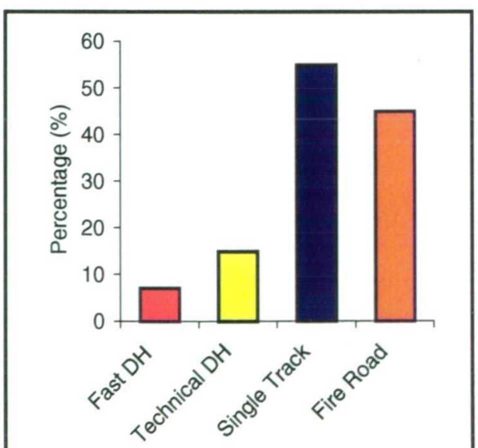
Course Description

The 7.9 km Madrid XC course requires both exceptional climbing and technical bike handling skills to be successful. The Madrid course has a significant climb, followed by traverses and steep rocky technical descents. The course has a 3km long broken and steep climb to begin, which is followed by a series of fast traverses and drop offs. Thereafter the course has very steep descents punctuated by tight and technical corners. About a 2km fast open, with gradual power climb loop through the feed zone completes the lap.

The trail surface is very loose and dusty with the surface conditions varying from one lap to another, as the rider's change the position of the soil and rocks through braking. A race that taxes mind and body during the descents as much as the climbs. A punishing course that requires excellent all-round skills and exceptional concentration. A difficult race to win and one for the top climber/ bike handler.



XC country riders get air too



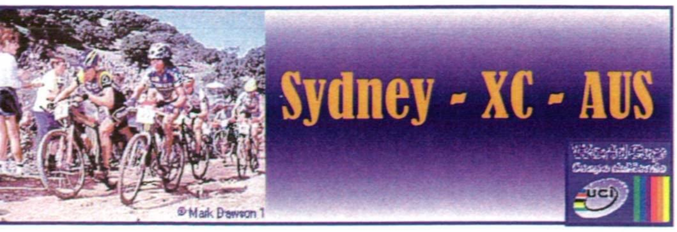
Technical course details

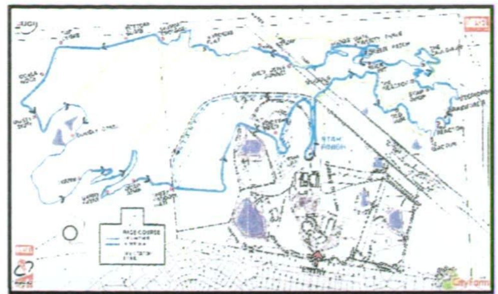
Race Facts

- Race distance: M. 48.3km, W. 28km.
- Laps: M. 7 x 7km; W. 5 x 7km,.
- Lap ascension: 330m.
- Race ascension: M. 2310m, W. 1540m.
- Weather conditions 18-22°c.
- Winners speed: M. 17.1 km.hr., W. 14.6 km.hr.
- Race duration: M. 147 min., W. 115 min.
- Average gradient: 4.8%
- Percentage time to 20th: M. 8.0%, W. 12.0%.
- Field size: M.>130, W. >80.

Course type: Climbing and technical course.


Riders weave through rocks



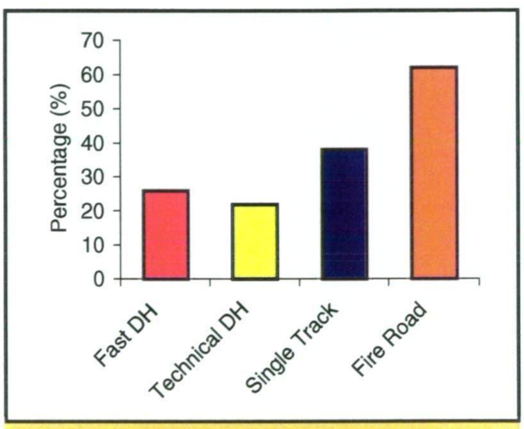

Race-course lap

Course Description

he 6.9km Sydney Olympics 2000 ourse has a generous mixture of ght single and open fast and flow- g double track. The Sydney ourse has a considerable amount of umulative climbing at 320 metres er lap, along with constant changes direction in the first third. The rst half of the course has been de- gned to make use of a ridge that akes up the only significant rise in e area. In addition, spectators and edia will have excellent viewing ptions in the first third of the race r this reason. Through this ter- in there are numerous tight, twisty nd precarious sections, including e cauldron which is considered to e the most difficult part of the ourse. Further along the course pens up with fast traverses across the top of the ridge and less di- ctional changes. The back half of e course has the fastest and most pen sections, but still has signifi- ant climbs and technical sections so.

verall the course requires high ower, is fast and is physically and chnically demanding. This course quires some tactical sense also, as e climbs and technical sections are ot long enough for any one type of der to dominate.

World Cup start in Sydney



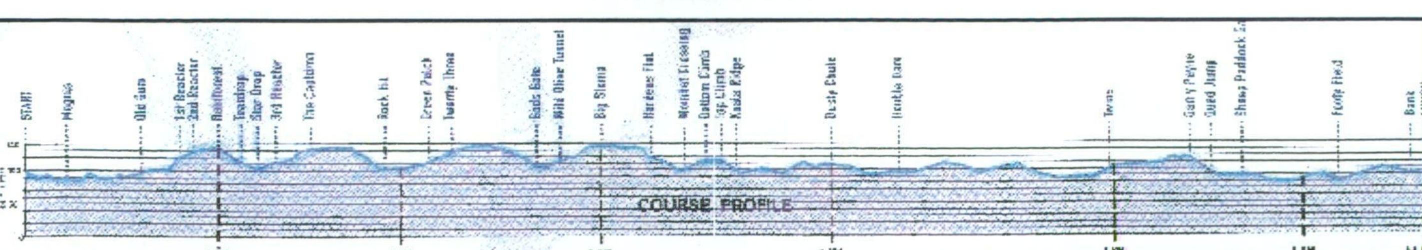
Technical course details


Cadel at home

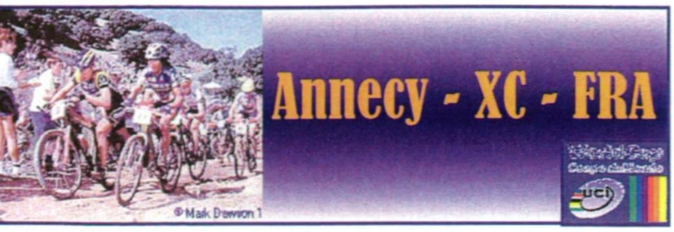
Race Facts

- Race distance: M. 50.8km, W. 31.2km.
- Laps: M. 7 x 6.9km; W. 4 x 6.9km, plus 1 x 1.1km start loop.
- Lap ascension: 320m.
- Race ascension: M. 2280m, W. 1320m.
- Weather conditions 18-23°c.
- Winners speed: M. 20.9 km. hr., W. 18.6 km.hr.
- Race duration: M. 141 min., W. 100 min.
- Average gradient: 4.5%
- Percentage time to 20th: M. 4.8%, W. 12.3%.
- Field size: M.>120, W. >60.

Course type: Fast, power, technical and tactical course.



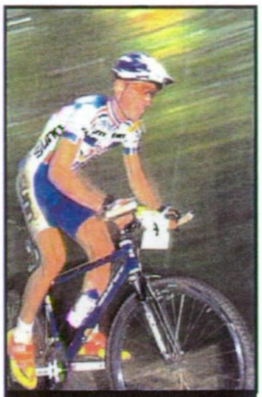
Race-course lap and profile



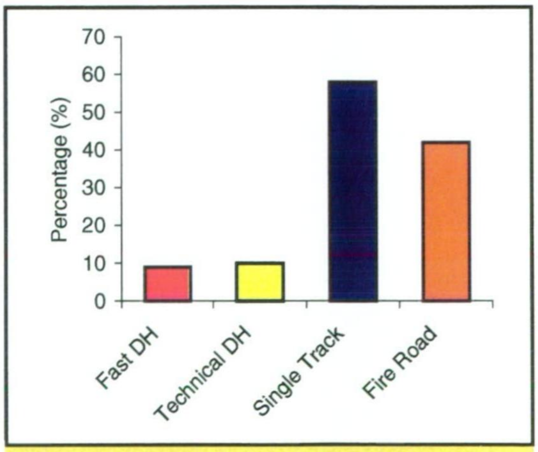
Course Description

The Annecy course is regarded as one of the most technical of the European races. With a longer than average lap distance at nearly 11km and plenty of rocky single track climbs and descents, the Annecy course is difficult to win. Many top 10 riders have succumbed to punctures and mechanical failures on this course, suggesting that it is rugged and not to be underestimated.

The course takes in a considerable amount of climbing in total, although it is not considered to be a pure climbers race. The high amount of single track makes for difficult passing and favours the strong climber and technical rider who can use every pedal stroke to his/her advantage. The Annecy XC course requires confident descending and sustained speed to do well.


Dupouey in flight


Fullana is a strong contender in Europe

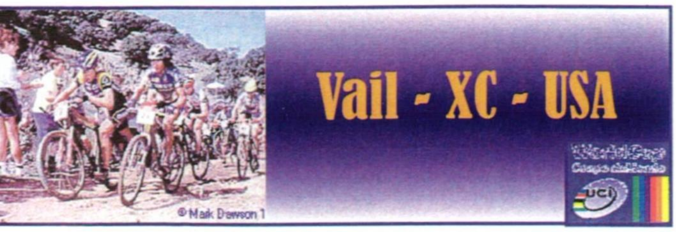


Technical course details

Race Facts

- Race distance: M. 49km, W. 33km.
- Laps: M. 5 x 10.75km; W. 3 x 10.75km.
- Lap ascension: 425m.
- Race ascension: M. 2060m, W. 1250m.
- Weather conditions 21-25°c.
- Winners speed: M. 19.7 km.hr., W. 17.6 km.hr.
- Race duration: M. 153 min., W. 105 min.
- Average gradient: 3.9%
- Percentage time to 20th: M. 8.0%, W. 14.8%.
- Field size: M.>130, W. >80.

Course type: Power, climbing and technical course.

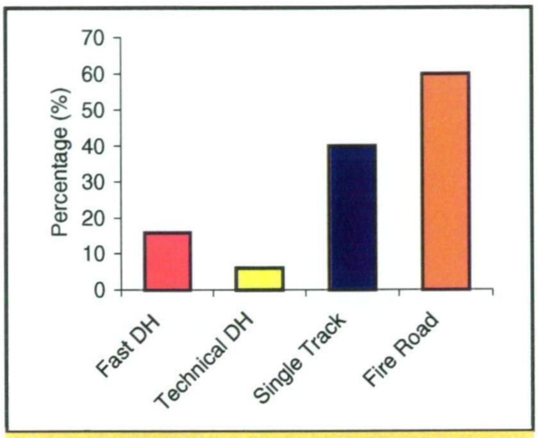



Fast DH at Vail

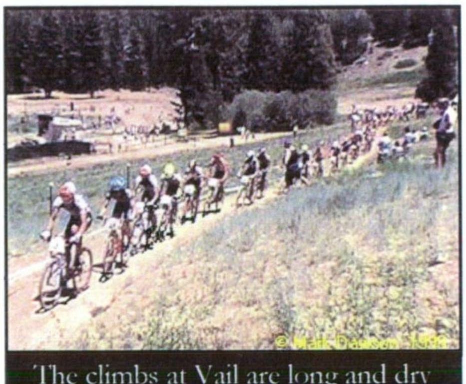
Course Description

With a base elevation of 2600m the Vail World Cup course is a true altitude race. The Vail course has the longest lap on the circuit at 15.77km. However, the course has a "clover leaf" design, which effectively means three smaller loops within an overall lap. The Vail course is punctuated by compact double track climbs, sometimes very fast descents and off camber rocky single track. Most of the climbing is done in the middle ring and although at altitude the actual amount of climbing is not extreme. However, traditionally strong climbers and fearless descenders have done well on this race-course. Plenty of passing opportunities at this venue Also.

The elevation of the Vail World Cup venue means that riders need at least 2 weeks to acclimatise. Rider's who have by passed this requirement have usually struggled. Very limited flat sections make this a straight up and down circuit, which does not afford many natural breaks during a race.



Technical course details


The climbs at Vail are long and dry

Race Facts

- Race distance: M. 51.8km, W. 32.8km.
- Laps: M. 3.5 x 15.77km; W. 2 x 15.77km,.
- Lap ascension: 517m.
- Race ascension: M. 1950m, W. 1090m.
- Weather conditions 19-25°c.
- Winners speed: M. 21 km.hr., W. 17.5 km.hr.
- Race duration: M. 154 min., W. 115 min.
- Average gradient: 3.3%
- Percentage time to 20th: M. 8.6%, W. 17.4%.
- Field size: M.>100, W. >50.

Course type: Fast, power and tactical course.

Mt Snow - XC - USA

Fast single track

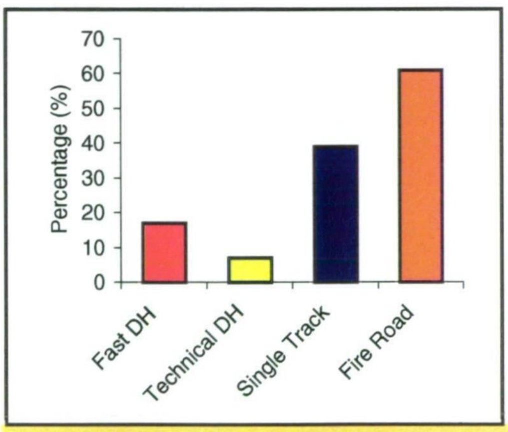
The start turn is taken with care

Course Description

The 8.5km course Mt Snow, on the east coast of North America, is steep and hard packed and has a mix of rooty single- and fast double-track which makes for a classic MTB race. The Mt Snow course has been the site of some epic battles between two icons in the sport, John Tomac and Thomas Frishknecht. Tomac chose to ride the rooty and twisty forest sections that are characteristic at Mt Snow, whilst Frischknecht used his Cyclo-cross skills to good effect, by running closely behind. The weather has played a big part in the results at Mt Snow, as rain makes it a slippery mud bath, whilst high humidity and temperatures have ended many rider's chances in Hospital.

The Mt Snow venue is traditional in the sense that it is a straight up and down course. The track is fairly much equally divided between climbing and descending. Mt Snow has a considerable amount of climbing, which takes place in one go. It has a mixture of fire road and narrow woodland tracks featuring tight corners, steep drops and tree roots.

A classic climber and descender course, for the complete rider. A course famous for punctures also.



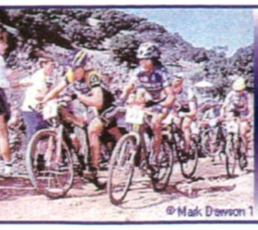
Technical course details

Mt Snow becomes tougher when wet

Race Facts

- Race distance: M. 42.5km, W. 37.6km.
- Laps: M. 5 x 8.85km; W. 4 x 8.85km,.
- Lap ascension: 411m.
- Race ascension: M. 2055m, W. 1337m.
- Weather conditions 18-33°c.
- Winners speed: M. 18.8 km.hr., W. 14.1 km.hr.
- Race duration: M. 136 min., W. 122 min.
- Average gradient: 4.6%
- Percentage time to 20th: M. 7.2%, W. 15.5%.
- Field size: M.>120, W. >70.

Course type: Climbing, technical and tactical course.

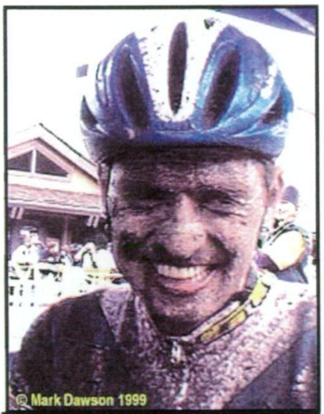


Prague - XC - CZ

Course Description

The 10.6km Spinderluv course is physically less challenging than perhaps many on the entire world cup circuit. This event in dry conditions is somewhat of the "roadie" race of the circuit, with fast speeds and relatively little climbing - even though there's a total of 330 metres of uphill each lap. The Spinderluv venue has some short and steep hills were decisive moves are often made. However, the course is often filled with attacks, counter-attacks and road style tactics.

Winding through the trees on smooth hardpacked singletrack, the track drops right down a steep section of leafy s-turns through the trees on the main descent. In dry conditions the course is not overly technically demanding, with power and tactics being perhaps the more important qualities.

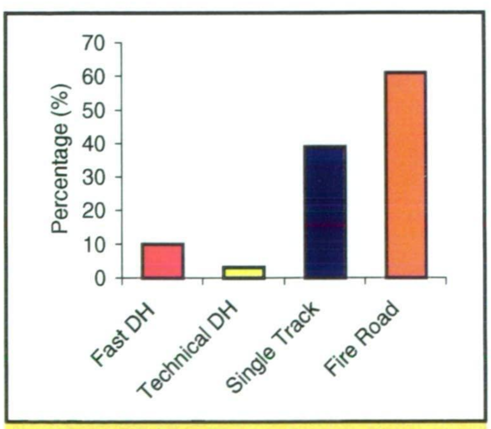


A muddy post race grin

Race Facts

- Race distance: M. 48.8km, W. 32km.
- Laps: M. 5 x 10.6km; W. 3 x 10.6km.
- Lap ascension: 350m.
- Race ascension: M. 1750m, W. 1295m.
- Weather conditions 17-20°c.
- Winners speed: M. 21.7 km.hr., W. 17.8 km.hr.
- Race duration: M. 139 min., W. 107 min.
- Average gradient: 3.5%
- Percentage time to 20th: M. 4.8%, W. 13.3%.
- Field size: M.>130, W. >80.

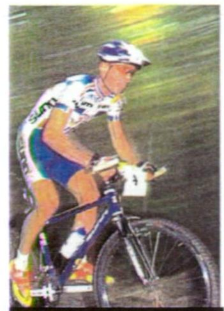
Course type: Fast, power and tactical course.



Technical course details

Race-course lap and profile

Mt St Anne - XC - CAN



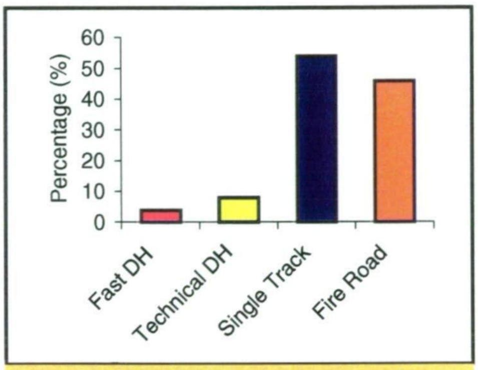
World champion

Course Description

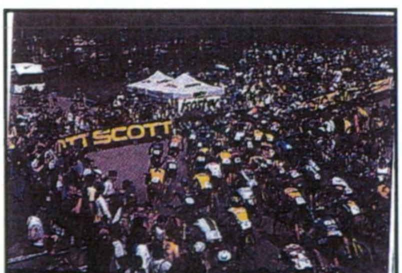
The Mt St Anne XC course has been used since 1991 as a World Cup and World Title venue. The Mt St Anne course has a large percentage of low speed and technical single track, coupled to a significant amount of overall climbing. The lap takes in many direction changes, rooty and rock strewn single track, as well as steep climbs one after the other.

The course sets off like a roller coaster with the first climb of three, a gruelling ascent of a steep gravelled road. The lap then heads out on a 5km loop, where riders catch only a glimpse of their opposition as the trail winds it way along the XC ski tracks. The large percentage of technical single track means that concerted efforts sees a rider clear out of sight quickly, which is always considered to be a tactical advantage. The surface conditions change dramatically from fast gravel and hard pack to stone, slow rooty and sand trails. Weather conditions can be hot and humid, further adding to the overall difficulty of the course.

A rider with all round abilities is favoured on the Mt St Anne circuit.



Technical course details

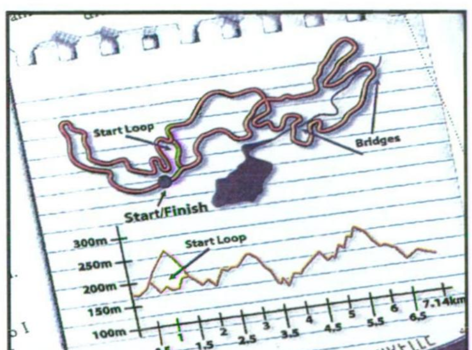


Racers take the first corner

Race Facts

- Race distance: M. 47.4km, W. 39.7km.
- Laps: M. 6 x 7.14km; W. 4 x 7.14km, plus 1 x 1km start loop.
- Lap ascension: 384m.
- Race ascension: M. 2284m, W. 1705m.
- Weather conditions 17-30°c.
- Winners speed: M. 20 km.hr., W. 17.3 km.hr.
- Race duration: M. 124 min., W. 118 min.
- Average gradient: 5.3%
- Percentage time to 20th: M. 9.4%, W. 12.8%.
- Field size: M.>130, W. >90.

Course type: Climbing and techni-



Race-course lap and profile

Course Description

he Chateau doex race course has een used in various forms as a Vorld Cup, Swiss Nationals, Tour le Suisse and recently as the World 'itle venue. The course is centred n the village of Chateau doex, but raverses the Sarine river on several ccassions, as well takes in the teep climbs of the slopes to the outh.

he course has two sections, with he village side of the track taking pen fields and a fast and rooty iver flats section. The southern ection of the course takes in some teep and sustained climbs, with hen slippery switch back wooded lescents. Some fiercely steep decents are not for the faint hearted nd requires a deft hand on the ront brake. The forest and river ections tend to hold moisture naking them technically more difficult, whereas the village sections end to be slow and wearing on the egs.

Considerable passing opportunities re afforded on the double track. Both fire road and single track has ompact gravel, slow grass and ometimes slick mud.

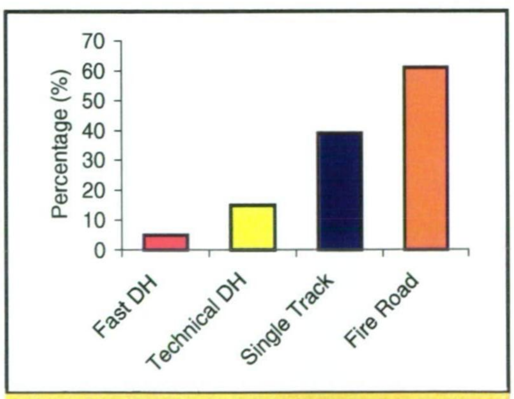
Coupled with a long race duration he Chateau doex course is a physially exacting and technically chalenging race-course.

Steep descending in Switzerland

Race Facts

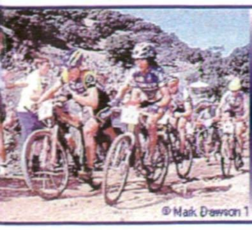
- Race distance: M. 50.4km, W. 33.1km.
- Laps: M. 7 x 7.5km; W. 4 x 7.5km, plu 1 x 1km start loop.
- Lap ascension: 306m.
- Race ascension: M. 2000m, W. 1224m.
- Weather conditions 16-21°c.
- Winners speed: M. 18.9 km.hr., W. 16.5 km.hr.
- Race duration: M. 162 min., W. 120 min.
- Average gradient: 4.0%
- Percentage time to 20th: M. 7.3%, W. 16.5%.
- Field size: M.>130, W. >100.

Course type: Fast, power, climbing and technical course.



Technical course details


Even the worlds best riders crash out!



Are - XC - SWE

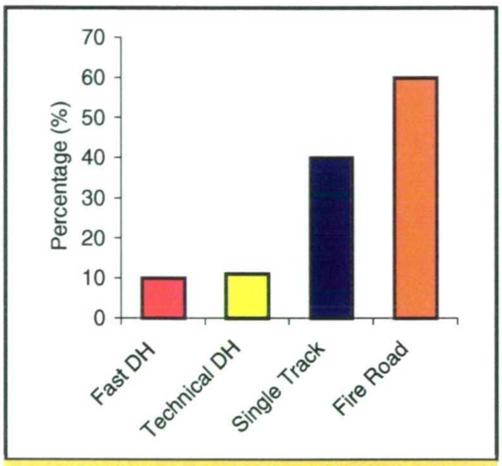

Rider against the mountain

Course Description

e Are XC course is based on the v popular clover leaf design, with hort start village loop, the longest p at 5.5km Olympia loop and fi- y the Fjallgarden loop at 3.2km. e Village loop is basically quite flat fore it hits the Olympia loop ich starts with a sustained and ep climb. After the climb the urse hits a single track which trav- es the side of the hill and grades stly down, with a few counter nbs thrown in. Immediately after Fjallgarden the Olympia loop ns a fast downhill section to the t and finish area.

e surface conditions in Northern rope tend to be heavy and slippery Autumn, whilst firm and dry track nditions are expected in the Sum- r months. Muddy and slick trails a possibility when wet, whilst pery exposed roots also adds to technical difficulty under such nditions.

limbers race, with a pacing an im- tant consideration due to the de- tively heavy nature of the sur- es.



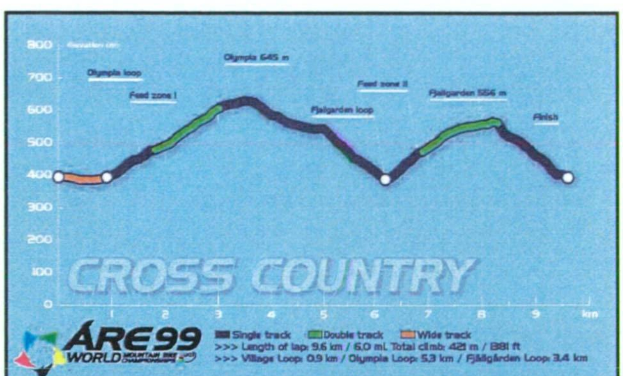
Technical course details

Race Facts

- Race distance: M. 43km, W. 37.7km.
- Laps: M. 4.5 x 9.6km; W. 3.5 x 9.6km, plus 1 x 1 km start loop.
- Lap ascension: 460m.
- Race ascension: M. 2070m, W. 1610m.
- Weather conditions 16-18°c.
- Winners speed: M. 17.4 km.hr., W. 15.1 km.hr.
- Race duration: M. 134 min., W. 152 min.
- Average gradient: 4.8%
- Percentage time to 20th: M. 11.7%, W. 12.8%.
- Field size: M.>130, W. >100.

Course type: Heavy, climbing and technical course.


Wet races requires pushing



Race-course lap and profile