Physiological Contributions to Successful Downhill Mountain Bike Performance

Edinburgh Napier University, MSc by Research

Suzanne L. Hadden

A thesis submitted in partial fulfilment of the request of Edinburgh Napier University, for the award of Master of Science by Research.

June 2011

ABSTRACT

Purpose: To, one, investigate the anatomical and physiological attributes of Downhill mountain bike athletes and, two, to determine the influence of these inherent physiological attributes on Downhill race performance. **Methods:** The study consisted of two testing components; laboratory- and field-based testing. Laboratory study: An anthropometric profile was determined from seven trained and competitive DH athletes (age 21 ± 5 years). Peak power output and time to peak power were determined by six, 6-second maximal sprints, performed on an SRM stationary ergometer. Cadence was restricted during five sprints (60, 80, 100, 120 and 140 rpm) to determine optimal cadence for achieving peak power. Field study: Twelve trained and competitive DH athletes (age 20 ± 5 years) performed two timed runs of a National Championship DH course. Heart rate was recorded and two GPS units (attached to the bicycle and helmet) recorded speed ($km{\bullet}hr^{-1}$), distance (m), time (seconds) and impacts (g). **Results:** Laboratory study: DH cyclists have predominantly mesomorphic somatotypes (mean somatotype values, 2.1,4.7,3.0) with a mean sum of 8 skinfolds, 68.7 ± 19.8 mm. Sprint testing revealed peak power output (23.36 ± 2.12 $W{\bullet}kg^{-1}$) was achieved at restricted cadence of 110 rpm and time to peak power output was 1.5 ± 0.9 seconds. Field study: DH race run time was 178.57 ± 12.10 seconds. Analysis showed two areas of the DH course to affect overall performance; start of the race and the technical section ($r = 0.76$ and $r = 0.94$, respectively). Correlation equations identified mean distance travelled in the first 5, 6 and 10 seconds of the race (22.0 ± 2.8 m, 30.5 ± 3.1 m and 70.4 ± 6.2 m, respectively) had a positive influence ($p < 0.05$) on overall run time. Peak (28.5 ± 3.4 $km{\bullet}hr^{-1}$) and mean (16.8 ± 1.9 $km{\bullet}hr^{-1}$) speed during the technical section (course Section 4) had a positive effect on performance time ($p < 0.05$) Correlation equations between laboratory and field-testing identified peak power output and time to peak power had a positive influence ($p < 0.05$) on the start of the race (first 15 seconds) and thus, overall performance. **Conclusions:** DH is a dynamic, high intensity cycling discipline with many factors influencing performance. Whilst technical skills are essential, results identified that physiological parameters (peak power output and time to peak) can positively affect the start section of a run ($p = 0.049$ and $p = 0.032$), and in turn, overall race time. Therefore, training to improve these measures would be appropriate for DH athletes.

Key Words: Downhill mountain biking, peak power output

CONTENTS

Page

ABSTRACT 1

CHAPTER ONE – INTRODUCTION 10

CHAPTER TWO – REVIEW OF CURRENT LITERATURE

~ Energetics of Off-Road Cycling 14

Introduction to Off-Road cycling 14

Maximal Oxygen Uptake (VO_{2max}) 17

Exercise Intensity During Competition 20

Exercise Intensity of Downhill Mountain Biking 22

Anthropometric Characteristics 23

~ Assessment of Exercise Intensity in the Field 25

Introduction to Exercise Intensity 25

Heart Rate Monitoring 26

Accuracy of Heart Rate Monitors 28

Limitations of Heart Rate Monitors 28

~ Power Output 31

Introduction to Power Output 31

Power Output and Cadence/Power Velocity Relationship 33

Peak Power Output During Short Duration Maximal Exercise 36

Power Output in the Field 39

Validity of Powermeters 39

Downhill Mountain Biking and Power Output 44

~ Ergometers 46

Introduction to Ergometers 46

Validity of Ergometers 46

~ Global Positioning System (GPS) 49

Introduction to GPS 49

Accuracy 51

Downhill Mountain Biking and GPS 56

~ Acceleration 58

Introduction to Acceleration 58

Push Start Sports 63

~ Hypotheses 66

CHAPTER THREE – LABORATORY-BASED ASSESSMENTS

~ Methodology 67

Participant Characteristics 67

Materials and Equipment 68

Anthropometric Measures *68*

6-second Sprint Test 70

Statistical Analysis 72

~ Results 73

Anthropometric Characteristics 73

6-second Sprint Test 74

Relationships between Anthropometric and Power Profile 80

~ Discussion 82

~ Conclusions 93

CHAPTER FOUR – FIELD-BASED ASSESSMENTS

~ Methodology 95

Participants 96

Materials and Equipment 96

Course Description 97

Field Test Protocol 100

Statistical Analysis 104

~ Results 105

Heart Rate Profile 106

Course Sections 107

Speed Zones 109

Race Start 110

Technical Section (Section 4) Analysis 113

Body Load and Impact Intensity 115

~ Discussion 122

~ Conclusions 137

CHAPTER FIVE – SYNTHESIS OF LABORATORY AND FIELD ASSESSMENTS

~ Introduction 139

Statistical Analysis 140

~ Results 140

Anthropometric Profile and DH Performance 141

Power Output 142

Mean Power Output 142

Peak Power Output 143

Time to Peak Power Output 145

~ Discussion 148

~ Summary 157

CHAPTER SIX – FURTHER DISCUSSIONS FOR FURTURE RESEARCH

~ Fatigue During a DH Race Run 159

~ Standing Riding Position 160

~ Breaking Pattern and Line Choice 161

~ Caffeine 162

~ Measuring PO in the Field 163

REFERENCES 164

BIBLIOGRAPHY 171

APPENDICES

i.	List of Abbreviations	174
ii.	Glossary of Terms	175
iii.	Assessment Information Sheet	176
iv.	Participant Consent form	177
v.	Anthropometric Profile Record Sheet	178
vi.	Detail of Anthropometric Measures	179
vii.	Sprint Test Protocol Testing Sheet	181
viii.	Sample of Raw SRM data (Hyperbolic 6-second sprint test)	182
ix.	Sample of Raw GPS Data	183
x.	Relationship between PPO (relative) and Thigh Girth	184
xi.	GPS Reliability Study	185
xii.	SDA Series Pilot: Fort William	195
xiii.	National Championships Practice Day GPS	204

LIST OF TABLES AND FIGURES

Page

Tables

3.1. Participant anthropometric characteristics of interest. 73

3.2. Absolute and relative MPO for each sprint 75

3.3. Peak power outputs and time to peaks during 6-s sprints 77

4.1. Participant overview; age, race category and bicycle model (minus NC group) 96

4.2. Participant overview; age, race category and bicycle model 102

4.3. Speed Zones for field testing 103

4.4 Full race time (seconds), mean, minimum and peak speeds for the run 106

4.5 Mean course Section durations 108

4.6 Duration (% of total run time) spent travelling in speed Zones 1 – 6. 110

4.7 Distance travelled (m) after first 5-s, 6-s, 10-s and 15-seconds of the race run 111

4.8 Analysis of the technical course Section 4 115

5.1 Participant characteristics (synthesis participants) 141

5.2 Participant power output characteristics (synthesis participants) 142

5.3 Run and course Section times (synthesis participants) 143

5.4 Run times, PPO and speed characteristics of run (synthesis participants) 144

5.5 Mean distance in first 5, 6, 10 and 15-s of run and PPO (synthesis participants) 145

5.6 Mean course Section durations (synthesis participants) 146

5.7. Mean distance in first 5, 6, 10 and 15-s of run and ttp (synthesis participants) 147

x.1. Comparison of distances recorded by GPS and SRM during road trial 191

x.2. Mean and peak speeds from GPS and SRM 192

xi.1. Race characteristics from SDA series 198

xi.2. Differences between Innerleithen and Fort William DH courses 199

xii.1. Practice day participant 1 203

xii.2. Practice day participant 2 204

xii.3. Practice day participant 3 204

Figures

1.1. Annotated Downhill mountain bicycle	12
2.1. Downhill course: Loose rock and steep tight track	15
2.2. Downhill course: Rooty tight bending track	16
2.3. Downhill course: Wide cambered corner	16
2.7. Schematic of how GPS system works	50
2.8. Acceleration vectors in relation to the 3 body axes	59
3.1. Polynomial curve showing the MPO across the 5 Isokinetic mode tests	75
3.2. Group mean PPO across the 5 restricted cadences	77
3.3. Relationship between absolute peak and mean power output	78
3.4. Group mean times to peak power output (seconds) for each sprint test	79
3.5. Relationship between time to PPO and relative PPO ($W \cdot kg^{-1}$)	80
3.6. Relationship between absolute PPO (W) and thigh girth (1 cm distal of gluteal fold)	81
3.7. Relationship between time to PPO and trochanterion-tibiale length	82
3.8. Power profile of Participant 3 during the hyperbolic sprint test	88
3.9**.** Force-velocity curve	92
4.1. GPS attachment to the seat post of a DH bicycle	97
4.2. GPS attachment to the helmet of a Study participant	97
4.3. Google Earth image of full testing course (Study Two)	99
4.4. Test course: Course Section 1	99
4.5. Test course: Course Section 2	99
4.6. Test course: Course Section 3	100
4.7. Test course: Course Section 4	100
4.8. Test Course: Course Section 5	100
4.9. National Championships course: Course Section 5	100
4.10. Schematic of the course profile of the Downhill course used for field-testing	103
4.11. Example of speed and heart rate profile of the race run	107
4.12. Speed characteristics for each course Section	109
4.13. The relationship between run performance and distance travelled (5 seconds)	112

4.14. The relationship between run performance and distance travelled (6 seconds)	112
4.15. The relationship between run performance and distance travelled (10 seconds)	113
4.16. Speed profile of the most technical section of the test run.	114
4.17. Mean number of impacts (bicycle GPS) in each zone	116
4.18. Mean number of impacts (body GPS) in each zone	116
4.19. Bicycle and body GPS impact intensity for each course Section	117
4.20. Total sum of impacts in each impact zone (bicycle GPS)	118
4.21. Impact intensity of each impact zone (bike GPS)	119
4.22. Sum of impacts in each course Section	120
4.23. Sum of impacts in Section 4	121
4.24. Impact intensity of Section 4	122
5.1. Force-velocity curve	157
x.1. Speed from GPS and SRM during full road trial	190
x.2. Speed from GPS and SRM during third split from road trial	191
xi.1. GPS schematic of Fort William SDA Series course	197
xi.2. Example of speed and heart rate profile of Fort William	199
xi.3. Graph showing the difference in speed characteristics between 2 courses	200

Chapter One - Introduction

To date, both road and track cycling have been extensively researched and the physiological demands of these disciplines are well understood (Mujika & Padilla, 2001; Atkinson *et al.,* 2003). Mountain biking (off-road cycling), although a relatively new sport, is one of the fastest growing sports in the world, both recreationally and professionally (Baron, 2001). The most high profile disciplines within mountain biking are Cross-Country (XC) and Downhill (DH), both holding their first World Championships in 1990. Cross-country gained approval from the International Olympic Committee (IOC) and made its debut as an Olympic event at the 1996 Atlanta Olympic Games. Despite not having Olympic status, Downhill continues to host its own World Cups and other high profile global events. It was in fact noted that almost 20,000 spectators viewed the most recent World Cup event at Fort William, Scotland, in 2010 (personal correspondence with event organiser), highlighting the popularity of the discipline.

Downhill mountain biking is a sport that requires the athlete to skilfully manoeuvre a technically and physically demanding, descending course. DH consists of sporadic efforts of fast pedalling and high power output and as such has been characterised by British Cycling as an ‘intermittent sprint sport’. The terrain in a DH race is made up of a succession of challenging jumps, drops and berms (cambered corners) over a varying terrain surface (rocky, muddy, rooted) and the rider competes against the clock. Two runs are performed; the first being a seeding run and the second, the final race run. Riders can descend between 300 and 600 metres during a course of ~2.5 km for a duration of between 2 and 5 minutes.

The governing body for Downhill, Union Cycliste Internationale (UCI) state that full-face helmets with visors are mandatory during races and recommend body armour protecting neck, back, elbows, knees and shoulders (UCI Regulations, Part IV, Chapter 3, p. 24). The Downhill bicycles themselves are highly specialised pieces of equipment (Figure 1.1) and are designed primarily for speed and highly technical racing and little else. Suspension is essential and Downhill bicycles typically have a dual-suspension system that serves two purposes; to smooth the transition across the terrain without losing speed or control and to decrease muscular stress on the rider.

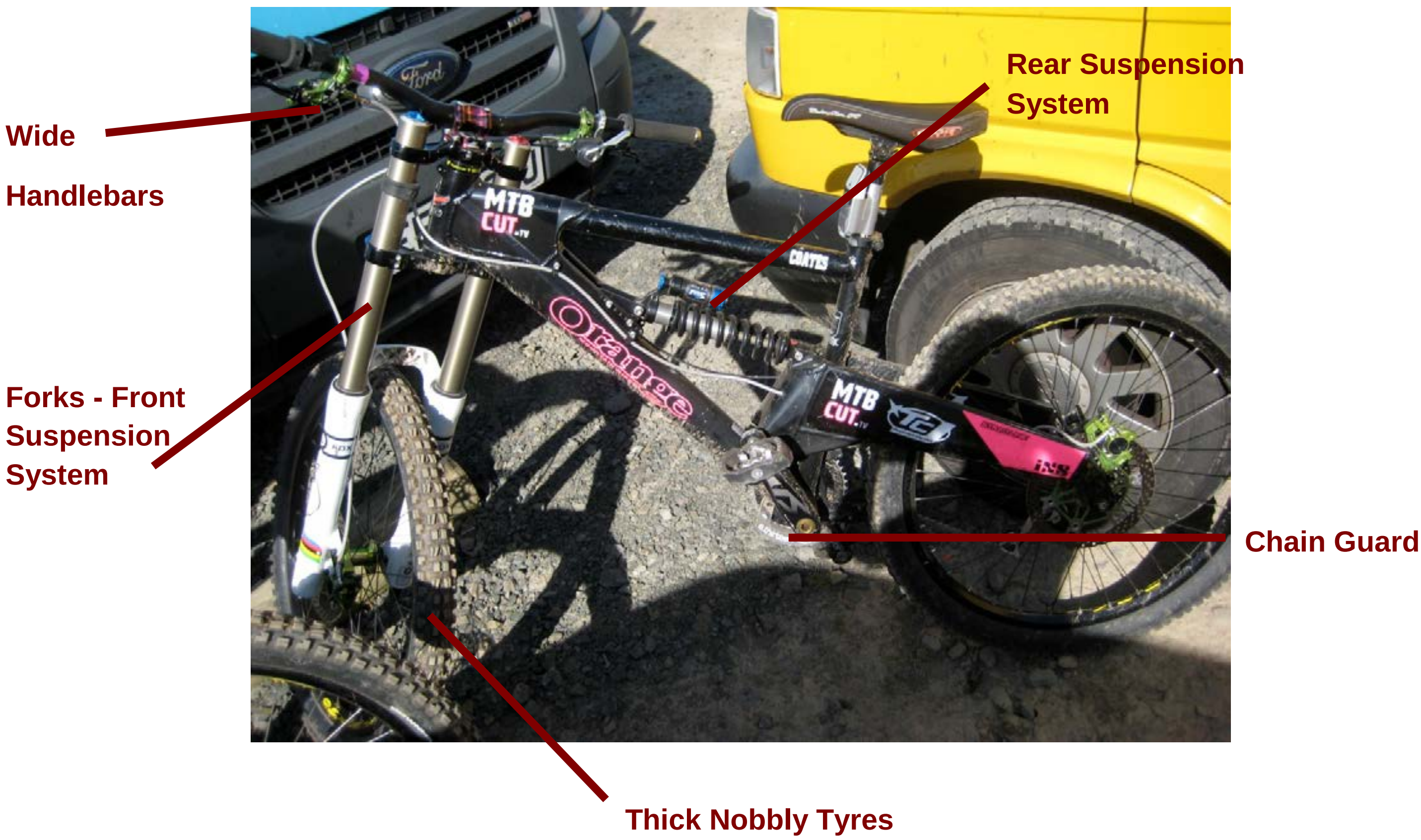


Figure 1.1 Annotated Downhill Mountain bike. Picture taken 10/09/09

Despite the growing popularity of mountain biking, both recreationally and professionally (Baron, 2001), there remains a lack of research into the off-road cycling disciplines. There have been a number of investigations into the higher profile, XC endurance discipline but as yet, only one study (Hurst & Atkins, 2006) has investigated the physiological demands of Downhill mountain biking. It is clear XC and DH require different types of physiological prowess. The endurance XC discipline can last up to two and a half hours in comparison to the intermittent shorter discipline of DH and athletes tend to specialise in one of the two disciplines. Comparisons drawn from the literature are limited due to the differing natures of the two disciplines, thus, it is necessary for further research to focus specifically on Downhill mountain biking.

Physiological testing is an essential component of athlete monitoring and preparation in many professional sports. This information and insight can allow detailed and specific programmes to be designed so that athletes can train for optimal performance. Currently, little is known about the physiological demands of downhill mountain biking thus, the primary aim of this study was to quantify the demands of DH mountain bike riding in physiological terms. Furthermore, the project aimed to obtain anthropometric and power output data from laboratory testing from competitive DH mountain bikers and correlate this data with DH mountain bike race performance in the field.

Chapter Two – Review of the Current Literature

Energetics of Off-Road Cycling

Introduction to Off-Road Cycling

The governing body of Mountain Biking, Union Cycliste Internationale (UCI), identifies three types of mountain bike event: Cross country (XC), Downhill (DH) and stage races (UCI Cycling Regulations, Part IV: Mountain Bike Races, version on 10.02.2009). Despite the increasing popularity of mountain biking (Baron, 2001), few studies investigate the physiological characteristics of the sport. XC is the most high profile of the mountain bike sub-disciplines due to its Olympic status and races last between 2-3 hours, held over a single day. Typically, competitors complete several laps of an off-road circuit, covering distances between 6km and 9km, per lap. The course consists of a series of technical descents and steep inclines over diverse terrain of dirt and gravel trails, narrow wilderness trails and open fields. Approximately 40% of the total distance is the hill-climbing component and thus the race tests riders' technical skills as well as their physiological fitness (Gregory *et al*., 2007; Lee *et al*., 2002).

Downhill mountain bike events are held over a two-day period; the first day is an allocated practice period and the second day will typically consist of two timed runs; a seeding run determining the start order for a final placing run. The cyclist with the fastest time is declared the winner. Similarly, the format of a qualifying run acting as a ‘semi-final’, allowing a reduced number through to the final timed run, may also be adopted. The descending course is comprised with sections of varied terrain: narrow and broad tracks, woodland roads and paths, fields and rocky tracks. The course will typically feature several ‘lines’ which the rider can take to overcome an obstacle or sections of the course. For example, Line ‘A’ may be the most direct route but will involve a jump with a challenging landing, whereas Line ‘B’ could avoid the jump altogether but is longer in length. Course dependant, the race duration will be between 2 and 5 minutes (UCI Cycling Regulations, Part IV: Mountain Bike Races, version on 10.02.2009). Downhill performance relies on riders’ technical ability and high levels of concentration and decision-making, however, the explosive injections of power necessary to create and sustain speed should not be overlooked as an important aspect of performance and thus the sport has been termed as an ‘intermittent sprint sport’ by British Cycling. Figures 2.1, 2.2 and 2.3 (photographs taken 10/09/2009) show examples of the different terrain of a Downhill course (Innerleithen British National Championships 2009 course).

Figure 2.1 Loose rock and steep tight track.

Figure 2.2. Rooty tight bending track.

Figure 2.3. Wide cambered corner.

Maximal Oxygen Uptake (VO_{2max})

Off-road cycling is a high intensity activity (Gregory *et al.,* 2007; Impellizzeri *et al.,* 2002; Padilla *et al.,* 2001). To cope with the high energy demands of XC mountain biking, it would naturally be assumed that these athletes would have strong aerobic fitness levels and existing studies confirm this (Gregory *et al.,* 2007; Impellizzeri *et al.,* 2002; Padilla *et al.,* 2001). Impellizzeri *et al.,* (2002) performed an incremental maximal exercise test on an electromagnetically braked ergometer to determine the VO_{2max} of nine high level mountain bikers (n=6, under 23; n=3, elite, conforming to UCI categories). Mean VO_{2max} for the group was 75.9 ± 5.0 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$. This value depicts a very high level of relative aerobic fitness and is just above the normative values suggested for cycling athletes (62 – 74 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ (Wilmore and Costill, 1994)). The high values are in agreement with those reported by Wilber *et al.,* (1997) who had ten elite male athletes, representing the United States National Off-Road Bicycle Association, (NORBA) perform a standardized progressive exercise protocol on an electrically braked cycle ergometer. The protocol consisted of a submaximal stage and a maximal stage to determine VO_{2max} (70.0 ± 3.7 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$). Although still high levels of aerobic fitness, other studies conducted by Gregory *et al.,* (2007), Warner *et al.,* (2002) and Baron (2001), suggest slightly lower VO_{2max} values (64.8 ± 8.2 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$, 67.4 ± 4.6 $ml{\bullet}kg^{-1}{\bullet}min^{-1}$ and 68.4 ± 3.8 $ml{\bullet}kg^{-1}{\bullet}min^{-}$1, respectively). From the above data it is clear that XC athletes do present high levels of aerobic fitness and this is in part due to their low body mass. Low body mass of XC athletes have been reported by a number of investigations; Baron (2001) (summer: 64.9 ± 4.6 kg, winter: 64.3 ± 4.8 kg); Wilber *et al.,* (1997), (72.6 ± 6.4 kg). These are all low in comparison to sports science students, who have a mean body mass of 69.4 ± 6.5 kg (Baron, 2001). Since no downhill riders were included in these studies, unfortunately, the VO_{2max} values reported cannot be directly compared to DH athletes.

The VO_{2max} values reported for XC cyclists are similar to those of road cyclists. Professional road cycling is described by Lucia *et al.,* (2001) as an 'extreme endurance sport' with training and competition covering ~ 30 000 – 35 000 km per year. The authors reported mean VO_{2max} values of professional road cyclists to be 70 – 80 $ml•kg^{-1}•min^{-1}$, demonstrating very high aerobic fitness levels amongst this athlete population. Wilber *et al.,* (1997) showed the mean VO_{2max} of ten male road cyclists representing the United States Cycling Federation (USCF) National Road Team to be 70.3 ± 3.2 $ml•kg^{-1}•min^{-1}$. When compared to the previously discussed VO_{2max} data from the off-road NORBA athletes, there was no significant difference ($P < 0.05$) between the two groups. In addition, a more recent study made a direct comparison between top level off-road and professional road cyclists. Lee *et al.,* (2002) showed a significant difference in VO_{2peak} between the mountain bike and road cyclists (78.3 ± 4.4 $ml•kg^{-1}•min^{-1}$ Vs. 73.0 ± 3.4 $ml•kg^{-1}•min^{-1}$, respectively). Values were reported as VO_{2peak} due to no distinct plateau in VO2 being demonstrated in both groups. VO_{2peak} was defined as the sum of the highest two consecutive 30 second VO_2 readings. The significant difference between the VO_{2peak} values may have been due to the higher calibre mountain bike athletes compared to the road athletes (National and International level mountain bikers vs. National level road cyclists) or due to differing body masses (mean difference was 1.1 kg) which would influence the relative VO_{2peak} values presented.

To date, only one group has specifically assessed physiological characteristics in Downhill athletes (Hurst and Atkins, 2006) and they did not investigate the VO_{2max} of their subject group. However, a review article by Impellizzeri and Marcora (2007), gives some values collected from the Italian National Downhill team. The lower VO_{2max} (63.2 $ml \cdot kg^{-1} \cdot min^{-1}$) suggests that aerobic fitness may be of less importance to Downhill cyclists than for XC cyclists. This seems logical due to the shorter duration, intermittent and descending nature of DH. More data on DH riders is needed to confirm or dispute these findings.

Some studies investigating road cycling have identified a weak relationship between VO_{2max} (absolute) and performance in road time trials (Bentley *et al.,* 1998; Coyle, 1999) and thus it has been suggested that VO_{2max} is not a good predictor of road cycling performance. However, a strong relationship ($r = -0.80$) reported by Gregory *et al.,* (2007), between relative VO_{2max} and time trial speed in XC athletes suggests VO_{2max} may be a more valid indicator in the off-road discipline. XC time trials are typically completed over undulating terrain; the low body mass of XC competitors may pertain to their high relative

VO_{2max} values whilst also better enabling the maintenance of high speeds, particularly uphill. However, in XC it is perhaps lower body mass (which inherently leads to a higher relative VO_{2max}), and not solely the VO_{2max}, which is a valid predictor of time trial performance.

Exercise Intensity During Competition

Impellizzeri *et al*. (2002) used heart rate (HR) to quantify the exercise intensity of four International and National level XC races (two winter races and two summer races, mean distance: 34.3 ± 3.9 km) in nine XC competitors. Mean exercise intensity was expressed as % HR_{max} and %VO_{2max}. They confirmed the very high intensity nature of XC competitions with intensities of 90 ± 3% HR_{max} and 84 ± 3% VO_{2max} recorded. Similar high intensities were demonstrated during a short road cycling time trial (TT), n=18, (85 ± 5 % HR_{max}, 172 ± 9 bpm). As expected, their values were higher than longer duration road races (80 ± 5 % HR_{max}, 162 ± 6 bpm) (Padilla *et al.,* 2000).

Gregory *et al.,* (2007) measured exercise intensity during a shorter distance (15.5 km) cross country time trial (n=11). By dividing the terrain of the course into different sections (Ascent sections – 5-10%, 10-15%, 15-20%; Flat post ascent; Flat post-technical; Downhill – 5-10%, 10-15%, 15-20%) it gave a clearer explanation of the varying physiological responses during a XC race. Unsurprisingly, HR was highest during the steepest ascent section (179 ± 8 bpm or 93.8 ± 2.6 % HR_{peak}) and lowest during the steepest downhill section

(150 ± 9 bpm or 78 ± 4.4 % HR_{peak}). Mean HR (174 ± 7 bpm) during this time trial was similar to that reported by Impellizzeri *et al.,* (2002) (171 ± 6 bpm) and Padilla *et al.,* (2000) (172 ± 9 bpm). Distance of this time trial was somewhat shorter than the time trial completed by Impellizzeri's cyclists (15.5 km compared to 34.4 km). In this case, pacing strategies may have accounted for the lower heart rate and certainly, the differing terrain cannot be discounted. However, maintaining HR above 78% HR_{peak} continues to demonstrate the high intensity nature of this sport, also accounting for these being XC specialists and not DH athletes.

Gregory *at al.,* confirmed that HR was strongly related to the terrain and that both HR and power output increased with ascent. Interestingly, heart rate remained elevated despite a decrease in power output on the downhill sections and did not fall below 78.5 % HR_{peak} at any point during the time trial. The effects of the energy demands of isometric contractions, required for shock absorption and stabilisation and increased stress caused by the difficult terrain in the downhill sections may explain this. Stress can stimulate several hormonal responses. Catecholamines secreted from the adrenal medulla and corticosteroids from the adrenal cortex may be secreted in response to stress induced by off-road cycling which may effect and elevate heart rate (Axelrod and Reisine, 1984). Furthermore, drafting in road cycling is shown to reduce energy utilisation by as much as 40 % (Faria *et al.,* 2005). This may also explain why heart rate is higher in off road cycling compared to road cycling (Impellizzeri and Marcora, 2007; Faria *et al.,* 2005).

Exercise Intensity of Downhill Mountain Biking

As mentioned, only one study to date, examines the exercise intensity of Downhill mountain biking. Hurst and Atkins (2006) investigated seventeen National level male Downhill cyclists whilst they performed two runs of a measured Downhill course. Cadence and power output data identified the intermittent nature of DH, however, it also demonstrated that HR remained stable (158 – 177 bpm) despite the fluctuating power output (peak power output of 834 ± 129 W despite a low mean of 75 ± 26 W). As mentioned previously, the isometric contractions required to absorb the terrain could account for this stable and elevated HR. Another explanation may be that the time between efforts is too short for the cardiopulmonary system to recover following elevations in response to the intermittent efforts, resulting in the elevated HR profile. HR data collected from the DH cyclists support the HRs seen during the downhill sections of the study conducted by Gregory *et al.,* (2007) (Downhill 5 – 10 %, 168 ± 9 bpm; Downhill 10 – 15 %, 152 ± 9 bpm; Downhill 15 – 20 %, 150 ± 9 bpm). A further explanation for the relatively high HR experienced during downhill may be the requirement to lift or jump over obstacles. A typical Downhill mountain bicycle weighs between 17 – 25 kg in comparison to its lighter XC counterpart, which weighs between 7 – 16 kg. Lifting and manoeuvring the DH bicycle would increase the energy demands, especially over technical sections. Furthermore, the speed of decent will also cause greater forces, e.g. centripetal, when cornering, again increasing physical demands. Downhill athletes also spend the whole run standing on their pedals as opposed to the common sitting position adopted by all other cycling disciplines. This means DH athletes pedal standing up and have to deal with a certain amount of 'pedal bob' due to the suspension characteristics of the bicycles; all requiring more energy input that a rigid frame and forked road bicycle does not necessitate.

Anthropometric Characteristics

The mean height for cross-country athletes finishing in the top 10 in the 2008 Beijing Olympics was 176.4 ± 4.9 cm and mean body mass was 67.2 ± 3.1 kg (en.beijing2008.cn accessed 27/03/2009 11.00am). These body mass values are similar to those reported in the existing literature; 65 – 69 kg (Impellizzeri *et al.,* 2005; Lee *et al.,* 2002) and 67 ± 4 kg reported by Impellizzeri and Marcora (2007) detailing XC athletes competing in the 2004 Athens Olympics. Interestingly, the silver and bronze medallists from the 2008 Beijing Olympics have a 5 kg body mass difference. Although not empirical, this introduces the idea that perhaps body composition, rather than body mass, is the influential factor on XC mountain bike performance.

Interestingly, a relationship between relative body composition and competition level is apparent. This was implied by the low mean body fat % (6.1 ± 1.0 %) of National and International XC cyclists collected by Lee *et al.* (2002) and the higher values (11.5 ± 2.7 %) of lower level XC athletes collected by Warner *et al.* (2002). Measurement techniques were however, different. Lee *at al.* (2002) used a regression equation with 7-site skinfolds to estimate body fat percentage, whilst Warner *et al.* used a total body DXA scan, a far superior and direct measure of body fat percentage. Due to the differing measuring techniques, comparison of the data from Lee et al (2002) and Warner et al. (2002) is unreliable. However, the results seem reasonable since low inert body mass would be advantageous for the climbs during a cross-country race (Swain, 1994). As mentioned in the 'Power Output' section of the literature review (below), power: weight ratio is of high importance in mountain biking (Impellizzeri and Marcora, 2007; Swain, 1994) and in any cycling event requiring work to be completed against the force of gravity (Swain, 1994). Thus, riders with competitive aerobic power outputs but very low body mass (high power: weight ratio) will enjoy much more success or maintain a higher speed over undulating terrain when compared to their heavier counterparts (Impellizzeri and Marcora, 2007)

Assessment of Exercise Intensity in the Field

Exercise Intensity

Physiological testing and monitoring of athletes is an essential process for preparation and optimal performance. Laboratory-based testing provides a controlled environment essential for determining physiological parameters for an athlete. The controlled environment allows accurate replication of tests to take place, time and time again, ensuring the data collected is valid, comparable and useful to the athlete. Laboratory testing cannot however replicate the sport 100% and this will always mean that laboratory data will not be an ecologically valid indicator of the ‘real’ sporting performance of an athlete. Field-testing, although with its own variables, can offer a more ecologically valid assessment of physiological state, albeit often at some expense of tightly controlled variables (Townshend *et al.,* 2008; Faria *et al.,* 2005).

Exercise intensity can be defined as the amount of energy expended (per minute) to perform a certain task ($kJ \cdot min^{-1}$) and has been expressed in terms of speed, % VO_{2max}, % lactate threshold, heart rate (HR) and power output (PO). Unlike running or swimming, speed is not necessarily a good indicator of exercise intensity in sports such as skiing or cycling (Jeukendrup and van Diemen, 1998). There are a number of factors, environmental as well as physiological, which affect speed at a given power output, such as terrain, air temperature and wind. With this in mind, heart rate monitors provide a more accurate account of the exercise intensity of cycling than measuring speed (Jeukendrup and Van Diemen, 1998). It should also be mentioned that powermeters are becoming increasingly popular and superior at measuring characteristics of cycling performance and intensity (speed, distance, time and power output) in the field and will be discussed later in the review.

Heart Rate Monitoring

It has long since been established that the relationship between HR and oxygen consumption (VO_2) is linear (Astrand, 1986). By determining this relationship, HR can then be used to estimate VO_2, providing further indication of the intensity of the exercise performed. Heart rate monitoring is the most common method of assessing the intensity of an exercise session and can be used in training sessions and during competition. Monitoring intensity during training allows optimal preparation for competition. The American College of Sports Medicine produced a very general classification of exercise intensity based on % $HR_{reserve}$ and % HR_{max} (Pollock *et al.*, 1998). This approach however, lacks specificity to an athlete who may be physiologically more advanced at certain intensities, affecting the relative HR at which they need to be at to be training at a specific level. So while the ACSM guidelines may be useful for recreationally active people, a more individualised approach should be adopted with highly trained athletes to ensure they train at physiologically relevant intensities.

HR zones associated with blood lactate parameters can be used to determine intensity zones (Achten and Jeukendrup, 2003). Coyle *et al.,* (1999) demonstrated that VO_2 at lactate threshold (LT) was a strong predictor (r = 0.96) of endurance performance in cyclists and thus zones indicating HRs at LT and OBLA (blood lactate value of 4 $mmol \cdot l^{-1}$) give a good indication of exercise intensity relating to performance. Superior performance requires a high threshold. These parameters are often referred to in the literature, most often when investigating endurance cycling, and are a more valid predictor of performance than VO_{2max} (Atkinson *et al.,* 2003; Coyle *et al.,* 1999; Impellizzeri and Marcora, 1997). Monitoring blood lactate parameters for the shorter duration DH discipline are less likely to provide useful information for the coach and athlete (and to date have not been reported). DH is a short duration, intermittent discipline. For not only logistical reasons, i.e. not being able to take a blood lactate sample during a DH run, but for physiological reasons, i.e. the around 30 s transient time for blood lactate to appear in the blood following anaerobic bursts of work, obtaining blood lactate samples during a DH run would likely be of little worth. Furthermore, taking a lactate sample at the end of the run would not be representative of the whole performance load, thus lactate sampling may not be of use in DH field testing. However, if only to discount the importance, perhaps research should be directed in this direction.

Accuracy of Heart Rate Monitors

The accuracy of HRMs have been thoroughly investigated. It was established early that only HRMs with the chest electrode transmitter were valid in comparison to ECG (Léger and Thivierge, 1988). Léger and Thivierge determined this was a more reliable and valid method of HR monitoring, rather than transmitter electrodes worn on the fingertips, hands or earlobes. Seaward *et al.,* (1990) and Godsen *et al.,* (1991) both agreed chest electrodes were a suitably valid and reliable method of assessing HR during rest and varying exercise intensities that the HRMs measured within 6 bpm of actual HR, measured by ECG, 95% of the time (Godsen *et al.,* 1991). In addition to the measure of HR during exercise, Goodie *et al.,* (2000), investigated validity of HRMs during mental stress. ECG measured the mean HR of 30 subjects to be 80.7 ± 10.4 bpm during a mental stress test. The wireless HRM reported mean HR to be 81.3 ± 10.4 bpm. This was a highly significant correlation ($r = 0.98$, $p < 0.0001$), concluding that HRMs were also a valid and reliable method of recording HR during mental stress. This is an aspect applicable to Downhill performance, as athletes are required to negotiate steep and technical terrain at high speeds, which is likely to be psychologically stressful.

Limitations of Heart Rate Monitoring

HR monitoring is an easy method for determining exercise intensities during training and competition but the limitations must be considered. Gnehm *et al.,*

(1997) showed different body positions during cycling can affect HR. 14 elite male cyclists were studied in three different positions: upright, hands on the drops and hands on clip-on aerobars. The clip-on aerobars cause the frontal area to be lower and thus reducing the drag coefficient. However, the study suggests this position to be less efficient with a mean HR of 5 bpm higher compared to the upright position. The elevated HR was attributed to an increased contribution of the shoulder musculature and a less efficient hip angle (Jeukendrup and van Diemen, 1998). Heil *et al.,* (1995), also report elevated HR with smaller seat tube angles resulting in a more severe trunk angle.

HRM may not be an accurate representation of physiological load in DH. Whilst HRM measure the intensity of exercise, in the case of DH, the variable terrain experienced (rocky, tight corners, tree roots, vertical drops) means there are many areas where the rider is not pedalling, thus not all of the exercise results in useful 'work'. A state of fear or anxiety can be characterised by an increase in autonomic activity such as blood pressure, ventilation and/ or heart rate. Stimulation of the amygdala, a part of the brain associated with fear and anxiety, can alter heart rate and blood pressure. The challenging nature of DH ensures a psychological aspect is present and perhaps a high heart rate observed during DH mountain biking should take in to account the possible effects of fear/ anxiety on its value. Further research in to the use of HRM during DH may be of use.

Altitude is another factor that may affect HR during exercise and thus may affect the normal relationship between HR and energy expenditure. Hypoxic conditions will induce an elevated HR response due to the lower partial pressure of oxygen in the blood in comparison to normoxic conditions. Downhill competitions often take place in ski resorts (e.g. Whistler Mountain, BC, Canada, elevation: 1219 m and Fort William, Nevis Range, Scotland, elevation: 670 m) and thus heart rates could be affected by altitude; another consideration when using HR as the indicator of exercise intensity.

Power Output

Introduction to Power Output

Power is the work accomplished per unit time and is expressed in watts (W; Joules (Nm)/second (s)) (Foss and Keteyian, 1998). Cycling involves the repeated application of force to the pedals in order to move forward. This action requires the application of sufficient force to overcome forces resisting forward motion, such as air resistance, friction and gravity. The ability to travel quickly when racing is important and is influenced by many factors; muscular endurance, strength and power, nutrition, cadence and gear selection, frame size and body position. Jeukendrup and Van-Diemen (1998) observed power output to be a more direct and reliable measure of exercise intensity than heart rate monitoring.

Power output can be of an aerobic or anaerobic nature. In predominantly aerobic cycling disciplines such as road racing and XC, power output has been researched extensively (Lucia *et al.,* 2001, Padilla *et al.,* 2000, 2001). Maximum aerobic power (MAP) produced during a maximal incremental test can be used as a predictor of performance in endurance cyclists (Hawley and Noakes, 1992; Balmer *et al*., 2000). Lucia *et al.,* (2001) concluded that MAP produced during incremental lab-based tests was dependent on the protocol. Values of 400-450 W (6.0-6.5 $W \cdot kg^{-1}$) were recorded during longer increments of 4 minutes in comparison to shorter protocols with 1-minute increments

(450-500 W or 6.5-7.0 $W \cdot kg^{-1}$). Lucia also claims that peak values of 500 W (relative values not reported) are not unusual amongst top-level athletes, when using the more rapidly incrementing protocol. Padilla *et al.,* (2000; 2001) reported similar values (439 ± 45 W or 6.4 ± 0.3 $W \cdot kg^{-1}$ and 433 ± 48 W or 6.3 ± 0.3 $W \cdot kg^{-1}$ respectively).

In addition to the aerobic component, XC also involves short bursts of high intensity anaerobic efforts (Baron, 2001). The ability to generate high power outputs during hill climbing and sprinting for the finish line is vital to successful performance. However, despite its obvious importance, research in this area is limited. Baron (2001) investigated both the aerobic and the anaerobic characteristics of National and International off-road cyclists compared to sports science students. Predictably, the off-road cyclists had a significantly higher ($P < 0.01$) maximal aerobic power output during an incremental test (40 W every 4 minutes) than the sports science students (5.5 ± 0.4 $W \cdot kg^{-1}$ vs. 4.3 ± 0.7 $W \cdot kg^{-1}$ respectively). Furthermore, the incremental test also showed the cyclist group to produce a higher power output at OBLA (blood lactate concentration of 4.0 $mmol \cdot L^{-1}$) than the sports science group (4.7 ± 0.6 $W \cdot kg^{-1}$ vs. 3.2 ± 0.7 $W \cdot kg^{-1}$). A 10-second anaerobic power test showed the off-road cyclists to have a significantly higher ($P < 0.01$) PPO than the sports science students (14.9 ± 1.1 $W \cdot kg^{-1}$ vs. 13.3 ± 1.4 $W \cdot kg^{-1}$ respectively). Impellizzeri and Marcora (2007) reported their unpublished data testing six National level off-road cyclists (no DH) to reveal a similar relative PPO (14.2 $W \cdot kg^{-1}$); both data sets allude to the importance of the ability to generate a high PPO in the XC cycling discipline.

Downhill Mountain biking, as mentioned, is a high intensity intermittent cycling discipline (Hurst and Atkins, 2006), which can be assumed, would place a higher emphasis on the ability to generate very high power outputs (anaerobic system) rather than the aerobic system. Hurst and Atkins (2006) aimed to assess the power output during actual Downhill Mountain biking. Using a crank-arm-based power meter (SRM), power, cadence and speed were recorded at 1-second intervals throughout DH runs in 17 male athletes. PPO was 834 ± 129 W or 10.7 ± 1.3 $W \cdot kg^{-1}$; lower than the values reported by Baron (2001). A reliable comparison cannot be made, however, due to the different testing environments (laboratory vs. field). Furthermore, Baron (2001) conducted their research on athletes competing at a higher level (National and International) whereas Hurst and Atkins (2006) used National Level DH cyclists only.

Power Output and Cadence / Power Velocity Relationship

Cadence affects PPO (Sargeant, 1981; Baron, 2001). Although an investigation into the force-velocity relationship by Thorstensson *et al. (*1976) discovered that peak torque, tested via isokinetic dynamometry, decreased when muscle-shortening speeds increased, this can be easily applied to cycling due to the similarity between muscle shortening speeds and cycling cadence. With high cadence bursts, rapid concentric muscle contractions are required. The capacity of the muscle to generate power during a single maximal short-term (< 10-s) cycling exercise is described by a polynomial power-velocity relationship (Dorel *et al.,* 2003). This sees the power output reach a peak value, occurring at an optimal cadence. The optimal velocity for producing PPO has been subject of many investigations (Dorel *et al,.* 2003; Baron 2001; Sargeant *et al.,* 1981).

Sargeant *et al.* (1981) investigated force exerted and power generated during short-term exercise performed on a modified bicycle ergometer, which controlled the speed of the contraction. Subjects performed a series of 20-second maximal efforts over a range of shortening velocities (23 – 171 rpm). The investigation concluded that the optimal velocity for producing the PPO was 110 rpm. During a DH race, riders will only pedal for short periods of time (5 – 15 seconds) (Hurst and Atkins, 2006), thus a mean cadence of 110 rpm may be applicable to DH. 110 rpm is not an unrealistically fast cadence and could be reached/ obtained in the short periods of pedalling during DH cycling, generating PO (and thus speed). However, it must be noted, Downhillers are not seated during their race, instead are standing on their pedals; so with the difference in rider position, this hypothesis remains unsupported without further, specific research.

Hurst and Atkins (2006) examined the mean and peak cadence values of DH mountain bikers on a measured course using the SRM Powercranks. Mean cadence was as low as 27 ± 5 rpm, however due to the intermittent nature of Downhill and the periods of 'freewheeling', reported to account for up to 55% of overall run time, this value included the zero values recorded. Hurst and Atkins reported mean pedalling periods to be less than 5-seconds. When zero values were omitted, mean cadence increased to 60 ± 6 rpm. Van Soest and Casius (2000) investigated PO in sprint cycling and agreed that this was influenced by pedalling rate and concluded an optimal cadence of 130 rpm. Hurst and Atkins reported peak cadences of 128 ± 20 rpm, close to those proposed by Van Soest and Casius, which is the figure of most interest due to the very sporadic power demands of DH. It was the poor relationship between PO and cadence that led to the hypothesis that for DH riders, it is the quality of force generation which is more important than the rate of turning the pedals (Hurst and Atkins, 2006). The initial, near maximal effort, at the start of the race saw the greatest cadence and PO (128 ± 20 rpm and 834 ± 41 W respectively), which took a mean of 7 ± 1.3 seconds to achieve (Hurst and Atkins, 2006). During short duration sprints, as seen during DH mountain biking, the optimal pedal rate (rather than a preferred pedal rate) for producing PPO would be the most advantageous as the energy supply, for this duration of effort, is not the predominant limiting factor (Kohler and Boutellier, 2005). Downhill mountain biking is composed of short bursts of pedalling and thus it could be hypothesized that the ability to attain PPO rapidly is important for performance and thus, determining the optimal pedal rate for producing PPO should be taken into account for this sport.

Peak Power Output During Short Duration Maximal Exercise

Peak power obtained from maximal incremental (aerobic) tests can be a predictor of cycling performance (Hawley and Noakes, 1992). The speed of a cyclist is determined by the power provided by skeletal muscle contraction. Optimal performance is achieved when energy from all available sources is used to generate power to maximize speed over the total race distance (Craig and Norton, 2001).

Sprint cycling sees a much higher production and output of power than endurance cycling due to the higher speeds and shorter duration of sprint events (Craig and Norton, 2001). The energy pathway fuelling the muscle when producing power during sprinting differs from the aerobic energy pathway of endurance cycling (Craig and Norton, 2001). Craig and Norton suggest that during short duration (10-s) maximal sprints, the percent contribution from three energy systems are as follows (alactic, 40 %; anaerobic, 55 %; aerobic, 5 %). The very high PO observed during sprinting is therefore mainly derived from anaerobic sources.

The metabolic responses to short-duration maximal exercise have been investigated by a number of studies. At the onset of a maximal sprint, the phosphagen and glycolytic systems are fully activated (Faria *et al.,* 2005). Phosphocreatine (PCr) degradation starts immediately and stores are emptied within ~ 10-seconds of maximal dynamic exercise (Faria *et al.,* 2005). By 10-s there is a substantial increase in glycogenolysis, producing lactate. McCartney *et al* (1986), had subjects perform four, 30-second maximal sprint efforts with 4 minutes recovery intervening, to identify associated metabolic changes in muscle. Sprints were restricted to a cadence of 100 rpm. The first maximal bout elicited the greatest PPO and subsequently, saw the largest fall in muscle glycogen and greatest increase in lactate and glycolytic intermediate concentrations. This is in agreement with other investigations (Hultman and Sjoholm, 1983; Jacobs *et al.,* 1983) and suggests that the metabolic changes from the first bout indicate an extensive activation of glycogenolysis. Furthermore, the concentrations of glycolytic intermediates serve to identify the control of glycogenolysis in the muscle. The measurements after the first effort showed the fall in muscle glycogen concentration to be 18 $mmol{\bullet}kg^{-1}$ which was accompanied by an increase in lactate concentration in the muscle to 28.9 $mmol{\bullet}kg^{-1}$ and 7.0 $mmol{\bullet}l^{-1}$ in the blood which is more than 75 % of the expected anaerobic lactate yield McCartney *et al* (1986), thus, supporting the hypothesis that most of the glycogen was metabolized through the anaerobic pathway. Furthermore, the magnitude of this activation is identified by the increase in glucose 6-phosphate and fructose 6-phosphate. Electrical stimulation experiments conducted by Hultman and Sjoholm (1983) demonstrated that lactate production may generate 20% of the ATP resynthesis within 1.26-s and within 1.26 and 2.5-seconds ~50% of the amount resynthesized. Studies consistently conclude that maximal power during short duration sprints (< 10-seconds) is fuelled by the breakdown of creatine phosphate and from the anaerobic glycolytic pathway.

De Koning *et al.,* (1999) investigated pacing strategies in sprint cycling. Mathematical modelling showed that with the same amount of anaerobic energy, a 1000 m sprint cyclist performs considerably better when a large amount of the anaerobic energy is released early in the race. Their protocol kept anaerobic contribution constant and changed the 'time to constant anaerobic power (TC)'. The three time trials showed the 'all-out' strategy to have a quicker final race time (s) than the '30-s of all-out' or 'constant energy contribution' (58.09 seconds, 58.33 seconds and 61.04 seconds respectively). Although the 'all-out' pacing strategy released the highest initial power, it showed the greatest amount of energy lost through friction. However, it did have the largest amount of kinetic energy present at the end of the race. A major concern with this study is the apparent miscalculations possible when ascribing the intensities of the 'constant anaerobic contribution' trials; it is possible that these trials resulted in a slower overall performance due to the subjects not being exhausted, or not having fully expended their anaerobic system at the end of the race. However, the data, nonetheless, suggest that the strategy of producing PPO as quickly as possible, to achieve the highest mean velocity is more advantageous in terms of short duration performance. The benefits of this strategy outweigh the frictional loss associated with the higher velocity.

Whilst pacing strategies in DH may not be applicable due to the undulating terrain, the theory of a maximal and 'all out' start may be and thus, should be investigated further to determine its impact on DH performance.

Power Output in the Field

Assessing PO in the field has become easier since the introduction of mobile power measuring systems. There are a number of manufacturers which produce these systems (e.g. Polar® S710, Power Tap, SRM). The ability to measure power in the field is extremely advantageous to cyclists and their coaches as they are able to obtain objective cycling data from every ride and they enable laboratory testing to be completed on the cyclists own bike. It is however, extremely important that the data from the power meter is accurate and reliable or else it is of little use.

Validity of Power meters

There are a number of studies investigating the reliability and validity of different cycling power meters. Millet *et al.,* (2003) investigated the validity and reliability of the mobile power meter, Polar® S710 in a laboratory setting and a field setting and used the SRM power meter as a comparison. The study demonstrated that the Polar® S710 recorded higher PO (7.4 ± 5.1 %, $p < 0.001$) when compared to the SRM, with cadence and exercise intensity affecting the mean power output (MPO). They concluded that the Polar® S710 was not appropriate for use with elite athletes or research, due to the reduced accuracy and reliability.

Bertucci *et al.,* (2005) investigated the validity and reliability of the PowerTap mobile cycling power meter in comparison to the scientific model of the SRM power meter. It was concluded that during submaximal intensities, (100 - 450 W) the PowerTap showed a good validity ($r = 0.99$, $P < 0.001$) compared to the SRM device. Results also highlighted PowerTap was less reliable when measuring PPO during sprint exercises. Three sprints were conducted each in different gear ratios (low, middle and high gear ratios of 39/23, 39/17 and 39/14). PO was significantly lower (8%, $p = 0.016$) during the sprint test with the low gear ratio. There was no significant difference in PO with the two other gear ratios. Gear selection is important in Downhill for producing PPO to generate speed as quickly as possible, especially at the start of the race. As the PowerTap systems' PPO deteriorates during sprints and at cadences of ~ 115 rpm and above, this may not be an appropriate method of assessing PO in the field for DH. It would be more suitable during submaximal intensities. Furthermore, PowerTap appears to be unsuitable for Downhill mountain biking due to its setup. PowerTap measures torque at the rear hub (centre of rear wheel) with the angular velocity measured by a sensor in the hub. The turbulent terrain and obstacles that make up a Downhill course could cause damage to the PowerTap and thus, use of this device with Downhill mountain bikes was advised against (determined through personal communication with PowerTap).

The SRM (Schoberer Rad Messtechnik) Training system is made of high-strength, specially tempered aluminium alloy and are available in four different versions; road, mountain bike, BMX and track. The Powermeter is mounted onto the bike in place of the normal crank/chain-ring combination to measure net torque, continuously, giving an indication of the demands of cycling (in Watts (W)) in its true environment. PO is calculated from the torque and the angular velocity of the pedalling action by converting the force applied to the strain gauges (a known distance along the crank arm from the pedal) by the speed at which the crank arm is being rotated (Hurst and Atkins, 2006; Faria *et al.,* 2005). The signal is transmitted to a receiver mounted on the handlebars, which is able to store data such as speed, total distance covered, cadence, HR and PO (Jeukendrup and van Diemen, 1998).

A number of studies assess the validity of the SRM power meter both in the laboratory setting (Duc *et al.,* 2007; Bertucci *et al.,* 2005; Balmer *et al.,* 2000, 2004; Davison *et al.,* 2000) and in the field (Gardner *et al.,* 2004). For mountain biking, only a four strain gauge model (professional) exists compared to eight strain gauges (scientific) available for track and road cycling. The manufacturers report that the accuracy of the power meters increases with the number of strain gauges (amateur = ± 5 %; professional = ± 2 %; scientific = ± 0.5 %) (Gardner *et al.,* 2004). Martin *et al.,* (1998), concluded that the SRM power meter was a valid measure of cycling power due to its high validity and reproducibility. They mounted the SRM system onto a Monark cycle ergometer (a known "gold standard") to determine if the SRM was a valid measure of cycling power. Following calibration, subjects completed 3-minute stages at 6 workloads (45, 90, 135, 180, 225 and 270 W) at a cadence of 90 rpm to measure. 20-seconds between each workload allowed the pendulum to be adjusted, so each workload collected 160-

seconds of data. Power and cadence were measured by the SRM at 1-second intervals. Power measured by the SRM system and the power delivered to the Monark ergometer flywheel were significantly different ($p > 0.001$), however this difference (2.3564 %) was similar to friction losses normally associated with chain drive systems and it was concluded that the SRM power meter was a valid measure of PO. This conclusion was also reported in an unpublished study conducted by Paton and Hopkins in a review paper (Paton and Hopkins, 2001), where they determined that the (~ 1 %) higher power recordings from the SRM power meters in comparison to a motor-driven Monark ergometer was due to frictional losses.

Paton and Hopkins (2001) cited studies investigating systematic errors in mobile SRM power meters. Lawton *et al.,* (1999), measured 19, 4-guage SRM power meters at a constant pedalling frequency of 100 rpm. A bicycle fitted with the SRM cranks was mounted onto a stationary wind trainer and the gears were used to create 18 resistive loads between 50 – 900 W. For each resistive load, the power from the calibration rig was subtracted from the SRM reading and then the average systematic error across the 18 loads was recorded. The mean average from the 19 crank sets was 2.5 % with a variation between crank sets to be ± 5.0 %. It was concluded that, although the exact source of the error was unknown, it was most possibly due to the calibration rig. This systematic error could be reduced if an SRM ergometer is used in a laboratory setting as it could be stabilised within the laboratory setting. Paton and Hopkins (2001) also report that random error can be as low as ~1 % when measuring power in ‘all-out’ sprints, a protocol that would be applicable to the Downhill sprint athletes.

More recently, Gardner *et al.,* (2004), conducted a number of experiments to determine the accuracy of SRM under different conditions. This included; investigating the reliability after a full 11-month racing season, the effect of changes of cadence on PO, the effect of temperature on SRM data and investigating the reliability of data collected in the field. The authors concluded that the calibration of SRM power meters are stable throughout an 11-month racing season, however, it does appear to be sensitive to changes in ambient temperature. When the device was zeroed in cool conditions (exposed to 6°C for 12 hours), it gave a positive error of 3.7 ± 0.4 % in contrast to the negative error (-1.5 ± 0.4 %) seen when zeroed in standard laboratory conditions (exposed to 21°C for 10 hours). Therefore temperature should be taken into account when recording outdoors. In addition, special consideration should be taken when comparing data collected from different times in the season (i.e. winter/ summer months). The ambient temperature may affect the data collected as the mean percent difference in PO values may be as significantly different as 5.2 %. However, ensuring the device is zeroed regularly reduces this error.

Validity of the SRM device in the field has not yet been investigated. Although Gardner *et al.,* (2004) included an experiment collecting data from the SRM device in the field (power output, speed and cadence were collected from a 7-minute hill climb using a standard road bicycle), the data was compared with another power meter (Power Tap) and not with a comparable laboratory test. This would have given a more reliable indication of how valid the SRM device was at measuring in the field setting.

Hopkins *et al.,* (2001), concluded that cycle ergometers which allow the use of the athletes own bicycle, produce some of the smallest coefficient of variances (CV), with an investigation using SRM power meter by Balmer *et al.,* (2000), reporting 1.5 and 0.8 %. This is useful as SRM power meters can be mounted onto an athletes' own bicycle and data can be collected in the laboratory or in the field. It must be noted however, that with the advance in DH bicycles, mountain bike specific SRM cranks can no longer be fitted to the rigs. The more modern bicycles have a bottom bracket which is wider than the axel arm of the SRM crank. This means that in order to measure power output during DH mountain biking, the riders would have to use an older style bicycle which would not be appropriate as it would athletes would not perform to their potential on a bike they are not accustomed to.

Downhill Mountain Biking and Power Output

There are many variables that will influence performance in DH mountain biking such as technical skills, suspension and braking patterns to name a few. Measuring PO characteristics during performance will allow a profile of a

DH ride to be obtained showing pedal rate and time, and the PO at which these occur. When these parameters are determined, coaches can prescribe training specifically to match cadences and PO to achieve optimal performance. As mentioned, only one study to date reports PO in DH performance (Hurst and Atkins, 2006) and future investigations into this area will be of interest to the development of the sport.

Ergometers

Introduction to Ergometers

As mentioned, laboratory-based performance tests are an important aspect of a competitive cyclists' preparation for performance. Cycle ergometers are a stationary piece of laboratory equipment that generate resistance via friction-braking (e.g. Monark ergometer), air-braking (e.g. Kingcycle ergometer) or electromagnetically-braking (e.g. Lode ergometer) of a flywheel.

Validity of Ergometers

There are two types of error in cycle ergometry: systematic and random. Systematic error is a consistent offset in the power reading from the ergometer and causes issues when monitoring performance on different ergometers. Random error (noise) is the fluctuation in the readings seen from reading to reading and thus reduces the reliability of monitoring changes in performance when testing on the same ergometer. Ergometer calibration is an essential process which must be carried out periodically in order to maintain reliability and accuracy of the test data (Paton and Hopkins, 2006, 2001; Maxwell *et al.,* 1998; Wilmore *et al.,* 1982).

The Monark is the most commonly used friction-braked ergometer (Paton and Hopkins, 2001). The ergometer generates frictional force by a belt sliding around a flywheel. The belt is attached to a spring and weights are added to a pendulum or a basket to increase the tension on the spring. Force is determined by applying a braking force to the flywheel. Electromagnetically-braked ergometers such as the Lode bike create a resistance by the rotation of a crank arm through a magnetic field. A useful aspect of this type of ergometer is that work rate can be kept constant, independent to pedalling rate, allowing investigations into optimal cadence etc to be conducted.

Air-braked ergometers such as the Kingcycle, use the cyclists own bicycle, which will improve the ecological validity of the results collected. The rear wheel of the bicycle drives a roller which is connected to a bladed fan and this action creates air resistance. A photo-optic sensor measures flywheel velocity and a computer attached to the sensor converts the electrical signal transmitted to a power value. Rolling resistance is similar to that experienced outdoors with this being another benefit of using air-braked ergometers (Faria *et al.,* 2005; Paton and Hopkins, 2001). Palmer *et al.,* (1996) investigated the reliability and reproducibility of the Kingcycle air-braked ergometer. A small co-efficient of variance was detected for a repeated 20 km and 40 km time trial (TT) (1.1 ± 0.9 % and 1.0 ± 0.5 % respectively). These results suggest that the Kingcycle is a reliable measure of performance. Finn *et al.,* (2001), however, show that reliability of PO measured by air-braked ergometers can be affected by environmental conditions such as air pressure, temperature and humidity. They showed that PO increased 1 % from a 2.7°C change in temperature or from a decrease of 7.6 mmHg in atmospheric pressure.

It must be noted that, to the authors' knowledge, there are no published reliability and/ or validity studies completed on the SRM ergometer which was used in the laboratory testing for the current study.

Global Positioning System (GPS)

Introduction to GPS

Physiological laboratory-based testing, whilst controlling the environment, will often be unable to mimic the true, sport-specific performance and therefore the usefulness of data extracted from the laboratory is often limited. Sport-specific field-testing can provide useful performance data impossible to gain from a laboratory. However, with field-testing, there are many uncontrolled external factors making it difficult to achieve standardised conditions required for valid results (Townshend *et al.,*2008) (e.g. air-resistance, environmental conditions).

The continual acceleration and deceleration experienced during the course of a DH track means it is very difficult to measure important characteristics of the sport such as speed. Previous field-based tests across a range of sports used the time taken to travel a known distance to measure speed (Coutts and Duffield, 2008) or used equipment such as timing gates (Townshend *et al.,* 2008). This, however, will only provide a mean speed, which is no use when determining the 'real' speed of a DH racer. The introduction of global positioning system (GPS) in the 1990's provides a solution to this problem when monitoring DH, allowing speed, distance and location data to be collected in real time.

GPS was originally developed as a military tool by the U.S Department of Defence (Townshend *et al*., 2008). GPS is a navigation system, which uses up to 24 operational satellites, orbiting the earth twice daily following, one of six paths. Each satellite emits a radio signal with a unique code sequence and encrypted navigation message. A GPS receiver synchronises with the satellite (Figure 2.4) and decodes the navigational signal which allows distance to each satellite to be calculated by multiplying the signal travel time with the speed of light (Townshend *et al*., 2008). The GPS receiver must be synchronised with at least four satellites so the distance to the satellites can be calculated allowing a three-dimensional position to be determined trigonometrically (Townshend *et al*., 2008; Larsson, 2003).

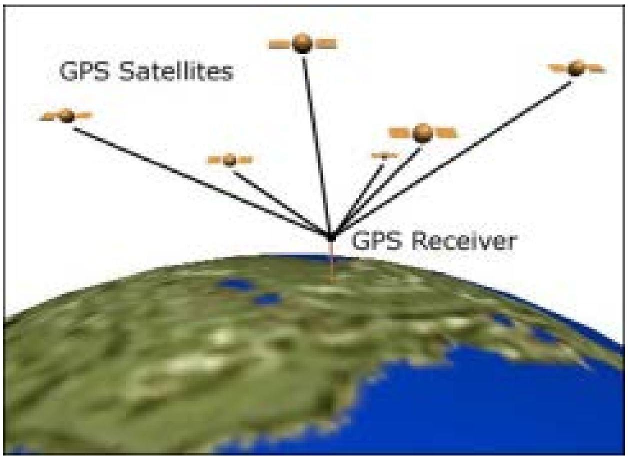


Figure 2.4. Schematic of GPS receiver triangulating signal with a number of satellites. (www.gpsports.com) Accessed - 05/05/2009).

Speed of displacement can be determined by measuring the rate of change in the satellites signal frequency attributable to the movement of the GPS receiver. This is a process known as the Doppler shift (Schutz and Herren, 2000).

Accuracy

GPS accuracy can be influenced by a number of factors such as the number of satellites available. The main factor, however, was a deliberate imprecision inserted into the system in 1999 by the US Department of Defence in an attempt to reduce the risk of hostile forces by scrambling the signal. Various methods were developed to improve accuracy and ‘correct’ the error in the standard signal, namely differential GPS (dGPS). dGPS increases the accuracy of speed and distance measured compared to standard GPS receivers. It requires stationary receivers to be fixed to the ground that act to correct the signal by sending radio signals via the differential receiver to the GPS receiver. Larsson and Henriksson-Larsen, (2001) compared dGPS distance data against two manually measured distances in ten subjects. Mean measurement error of the dGPS was reported as ~2 m and the precision measurement of the dGPS were within 0.6 m.

Differentiated GPS is an expensive method of increasing accuracy so when selective availability was removed in May 2000, the accuracy of the more affordable, non-differentiated GPS systems, should have been significantly improved. Adrados *et al* (2002) sought to determine whether this was the case. They studied the accuracy of the location of a non-differentiated GPS receiver before and after SA elimination. 354 and 339 fixed locations were recorded and results showed a significant ($p<0.001$) decrease in the mean location error from 78.0 m with SA to 11.9 m without SA. Adrados *et al.,* concluded that although dGPS systems were still more accurate than non-differentiated GPS systems, the removal of SA significantly decreased the maximum location error, improving the validity of using non-differentiated GPS.

Triangulation quality can be influenced by the position of satellites in relation to each other and in relation to the GPS receiver. This is quantified in a measurement described as dilution of precision (DOP). Optimal DOP would be a value of 1, with one satellite directly overhead the GPS receiver and the other satellites equally spaced along the horizon. Higher DOP values (a maximum value of 50) will be recorded when the satellites are closely clustered together and values collected will be unreliable. Orientation and number of satellites changes during the day and since these changes have an impact on the accuracy of data collected then it must be noted that experimental conditions cannot be fully standardised (Witte and Wilson, 2004).

Many studies specifically aim to determine the accuracy and reliability of GPS in the assessment of human movement in relation to both health and athletic performance. Witte and Wilson (2004) aimed to discover the accuracy of GPS for determination of speed during cycling. Accuracy was determined by comparing GPS data with data obtained from a custom-designed bicycle speedometer. Cycling was conducted at a constant speed around a running track, on curves of two different radii, on a straight road and during rapid changes of speed (acceleration/ deceleration). The study was composed of two experiments. Experiment 1 collected data from a head mounted GPS receiver during curve, straight and curve-straight transition cycling around a 400 m athletics track. The subject performed four laps at each of the following speeds; 15, 20, 25, 30 and 35 $km.hr^{-1}$. 45 % of the speed values determined by the GPS receiver were within 0.2 $m \cdot s^{-1}$ of the true speed measured, an additional 19% measured within 0.4 $m \cdot s^{-1}$. This shows that GPS can accurately measure speed. The data shows that the GPS tends to overestimate speed (negative error) rather than underestimate speed. Experiment 2 specifically aimed to discover the effect of curved paths and acceleration characteristics on the accuracy of speed values recorded by GPS. The subject cycled two roundabouts (diameters of ~16 and 30 m) at speeds of 15, 20 and 25 $km.hr^{-1}$ and performed rapid changes in speed (acceleration/ deceleration) on a straight road at speeds of 10, 15, 20, 25, 30 and 35 $km.hr^{-1}$. Results showed more errors whilst cycling the smaller roundabout (16% values within $\pm$0.2 $m.s^{-1}$ and 28% within $\pm$0.4 $m \cdot s^{-1}$) compared with the larger roundabout (23% values within $\pm$0.2 $m \cdot s^{-1}$ and 41% within $\pm$0.4 $m \cdot s^{-1}$). Data recorded from the straight line showed a higher accuracy level (57% within ±0.2 $m \cdot s^{-1}$ and 82% within ±0.4 $m \cdot s^{-1}$) when determining location. Witte and Wilson (2004) concluded that whilst GPS is accurate for determining speed when travelling in a straight line, accuracy is reduced when travelling on curved paths. Although they concluded that it was still competent. They further reported that the GPS tends to over-estimate the speed in transitions of straight-curve paths. Interestingly, the study also concluded that inadequacies in the data collected are apparent when there are rapid changes of speed (acceleration/ deceleration). The results showed that the system appeared to smooth the peaks and troughs of the changes in speed, which would be problematic when trying to determine a speed profile of a sport which requires rapid speed changes such as DH. It must be highlighted however, that the GPS receiver used had a sample rate of one per second. This is a very low sample rate in comparison to the SP1 Pro (GPSports, Australia) which measures 5 per second. Thus, the conclusions made by this paper may not be valid in a true sporting context (such as DH) as a higher sample rate would be essential to accurately measure the changes in speed.

In contrast to the conclusion that GPS underestimates distances, Edgecomb and Norton (2006) found GPS devices to overestimate true distances by 4.8%, but they did however agree that, despite these errors, it could be confidently used to track human locomotion, specifically player movement during Australian Football.

Townshend *et al* (2008) produced a study that aimed to validate GPS as a measure of characteristics of human locomotion such as speed, displacement and position. Four experiments were undertaken: validation of distance, speed on a straight path, speed on a circular path and position. The results of this study concluded that non-differential GPS provides an accurate estimation of speed, displacement and static position during human locomotion. They also agreed with Witte and Wilson (2004), that there is an increase in errors when determining speeds (GPS underestimating speed) around bends and was further increased at higher velocities (Townshend *et al* (2008)). The sample rate of the GPS used was one per second so may not be fast enough (especially at the increased velocities) to accurately measure the bends.

Most recently, Coutts and Duffield (2008) assessed the validity and more specifically, intra-model reliability of different GPS devices. When studying characteristics of human locomotion during sport, one of the leading manufacturers is GPSports, Canberra, Australia. Coutts and Duffield (2008) collected data from six of their devices: 2 SP1-10, 2 SP1-Elite and 2 WiSP1 and measured total distance travelled, high-intensity running distances (>14.4 $k.hr^{-1}$) and very high-intensity running distances (>20 $km.hr^{-1}$) during each bout. Six laps of a measured circuit (128.5 m) were performed eight times by two moderately trained males whilst alternating intensity; walking, jogging, fast running and standing still. The study concluded that all the GPS devices showed a reasonable level of accuracy ($<5\%$) with SP1-10, SP1-Elite and

WiSP1 recording -4.1 ± 4.6%, -2.0 ± 3.7% and 0.7 ± 0.6% from the true bout distance, respectively. It can be concluded that different GPS devices should not be used interchangeably to ensure optimal reliability. Interestingly, this study also looked at peak speeds recorded by GPS and aimed to look at whether GPS was reliable when analysing sprint performance in team sports. The sprint distance measured in the study was a standard 20 m, which is not truly representative of team sports as often sprints will be of shorter distance (de Koning *et al.,* 1999). The coefficient of variation (CV) for the low intensity activity (LIA) were 5.3 % but showed an increase during high intensity activity (HIA) to 32.4 % and very high intensity activity (VHIA) to 30.4 %. This reduction in accuracy at these high speeds suggests that vital speed and distance data could be missed when performing at high speeds and intensities. This may have some implication when assessing locomotion of subjects riding bicycles. However, as technology develops there are GPS units (SP1 Pro, GPSports, Australia) widely available which measure at a faster rate (5 Hz instead of 1 Hz) and perhaps these would be able to overcome these issues with more data points being recorded and thus a higher resolution of data being collected; particularly important during changes of speed and navigating turns/corners at high speed.

Downhill Mountain Biking and GPS

A number of authors (Pino *et al*., 2007; Edgecomb and Norton, 2006; Larsson and Henriksson-Larsen, 2001) aimed specifically to assess the use of GPS during sports such as Australian Football, soccer, cross-country skiing and hockey. GPS can allow a greater understanding of activity patterns and energy demands of sports and specific team position characteristics. This type of knowledge and understanding can ensure training specificity to enhance athlete performance. This technology may have a particular impact when working with off-road cyclists and in particular, DH specialists. Significant time can be lost in corners and GPS can be used to analyse speed and acceleration of specific sections of the course. With this knowledge, identification of technical areas of the track may allow for optimal preparation.

Acceleration

Introduction to Acceleration

Acceleration is the rate of change of displacement and is measured in $m \cdot sec^{-1} \cdot sec^{-1}$. To accelerate an object is to change its velocity which includes either an alteration in speed or direction in relation to time. It is a vector quantity having both magnitude and direction and being positive (acceleration) or negative (deceleration) (Pandolf *et al*., 2001).

Acceleration vectors are described in relation to three body axes (x, y and z) (Figure 2.5). The unit, g, describes the gravity at the surface of the earth which is equal to acceleration (9.812 $m \cdot sec^{-1} \cdot sec^{-1}$). The unit, G, is calculated as the observed acceleration divided by the g, therefore an example of an acceleration of 29.4 $m \cdot sec^{-1} \cdot sec^{-1}$ can be expressed as 3 G. +Gz describes the force travelling from head to foot, +Gx from front to back experienced during sudden acceleration or –Gx which can be experienced during braking and Gy are acceleration forces experienced on the diagonal plane (Barth *et al*., 2001; Pandolf *et al.,* 2001).

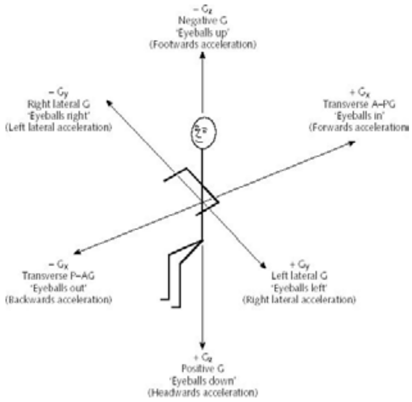


Figure 2.5. Picture adapted from: http://content.answers.com/ - Accessed 5/5/2010.

GPS units have the ability to record the frequency and intensity of impacts up to 400 Hz with an inbuilt accelerometer (SPI Pro, GPSports), which can highlight acceleration forces on the body during different sports, such as Australian Rules Football, rugby and cycling. The majority of literature investigating gravitational forces and G-toleration, however, are in relation to fighter pilots and their experience of these forces and the associated effects (Bateman *et al.,* 2006; Barth *et al*., 2001; Pandolf *et al.,* 2001). Although this may not be directly comparable to the sporting context, these studies allow an interesting insight to the magnitude of g-forces and should serve to add perspective to the impacts experienced during Downhill mountain biking.

+Gz can have a mechanical effect on soft tissue and can cause the spine to compress. This is the same force that may be experienced during mountain biking as the cyclists cover the challenging terrain. This type of acceleration force can also have effects on the cardiovascular and pulmonary systems. –

Gz is less common although will also have an effect on the cardiovascular system and may additionally effect vision and cause LOC (loss of consciousness). Providing some perspective on the effects and values of g, the paper describes that acceleration forces above 2.5 g would cause difficulty to rise from a seated position and forces greater than 3 g would results in a difficulty to raise the limbs. Forces greater than 8 g will render any gross movement impossible. It must be noted that these forces are sustained and not short duration impacts that may be observed in the sporting impact (e.g. tackles in rugby and importantly terrain-induced forces during cycling). A human time-tolerance curve, shows that humans have a high tolerance for short duration exposure of large magnitudes. As such, 9 g can be tolerated without symptoms for short durations such as ~ 5 seconds, whereas toleration of longer duration exposure such as 15 - 30 seconds, where full activation of cardiovascular defence mechanisms is maintained, will be at a lower force of 5 g.

Studies which look at gravitational impact forces during sport are largely aimed at impacts to the head, leading to concussion and injury (Mihalik *et al.,* 2007; Duma *et al.,* 2005; Barth *et al.,* 2001). Barth *et al.,*(2001) investigated acceleration/ deceleration in sport-related concussion. They highlight that a change in vector of acceleration/ deceleration (e.g. rotational or twisting forces) will complicate the synthesis of the sum of forces and will thus alter the magnitude of the g-force experienced. They note that 1 g is the equivalent to 9.812 $m{\bullet}sec^{-1}{\bullet}sec^{-1}$ and provide the example that if a running back in American Football was travelling at 3.658 $m{\bullet}sec^{-1}$ and his head is stopped in

0.152 m, the deceleration would be 4.46 g. To give some perspective, they explain that irreparable brain damage would occur when the head was exposed to 30 g (for example during a car crash). Duma *et al.,* (2005) suggested that the head can withstand higher g-forces than that and report that an incidence of a concussion occurred at 81 g during American football, although this was whilst wearing a helmet which is why the value is higher than the 30 g reported by Barth *et al*. Duma *et al* reported average peak head accelerations during games to be 32 ± 25 g and although slightly less, another study conducted by Mihalik *et al., (*2007) report football players to consistently sustain head impacts of between 21 – 23 g. These values appear grossly larger than those reported by Pandolf *et al.,* (2001) in relation to g-forces experienced by fighter pilots, although it must be reminded that the head impacts are of much shorter duration and this probably explains the higher tolerance to the high g-forces.

It has been suggested that strength training may improve acceleration tolerance (Bateman *et al.,* 2006). As strength training may be an area of importance for Downhillers (future research is required to determine this) then this may be of importance. The programme must focus on the major leg, arm and abdominal muscles. The focus of the strength programme (hypertrophy, strength endurance) is not restricted, as muscle biopsies taken after subjects underwent a time in a centrifuge showed that there is no correlation between acceleration tolerance and fiber type (fast or slow twitch).

It has been further suggested that acceleration tolerance is enhanced with moderate aerobic fitness levels and will also decrease with associated fatigue. However, this statement is under debate as others (Pandolf *et al.,* 2001) suggest that high aerobic fitness levels and its associated low heart rates may decrease tolerance as these subjects would take longer to respond to sudden acceleration stresses. It is clear that further research is therefore required in this particular area.

Only one study to date reports impacts directly in a sporting context. Cunniffe *et al.,* (2009) documented the physiological demands of elite rugby union. Player impacts (number, intensity and distribution) were determined from accelerometer data and presented in g force. The intensity of impacts were graded and split into six zones: light (5 – 6 g); light to moderate (6 – 6.5 g); moderate to heavy (6.5 – 7 g); heavy (7 – 8 g); very heavy (8 – 10 g) and severe (10 + g). The light impact zone is generally characterised by a hard acceleration/ deceleration/ change in direction and the severe impact zone is characterised by a severe impact/ tackle or collision. These zones help to quantify the body load and impact experienced during sport and can be compared to other findings from other sports when they become available.

Data on body impacts and load available through use of GPS technology not only provides a valuable insight into the physiological demands during sport it could also be used to help devise recovery programmes specific to player positions or competitions. This would help with injury prevention and also optimal preparation for the next match/ competition.

Push Start Sports

Hurst and Atkins (2006) identify the largest power output to occur at the start of a DH race run. This power output was recorded after just 4.5 ± 1.3 seconds, suggesting that DH riders aim to accelerate from a stationary position as quickly as possible to gain a powerful start. This rapid acceleration will provide a momentum to help carry their speed through the rest of the race. Whilst the winter sliding sports such as bobsled, luge and skeleton may not seem particularly similar to the cycling discipline of DH, many parallels can be drawn.

Bobsled is a sport where 2 – 4 person teams slide a descending iced track of approximately 1.6 km. The start requires athletes to accelerate a 200 – 250 kg bobsled from a stationary position, for approximately 30 – 40 m, before entering the bobsled. High speeds are reached and during competition can exceed 140 $km.hr^{-1}$, thus bobsled is a sport which is highly technical and skill dependent. The luge is another sliding sport which is similar to bobsled in that they descend the same iced track, however, athletes ride alone and lie on their backs on a much smaller sled. They steer by a combination of shoulder movement and runner control with their feet. The start of the luge also requires rapid acceleration from a standing start before mounting the sled.

Both of these skilled and technical sliding sports are Olympic events and as such the difference between Gold and fourth is often thousandths of a second (Garrett and Kirkendall, 2000). This homogeneity in technical ability has resulted in a high emphasis being placed on the athletes' performance at the start of the race. From the Hurst and Atkins (2006) investigation into DH, the parallel between these sports would seem to be the necessity for a fast and powerful start.

As with DH, performance in bobsled and luge is influenced by several external factors such as the environment and equipment. A number of studies have investigated the importance of the start in these sliding sports and found that start time and overall acceleration in the starting straight (before entry to bobsleigh/ luge) is significantly correlated with the final race run (Platzer *et a*l., 2009; Bruggemann *et al.,* 1997). Both studies agreed that the starting performance was in fact, a prerequisite for excellent overall performance.

Zanoletti *et al.,* (2006) investigated another winter sliding sport; skeleton. Skeleton requires the athlete to ride their sled lying face down (opposed to luge, where athletes are lying on their back). Skeleton uses the same track as bobsled and luge and again, as there are no brakes, performance is highly skill dependent and technical ability is essential. Zanoletti *et al.,* (2006), investigated elite athletes during a series of International events. Significant correlations ($p < 0.05$) were identified between push time (start acceleration) and final race time in both men and women. They too concluded that a fast push phase was a prerequisite for successful performance. They further claim that an athlete should be chosen, based on their ability to accelerate to peak speed quickly. This reinforces the importance of the start phase of the race and the necessity to execute it as quickly as possible in order to achieve a successful all-round performance.

With the data from Hurst and Atkins (2006), showing DH to reach their peak PO (834 ± 129 W) in the start phase of their race, the claims from the sliding sport investigations could possibly be applied to DH.

Hypothesis

1. Chosen anthropometric measures of a Downhill athlete (body mass, somatotype, sum of 8 skinfolds, femur length) will positively correlate to aspects of DH performance, such as PPO and time to PPO, attained from the laboratory-based tests.

2. Measures attained from the laboratory-based tests, such as PPO and time to PPO will show a positive correlation with DH race performance attained from the field-based tests.

3. Performance at the start of the race will be positively correlated to DH race performance.

CHAPTER THREE – LABORATORY-BASED ASSESSMENTS

Methodology

Each laboratory testing session had two components; a body composition assessment and sprint test protocol. Participants were asked not to consume food 90-minutes before attending the session and were told to keep hydrated throughout the day. Each session commenced between 3 pm and 7 pm in an attempt to minimize the effects of circadian rhythm on performance. A detailed outline of the test protocol and familiarization of the equipment was undertaken with each participant prior to the laboratory testing.

Participants Characteristics

Seven male volunteers provided written, voluntary informed consent prior to participating in this study, approved by the Edinburgh Napier University ethics committee (January 2009) (Appendix iii and iv). All participants were trained and competitive Downhill mountain bikers who were each successful within their own competition categories (n=1, youth; n=1, junior; n=2, expert male; n=2, elite male; n=1, master). The mean physical characteristics of the participant group were as follows: age, 21 ± 5 years; stretch stature, 184.7 ± 9.4 cm; mass, 78.7 ± 9.0 kg.

Materials and Equipment

Body mass was measured using Weylix balance scales and stretch stature was measured using a wall mounted stadiometer (SECA, Germany). Skinfold thickness (mm) was measured using calibrated Harpenden skinfold callipers (Harpenden, UK). The callipers require a constant closing compression of 10 $g.mm^{-2}$ throughout a range of measurements. They were calibrated to 40 mm in 0.2 mm divisions. Limb girths (cm) were measured using a flexible steel measuring tape (Rosscraft, Canada), limb lengths (cm) were measured using Segmometer 4 (Rosscraft, Canada). The segmometer is made from steel tape which is 100 cm long and 15 mm wide which has 2 straight branches attached. Bone breadths (mm) were measured using Campbell 10 small bone callipers (Rosscraft, Canada), accuracy of the small bone callipers are to within 0.05 cm. A standardized box was used to measure iliospinale and trochanterion height. Box dimensions are 40 cm (tall) x 50 cm (wide) x 30 cm (deep) and there is a cut-out section on one side of the box which enables the participant to position their foot under the box, allowing iliospinale height to be determined.

Anthropometric Measures

Body composition was measured prior to the sprint testing protocol. During the anthropometric testing, participants were instructed to remove all clothing and footwear apart from shorts to ensure reliability of all body composition measures. A Level 1 anthropometrist, accredited by the International Society for the Advancement of Kinanthropometry (ISAK), performed an adapted, restricted ISAK profile on each participant (additional measures were included as they were believed to be specific to DH mountain bike athletes and are detailed further in Appendix vi). All measures were taken from the right side of the body. The anthropometric record sheet can be found in Appendix v.

Skinfolds

Specific anatomical landmarks were located on the participant to identify the location of eight skinfold sites (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf). The skinfold was conducted by pinching the skin between the forefinger and the thumb at the identified site, ensuring that the double thickness fold contained only the epidermis, underlying fascia and subcutaneous adipose tissue and no muscle. The callipers were then placed 1 cm away from the fingers along the skinfold site about midway between the crest and the base (about a fingernail deep). Each anthropometric measure was taken twice and entered into a spreadsheet which would require a third measure if the first two measurements were not within 1.5 % of each other. All eight skinfolds were completed once before the second measure at each site was taken. This allowed time for the skin to re-group ensuring reliability.

Limb Lengths and Girths

Limb girths measured were as follows: arm relaxed, arm flexed and tensed, forearm, wrist, waist (minimum), gluteal (maximum), thigh (1 cm distal of gluteal fold), mid thigh and calf (maximum). Again, all ten girths were measured once before the second measure was taken. The tape measure was pulled tight enough around the limb to get an accurate reading although not so tight that it indented the skin (unreliably reducing the girth measurement).

Anatomical landmarks on the body were used to identify points to enable eight limb length measurements made by a segmometer. These measures were as follows: acromiale-radiale, radiale-stylon, midstylon-dactylion, iliospinale (-to box height), trochanterion (-to box height), trochanterion-tibiale laterale, tibiale mediale-syphyrion tibiale and foot length.

6-second Sprint Test

Materials and Equipment

Participants wore their own cycling clothing and training/ competition cycling shoes. They were asked to bring their own pedals allowing them to clip their feet in during the protocol. One participant did not have clip-less pedals and on this occasion, laboratory pedals with toe clips were used to ensure feet were secured to the pedals. The sprint test took place on an SRM (Schoberer Rad Meßtechnik, Germany) High Performance cycle ergometer which was adjusted to suit each participant; this included altering handlebar height, reach and saddle height. Protocols were entered into the SRMWin computer software which timed each 6-second sprint automatically. The SRM ergometer can be run in two modes: Hyperbolic and Isokinetic. The Hyperbolic mode runs independent of pedal rate whilst the Isokinetic mode restricts the pedal rate at a set cadence. A stop clock was used to time the rest period between sprints which was fully visible to the participant at all times.

Sprint Test Protocol

The sprint testing protocol was devised in order to give as much of a representation of the nature of the sport as possible and thus, maximal sprints of 6 seconds was agreed on as previous literature (Hurst and Atkins, 2006) states pedal periods during DH to be of this duration. After a sufficient, self-paced warm-up, participants performed six, 6-second maximal sprints on the SRM cycle ergometer but remained seated throughout each sprint. Each 6-second sprint was conducted at a different set cadence. Cadence was restricted (at 60, 80, 100, 120 and 140 rpm) for five of the sprints using the Isokinetic mode. One of the sprints was conducted in Hyperbolic mode where the cadence was not restricted. Sprint order was randomized. The sprint test protocol sheet can be found in Appendix vii. Participants were instructed of the next test cadence immediately prior to each sprint. The participant spent ~ 15 – 30-seconds (depending on the cadence) accelerating to the required cadence and when this cadence was reached, they were given a verbal countdown to begin the maximal sprint test. Test began on the verbal ‘Go’ command. Verbal encouragement was given to participants throughout each test.

After each 6-second effort, participants immediately performed 30-seconds of active rest (0 W) followed by 4-minutes of passive rest, where the subject dismounted the cycle ergometer and rested in a seated position on a chair next to the ergometer. Participants could consume water at this stage. After 4 minutes rest, they would mount the cycle ergometer again and spend the final 30-seconds of the rest period getting into position, clipping in and accelerating to the cadence required for the next sprint. The next sprint commenced 5-minutes after the previous test finished. Once the sprint testing protocol was completed, the participant undertook a self-paced cool down.

Statistical Analysis

Raw SRM data was exported from SRMWin software to Excel (Microsoft Office 2007) for analysis. Descriptive data are presented as means ± standard deviation (SD). Relationships between variables were determined using Pearson's Product Moment correlations and differences in mean values were determined by paired t-tests both generated in SPSS statistical software package (version 15). Significance level for all statistical tests was set at $p < 0.05$.

Results

Anthropometric Characteristics

The group mean for stretch stature was 187 ± 9.4 cm, body mass 78.7 ± 9.0 kg and the sum of 8 skinfolds, 68.7 ± 19.8 mm. All participants were identified to have predominantly mesomorphic somatotypes (mean somatotype, 2.1 ± 0.6, 4.7 ± 0.7, 3.0 ± 0.7). A number of anthropometric measures were highlighted as of possible relevance to DH mountain bikers (as they focused on lower limb measurements) and are detailed in Table 3.1

Table 3.1. Participant anthropometric characteristics of interest.

Participant Number	**Age (years)**	**Body Mass (kg)**	**Stretch Stature (cm)**	**Trochanterion-tibiale length (cm)**	**Sum of 8 s.f (mm)**	**Forearm girth (cm)**	**1cm dist Thigh girth (cm)**	**Mid Thigh girth (cm)**	**Somatotype**
1	30	79.7	183.5	47.2	77.0	29.3	61.7	57.1	2.1, 5.5, 2.7
2	17	70.0	174.3	42.5	58.6	28.4	56.0	51.5	2.1, 5.3, 2.4
3	21	96.9	199.9	54.2	52.7	30.8	57.3	55.7	1.5, 3.8, 3.3
4	16	78.4	190.2	49.2	76.4	28.6	55.5	52.3	2.2, 4.3, 4.0
6	25	76.5	187.3	51.4	106.5	28.6	51.5	55.4	3.3, 4.2, 3.8
7	22	79.2	185.2	47.7	60.4	27.4	55.0	56.3	1.9, 4.5, 3.0
8	19	70.4	172.2	45.2	49.6	28.1	55.1	54.8	1.8, 5.3, 2.0
Mean	**21.4**	**78.7**	**184.7**	**48.2**	**68.7**	**28.7**	**56.0**	**54.7**	**2.1, 4.7, 3.0**
± SD	4.9	9.0	9.4	3.9	19.8	1.1	3.1	2.1	0.6, 0.7, 0.7

Some anthropometric measures were shown to be indicative of power output characteristics. Body mass was significantly related to mean power output (MPO) over the 6 s sprints ($r = 0.87$, $p < 0.05$). Furthermore, the size of the thigh (1 cm distal of the gluteal fold) was identified as influential in MPO and PPO characteristics. MPO (relative to body mass) was strongly correlated to thigh girth ($r = 0.88$, $p < 0.05$) as was absolute and relative PPO ($r = 0.84$ and $r = 0.76$, respectively. $p < 0.05$).

6-second Sprint test

Mean Power Output

Absolute and relative mean power output (MPO) during hyperbolic, 60, 80, 100, 120 and 140 rpm sprint tests are displayed in Table 3.2. Greatest MPO from the testing session was achieved during the Hyperbolic test (cadence independent). From the Isokinetic tests, the greatest MPO was seen during the 100 rpm sprint, although this was not significantly greater than 120 rpm ($p = 0.69$). The MPO for each test is demonstrated in Figure 3.1. The polynomial curve depicts the power-velocity relationship and identifies an optimal cadence of ~ 100 rpm for producing greatest MPO over 6-second maximal sprint.

Table 3.2. Absolute and relative MPO for each sprint test.

Sprint Test	**MPO (W)**	**MPO (W·kg^{-1})**
Hyperbolic	1056.76 ± 141.48	13.43 ± 1.05
ISO 60	864.32 ± 121.4	11.01 ± 1.28
ISO 80	955.80 ± 135.21	12.13 ± 0.95
ISO 100	1048.82 ± 185.10	13.30 ± 1.01
ISO 120	967.37 ± 193.31	12.21 ± 1.39
ISO 140	810.50 ± 164.32	10.24 ± 1.31

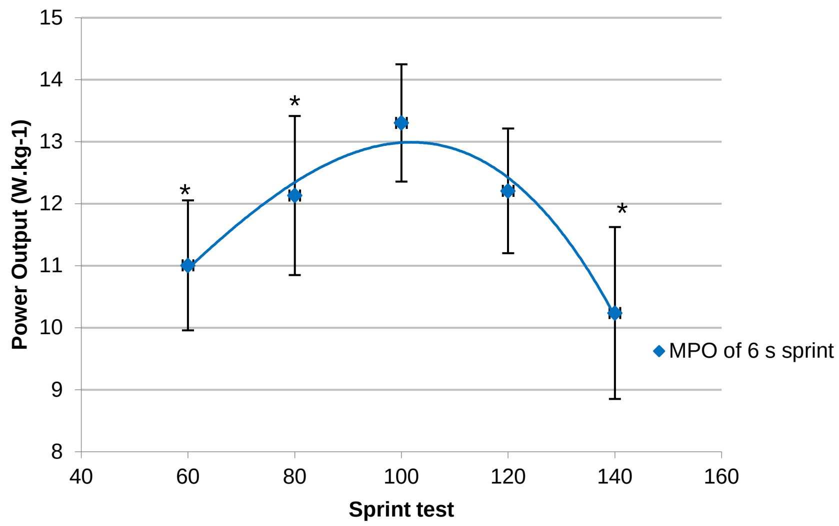


Figure 3.1. A polynomial curve shows the MPO across the five Isokinetic mode tests. * shows MPOs that are significantly different to 100 rpm ($p < 0.05$).

Peak Power Output

Participant peak power output (PPO) was determined for each of the six sprints tests and absolute and relative values are detailed in Table 3.3. A sample of the raw output data can be found in Appendix viii.

Table 3.3. Absolute and relative Peak power outputs achieved by each participant, at what cadence it occurred and the time it took to reach peak (seconds). Participant marker with * on their cadence achieved a higher peak power in hyperbolic mode. Highest absolute and relative PPOs for the group are in bold.

Participant Number	Peak Power Output (W)	Peak Power Output ($W \cdot kg^{-1}$)	Cadence at Peak Power	Time to Peak (seconds)
1	2102.75	**26.35**	100	0.695
2	1824.90	26.07	100	1.005
3	**2123.64**	21.92	100*	2.335
4	1725.88	21.99	100*	1.760
6	1535.88	20.08	100	2.925
7	1805.95	22.8	100*	0.760
8	1585.80	22.53	100*	1.005

Greatest mean PPO was achieved during the Hyperbolic test, 1838.89 ± 260.86 W (23.36 ± 2.12 $W \cdot kg^{-1}$) and greatest mean PPO achieved in Isokinetic mode was 1814.97 ± 229.72 W (23.1 ± 2.29 $W \cdot kg^{-1}$). Optimal cadence for achieving PPO during the 6-second test was 100 rpm determined during the Isokinetic tests. PPO achieved during the 100 rpm test was not significantly different to the second optimal cadence of 120 rpm ($p = 0.064$). PPO at 100 rpm was, however, significantly different to PPO attained at all other isokinetic cadences (60, 80 and 140 rpm) ($p < 0.001$). This is displayed in Figure 3.2. During the hyperbolic test where the cadence was unrestricted, PPO was achieved at a mean of 106 ± 10 rpm.

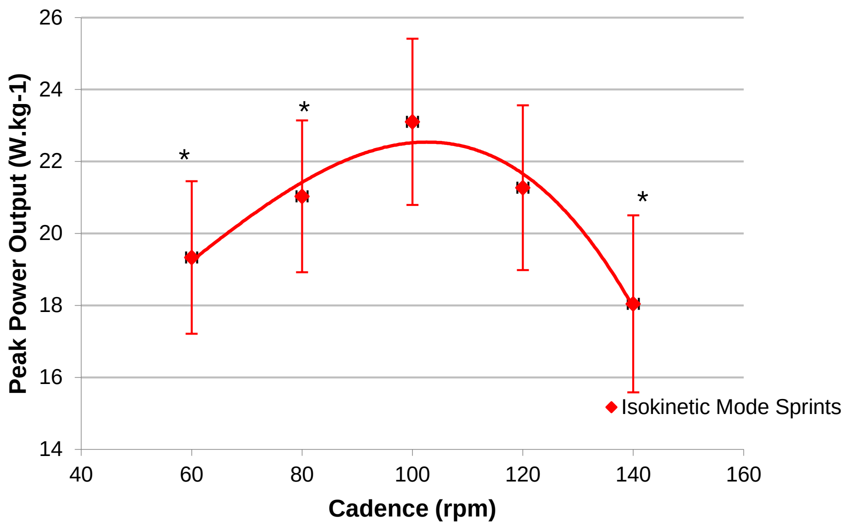


Figure 3.2. Group mean PPO ($W{\cdot}kg^{-1}$) across the five restricted cadences (60, 80, 100, 120 and 140 rpm). Polynomial curve depicts optimal cadence for achieving PPO. * shows significant difference ($p < 0.05$) from PPO achieved at 100 rpm.

A Pearson's product moment correlation identified a positive and significant relationship between absolute and relative PPO and MPO. Figure 3.3 shows the correlation from the comparison of the absolute powers ($r = 0.92$, $p = 0.004$). Relative power, although not as strong, also shows a significant positive relationship ($r = 0.82$, $p = 0.025$).

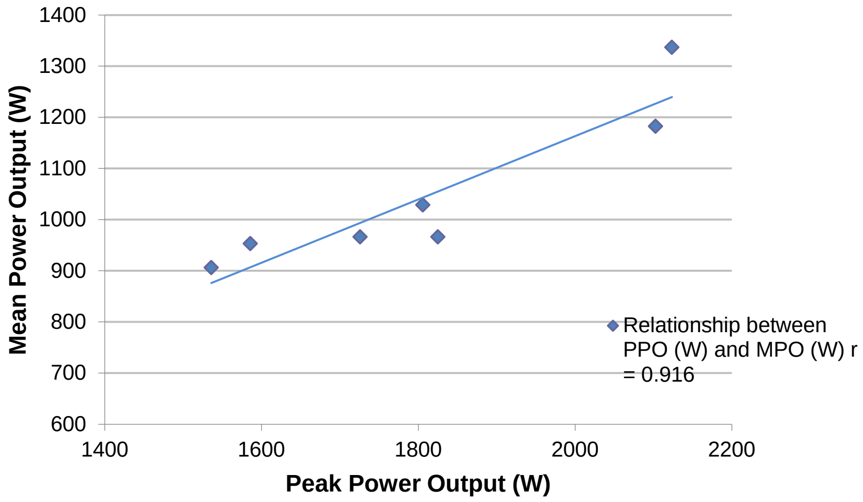


Figure 3.3. The significnt positive relationship between absolute peak and mean power output (W). P = 0.004, r = 0.92.

Time to Peak Power Output

Time to peak PO was fastest during the higher cadence tests (120 rpm followed by 140 rpm). There was no significant difference in time to peak PO between 120 and 140 rpm ($p > 0.05$) but both were significantly quicker than the time to peak PO achieved during the other tests ($p < 0.05$). Time to peak progressively increased as the cadence decreased and the hyperbolic test showed the slowest time to PPO (Figure 3.4).

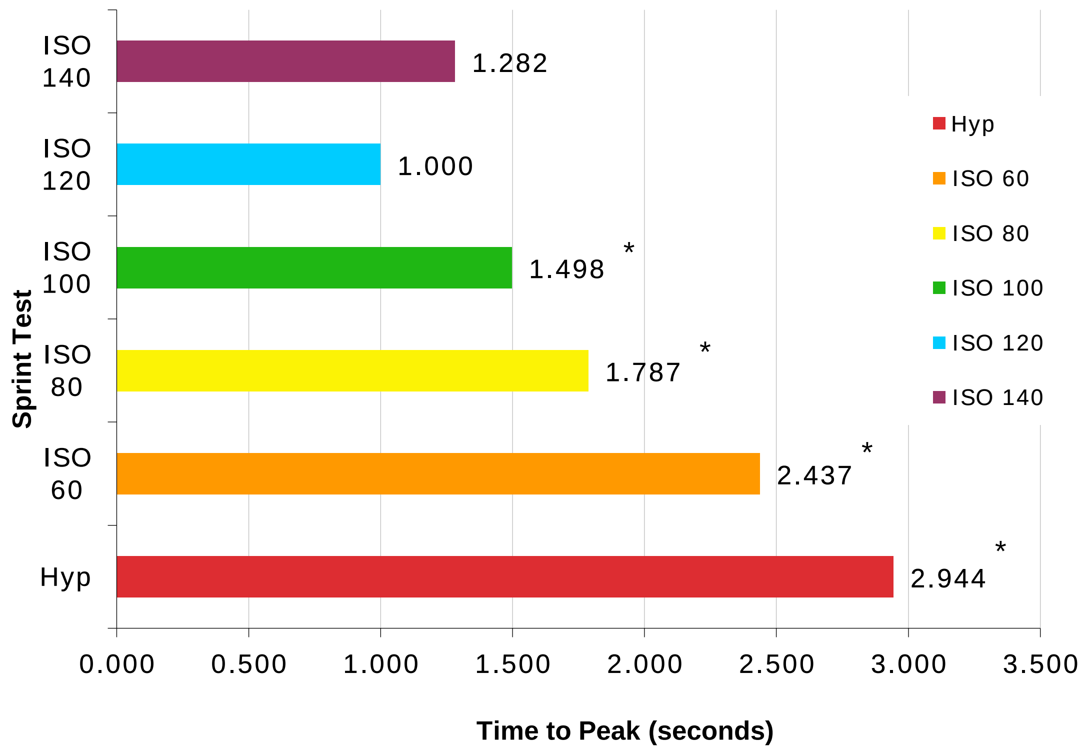


Figure 3.4. Group mean times to peak power output (seconds) for each sprint test. * shows times that are significantly different to time to peak achieved during 120 rpm.

A positive correlation was identified within the power profile of the DH athletes. Figure 3.5 shows a significant ($P < 0.05$) relationship between time to peak power and relative PPO ($W{\cdot}kg^{-1}$).

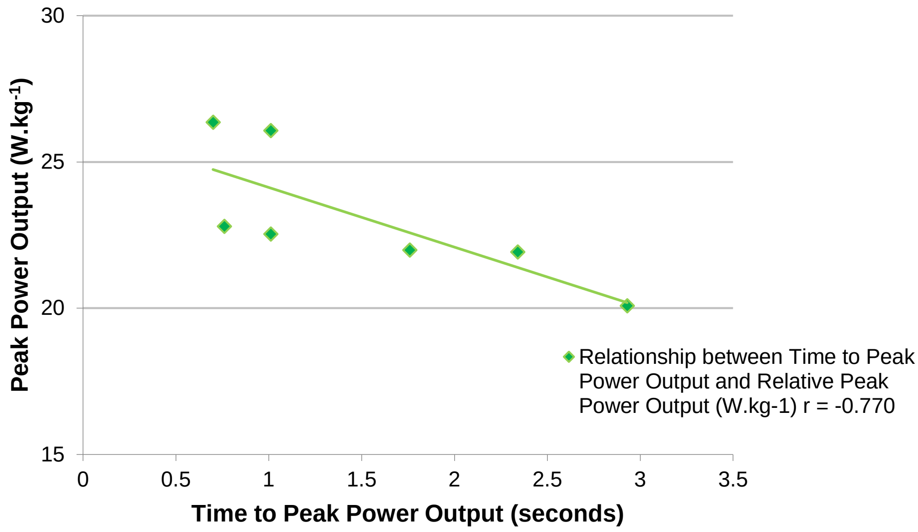


Figure 3.5. The significant negative correlation between time to PPO and time to peak PO. P = 0.043, r = - 0.77.

Relationships between Anthropometric Characteristics and Power Profile

The synthesis of the laboratory-based test data identified some significant relationships between participants' anthropometric and power characteristics. Pearson's product moment correlation showed a positive relationship between thigh girth cm (1cm distal of gluteal fold) and peak power output (absolute PPO (W), r = 0.84, p = 0.018 (Figure 3.6). Relative PPO ($W{\cdot}kg^{-1}$) also shows a positive significant correlation, r = 0.76, p = 0.049, (Appendix x).

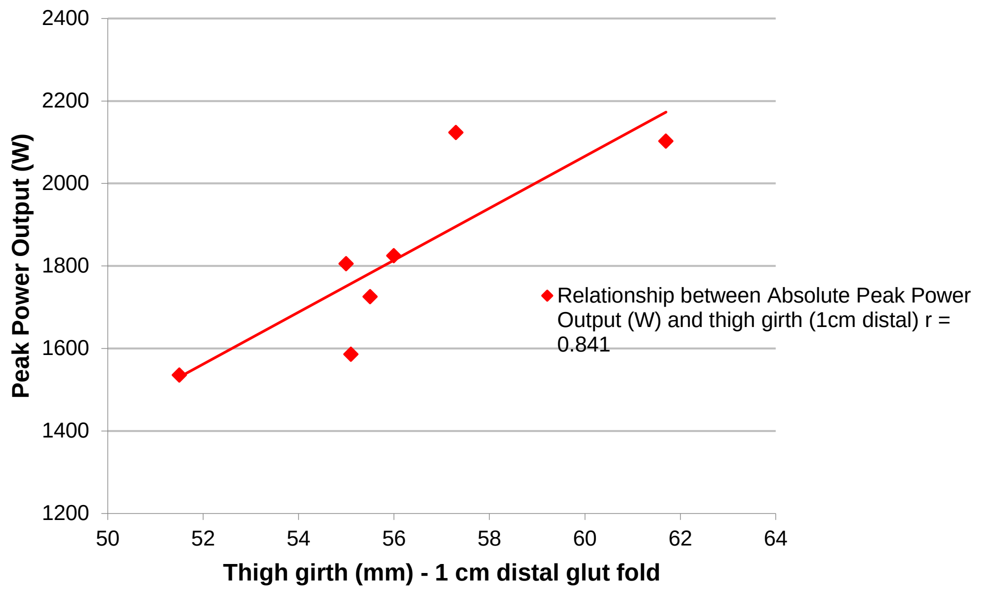


Figure 3.6. The significant positive correlation between absolute PPO (W) and thigh girth (1 cm distal of gluteal fold). r = 0.84, p = 0.018.

When relationships between the time taken to reach peak power output and anthropometric measures were investigated, a significant relationship was identified between time to peak PO and trochanterion-tibiale length (r = 0.76, p = 0.046) (Figure 3.7).

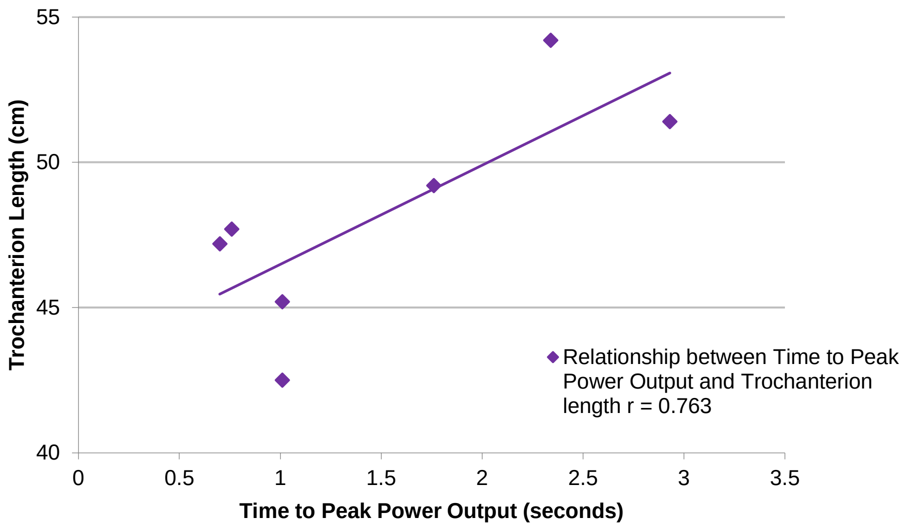


Figure 3.7. The significant positive correlation between time to PPO and trochanterion-tibiale length. r = 0.76, p = 0.046.

Discussion

Anthropometric Characteristics of Downhill Mountain Bikers.

Athlete physique is considered an important determinant of successful performance in many sports and inherent anthropometric characteristics can even determine the sport (or position within a sport) an individual may compete in. For example, athletes with predominantly endomorphic body shapes tend to be shorter in stature with a large mass for their small frame and thus are suited to sports such as hammer throw, power lifting or front row positions in rugby. At the opposite end of the somatotype scale, ectomorphic athletes are tall and slender and are more suited to endurance-type sports such as marathon running (Carter and Heath, 1990). This is a crude example of how body shape and composition can be a major influential factor in sporting performance. Cycling is one of the few sports where performance is determined by the direct interaction of the physical output with a mechanical device (Craig and Norton, 2001). With this in mind, anthropometric parameters need to be taken in to account when optimising bicycle set-up and rider position as body composition can influence cycling performance. A number of studies have investigated the anthropometric characteristics of cyclists (Impellizzeri *et al.,* 2007, 2005; Lee *et al.,* 2002; Craig and Norton, 2001; Lucia *et al.,* 2001; Foley *et al.,* 1989). To the best of our knowledge, there has been no such investigation into the body composition of Downhill mountain bikers. Anthropometric characteristics for the subject group of the present study are displayed in Table 3.1. As there has been no other investigations into Downhill athlete body composition comparisons can only be made against athletes from other cycling disciplines and thus anthropometric measures were chosen accordingly in order to be specific to all cycling disciplines as well as DH.

Foley *et al.,* (1989) reported femur length in sprinters to be shorter than in other endurance-based cycling events (pursuit and time-trial). They suggest that the shorter limbs can tolerate a greater quickness of movement and therefore would be advantageous when coping with the high pedal rates. The Downhill athletes from the present study had a longer femur length (482 ± 38.7 mm vs. 366 ± 10.6 mm) and in keeping with this, were of greater stretch stature to the sprint athletes (184.7 ± 9.4 vs. 169.2 ± 2.5 cm). In fact, the Downhill specialists had a stature and body mass profile similar to time-trial specialists (10 miles – 12 hr) measured in Foleys investigation (time-trial characteristics: stretch stature, 186.3 ± 3.0 cm; body mass, 76.0 ± 2.8 kg; femur length, 424 ± 8.5 mm). It is important in Downhill mountain biking to produce large powers and generate them quickly, as periods of pedalling are short and intermittent (Hurst and Atkins, 2006). It is suggested that sprint specialists produce greater PPO than endurance cyclists (Craig and Norton, 2001). Tying together the suggestion that sprinters have shorter femur lengths, the current study identified a negative correlation between time to peak power output and femur length (r = -0.76) (Figure 3.7). This suggests that Downhill riders with shorter femurs could achieve PPO quickest. This study did not however, identify a significant relationship between PPO and femur length. Therefore, for the Downhill specialists, shorter limb length may well be advantageous in the speed of power generation, but this does not appear to be a limiting factor in absolute or relative peak power generation. Hurst and Atkins (2006) suggest that Downhillers pedal for periods of ~ 5 seconds. The sprint tests lasted 6-seconds and therefore is representative of intermittent bursts of pedalling experienced during a race. In this case, both peak power output and speed of power generation may be important and influential factors in Downhill performance and this is discussed further in Chapter Five. Lee *et al.,* (2002) investigated the anthropometric characteristics of XC mountain bikers and reported a smaller mean height of 1.78 ± 0.0.7 m and lighter body mass of 65.3 ± 6.5 kg, than Hurst and Atkins (2006) investigating DH bikers. The mountain bikers were classified as ‘elite’ and the lean structure of the athletes would be representative of endurance athletes and not sprint athletes such like the DH athletes (Lee *et al.,* 2002). Although the Downhill athletes are the heaviest measured across the different cycling disciplines discussed, the higher absolute body mass would be advantageous to Downhillers as they compete on a descending course. The heavier body masses therefore, would not have the negative impact on performance as seen in cycling disciplines involving hill climbing. Furthermore an increased body mass may be desirable for DH athletes to absorb forces as an increased body mass can take more force if trained properly.

Somatotype

The literature reports a high correlation between mesomorphy and body strength (Foley *et al.,* 1989). Strength is a major contributor to the generation of power and thus it would be expected that sprinters, who have to generate large amounts of power during short periods (peak power of 1020 W and mean power of 752 W during 200 m flying sprint (Craig and Norton, 2001) compared to the DH athletes who generated peak values of 1838 W for PPO and 1048 W for MPO) would have greater mesomorphic somatotypes than endurance cyclists. The present study showed a significant relationship between relative PPO and mesomorphic somatotype ($r = 0.78$, $P < 0.05$) which supports this notion. The confirmation that successful DH athletes are more mesomorphic in their somatotype is a crucial finding as it introduces the hypothesis that physiology may be a positively influencing factor on DH performance. The ability to produce power and its importance in DH is discussed in further detail in Chapter Five.

Body composition of Downhill athletes – sum of skinfolds

Much of the existing literature presents findings as body fat percentage (Impellizzeri and Marcora, 2007; Lee *et al.,* 2002; Warner *et al.,* 2002; Lucia *et al.,* 2001). The current study has not done this as many investigations show this to be an unreliable method of presenting body composition (Deurenberg *et al.,* 2001; 1990; Reilly *et al.,* 1995). Deurenberg *et al.,* (1990) suggest that there is a prediction error of 3 – 5 % when converting skinfolds to body fat %. Reilly *et al.,* (1995) also states that there are large random errors associated with the conversion equation. Thus the most reliable way of reporting body fat is as a sum of skinfolds (mm). Sports scientists who monitor an athletes' body composition regularly generally adopt this.

ISAK present sum of skinfolds as the sum of 8 sites (triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf). The sum of skinfolds from the literature is presented in a number of different ways. Some use the 4-site method (Jackson and Pollock, 1978), however this does not take into account lower limb skinfold which has been shown to be an influential measure in total body fat (Eston *et al.,* 2005). Foley *et al.,* (1989), report the cyclists sum of 6 skinfolds (biceps, triceps, suprailiac, abdominal, subscapular and medial calf) to be 42.7 ± 6.04 mm, 41.7 ± 4.12 mm, 41.3 ± 3.17 mm, 52.4 ± 8.18 mm (sprint, pursuit, road and time-trial cyclists respectively). These were not different from each other ($p > 0.05$) and when sum of skinfolds for the Downhill athletes was adjusted and presented as the sum of 6 skinfolds, mean value was 41.26 ± 20.19 mm, in accordance to the professional cyclists used by Foley *et al.,* (1989). Lee *et al.,* (2002) presented sum of 7 skinfolds (sum of 6 with the addition of front thigh). They reported XC cyclists to have a significantly lower sum than when compared to road cyclists during the same study (33.9 ± 5.7 mm vs. 44.5 ± 10.8 mm, respectively). The Downhill specialists had a higher sum of 7 skinfolds than both of these groups (57.27 ± 16.99 mm). Lee *et al.,* (2002) used a very high calibre of athlete which may account for the reduced body fat. Furthermore, XC events are of an aerobic nature and are composed of hill climbs which benefit from lower body mass and therefore most likely body fat. Whilst the sum of skinfolds of the DH athletes were comparable to the cyclists in the Foley study, the higher skinfolds seen in comparison to the cyclists measured in Lee *et al.,* would be expected as Downhill athletes spend substantially less time training the aerobic system than their endurance counterparts and in this case, body fat may be less of an influential factor on performance than other composition constituents such as muscle mass.

Cadence

Pedal rate has been hypothesised to be a major influential factor in power output production and can be described by the force-velocity relationship (Thorstensson *et al.,* 1976). Power output during a single short-term (< 10 s) maximal cycling effort shows a polynomial power-velocity curve where power output increases to reach a peak value at an optimal cadence and then decreases with the onset of muscular fatigue. Each power profile from the current study shows this relationship and an example can be seen in Figure 3.8.

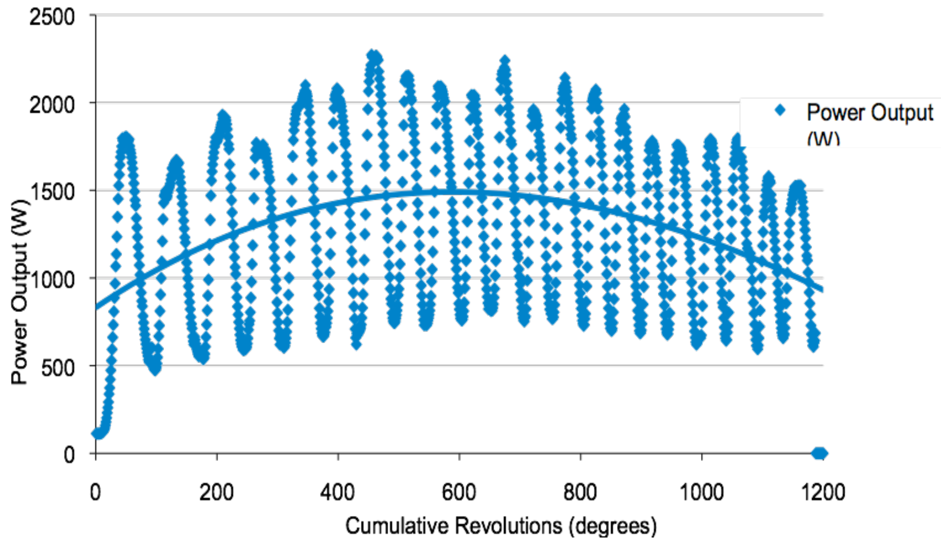


Figure 3.8. Power profile of Participant 3 during the hyperbolic sprint test. The profile shows the power-velocity parabolic relationship. Peak power output was achieved at a cadence of 107 rpm.

The results from this study show that during the Isokinetic sprint tests, peak power output (PPO) was achieved during the test where cadence was restricted not to exceed 100 rpm. This was not statistically significantly greater than PPO achieved at 120 rpm ($p > 0.05$) although when presented as group means (Figure 3.2), the polynomial relationship is clear. Four of the seven participants achieved their PPO during the unrestricted Hyperbolic mode test and further investigation into the hyperbolic mode sprints confirms that an optimal cadence lies between 100 and 120 rpm (106 ± 10 rpm). This supports the Isokinetic results, that optimal cadence for producing PPO is between 100 and 120 rpm.

The results presented are in agreement with a number of other studies that investigate optimal cadence for producing PPO during short-term maximal exercise (Baron, 2001; MacIntosh *et al.,* 2000; McCartney *et al.,* 1983; Sargeant *et al*., 1981). Sergeant *et al.,* (1981) identified that maximal power output was achieved at a cadence of 110 rpm (when averaged per revolution). This was very closely related to the optimal cadence seen during unrestricted cycling (Hyperbolic mode) in the current study (106 ± 10 rpm). It must be noted however, that this pedal rate is identified from maximal tests of longer duration than the 6-second tests during the current study (20-seconds). With more relevance to the current study, McCartney *et al.,* (1983) concluded that for 6 – 7-second maximal cycling efforts, a cadence of 120 rpm should be adopted in order to generate maximal power output. Interestingly, they further concluded that slightly longer sprints (10 – 20-seconds) optimal pedal rate would be ~100 rpm. Baron (2001), studied off-road cyclists during a similar protocol to the one completed during the current study. Power profiles over similar cadences (Baron: 50, 60, 70, 80, 90, 100, 110, 120, 130 and 140 rpm, current study: 60, 80, 100, 120, 140 rpm) were investigated. The duration of the sprint was slightly longer than the present study (10-s vs. 6-s) however they too identified optimal cadence to be 100 rpm when PO was adjusted for body mass. These studies clearly showed that optimal pedal rates for producing PPO during maximal sprint efforts from between 5 – 20-seconds is between 100 and 120 rpm which is in accordance with the conclusions drawn from the current study.

This study hypothesised that performance at the start of the race would be influential on overall DH race performance (investigated in Chapter 4 and 5). Determining optimal cadence in the laboratory is important as the data can be used to aid maximal peak power production and therefore speed/ acceleration in the field setting. An enhanced understanding of cadence and power output production will help athletes in gear selection and training can be tailored towards is generating PPO to achieve a successful start.

Power Output

To describe the power characteristics of Downhill mountain bikers, PPO and MPO were measured across five cadences (60, 80, 100, 120 and 140 rpm). The results from the current study showed the greatest MPO (955.80 ± 135.21 W, 13.30 ± 1.01 W•kg^{-1}) to be produced at ~ 100 rpm. Mean PPO (1814. 97 W, 23.11 W•kg^{-1}) was also achieved during this cadence. Studies that investigate power output during sprint cycling show similar MPO as the current study. McCartney *et al*., (1986) investigated muscle power and metabolism in response to maximal intermittent exercise. Mean absolute PPO was comparable to the PPO achieved from the current study (1626 ± 102 W) as well as the highest MPO for a revolution (992 ± 71 W). Although the maximal tests in the study, conducted by McCartney *et al,* were of longer duration (30-seconds), these values were achieved in the first 2-seconds of the sprint and thus, PPO can be compared to the values from the current study. Other studies (Weyand *et al.,* 2005; Gaitanos *et al.,* 1993; Sargeant *et al.,* 1981; Davies *et al.,* 1980) determined PPO during short-duration (< 10-s) maximal tests and show values from healthy males (non-cyclists), to be 1127 ± 143 W, 13.3 ± 1.4 W•kg^{-1}, 1253.3 ± 334.8 W and 1019 ± 183 W, respectively. These values are substantially lower than PPO achieved by the Downhill athletes (1838.89 ± 260.86 W or 23.36 ± 2.12 W•kg^{-1}) however, this would be expected from non-cyclists. Baron (2001) investigated National and International XC cyclists who also displayed a lower relative PPO than the Downhillers (14.9 ± 1.1 W•kg^{-1}). No comparison of absolute PPOs could be made between these two subject groups because absolute power values were not reported by Baron (2001). Peak powers more comparable to the Downhill athletes appear to be the PPO elicited by sprint cyclists and this may be expected as trained cyclists can reach mechanical powers during short-duration sprints that are four times as great as can be produced when supported by the aerobic system (Weyand *et al.,* 2005). Davies *et al.,* (1989) showed sprint cyclists to have a higher absolute PPO during short-term maximal sprint cycling than students (1241 ± 266 W vs. 1019 ± 183 W). Craig and Norton (2001) reported a high PPO of 1799 W from a 1000 m time-trial performance. This shows clearly that sprint specialists are required to generate very large power outputs in order to generate the high speeds required for successful performance. The 1000 m time trial is of longer duration compared to the sprint tests of the current study (60-seconds), however, the PPO is reached at ~ 6-s (Davies *et al.,* (1989)) and the high value clearly strengthens the hypothesis that sprint athletes produce greater peak powers than athletes in other endurance-based cycling disciplines.

Time to Peak Power Output

Velocity of muscle shortening and strength determines muscle power output (Jones *et al.,* 1989). Therefore an increase in velocity of shortening and/ or muscle strength would increase power output of an athlete (Figure 3.9). During short-duration maximal exercise, the ability to reach PPO quickly could be an influential factor on overall performance (and will be discussed further in Chapter Five). The speed a muscle can contract depends on the proportion of fibre types and enzymic properties of the actomyosin cross-bridge of an individual fibre (Jones *et al.,* 1989).

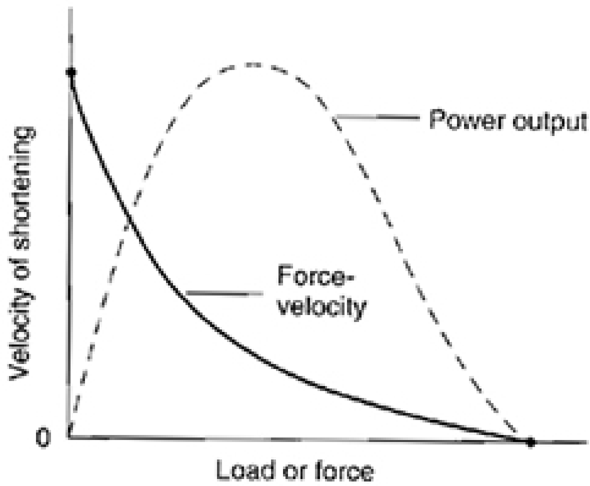


Figure 3.9. Force-velocity curve. An increase in muscle shortening velocity would increase the peak power. Adapted Imagine accessed (24.03.2010) from www.quintic.com/education/case_studies/power.htm

The DH participants from the present study show a negative relationship between PPO and time to peak PO (Figure 3.5). Producing peak power quickly may have an implication on overall performance (and will be discussed further in Chapter Five). The Downhill athletes that have the ability to produce peak power quickly, generate higher PPO. This should result in an overall greater mean velocity and the strong relationship between MPO and PPO ($p < 0.01$) (Figure 3.3) confirms this. The results from the current study can therefore be applied to some of the conclusions made by de Koning *et al* (1999), suggesting that speed of power generation has a positive influence on cycling performance. The aim of their paper was to investigate pacing strategies and this must be taken into account when using the outcomes of the de Koning *et al.,* (1999) study when applying to DH, as DH riders will use an all out pacing strategy rather than tactically pace their run.

Conclusions

Laboratory-based testing of Downhill mountain bike athletes identified a number of interesting findings. Downhill specialists can produce very high PPO during short-duration maximal sprint cycling (1839 ± 261 W/ 23.36 ± 2.12 $W \cdot kg^{-1}$) when compared to healthy males and cyclists from endurance-based cycling disciplines (Weyand *et al.,* 2005; Baron 2001; Gaitanos *et al.,* 1993; Davies *et al.,* 1980, 1989; Sargeant *et al.,* 1981) and sprint cycling (Craig and Norton, 2001; de Koning *et al.,* 1999; Davies *et al* 1980). Relationships identified between athlete power profiles and their anthropometric characteristics suggest the ability of the Downhill athletes to produce great peak powers is influenced by their somatotype with the more mesophorphic individuals producing the greatest powers. More specifically, a positive correlation is seen between PPO and thigh girth ($r = 0.84$). This could be due to a greater number or size of muscle fibres within the upper leg muscles, which enables the greater generation of power. Downhill mountain biking is characterised by British Cycling as an intermittent sprint sport and the ability to generate speed quickly during the short periods of pedalling (~ 5-s) (Hurst and Atkins, 2006) may be an influential factor on performance time. An optimal cadence for producing PPO was identified as between 100 – 120 rpm (106 rpm) which is in agreement with a number of other studies (Baron, 2001; MacIntosh *et al.,* 2000; McCartney *et al.,* 1983; Sargeant *et al*., 1981). Determining an optimal cadence for producing PPO may be particularly important for DH at the start of the race to allow them to select a gear that will help them attain the optimal cadence in the shortest time, allowing a power and fast start to the race. Furthermore, the present study, in the controlled laboratory setting, identified a relationship between peak power output (PPO) and time to peak power output (r = 0.77) during a 6s sprint, which tends to support the importance of fast power production in DH performance.

Chapter Four – Field-Based Assessments

Methodology

Two components made up the field-based assessments; 'Study Two' and 'National Championships'. The field-testing component of 'Study Two' required two runs of a measured Downhill track (used for the National Championships, Innerleithen, July 18th/ 19th 2009) and took place over one weekend, where weather and terrain remained dry and constant. Participants and their bicycles were transported to the top of the course via a pick-up truck (Uplift Scotland) and then athletes pushed their bicycles for ~ 5 minutes, to reach the start gate as per normal on this race course. Total duration from the start line, back up to the top was ~ 30 minutes. Participants were asked not to consume food 90 minutes before completing their race runs and were advised to remain hydrated throughout the day. Each participant was asked to treat the run as if it was a race. A detailed, verbal and written, outline of the test protocol and familiarization of the course was undertaken with each participant prior to their race runs. All but two participants competed in the National Championships (July 2009 – prior to 'Study Two' test date) and were thus, familiar with the course route. The remaining two participants were thoroughly familiar with Innerleithen tracks and prior to testing both participants followed another rider during their timed run and were confident with the route and track, prior to their own timed testing runs. No more than three practice runs were undertaken prior to the timed race runs.

Participants

Eight male volunteers provided written, voluntary informed consent prior to participating in this study, which was approved by the Edinburgh Napier University ethics committee (January 2009). All participants were trained and competitive Downhill mountain bikers who were each successful within their own competition categories (n=2, youth; n=1, junior; n=2, expert male; n=2, elite male, n=1, master). Mean physical characteristics of the participants were as follows: age, 20.8 ± 4.9 years; stretch stature, 184.7 ± 9.4 cm; mass, 78.7 ± 9.0 kg; sum of 8 skinfolds, 68.8 ± 19.8 (stretch stature, body mass and sum of skinfolds excludes Participant 5 who did not take part in the laboratory-based assessments and thus these measures were not obtained).

Table 4.1. Participant overview; age, race category and bicycle model.

Participant Number	**Age (years)**	**Race Category**	**Bicycle Model**
1	30	Master	Orange 225
2	17	Junior	Trek Session 88
3	21	Elite	Orange 225
4	16	Youth	Scott Gambler
5	16	Youth	Empire
6	25	Senior	Commencal
7	22	Senior	Giant Glory
8	19	Elite	Orange 225

Materials and Equipment

Participants performed both timed runs, one after the other, on their own Downhill bicycle (Table 4.1). Every participant wore the standard protective equipment in adherence to Union Cycliste Internationale rules and regulations

(UCI Regulations, Part IV, Chapter 3, p. 24). To assess the intensity of the field-based assessment, heart rate was recorded every 5 seconds by a downloadable heart rate monitor (Polar Electro, UK). Two 5Hz GPS receivers (SPI Pro, GPSports Australia) monitored speed (km.hr^{-1}), distance travelled (m), acceleration (m•sec^{-1}•sec^{-1}) and impacts (g). One was attached to the back of the helmet and the other to the front of the seat post of the Downhill rig. GPS units were attached to the equipment with duct tape ensuring that the satellite-receiving sensor was not covered (GPS unit attachment detailed in Figure 4.1 and 4.2). Reliability of GPS receivers was investigated and is presented in Appendix ix.

Figure 4.1. Detailing the GPS unit attachment to the seat post and Figure 4.2. Detailing the GPS unit attachment to the helmet.

Course Description

The track in Innerleithen is atypical of international standard downhill tracks and hence comprises fast open sections and more technical wooded sections of mixed gradients – from near vertical to flat and undulating. The top section of the track is composed of a muddy trail surface with exposed roots, tree stumps and rocks. Corners vary from wide and open, to tight 90° bends between tight pine trees. Speed from the start is high with Section 1 terminating in a disused quarry including a high-speed jump of over 4m in length. The landing of the jump marks the start of Section 2 which takes the riders down a section of trail known as the 'Tunnel' – a 3 m wide straight track that flattens in gradient throughout its length. The tree line at the end of the Tunnel marks the start of Section 3. From here, the course enters a mix of widely spaced pine and clear felled sections, with good visibility and a hard, compacted trail surface. Trail width narrows to within 1 m and some corners include manmade banks (known as berms), to hold the rider and generate speed. A steep drop onto the Forestry road marks the end of Section 3. From here the course enters the final plunge through the trees with gradients remaining consistently steep and the plantation forest becoming tighter, with less light, poorer visibility and varying surface – from loose soil to loose rock. The end of this more technical section marks the end of section 4 and the beginning of section 5 (final section); comprising of a straighter, faster drop into the finish. The National Championships race run was slightly longer than the track used for the 'Study Two' testing. This was due to a different finish area which could not be used for the study testing for safety reasons. Figures 4.8 and 4.9 show the different finishing lines of Section 5.

The course is 1223.4 m in length and drops from an elevation of 461 m to 143m , a total of 318m of descent. Figures 4.3 – 4.9 detail aerial views of the full course plus the five individual sections.

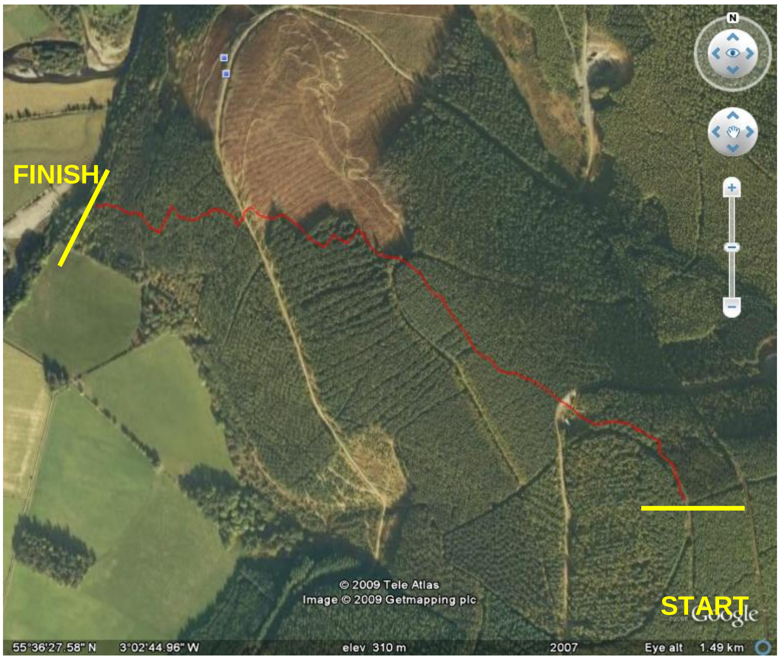
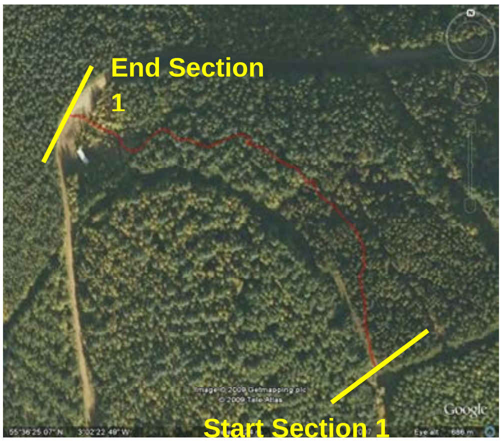


Figure 4.3. Google Earth image of full testing course (Study Two).



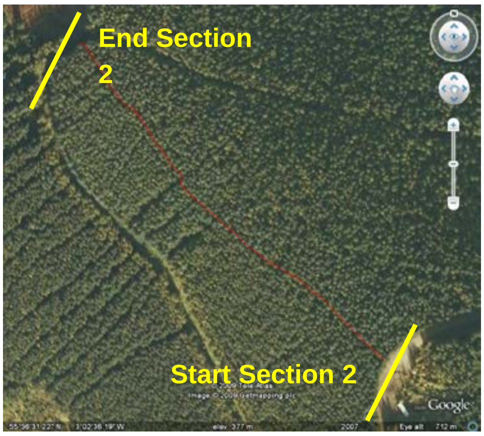


Figure 4.4. Course section 1.

Figure 4.5. Course section 2.

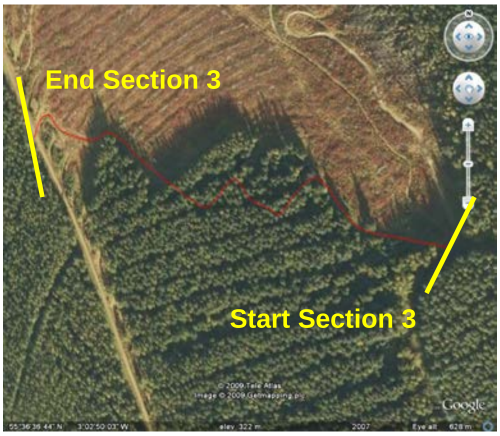


Figure 4.6. Course section 3.

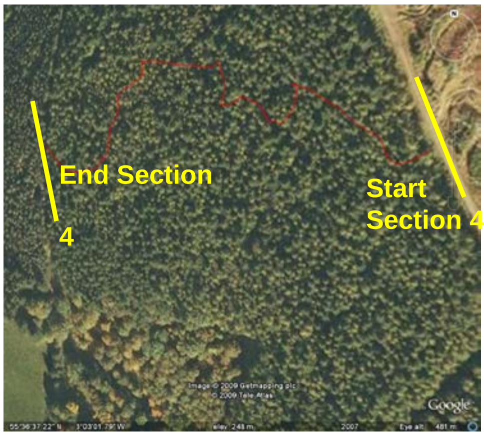


Figure 4.7. Course section 4.

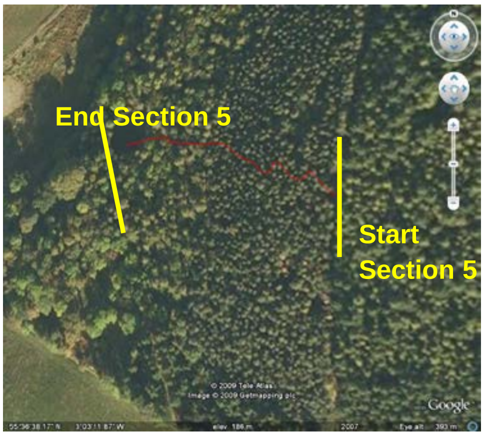


Figure 4.8. Course section 5
(Study Two only)

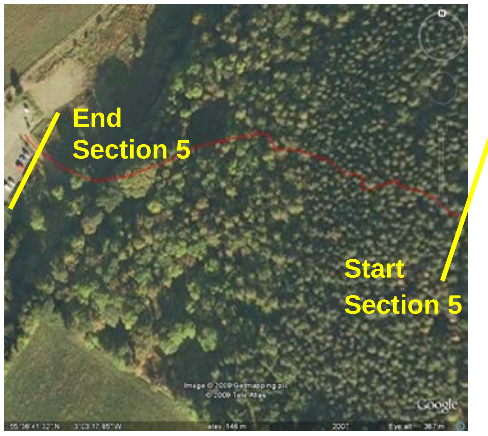


Figure 4.9. Course section 5.
(National Championships only).

Field Test Protocol

GPS was attached to the bicycle and helmet at the start area of each run which allowed five minutes (at least) of passive recovery between pushing the bicycle from the drop-off point of the uplift vehicle, to the start line. Participants were instructed to ride the track as if they were competing in a race. On the verbal start command ‘3, 2, 1, GO’ Participants left the designated start gate. The stopwatch was started through communication with a ‘helper’ at the finish, via mobile telephones, who then stopped the watch upon completion of the run at the designated finish line. After completion, the Participant reported any obstructions, which they felt might have hindered their performance, i.e. crashes and GPS units were switched off and removed from the helmet and the seat post of the bicycle. The quickest run of each participant was used for analysis.

National Championships – Testing Overview

Five males participating in the 2009 National Downhill Mountain Bike Championships (Innerleithen, Scotland) agreed to take part in this study. Participants were each successful within their own race categories (n = 3, youth; n = 1, junior; n = 1, expert male). The event took place over two days with the first day being practice and course familiarity and the second day consisting of two timed race runs. The first run was a seeded run and the second run was the final placing run. The weather was dry; however, the course conditions were muddy. One GPS unit was used and was attached to the bike (as seen in Figure 4.1). Uplift Scotland provided transport for racers and their bicycles to the start line where their race was started by an official marshal. Participant information is detailed in Table 4.2. Dependant on performance in the seeded run (which decided final race run order), Participants had at least 2 hours between race runs. This time was spent fuelling, hydrating and resting. The course was the same as used for ‘Study

Two' (detailed above), however, the National Championships course finish line was a further ~ 85 m from the finish line of Study Two. The variation of course Section 5 can be seen in Figures 4.8 and 4.9.

Table 4.2. Participant overview; age, race category and bicycle model. Note. NC1 crashed towards the end of the race and their data was therefore, extracted from analysis.

Participant Number	**Age (years)**	**Race Category**	**Bicycle Model**
NC 1	17	Junior	Trek Session 88
NC 2	17	Junior	Trek Session 88
NC 3	16	Youth	Trek Session 88
NC 4	25	Senior	Commencal
NC 5	16	Youth	Trek Session 88

Field-based Assessment Analysis - GPS Analysis

GPSports software was used to analyse the GPS data. Using the function to export the GPS map to Google Earth (Google Earth 5), course Sections were created (Figures 4.3 – 4.9). Speed zones were set to give a speed profile, specific to Downhill mountain biking. These 6 Zones are shown in Table 4.3 and Figure 4.10 shows the course profile with the different colours showing an example of the run in the speed zones.

Table 4.3. Zones set to show speed profile of Downhill course used for field-testing

Zone	Colour	Speed ($km.hr^{-1}$)
1		0-5
2		5-10
3		10-15
4		15-20
5		20-35
6		35 +

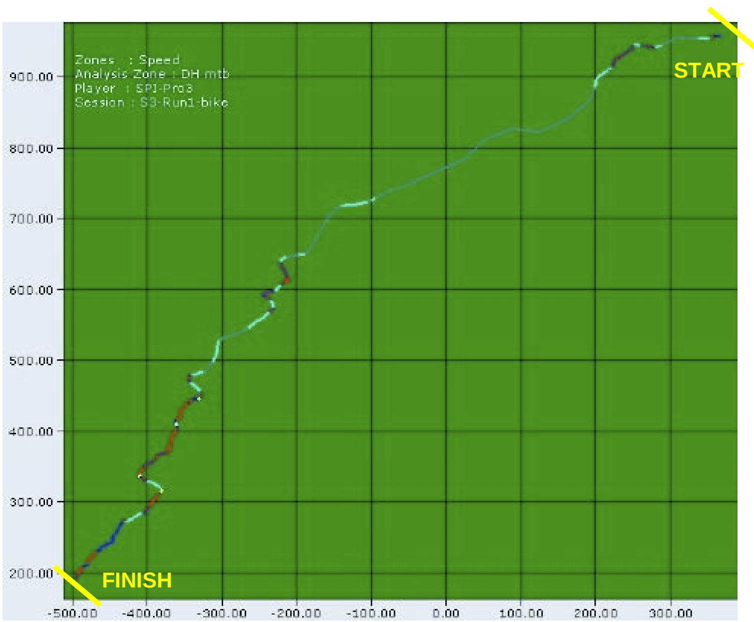


Figure 4.10. Schematic of the course profile of the Downhill course used for field-testing.

Statistical Analysis

Raw GPS data was exported from GPSports software to Excel (Microsoft Office 2007) for analysis. Descriptive statistics such as mean, minimum and peak speeds (km.hr^{-1}) and percent time spent in speed Zones were generated using Excel formulas. Relationships within the field-based assessments were determined in SPSS statistical package (version 15) using Pearson's Product Moment correlations and differences in the mean were determined using paired t-tests. It was agreed that due to multicollinearity there would be problems in fitting and interpreting regression models and thus the predictions of which variable is the most influential on performance (from regression equations) would not be reliable. For analysis and reliability, all durations (i.e. run duration, section durations) were converted from time (seconds) to speed (m·sec^{-1}). It must be noted that when results are presented in the Results section, the durations are presented as their 'actual' times (seconds) to allow quantification and easier understanding of the data for the reader. Initial comparisons of the speed profiles from 'Study Two' and the 'National Championships' showed them to be very similar and thus, it was agreed that the two could be merged to increase the total subject group number. Statistical analysis (Pearsons Product Moments correlation) of Section 5 for both subject groups, identified that time taken to complete both course Sections 5 (final section) did not have a significant impact on overall run time ($p > 0.05$). Thus, when statistics were run with the groups merged together, total run duration was presented as the sum of 4 course Sections and Section 5 was eliminated. This ensured reliability across the two testing periods as the ‘finish’ was the same for each rider’s race run. Significance for all statistical tests was set at $p < 0.05$.

Results

Characteristics of each individual’s race are presented in Table 4.4. Full run time (seconds) is shown for each individual along with mean, minimum and peak speeds ($km.hr^{-1}$) for the individuals’ race run. Group means are shown as 178.57 ± 12.10 seconds, 24.27 ± 2.06 $km.hr^{-1}$, 4.13 ± 1.51 $km.hr^{-1}$ and 49.41 ± 4.38 $km.hr^{-1}$ for total run duration (seconds), mean, minimum and peak speeds ($km.hr^{-1}$) respectively. Group mean for the National Championships race data are as follows: 184.3 ± 2.6 seconds, 24.2 ± 0.9 $km.hr^{-1}$, 3.5 ± 1.5 $km.hr^{-1}$ and 49.7 ± 3.6 $km.hr^{-1}$ for total run duration, mean, minimum and peak speeds ($km.hr^{-1}$) respectively.

Table 4.4. Full race (Section 5 included) time (seconds), mean, minimum and peak speeds for the run (km.hr^{-1}) for the 'Study Two' group and the same stats for the National Championship riders. Group means (± SD) shown. Note that Participant 1 (NC 1) of the National Championships group crashed during section 5.

Participant Number	Run Time (s)	Run Performance (m·s^{-1})	Mean Speed (km.hr^{-1})	Min Speed (km.hr^{-1})	Peak Speed (km.hr^{-1})
1	185.1	6.4	22.2	2.6	47.1
2	173.2	7.1	24.3	6.4	48.5
3	163.2	7.5	26.9	4.9	58.2
4	178.7	6.8	24.8	5.6	48.0
5	170.4	7.2	26.4	5.8	59.3
6	173.0	7.1	25.2	3.6	50.9
7	201.6	6.1	20.9	3.1	44.2
8	175.4	7.0	25.6	2.7	49.0
Mean	**178.6**	6.9	**24.3**	**4.1**	**49.4**
SD	**12.1**	**0.5**	**2.1**	**1.5**	**4.4**
*NC 1 **	*185.4*	6.4	*25.6*	*2.2*	*54.2*
NC 2	*182.8*	6.6	*24.2*	*5.8*	*47.4*
NC 3	*188.4*	6.5	*23.3*	*3.2*	*47.1*
NC 4	*183.0*	6.7	*24.3*	*2.2*	*53.0*
NC 5	*182.0*	6.7	*23.6*	*4.1*	*47.0*
Mean	***184.3***	**6.6**	***24.2***	***3.5***	***49.7***
SD (±)	***2.6***	**0.1**	***0.9***	***1.5***	***3.6***

Heart Rate Profile

Heart rate analysis shows high mean heart (bmp) rates during the race run. To allow for comparison of race heart rates across the Downhill athletes, heart rates were presented as a percentage of their age-predicted heart rate maximum (calculation: 208-(0.7*age)) (Tanaka *et al.,* 2001). Mean heart rate was 146 ± 33 bpm (91 ± 12 % HR_{max}) and peak heart rate was 178 ± 27 bpm (100 ± 5 % HR_{max}) for the race run. An example of the heart rate profile during the race run can be seen in Figure 4.11, which in addition to heart rate, shows the speed profile of the run.

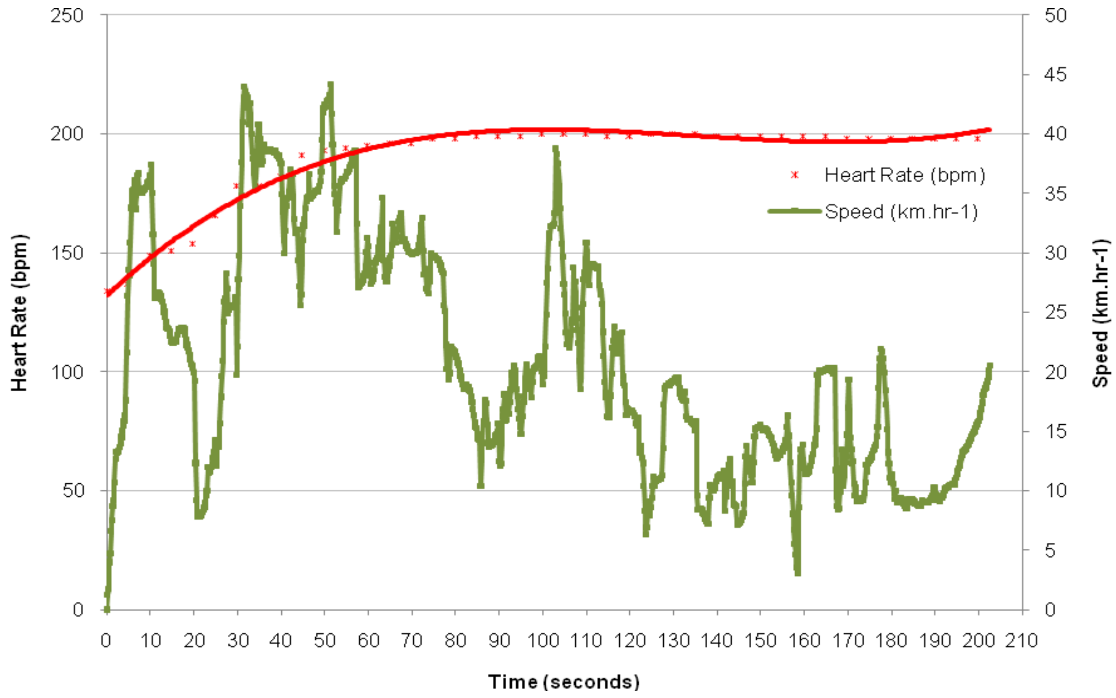


Figure 4.11. Example of speed and heart rate profile of the race run. Heart rate expressed in bpm and speed expressed in km.hr[1].

Course Sections

The course was split into 5 sections (Sections explained in Methods p 104 - 106). Mean duration of each section was 31.0 ± 1.9 s, 29.2 ± 1.5 s, 45.8 ± 3.0 s, 50.1 ± 4.8 s, 22.0 s (Section 1 – 5 respectively (Study Two)). Mean duration for Section 5 for the 'National Championship' group was 29.1 s – (Sections detailed in Figures 4.3 – 4.9). The correlations between total run time and course Sections 1 – 5 are presented in Table 4.5. Times taken to complete Section 1 – 4 were highly correlated to total run time (r = 0.90, 0.84, 0.96 and 0.95, respectively) and with the addition of the National Championships data, this relationship remained significant ($p < 0.01$). Speed characteristics (mean, peak and minimum speeds ($km.hr^{-1}$)) of each course Section is demonstrated in Figure 4.12. Total run time (performance) was significantly influenced by the mean speeds during course Sections 1 - 4 with Section 3 and 4 having the strongest correlations and statistical significance ($p < 0.01$). Peak speed significantly influences Section 1 and 4 ($p < 0.01$), whilst minimum speed only significantly influenced ($p < 0.05$) overall run duration during course Section 3.

Table 4.5. Mean duration (seconds), of each course Section is shown. Table shows means (± SD) from 'Study Two' participants only and 'Study Two plus National Championships' participants and the relationship between Section time and total run time (presented as speed). * denotes a correlation is significant at the 0.05 level. ** denotes a correlation is significant at the 0.01 level. Note: Study Two and NC data for course Section 5 could not be synthesised due to the different finish line locations.

		Study Two		***with* NC**	
Course Section	**Distance (m)**	*Mean Time (s)*	*r- value*	*Mean Time (s)*	*r- value*
1	~ 240	31.3 ± 2.3	0.90 **	31.0 ± 1.9	0.71 **
2	~ 300	29.0 ± 1.3	0.84 **	29.2 ± 1.5	0.63 *
3	~ 350	46.3 ± 3.6	0.96 **	45.8 ± 3.0	0.80 **
4	~ 230	49.9 ± 5.8	0.95 **	50.1 ± 4.8	0.87 **
5	~ 100	22.1 ± 1.3	-0.43	*n/a*	

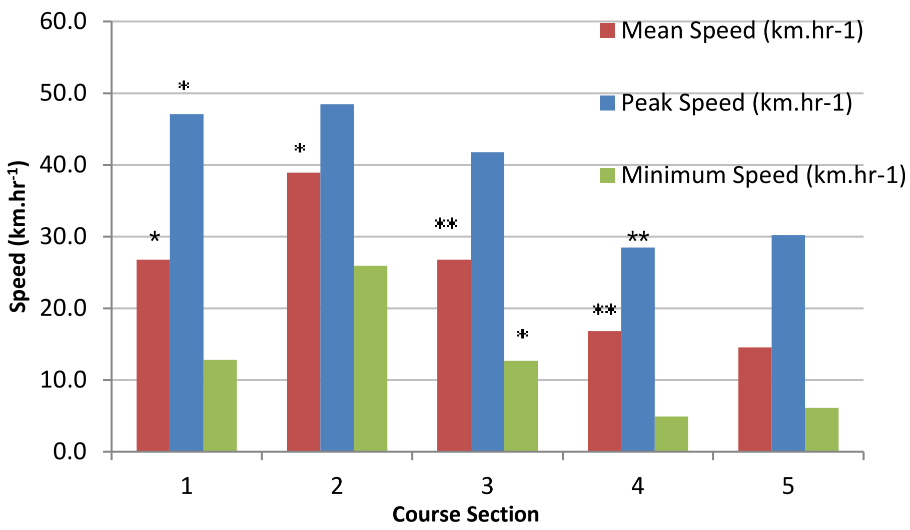


Figure 4.12. Speed characteristics for each section are displayed. Relationships between each speed characteristic and total run duration was determined. * denotes correlation is significant at the 0.05 level. ** denotes correlation is significant at the 0.01 level.

Speed Zones

Relationships between time spent (% total run time) in the six speed Zones and total run time were determined via correlation equations (Table 4.6). Analysis showed that with Study Two group, only the time spent travelling in speed Zone 6 (> 35 km.hr^{-1}) was negatively and significantly ($p < 0.01$) correlated to run time. When the National Championships data was added to the analysis, more significant relationships were identified. A positive correlation between run time and % time travelling in Zone 3 ($p < 0.05$) was seen. Furthermore, % time travelling in the faster speed zones (Zone 5 and 6) saw negative relationships. The significant ($p < 0.01$) relationship identified between run duration and % time spent in Zone 6 remained significant and a negative relationship ($p < 0.05$) was also identified between % time in Zone 5 and run duration.

Table 4.6. Duration (% of total run time) spent travelling in speed Zones 1 – 6. Table shows means from 'Study Two' participants only and 'Study Two plus National Championships' participants. * denotes correlation with total run time is significant at the 0.05 level. ** denotes correlation is significant at the 0.01 level.

	Study Two		***with* NC**	
Speed Zone ($km.hr^{-1}$)	*Mean Time (% run time)*	*r-value*	*Mean Time (% run time)*	*r-value*
1 (0 - 5)	0.8 ± 0.4	0.30	0.8 ± 0.4	0.20
2 (5 - 10)	7.0 ± 3.4	0.70	6.9 ± 3.0	0.54
3 (10 - 15)	13.3 ± 4.3	0.58	14.4 ± 4.0	0.61 *
4 (15 - 20)	18.0 ± 3.8	0.58	18.1 ± 3.2	0.56
5 (20 - 35)	40.7 ± 5.9	-0.63	40.5 ± 5.1	-0.58 *
6 (35 +)	19.4 ± 5.0	-0.87 **	18.8 ± 4.6	-0.78 **

Race Start

To determine characteristics and the importance of the start of a race in Downhill mountain biking, the distance travelled (m) in the first 5, 6, 10 and 15-seconds was determined. The relationship between total distance travelled (m) during these time points are presented in Table 4.7. 'Study Two' only data show that total distance travelled in the first 5 and 6-seconds have a positive influence on total run time ($p < 0.05$). With the addition of the National

Championships data, these relationships are strengthened ($p < 0.01$) (Table 4.7 and Figures 4.13, 4.14 and 4.15). Furthermore, the total distance in the first 10-seconds of the race becomes a significant determinant in overall race time ($r = 0.61$). Although total distance travelled in the first 15-seconds was not significant ($p = 0.06$), it is close and perhaps a larger subject group would achieve statistical significance.

Table 4.7. Distance travelled (m) after the first 5-s, 6-s, 10-s and 15-seconds of the race run. Table shows means from 'Study Two' only participants and 'Study Two plus National Championships' participants. * denotes correlation is significant at the 0.05 level. ** denotes correlation is significant at the 0.01 level.

	Study Two		***with* NC**	
Seconds	*Mean Distance (m)*	*r-value*	*Mean Distance (m)*	*r-value*
5	21.9 ± 3.3	0.87 *	22.0 ± 2.8	0.76 **
6	30.9 ± 3.6	0.77 *	30.5 ± 3.1	0.75 **
10	72.4 ± 6.7	0.15	70.4 ± 6.2	0.61 *
15	109.7 ± 6.6	0.18	109.0 ± 5.8	0.55

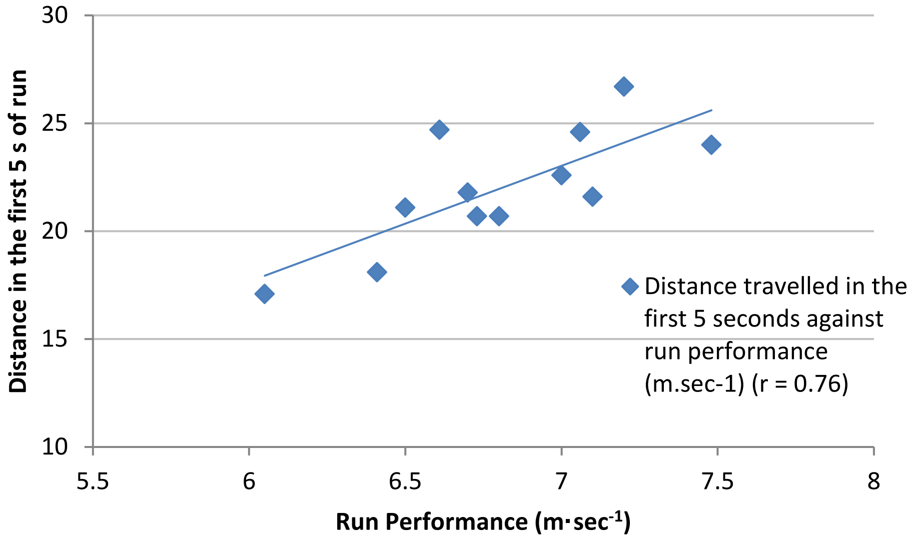


Figure 4.13. The relationship between run performance and distance travelled in the first 5 seconds of the race run.

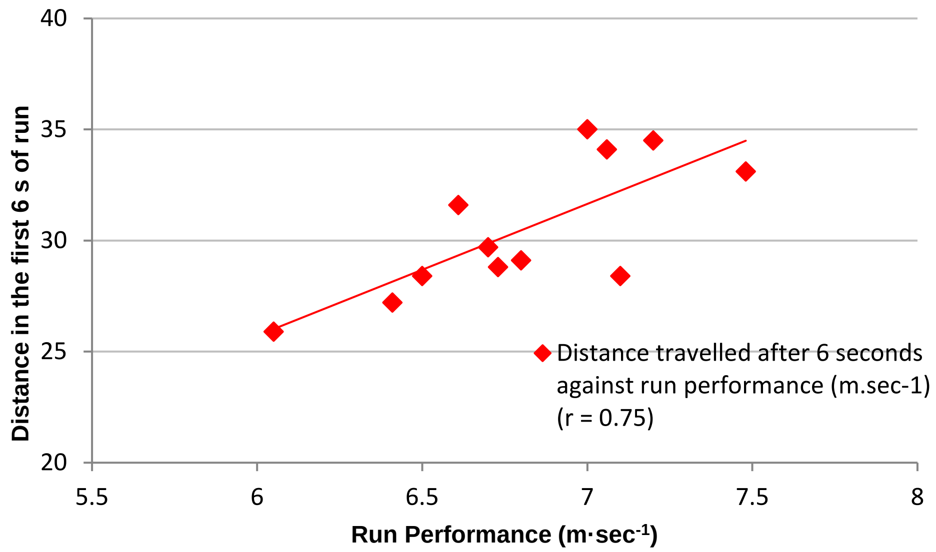


Figure 4.14. The relationship between run performance and distance travelled in the first 6 seconds of the race run.

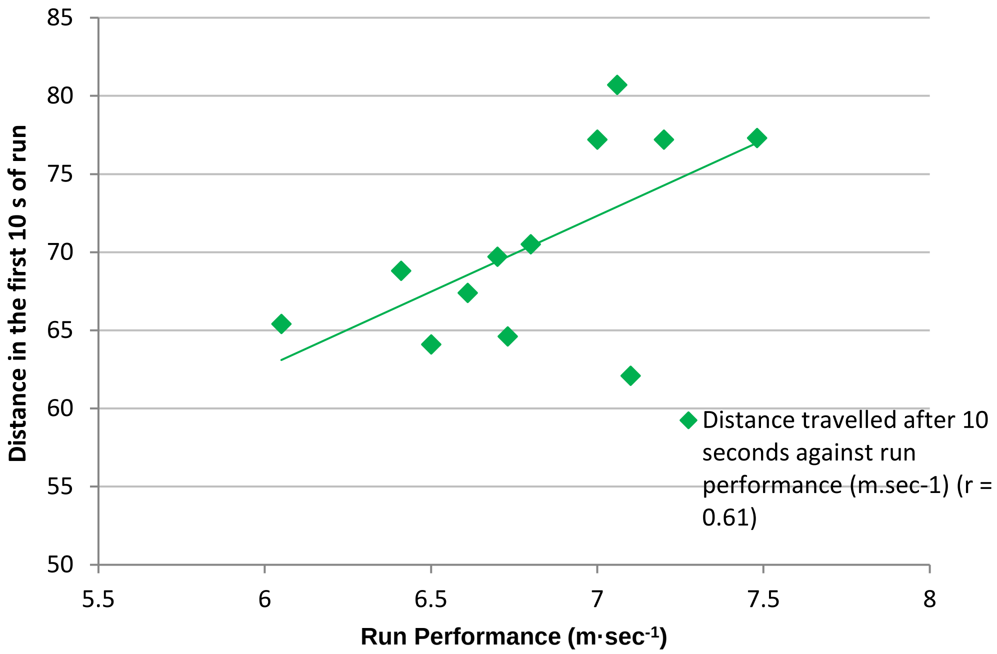


Figure 4.15. The relationship between run performance and distance travelled in the first 10 seconds of the race run.

Technical Section (Section 4) Analysis

Course section 4 was identified as the most technical section of the race run. This was initially suggested by the riders and coach and then reinforced by the GPS data. The GPS output shows many changes in speed to cope with the demanding steep and varying terrain through tight tree lines and poor visibility. A closer look at the speed profile of Section 4 can be seen in Figure 4.16 (note description of speed Zones can be found in Table 4.3). Table 4.8 shows the speed characteristics of each individual during the technical section of the course. Mean speed during course Section 4 has a strong, positive statistical influence on Section duration ($r = 0.86$, $p = 0.000$)). Mean and Peak speed ($km.hr^{-1}$) during Section 4 have a strong influence on total run duration (r = 0.91 and r = 0.94, respectively p = 0.000).

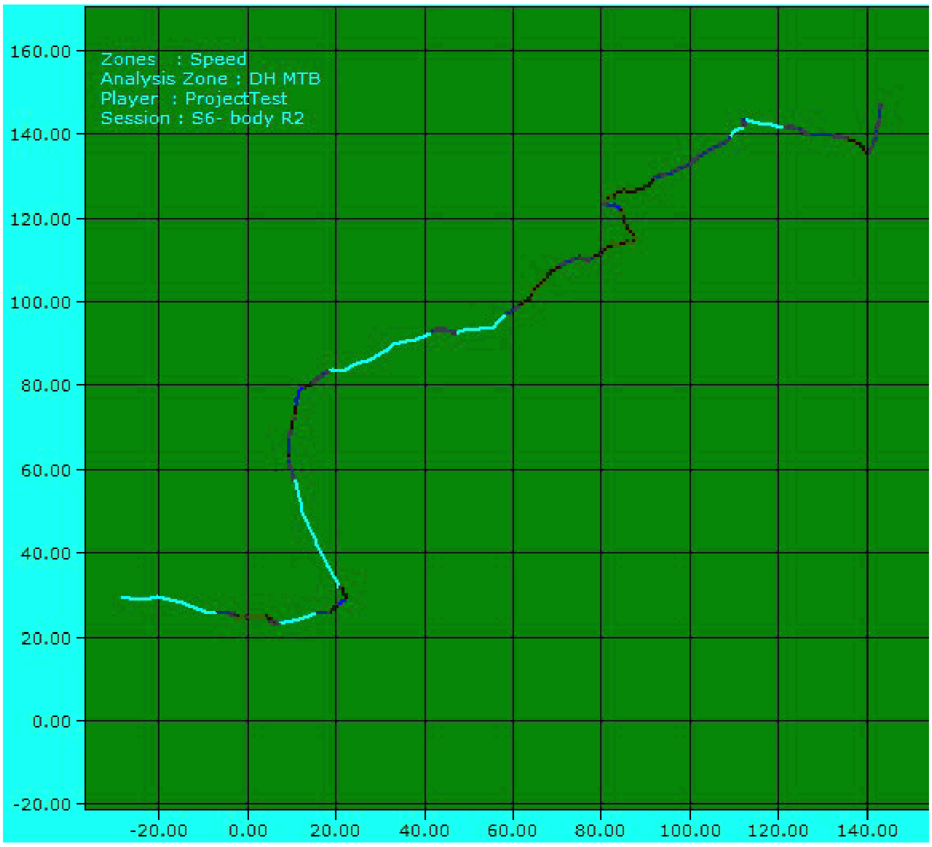


Figure 4.16. Speed profile of the most technical section of the test run. The different colours represent the different speed zones travelled in throughout the run.

Table 4.8. Analysis of the technical course Section 4. Section 4 and total run time displayed and the mean, minimum and peak speeds ($km.hr^{-1}$) of each participant during the section.

Participant Number	Section 4 Time (s)	Run Time (s)	Mean Speed ($km.hr^{-1}$)	Min Speed ($km.hr^{-1}$)	Peak Speed ($km.hr^{-1}$)
1	56.6	191.2	15.3	2.6	23.5
2	49.4	172.6	17.7	6.7	31.5
3	42.0	164.0	20.1	3.5	32.2
4	49.2	180.2	18.8	5.8	28.5
5	48.0	170.4	19.1	5.8	32.4
6	46.4	173.6	17.7	5.5	29.8
7	60.2	202.6	13.3	3.1	21.9
8	47.0	175.2	16.7	7.1	32.1
NC 1	49.8	185.2	16.0	7.3	26.8
NC 2	50.2	188.4	15.5	3.2	27.5
NC 3	54.0	183.0	16.4	2.2	27.8
NC 4	48.2	182.0	15.3	6.0	27.8
Mean	50.1	180.7	16.8	4.9	28.5
SD (±)	4.8	10.5	1.9	1.9	3.4

Body Load and Impact Intensity

Impact data was determined from the two GPS units attached to the seat post on the bicycle and to the riders helmet. Six impact Zones were created and Figures 4.17 and 4.18 show the mean number of impacts experienced in each impact zone for each of the five course Sections from the GPS attached to the bicycle and body (helmet), respectively.

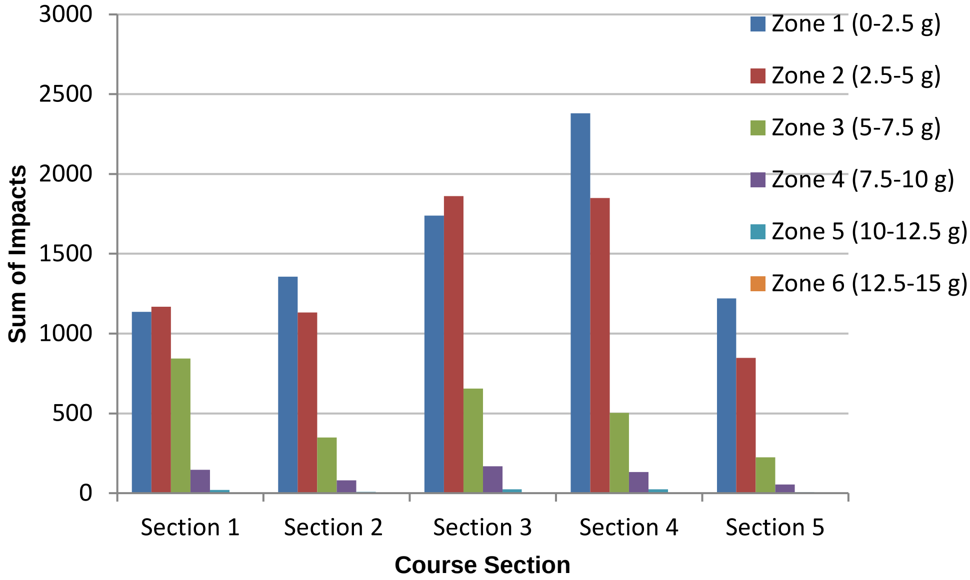


Figure 4.17. Mean number of bicycle impacts in each impact zone is detailed for each course section.

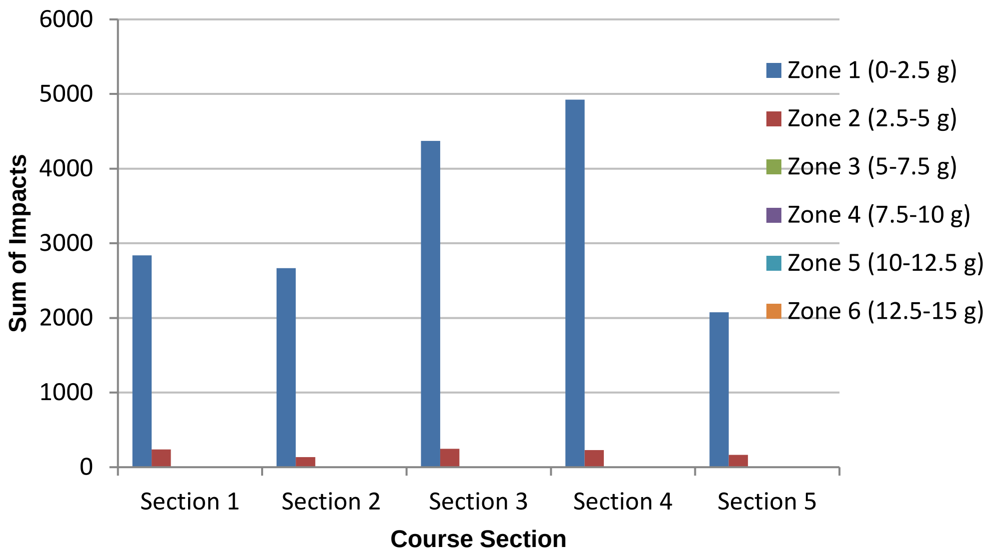


Figure 4.18. Mean number of body impacts experienced in each Impact Zone for the five course Sections (body GPS).

Analysis of both GPS units show the greatest number of impacts to occur in the lower impact zones (Zone 1; 0 – 2.5 g and Zone 2; 2.5 – 5 g). The greatest number of impacts were seen during course Sections 3 (4450) and Section 4 (4892) from the data received form the bicycle GPS. Figure 4.19 shows the difference in impact intensity received by the GPS unit on the bicycle and the unit placed on the body. It is clear that the bicycle absorbs almost 50 % of the g-force that the body endures.

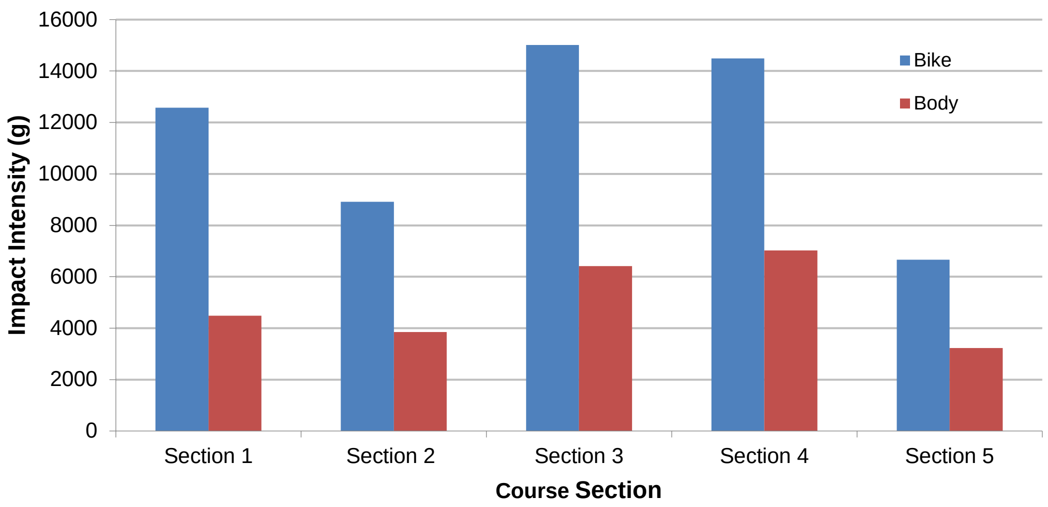


Figure 4.19. Bicycle and body GPS impact intensity for each course Section.

Statistical analysis identified a relationship between the number of impacts and overall performance. Figure 4.20 shows the total number of impacts in each Impact Zone. The correlation equations show that there is a positive and significant relationship between run time and number of impacts experienced in Zone 3 (r = 0.648), Zone 4 (r = 0.623), Zone 5 (r = 0.584) and Zone 6 (r = 0.742). The correlations identify that faster riders experience more impacts in the higher zones (e.g. Zones 5 and 6).

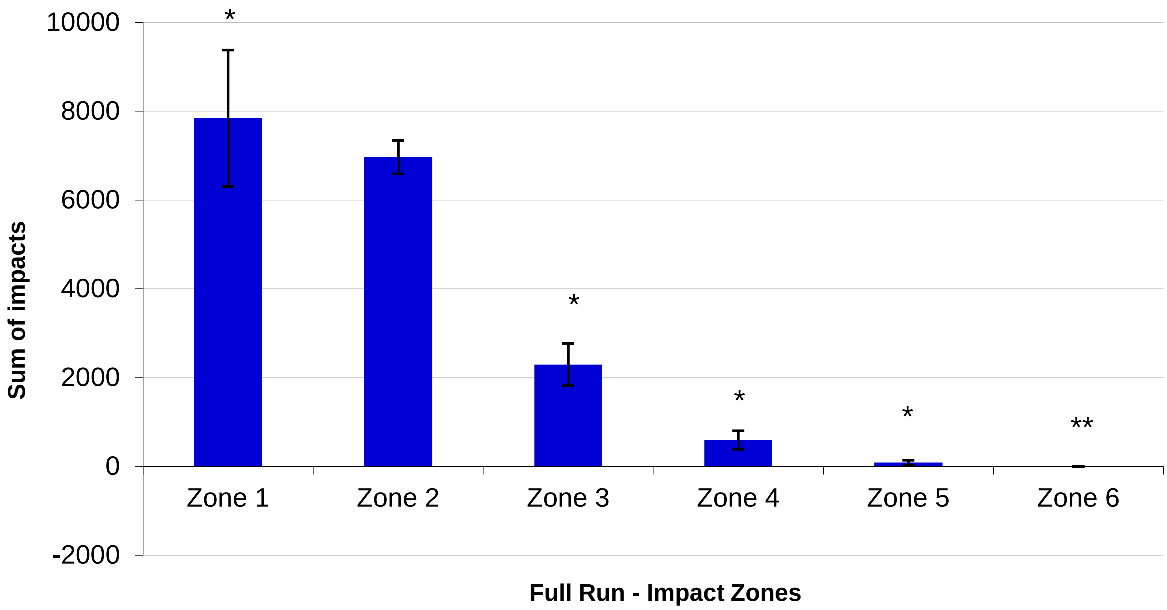


Figure 4.20. Mean sum of impacts in each Impact Zone (from the bicycle). * denotes a significant relationship (p = 0.05) between number of impacts in that zone and total run time, ** denotes the relationship was significant to p = 0.01.

The intensity of the impacts experienced throughout the race run were determined by the multiplication of the number of impacts and the mid-value of the zone. Figure 4.21 shows that the time spent in the lower impact zones are the most demanding periods of the run.

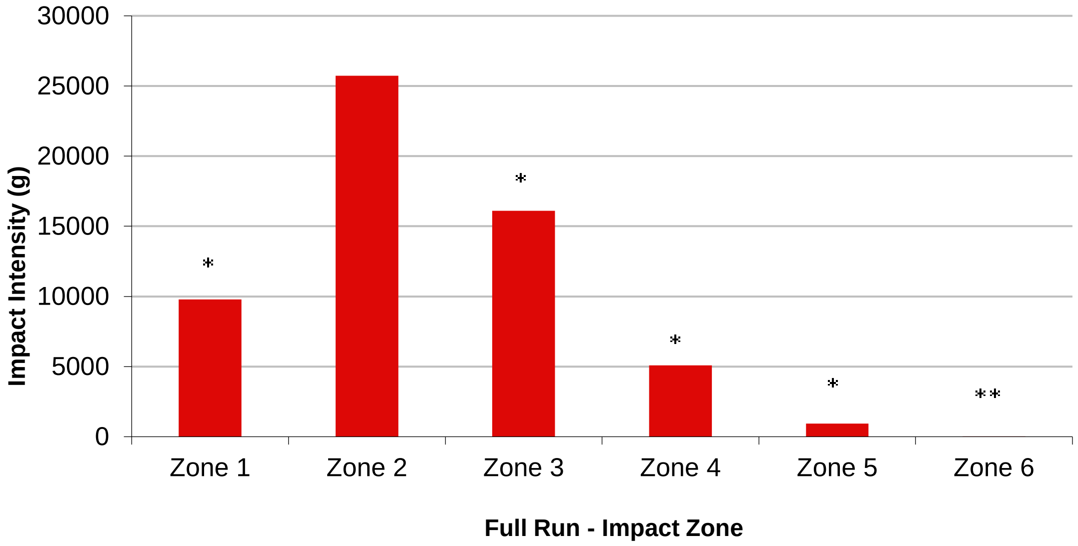


Figure 4.21. Impact intensity of each Impact Zone across the full run. * denotes a significant relationship (p = 0.05) between impact intensity of the zone and total run time, ** denotes the relationship was significant to p = 0.01.

Further analysis of the GPS impact data allowed identification of the most demanding course Sections, in terms of number of impacts, detailed in Figure 4.22. The graph shows that the greatest number of impacts are experienced during course Sections 3 and 4, both of which are significantly negatively correlated with total run time (r = -0.96 and r = -0.97, respectively, p = 0.05 and p = 0.01).

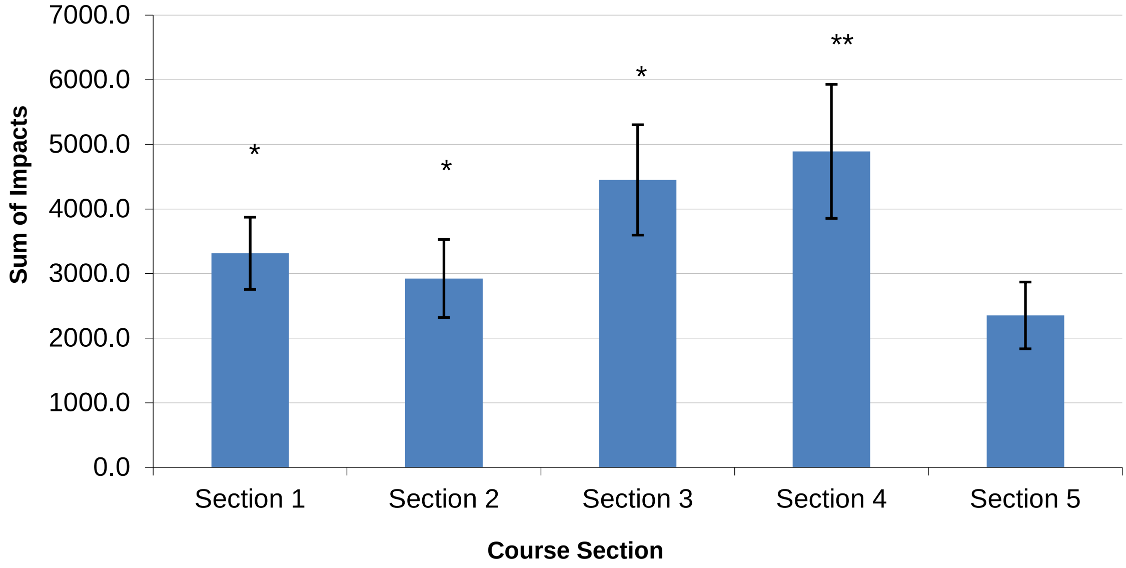


Figure 4.22. The sum of impacts experienced by the bicycle during each course Section. * denotes a significant relationship (p = 0.05) between number of impacts in the course Section and total run time. The riders that perform the best had the more impacts. ** denotes the relationship was significant to p = 0.01.

As mentioned, Course section 4 was highlighted as a technical and influential section and thus, further statistical analysis was undertaken to determine whether sum and intensity of impact had an influence on Section 4 performance. Positive correlations between Section 4 performance and sum of impacts, (Zone 3, r = 0.73, Zone 4, r = 0.78, Zone 5, r = 0.83). Note. Zone 1 showed a negative correlation (r = -0.78).

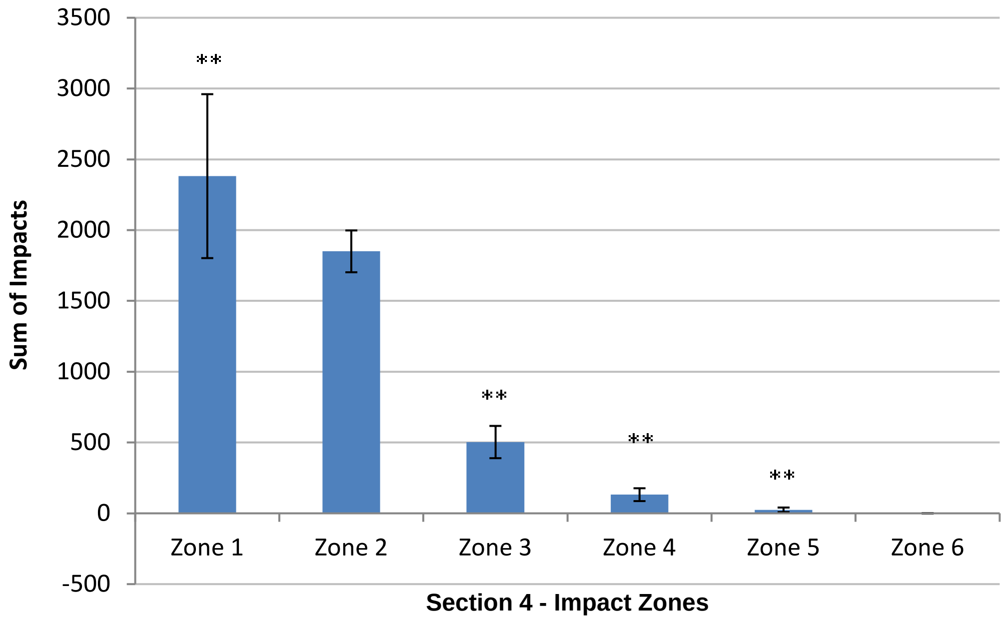


Figure 4.23. The sum of impacts experienced in each impact zone by the bicycle in course Section 4. ** denotes the relationship between Section 4 duration and sum of impacts was significant (p = 0.01).

Further analysis identified a slight shift in the sum of impacts graph looking solely at course Section 4 (Figure 4.23) in comparison to Figure 4.20, looking at the whole run. The greatest sum of impacts was experienced in Zone 1 which had a negative effect on run performance. Figure 4.24, showing impact intensity of Section 4, identified the most demanding period of the run was when the impacts were within Zone 3.

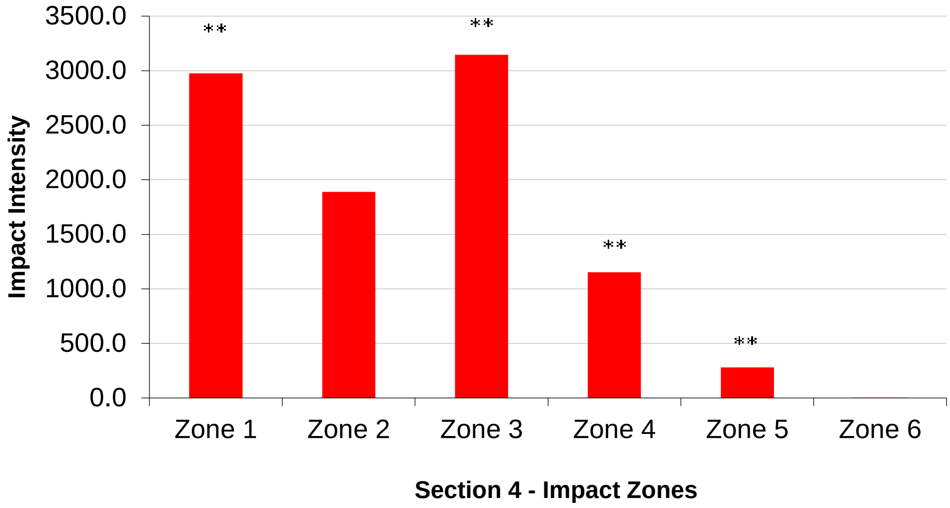


Figure 4.24. The impact intensity of each impact zone during course Section 4. ** denotes the relationship between Section 4 duration and impact intensity of the Zone was significant (p = 0.01).

Discussion

Many studies have investigated the physiological demands of road and track cycling but fewer have studied these parameters in the off-road disciplines. More specifically, only one study to date, investigates these demands in response to the intermittent cycling discipline of Downhill mountain biking (Hurst and Atkins, 2006). The current study aimed to give insight into the physiological demands of the sport and identify key attributes necessary for successful Downhill mountain bike performance.

Padilla *et al.,* (2000) investigated the intensity of professional road cycling. When heart rate (HR) was presented as a percentage of heart rate maximum (HR_{max}), high mean HRs were identified (> 76 % HR_{max} for each TT investigated: Prologue TT (< 10 km), Short TT (< 40 km), Long TT (> 40 km), Uphill TT (climb > 500m) and Team TT. Thus, Padilla *et al.,* concluded that professional road cycling TT was performed at ‘quite high’ exercise intensities. HRs during XC mountain biking have also been investigated. Studies conclude that XC mountain biking is a high intensity sport and mean HRs are consistently high during a number of races that have been investigated. Impellizzeri *et al.,* (2002) reported a mean HR, over four races, of 90 ± 3 % HR_{max}. Gregory *et al.,* (2007) also reported high mean HRs during a XC time-trial (~ 60 minutes in duration) as 174 ± 7 bpm. This was ~ 90 % HR_{peak}. Average exercise intensity during off-road cycling appeared higher than road cycling (not time trial) when mean competition HRs were compared. There are a number of possible explanations for this; course distance was mostly of shorter duration than the road TTs (15.52 km) so riders can perform at a higher mean HR due to the shorter duration of the race; or the ability for road cyclist to reserve energy through drafting. It is most likely, however, that the XC course was more challenging with one study reporting a total vertical distance climbed of 624 m at a mean gradient of 4.02 % (Gregory *et al.,* 2007). Clearly, Impellizzeri *et al.,* (2002) and Gregory *et al.,* (2007) demonstrate that mountain biking is a high intensity exercise. Course analysis identified HR was elevated in response to the steepest ascents (15 – 20 %)

and remained elevated even on the downhill sections. They introduced the idea that the sustained high HR during downhill section may be due to constant isometric contractions required to cope with the descending terrain.

Specific to the current study, Hurst and Atkins (2006) concluded that DH is a very high intensity activity despite mean power output during the activity only being 9 % of peak power values, established during laboratory testing. They too suggested the dynamic and isometric muscular contractions required to cope with the technical terrain may explain the elevated stable HR. DH bicycles have heavy suspension systems and it should be noted the research into bicycle suspension which suggests that suspension significantly reduces the mean HR during a flat looped course with artificial bumps when compared to rigid bicycles (Seifert *et al.,* 1997) cannot be accurately compared to DH mountain biking and the physical effort of the DH athletes withstanding the technical terrain on a steep downhill gradient at speed. The literature claims cycling to be a high intensity activity whether it be road cycling (Padilla *et al.,* 2002), XC cycling (Gregory *et al.,* 2007; Impellizzeri *et al.,* 2002) or indeed, DH mountain biking (Hurst and Atkins, 2006). The current study agrees with these claims and reinforces the statement that DH is a high intensity activity (Hurst and Atkins, 2006). Mean HRs for the full race run (presented as a percentage of age-predicted maximum), were 91 ± 11 % HR_{max}. Figure 4.11 shows that heart rate is elevated quickly to a high value and stabilises after ~ 30 – 40 seconds. Heart rate remains stable despite fluctuations in speed. Although the current study did not measure cadence, the changes in speed can also be associated with changes in cadence. Other studies investigating cycling performance in downhill sections identified low mean cadences despite high heart rates (Gregory *et al,* 2007 and Hurst and Atkins, 2006). Gregory *et al.,* 2007, showed that during the steepest downhill sections (15 – 20 %) heart rate only dropped to a mean HR of 78 ± 4.4 % HR_{peak} despite a significant ($p > 0.05$) decrease in cadence and power output (from ~ 73 rpm and ~ 78 % peak power to 6 ± 12 rpm and 19 ± 3 % peak power). The Downhill mountain bike study conducted by Hurst and Atkins (2006) also showed high mean HRs (89 % HR_{max}-percentage of age-predicted HR_{max}), despite a low mean cadence of 27 ± 5 rpm. This pedal rate was slightly higher than reported by Gregory *et al.,* (6 ± 12 rpm). This would also suggest that the isometric muscular contractions that occur to cope with technical terrain may play a part in the high heart rates observed during downhill cycling. Gnelm *et al* (1997) identified HR can be affected by rider position with the low position adopted when using aerobars showing a higher mean HR than if in an upright position. Gnelm *et al.,* (1997), suggested that this was due to the increased contribution of the shoulder musculature. DH riders stand on their pedals the entire race and thus, rider position may also account for the high HRs observed as there will be more stress placed on the body to maintain this position whilst steering and pedalling the bicycle. A state of fear or anxiety can be characterised by an increase in autonomic activity such as blood pressure, respiration and/ or heart rate. Stimulation of the amygdala, the part of the brain associated with fear and anxiety, can alter heart rate and blood pressure (Davis 1992). Thus, the psychological effects of a DH race cannot be discounted as a contributor to the high heart rates observed. Contributors to elevated heart rate other than physiological load in DH would be an interesting focus for future research.

Course Analysis

It has been reported that the dynamics of a Downhill course will change the energy demands of the rider (Hurst and Atkins, 2006). Some courses are composed of highly technical terrain through thick forested woods with poor visibility (such as the course used for the current study, Innerleithen, Scotland) whereas others (Fort William, Scotland) place more emphasis on the aerobic system as they are longer in distance (m) and require longer periods of pedalling (course profile of Fort William, Scottish Downhill Series run can be seen in Appendix xii). Due to vast differences in Downhill courses, it is important for athletes to be familiar with the course prior to competition. Usually a competition will take place over a weekend, with the Saturday being an allocated practice day (rider movement patterns during the practice day of the National Championships, 2009, can be seen in Appendix xiii). An insight into the demands of particular areas of the course before the race weekend would be of great advantage to the athlete and preparation of this nature is the job of the coach, sports scientist and support team. To date, there has been no published breakdown of a DH course which analyses and highlights the effects of different sections of terrain and the magnitude of their influence on overall performance.

The current study divided the test course into 5 sections to allow in depth analysis of individual runs. Table 4.5 (p 109) provides course section details such as distance (m), speeds ($km.hr^{-1}$) and duration. Course analysis identified that section duration had a positive influence on overall run time, with the exception of Section 5. When the relationship between performance and mean speed of each section was examined, the results were of interest. These relationships were determined to allow the identification of sections of the course which were of particular importance for DH performance. Speed ($km.hr^{-1}$) during Section 5 was not of significant importance on total run performance, however, Sections 1 – 4 were shown to be significantly influential ($r = 0.71, 0.63, 0.80, 0.87$, respectively, $p < 0.05$). Initial statistical analysis showed Sections 1 and Section 4 to be the most influential on full run performance as their correlations were the strongest ($r = 0.71$ and $r = 0.87$, respectively, $p = 0.01$). Note that Section 4 was not longer in distance than Section 1 and thus discounts the idea that an increased length of section was the determinant of the significantly stronger correlation). Analysis of speed characteristics (six Zones (Table 4.3) identified that high mean speeds are more advantageous than peak speeds for successful performance and thus carrying and maintaining speed throughout the race seems to be an important factor in DH performance. A positive correlation between run performance and total time spent in speed Zone 3 (10 – 15 $km.hr^{-1}$) identified that the less time spent in Zone 3, the faster the overall run time (Note: run time was presented as $m \cdot sec^{-1}$ during statistical analysis, thus explaining the positive nature of correlation equations). The hypothesis of maintenance of high mean speeds during a DH race was strengthened by negative relationships observed in the two fastest speed Zones (5 and 6); the longer the duration spent travelling in these zones, the faster the overall run time.

Results conclude that duration of each section (with the exception of Section 5) had a significant impact on DH performance. This would be expected as the quicker each section is completed the quicker to the finish line should be reached, providing the same distance is covered. However, what is important to note, is that it appears to be the riders ability to maintain speed throughout the course Sections, which is crucial to successful performance. The concept of maintaining a high mean speed in order to perform well is supported in the literature when investigating off-road cycling (Impellizzeri and Marcora, 2007). Maintenance of speed will result in a high mean speed, opposed to a fluctuating speed, which may be characterised by periods of going fast and then breaking hard. Analysis of the speed characteristics (e.g. peak, minimum and mean speeds and durations spent travelling faster or slower etc) gave an insight into course dynamics and their effects on performance. Section 2 was the quickest section of the run, recording the highest mean, peak and minimum speeds (38.9 ± 3.2 km.hr^{-1}, 48.5 ± 4.3 km.hr^{-1} and 25.9 ± 5.2 km.hr^{-1}, respectively). Analysis of the speed characteristics of Section 4 was able to confirm that it was the most technical Section of the course. The technical section was defined by the Scottish Downhill mountain bike coach as the area which the greatest obstacles and challenging terrain placing the most emphasis on the riders bike handling skills and ability. Although the slowest mean speed was recorded during Section 5 (14.5 ± 3.2 km.hr^{-1}), it saw a higher peak and minimum speed than the next slowest Section, which was course Section 4. This technical section sees the rider experiencing significant periods of reduced speed and then periods of trying to regain some of the lost momentum. Therefore, this analysis could confirm that course Section 4 was the most technically demanding area of the test course.

Sections 1 and 2 saw the highest peak speeds (47.1 ± 2.1 $km.hr^{-1}$ and 48.5 ± 4.3 $km.hr^{-1}$) showing that the greatest speeds were generated and reached at the start of the race. Investigation into race speed characteristics allows determination of areas of the course that are of particular importance to performance. As mentioned, the higher the mean speed, the shorter the run duration. Further investigation identified that peak speed in Section 1 (start) and 4 (most technical section) were influential on overall performance (Figure 4.13). Thus it can be hypothesized, from the analysis of the course speed profile, that preparation for a race should place particular emphasis on rider performance at the start and through the most technical sections. Further investigations into both Section 1 and Section 4 will be discussed in further detail below.

Course Section 1 – The Start of the Race

Literature investigating other highly skilled and technical descending sports such as bobsled, luge and skeleton (Platzer *et al.,* 2009; Zanoletti *et al.,* 2006; Bruggemann *et al.,* 1997) all conclude that a good starting performance is a prerequisite for successful performance and as such Hypothesis 3 queried the importance of performance at the start of the race and its impact on overall DH performance. As mentioned, preliminary course analysis identified that the mean and peak speeds during the first section of the race had a positive and significant impact on overall race performance (run time). Further investigation into the importance of the start of the race on performance looked at total distance travelled in the first 5, 6, 10 and 15-seconds of the race (Table 4.7). These findings strengthened the hypothesis that successful performance is significantly correlated to performance at the start of the race and the momentum generated at this point is important to carry the rider through the rest of the run. Synthesis of 'Study Two' participants and the 'National Championship' participants shows that the distance covered in the first 10-seconds is significantly related to overall run performance ($p < 0.05$). The distance travelled in the first 5, 6 and 10-seconds of the race is correlated to performance ($r = 0.76$, $r = 0.75$ and $r = 0.61$) and hence, power on the start line to produce acceleration is key. Researchers have investigated the start of sprint-sports such as running, speed skating and track cycling (Ingen Schenau *et al.,* 1994; de Koning *et al.,* 1999). Both reported that the most successful performance was achieved when an 'all-out' pacing strategy was adopted. When the largest amount of anaerobic energy was released at the start of the race, greater energy was lost to friction compared to other pacing strategies, due to the accompanying increased speed. However, the peak power achieved is still great enough to overcome this negative frictional loss effect. Obviously, the DH race surface will differ greatly from that investigated in the literature, however, the results from the current study still concur with the literature and it seems that for DH mountain biking, start performance will have a significant effect on overall performance. More specific to DH, Hurst and Atkins (2006) identified that the greatest power output and cadence was generated very early on into the race run (7 ± 1.3 seconds) which supports the current conclusions that when striving for optimal DH performance, riders will try and generate peak speeds (and power output) as quickly as possible. The next step would be to determine whether physiological factors such as peak power output and time to peak power (established during laboratory-based testing) would have a practical implication on DH performance. Determination of the importance of the first 10-seconds of the race would suggest that specific physiological training could have a positive impact on achieving an optimal start to the race. Chapter 5 will investigate and discuss this in closer detail.

Section 4 – Technical ability

Unlike road cycling, it has been suggested that the relationship between speed and power output in off-road cycling may be influenced by riders' technical ability (Impellizzeri and Marcora (2007). Downhill courses are composed of highly technical terrain such as rocky, muddy or wooded trails in wide open tracks or tight lines between trees. The courses also include tight corners and jumps, which during Downhill mountain biking or sections of Cross-country, is covered whilst travelling on a decent where speeds of greater than 60 $km.hr^{-1}$ can be reached (Hurst and Atkins, 2006). Using global positional system (GPS) technology, analysis of the rider speed profiles allowed areas of the course to be highlighted as important for DH performance. Areas where riders travelled at high speeds (~ 48 $km.hr^{-1}$) or at speeds as low as ~ 2 $km.hr^{-1}$ were identified.

Section 4 of the current study was identified as a ‘technical’ section of the course (by the Scottish Downhill Mountain Biking Coach and then reinforced by the course analysis). A forest road marks the end of Section 3 where the course enters the final plunge through the trees. Gradients remain consistently steep and the plantation forest becomes tighter, with less light, poorer visibility and a varying surface – from loose soil to loose rock (Section 4 is displayed in Figure 4.7). Mean speed through this section was 16.8 ± 1.9 $km.hr^{-1}$, with a mean peak speed of 28.5 ± 3.4 $km.hr^{-1}$. This was the lowest peak speed of all five course Sections (Figure 4.12). It also showed the lowest minimum speed (4.9 ± 1.9 $km.hr^{-1}$). Furthermore, Section 4 shows the greatest change in speed (percent of total section speed) in comparison to the other course Sections. Importantly, we know that speed of Section 4 is strongly correlated to overall performance ($r = 0.97$, $p = 0.000$) and closer investigation identifies speed characteristics are also influential. The mean speed of the section was significantly related to Section 4 performance ($r = 0.79$, $p = 0.003$), suggesting that riders who carry and maintain their speed effectively are more likely to finish the section quicker. The mean and peak speeds of the Section have a significant effect on overall performance. The higher these values the more likely the rider will finish the race quickly. The current literature suggests that competitive cyclists aim to produce the greatest mean power output over a given distance in order to win a race (Baron 2001; Sargeant *et al.,* 1981). Whilst power data was unavailable during the current study, the conclusions from the speed analysis follow a similar vein. Since power output will fluctuate a great deal (40 – 138 W, Hurst and Atkins, 2006) during a DH course due to the terrain, the maintenance of speed throughout the run, especially through the technical sections, appears to be of more importance. Due to the downhill nature of the course, the riders' skill and quick decision-making is crucial to allow speed to be carried successfully through the terrain. Downhill mountain biking performance can be affected by many factors; external, such as course conditions or internal, such as psychological nerve or riders physiology. An investigation into the technical Section 4 of the current study suggests that a riders' technical ability is a critical component of successful performance. Impellizzeri and Marcora (2007) report personal communications with Damian Grundy, coach of the National Australian cross-country mountain bike team, who agrees that technical ability is crucial to performance. Interestingly, he further suggests that the relationship between power output and speed may change in relation to the technical capabilities of a rider. The suggestion that technical competency can influence how much power output is generated is a concept that may be of interest to DH, especially if the power output is transferred to actual cycling speed. Further investigations into this area would be beneficial to the sport.

As mentioned, Downhill mountain bike racing, as the name suggests, is downhill in nature and higher velocities are associated with this type of riding than XC racing. It may be thought that travelling downhill would increase velocity due to gravitational forces. While this is true, downhill tracks present a more extreme technical challenge than XC tracks and speed, as a result of gravitational force, needs to be controlled in respect of the terrain and hence the technical ability of the rider is crucial. Indeed Gregory *et al.,* (2007) demonstrated that velocity did increase as a XC course changed from the flat to a decline of 5 – 10 % (10.9 ± 1.1 $km.hr^{-1}$ – 20.7 ± 2.3 $km.hr^{-1}$). They also show that speed increased further (22.7 ± 2.6 $km.hr^{-1}$) as the decline increases to 10 – 15 %. However, when the decline increased again to 15 – 20 %, speed decreased (19.4 ± 2.8 $km.hr^{-1}$). This can be accounted for by rider risk tolerance and by the increase in technical skills required by the rider during the higher velocities associated with riding downhill (Mastroianni *et al.,* 2000). This type of riding decreases the time to react to the irregular and constantly changing terrain and thus demands good bike handling skills from the athletes. When the speeds from the current study are compared to those from the Gregory *et al* study, mean speed is higher (mean speed, 24.8 ± 2.4 $km.hr^{-1}$ compared to 19.4 ± 2.8 $km.hr^{-1}$ (15 -20 %, most applicable decline % for comparison to DH). The differences in the race durations may also have an impact on the differences of these speeds however the differences may suggest that DH athletes have a superior technical ability in comparison to their XC counterparts.

Performance during technical areas of a course could win or lose time between riders, putting further demand on technical ability. The results have highlighted that high mean speeds and high peak speeds achieved during Section 4 are significantly related to performance and thus, preparation for competition should involve identification of areas of the course which are of a challenging technical nature. This will ensure they are thoroughly familiar and practiced at maintaining speed around these sections, whether it is a corner, an obstacle or a tight line.

Body Load and Impacts

For the first time, this study has provided data about body load and intensity of impacts received to the bicycle and the body during DH mountain biking. This can be of great value in the mechanical preparation for races such as bicycle set-up (suspension etc) as well as the physical preparation. DH is a complex cycling discipline, where many aspects can affect performance and the revelation that body load and impact can have a significant effect on performance will allow riders and coaches to maximise preparation for races.

Statistical analysis revealed that the faster riders (quickest run performance) receive a greater number of impacts in the higher impact zones than the slower riders. This is logical as it suggests that the faster, more successful cyclists are more aggressive riders, who enter technical areas of the course and corners faster and with more technical ease and thus, result in an overall quicker run time. This is further emphasized when the Section described as the most technical area of the course (course Section 4) was analysed. This revealed that the faster riders continue to experience more impacts in the higher Impact zones than the slower riders in the technical sections. Interestingly however, the faster riders have a smaller total sum of impacts compared with the slower riders, which suggests that, although they are aggressive (and therefore faster) in their approach to technical obstructions and cornering, they are more importantly, smoother riders and maintain their speed more efficiently than the slower riders. These impact conclusions tie in to our previous discussion which placed emphasis on the riders' ability to maintain their speed as the basis for successful DH performance.

Although the data set was reduced, the data from the body GPS was still of interest and value. As seen in Figure 4.19, the bicycle appears to absorb ~50 % of total g-force through suspension and greatest g force experienced by the body is 5.86 ± 1.12 g compared to that experienced by the bicycle, 12.23 ± 0.60 g. The data shows that the g force the body must withstand predominantly laid in Impact zones 1 and 2, and none greater than Impact Zone 3 (> body impact was 7.46 g). The bicycle and body impact data shown in Figures 4.17 and 4.18 suggests that the lower impact zones 'drive' the run and the rider will experience this in vibrations through the arms and to a lesser degree, the legs. The effects of these vibrations to the forearms during and after DH mountain biking, although not discussed in the scientific literature, is widely recognised amongst riders and participant of the sport. 'Arm pump' is a compartment syndrome overuse injury that is caused by the handgrip and the co-ordination between the muscle groups on the front (volar) and back (dorsal) of the forearm necessary to manoeuvre the large DH bicycle across demanding and technical terrain. In addition to the increased grip required for rapid acceleration and deceleration, the volar finger flexors used during braking and the changes in direction, ensure the forearms get little rest during DH.

The identification of the significance of impact (g) during DH mountain bike performance can be useful in a number of ways. It can confirm the technical section of a DH course and can aid in bike set-up. In terms of training, the fact that zone 2 seems to 'drive' the run suggests that the bike absorbs the bigger impacts so the preparation for performance should include withstanding smaller impacts. These impacts may be seen in the form of vibrations to the forearm resulting in arm pump and reduced grip strength. Reducing these elements of fatigue will ensure a superior race run.

Conclusions

It is clear through analysis of speed and time profiles, for the full run and for identified course sections, that particular sections of the course are more important than others in term of affecting overall performance. Analysis of the course used for the current study and the National Championships identified two specific areas of interest which may be useful for performance preparation if the course was to be used again. This was the distance travelled at the start of the race and performance during the course section identified as ‘technical’.

In other cycling events, such as track, where terrain remains constant, the main factor influencing performance may be tactics or pacing strategy. DH performance however, seems to be very much course dependant and thus thorough familiarization prior to competition is vital. If particular sections of the course are identified as technical then particular emphasis should be placed on these sections during race preparation/practice in order to maintain as a high a speed as possible through them.

CHAPTER FIVE – SYNTHESIS OF LABORATORY AND FIELD STUDIES

Introduction

For more than 20 years sports scientists have worked with and examined the physiological characteristics of successful athletes (Lee *et al.,* 2002). Physiological data obtained from laboratory testing is a large component of athlete monitoring and preparation in many professional sports. Data can provide information on athletes' current physical fitness allowing progression to be monitored. In addition to the assessment of current 'form', data can also have a prescriptive application, aiding and introducing specificity into training programmes. Within the sport of cycling, many studies extensively report the physiological characteristics of road cycling and only more recently has research begun to investigate the physiological demands of the off-road cycling disciplines (Gregory *et al.,* 2007; Hurst and Atkins, 2006; Impellizzeri *et al.,* 2002, 2005; Lee *et al.,* 2002; Baron, 2001; Wilber *et al.,* 1997).

Downhill mountain bike performance can be influenced by factors an athlete cannot control and therefore prepare for, such as: course conditions, mechanical failures etc. To date, no study has determined the physiological and technical characteristics of a DH course. The aim of the current study was to quantify and describe the exercise intensity of Downhill mountain biking

(Study Two) and to determine whether an athlete's anatomical and physiological attributes, (Study One; anaerobic power, anthropometry), were pre-requisites for successful DH performance.

Statistical Analysis

Results from Study One (Chapter Three) and Study Two (Chapter Four) were synthesised to identify relationships between all the data collected. Relationships were determined with the SPSS statistical package (version 15) using Pearson's Product Moment correlations and differences in the mean were determined by paired t-tests. Significance was set at $p < 0.05$. For analysis, all durations were converted from time to speed ($m \cdot sec^{-1}$) as to nullify each course sections' duration as a component of overall run time. Results presented in the Results section, show durations in time to allow for easier understanding of the data for the reader. Due to multicollinearity there would be problems in fitting and interpreting regression models and thus the predictions of which variable is the most influential on performance (from regression equations) would not be reliable.

Results

For synthesis of results, only data from Participants who attended both testing sessions (laboratory and field) was used ($n = 7$). Mean Participant characteristics used for synthesis are as follow: age, 21 ± 5 years; body mass, 78.7 ± 9.0 kg; stretch stature, 187 ± 9.4 cm, and sum of 8 skinfolds, 68.7 ± 19.8 mm. All participants were identified to have predominantly mesomorphic somatotypes (mean somatotype, 2.1 ± 0.6, 4.7 ± 0.7, 3.0 ± 0.7). Characteristics for each Participant can be seen in Table 5.1. For a more comprehensive overview of the anthropometric profile of each Participant, see Table 3.1 in Chapter Three: Laboratory-based Assessments (p 73).

Table 5.1. Participant characteristics for the individuals who took part in both the Laboratory and Field-based testing assessments, plus means (± SD).

Participant Number	**Age (years)**	**Body Mass (kg)**	**Stretch Stature (cm)**	**Sum of 8 s.f (mm)**
1	30	79.7	183.5	77.0
2	17	70.0	174.3	58.6
3	21	96.9	199.9	52.7
4	16	78.4	190.2	76.4
6	25	76.5	187.3	106.5
7	22	79.2	185.2	60.4
8	19	70.4	172.2	49.6
Mean	21	78.7	184.7	68.7
± SD	5	9.0	9.4	19.8

Anthropometric Profile and DH Performance

No significant relationships ($p > 0.05$) between anthropometric measures (body mass, trochanterion-tibiale length, sum of 8 skinfolds, thigh girth 1 cm gluteal fold, mid thigh girth, somatotype) and the identified parameters of DH performance (e.g. run duration, course Section duration, distance travelled after 5, 6, 10 and 15-seconds, run speed characteristics or within technical course Section 4) exist.

Power Output

Power output characteristics obtained from the 6-second sprint test are displayed in Table 5.2.

Table 5.2. Participant power output characteristics plus mean (± SD).

Participant Number	**MPO (W)**	**MPO ($W \cdot kg^{-1}$)**	**PPO (W)**	**PPO ($W \cdot kg^{-1}$)**	**Time to Peak (s)**
1	1183.0	14.8	2102.8	26.4	0.695
2	966.6	13.8	1824.9	26.1	1.005
3	1336.9	13.8	2123.6	21.9	2.335
4	966.5	12.3	1725.9	22.0	1.760
6	906.4	11.8	1535.9	20.1	2.925
7	1029.1	13.0	1806.0	22.8	0.760
8	953.3	13.5	1585.8	22.5	1.005
Mean	1048.8	13.3	1815.0	23.1	1.498
± SD	155.0	1.0	230.0	2.3	0.864

Mean Power Output

Statistical analysis of mean power output (MPO) obtained from the 6-second test which generated the greatest peak power output, did not identify any significant correlations when laboratory and field-based assessment relationships were investigated (run duration, course Section durations, run speed characteristics and start of the race parameters; distance after 5, 6, 10 and 15-seconds).

Peak Power Output – Course Sections

Peak power output (PPO) was examined against the DH performance parameters and significant relationships were identified (Table 5.3). Although there was no significant relationship between PPO and total run duration ($p = 0.537$), correlations between PPO (Table 5.3) and individual course Section durations (presented as speed for reliable analysis) identified a significant negative relationship existed between PPO and course Section 5 time ($p < 0.05$). The effect of PPO on the duration of course Section 1 was close to statistical significance ($p = 0.063$).

Table 5.3. Run and course Section times. * denotes correlation with PPO ($W \cdot kg^{-1}$) is significant at the 0.05 level.

Course Section	Mean Time (s)	r- value
Full Run	178 ± 12.2	-0.28
1	31.3 ± 2.3	-0.73
2	29.0 ± 1.3	0.11
3	46.3 ± 3.6	-0.17
4	49.9 ± 5.8	-0.48
5	22.1 ± 1.3	-0.78 *

Peak Power Output – Speed Characteristics and Speed Zones

No significant relationships were identified between PPO (absolute or relative) and full run speed characteristics. Speed characteristics can be seen in Table 5.4.

Table 5.4. Run times (seconds), PPO ($W \cdot kg^{-1}$) and speed characteristics of the full race run for each participant. Mean (± SD) also shown.

Participant Number	Run Time (s)	PPO ($W \cdot kg^{-1}$)	Mean Speed ($km.hr^{-1}$)	Min Speed ($km.hr^{-1}$)	Peak Speed ($km.hr^{-1}$)
1	185.1	26.4	22.2	2.6	47.1
2	173.2	26.1	24.3	6.4	48.5
3	163.2	21.9	26.9	4.9	58.2
4	178.7	22.0	24.8	5.6	48.0
6	173.0	20.1	25.2	3.6	50.9
7	201.6	22.8	20.9	3.1	44.2
8	175.4	22.5	25.6	2.7	49.0
Mean	178.6	23.1	24.3	4.1	49.4
(± SD)	12.1	2.3	2.1	1.5	4.4

Peak Power Output – Start of the Race

To investigate the start of the race in more detail, distances (m) after 5, 6, 10 and 15-seconds were determined (Table 5.5). When these markers were correlated to absolute PPO (W), no significant relationships were identified. However, when power was adjusted for body mass ($W \cdot kg^{-1}$), a significant positive relationship between PPO and distance after 10-s was identified ($p = 0.049$). Although a two-tailed correlation did not identify a significant relationship between PPO ($W \cdot kg^{-1}$) and distance after 15-s ($p > 0.05$), it was close to statistical significance ($p = 0.066$), which may show a trend towards the relationship becoming with a larger subject group.

Table 5.5. Mean distance travelled in the first 5, 6, 10 and 15-seconds of the race. * highlights correlation with PPO ($W \cdot kg^{-1}$) is significant at the 0.05 level.

Seconds	Mean Distance (m)	r-value
5	21.9 ± 3.3	-0.551
6	30.9 ± 3.6	-0.615
10	72.4 ± 6.7	-0.757 *
15	109.7 ± 6.6	-0.723

Peak Power Output – Technical Section (Section 4)

Initial analysis (Study Two) showed course Section 4 to be the most technical section of the course and when relationships between PPO and characteristics of this Section were investigated, no significant correlations ($p > 0.05$) were determined (Section 4 duration; speed characteristics: mean, minimum and peak speeds). These results strengthen the conclusion that this Section places emphasis on the riders' technical skills rather than on their power output capabilities.

Time to Peak Power Output

Time to peak PO was determined for each sprint test (Chapter 3) and its influence on DH performance was investigated. Times were obtained from their sprint test that generated the greatest PPO (Table 5.2).

Time to Peak Power Output – Course Sections

Investigation into the relationships between time to peak PO and DH performance identified significant relationships (Table 5.6 and 5.7). Although there was no significant relationship between time to peak PO and total run duration ($p = 0.1$), correlations between time to peak PO and course Section times (Table 5.6) identified a significant relationship between time to peak PO and course Section 1 time ($p = 0.031$). Although there was no significant relationship between time to peak PO and course Section 4, it was close to significance ($p = 0.066$). This may suggest that with a larger subject group, a significant relationship may be identified.

Table 5.6. Mean course Section duration. * denotes significant correlation between time to peak PO and section time $p < 0.05$).

Course Section	**Mean Time (s)**	**r- value**
1	31.3 ± 2.3	0.80 *
2	29.0 ± 1.3	0.34
3	46.3 ± 3.6	0.63
4	49.9 ± 5.8	0.72
5	22.1 ± 1.3	0.31

Time to Peak – Speed Characteristics and Speed Zones

There were no significant relationships identified between time to peak PO and time spent travelling in the predetermined, DH specific, speed Zones. No relationships were identified between time to peak PO and the speed characteristics of the full run (mean, minimum and peak speed).

Time to Peak – Start of the Race

When time markers demonstrating the distance travelled (m) in the first 5, 6, 10 and 15-seconds were correlated to time to peak PO (Table 5.7), two significant relationships were identified: distance after 5-seconds ($p = 0.032$) and after 15-seconds ($p = 0.027$). Furthermore, the high r-value seen from the correlation between PPO (Table 5.5) and distance after 10-seconds, may identify a trend towards this relationship becoming significant if the subject group was larger.

Table 5.7. Mean distances travelled (m) after the first 5, 6, 10 and 15-seconds. * denotes significant correlation between time to peak PO and distance at the 0.05 level.

Seconds	**Mean Distance (m)**	**r-value**
5	21.9 ± 3.3	0.796 *
6	30.9 ± 3.6	0.630
10	72.4 ± 6.7	0.734
15	109.7 ± 6.6	0.809 *

Time to Peak – Technical Section (Section 4)

Correlation equations were used to determine if significant relationships existed between the physiological parameter, time to peak PO, and the speed characteristics of the technical Section 4. The relationships were not of statistical significance, however, the duration of Section 4 when compared to time to peak PO was close to significance (p = 0.066).

Discussion

Physiological testing allows quantification and identification of parameters of physical fitness specific to a sport. This can ensure training is progressing the physiology in the desired direction. Specific fitness parameters important for successful sporting performance have been identified for a large number of sports such as running, swimming etc. (Winter *et al.,* 2006). The current study aimed to identify physiological parameters which influence DH performance to allow the introduction of training, specific to the sport, and to ultimately improve rider performance.

Lactate threshold and turn-point are unlikely to be important training markers for sprint cycling disciplines such as Downhill mountain with anaerobic indicators being more appropriate for these athletes (Hurst and Atkins, 2006). As such, the current study used laboratory-based testing (Study One) to assess the anaerobic power characteristics of DH athletes and obtain an anthropometric profile of the participants. To date, no research determines whether physiological attributes have a positive effect on DH performance. This also means there is no empirical evidence that current DH training and preparation is appropriate or whether some important aspects of fitness are presently being over looked during training. It must be noted that, as suggested in Chapter Four, DH courses can differ greatly from each other and as such (Appendix xii), the data from the current study must be built up on, to add depth to the conclusions extracted from these results.

A number of physiological attributes from the elite DH mountain bikers (measured in Study One) correlated and appeared to impact up on DH performance (Study Two). A riders' technical ability and bike handling skills are an essential component for DH performance, however, these results allowed identification of sections of the course where athletes' physiological attribute would have a positive influence on performance and primary recommendations for preparation for DH performance and the findings are discussed below.

Physiological Attributes and DH Speed Characteristics.

The power attributes (PPO and time to peak PO) of the DH riders had no significant influence on the speed characteristics (mean, minimum and peak speed; % time spent in sections, DH specific, speed Zones) of a DH mountain bike race. These finding concurred with results of the only other existing DH study (Hurst and Atkins, 2006). They presented mean and peak run speeds, but no relationships were determined between those values and other test variables such as run power output (peak or mean). Unlike the present study, Hurst and Atkins were able to measure power output during the DH run (SRM cranks) and noted that mean power output (MPO) for the run was only 9 % of peak power recorded (note that Downhill bicycles have changed since 2006 and with the modernisation the bottom bracket width has increased and no longer allows SRM cranks to be fitted and thus the current study was unable to obtain power values from the field study). This small percentage was due to a large number of zero values recorded, suggesting that the riders spent significant periods of the run not pedalling. Investigation into cadence confirmed this and showed that the riders spent 55 % of total run time not pedalling; confirmation that DH is intermittent in its nature. Furthermore, periods of pedalling were of short duration, (~ 5 seconds). As mentioned, both studies (Hurst and Atkins (2006) and the current study) showed no relationship between PPO and speed characteristics of the run (mean and peak speeds), however, perhaps it is not appropriate to compare the PPO from the two studies. The current study obtained PPO values from laboratory-based testing and Hurst and Atkins (2006), used field obtained PPO for identification of relationships. It may also be considered that where significance was not found (PPO and DH performance/ section performance, time to peak PO and DH performance/ section 4 performance) it may have been due to the size of the current study and perhaps a larger subject group may have achieved statistical significance. Certainly studies in the future should consider this. The results are still both in agreement, however, that due to the sporadic nature of the sport, PPO (and time to peak PO) will not influence full run speed characteristics. The intermittent nature may also suggest that anaerobic power may be influential during certain areas of the course where the rider is called upon to generate large speeds.

Power Characteristics and Course Sections

Peak power output (PPO) was shown to have a negative influence on course Section 5 duration. Previous analysis (Chapter Four) showed that course Section 5 duration was not significantly related to over all run time, so this would suggest that although the relationship between PPO and Section 5 duration was significant, it is unlikely to have a impact on DH performance. PPO and duration of Section 1, although not a statistically significant, showed a trend towards a relationship ($p = 0.063$) and with a larger subject group this relationship may become significant.

Cycling involves the repeated application of force to the pedals in order to move forward and the greater the force application the greater the power generated and the analysis and combination of the results from the current study would begin to suggest that speed (from power production) at the start of the race is important for overall performance and in the very least, important in gaining momentum for the run. As determined in Chapter Four, PPO and time to peak PO are significantly related to each other ($p = 0.043$). Time to peak power did have a positive influence on Section 1 duration (participants who could generate their PPO quickest were more likely to complete section 1 quickest), thus, supporting the theory that peak power is an important factor at the start of the race. Perhaps a larger subject group would see PPO become significantly influential on Section 1 duration.

Physiological Attributes Influencing the Start of the Race

Downhill efforts have been shown to be of short duration (~ 5-s) and independent of the initial starting effort, they seem to be a method of reducing deceleration rather than producing speed and power (Hurst and Atkins, 2006). Hurst and Atkins thus, conclude the power generation at the start of the race is potentially important for overall performance as it is here where the PPO is generated within the timed run. The energy required during short-duration maximal exercise (~ 10-s) is provided through anaerobic pathways; PCr hydrolysis and glycogenolysis (Gaitanos *et al.,* 1993), and thus, when determining whether the anaerobically obtained PPO had an influence on DH performance, the first few seconds of the race were investigated in greater detail. It was hypothesised that anaerobic PPO would influence the total distance travelled at markers within the first 15-seconds of the race and correlations did confirm this (Table 5.5). Furthermore, time to peak PO also positively influenced total distance travelled at the start of the run (Table 5.7). Thus, PPO and time to peak PO have a positive and significant influence on DH performance at the start of the race – already an area identified as an important determinant on DH performance (Study Two).

The importance of the static start has been discussed in a number of studies over a range of sprint sports (de Koning *et al.,* 1989, 1999; van Ingen *et al.,* 1994). De Koning *et al*., (1999) suggesting that when a rider adopted an 'all-out' pacing strategy during a 1000 m cycling time trial, they produced a better race time than if a strategy that released less anaerobic energy at the beginning of the race. They showed that although the 'all-out' pacing strategy saw considerably more energy lost to friction than the other strategies, the higher initial acceleration and subsequent lower end kinetic energy outweighed the disadvantage of these frictional losses. De Koning *et al.,* conducted their study on an indoor track in comparison to the highly variable terrain of the DH course, thus, direct comparisons cannot be conclusive. It would therefore be appropriate in future research to look in more depth at the start of the DH race and investigate pacing strategies in this discipline.

Identification of riders' physiological attributes as having a positive effect on the performance during the start of the race is of particular importance to coaches. Initial analysis (Chapter Four) indicated the first 10-seconds of the run were positively correlated to overall run duration (overall performance). Thus, these results not only identify that performance during the start of the race is important for overall performance but it confirms that a riders physiological attributes (PPO and time to peak PO) are an influential contributor to this performance.

To further support the importance of the starting performance, identified in the current study, are the claims of the investigations into push-start sports such as bobsled, luge and skeleton. Whilst these winter sliding sports may seem to be unconnected to DH, many important parallels can be drawn. Platzer *et al.,* 2009; Zanoletti *et al.,* 2006; Bruggemann *et al.,* (1997) all identified significant correlations between the start time (acceleration) and overall race performance of these three sliding sports. Equipment and environmental factors can be influential in these sliding sports as with DH and the identification of the importance of the start allows athletes to train their physiological systems accordingly (in addition to skill-based training) and know that the training could significantly impact and improve their overall performance. Although perhaps more research into the DH start would be useful, certainly these initial findings seem to mirror those of the investigation into the winter sliding sports and therefore the importance of the performance a the start of DH race should not be underestimated.

Physiological Attributes Influencing the Technical Section 4.

Impellizzeri *et al.,* (2005) note that whilst there are some similarities between the physical and physiological characteristics of on-road and cross-country cyclists (low body mass, high VO_{2max}) there are some differences between the demands of the disciplines such as course conditions, isometric contractions of the arm and leg muscles required for shock absorption and bike stabilisation during off-road descents and also the higher technical ability required of the off-road cyclists. Impellizzeri and Marcora (2007) expand further and state that technical ability is particularly important during the downhill sections of the XC course. Technical cycling ability is learnt and improved through much time spent on the bicycle practicing and riding the terrain. As it would appear that technical ability has a large effect on DH performance determined by the identification of the importance of course Section 4 and the performance within this section (Chapter Four). There needs to be further investigations into the physiological, motor skills and indeed psychological aspects that contribute to bike handling skills. Coaches should be aware that bike handling skills will be hugely dependent on physiological aspects such as strength, reaction time and energy systems and specific training to address these physiological aspects should not be dismissed.

The current study did not identify any significant relationships between selected physiological attributes (PPO and time to peak PO) of the DH athletes and characteristics of the technical course Section 4, although Section 4 duration was close to significance when correlated with time to peak PO, further suggesting that technique was the main factor influencing performance of this section. Perhaps the ability to produce peak power quickly may be influential when combating the deceleration encountered during the technical terrain. A larger subject group may confirm this. The main finding of the Section analysis (Study Two) identified that the Section 4 duration was related to mean speed and that overall run duration (DH performance) was influenced by mean and peak Section 4 speeds. Thus, the ability of the rider to skilfully navigate and control the bike through the technical obstacles and terrain appears to be the most important factor in successful Section 4 performance. In this case therefore it may not just be the ability to produce power and hence speed, but the ability to control speed that is important, this will require future investigators to look at braking patterns during the race run.

Hurst and Atkins (2006) showed no relationships between peak power output and time to peak powers on DH run time and thus concluded that a high level of technical ability could compensate for the lack of power in the explosive start of the race. In contrast however, we have shown that the start of the race has an impact on performance and hence power out of the gate needs to be considered by coaches and athletes alike. The data here highlights that DH performance may be course-dependant as the study on the current course did show PPO and time to peak PO to have a positive influence on aspects of performance. Interestingly, Impellizzeri and Marcora (2007) reported that preliminary studies from the Australian Institute of Sport suggest that technical ability can influence how much power can be generated. Thus, although physical training may help riders on the technical aspects of the course, if the technical skills are particularly poor then the physical training benefits may not be able to be fully utilised in performance.

Applications of Physiology into Downhill Mountain Biking

The power output of a muscle is determined by the velocity of shortening and strength of the muscle (Jones *et al.,* 1989). To increase power output to achieve the best start possible, one or both of these factors must be increased (Figure 5.1). It is unlikely that training can increase power output by increasing shortening velocity as a result of change in fiber type (Type I to Type II); however, shortening velocity may be improved by increasing muscle length (Jones *et al.,* 1989). The speed of a muscle contraction is proportional to its length and thus increasing the number of sarcomeres may improve muscle shortening velocity (Jones *et al.,* 1989). This can be achieved through stretching and will allow the Downhill athlete to generate power quickly at the start of the race and to maximise power generation during subsequent periods of (short-duration) pedalling. Power output can also be increased by improving muscle strength. An increase in maximum isometric strength should show a proportional increase in muscle strength achieved at all velocities and thus, increase peak power generated (Jones *et al.,* 1989). This method of increasing power would be particularly appropriate for DH athletes as it would not affect time to peak power output.

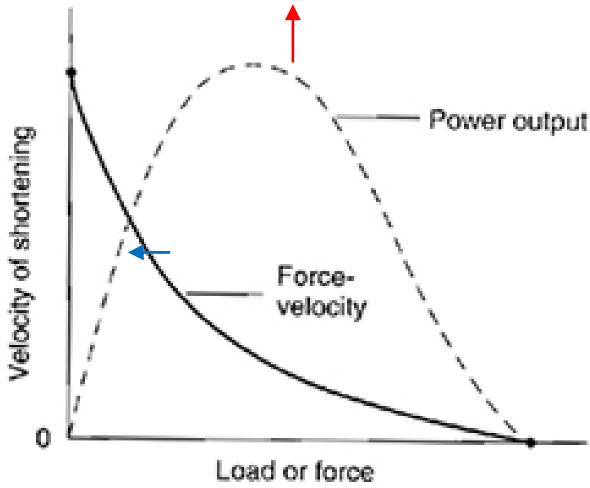


Figure 5.1. Force-velocity curve. An increase in the velocity of muscle shortening velocity would increase the peak power(red arrow) and the increase the speed of achieving powers in reaching peak power (blue arrow). Adapted Imagine accessed (24.03.2010) from www.quintic.com/education/case_studies/power.htm

Summary

The current study identified that PPO had a positive influence on DH performance, namely in the initial 5, 6 and 10 seconds of the race. The current study also identified two portions of the course whereby performance during these sections, would influence overall DH performance; the start and the technical Section 4. Anthropometric investigations highlighted a number of characteristics to be desirable to DH mountain bike athletes (somatotype, femur length) and thus Hypothesis 1 was accepted. For the first time, it was identified that the anaerobic power attributes of a rider (determined from the laboratory-based testing) could influence performance during the start of the race, making this an important component of the overall run and thus Hypothesis 2 and 3 were accepted. The ability of the rider to skilfully navigate and control the bike through the technical obstacles and terrain of a DH race track would also appear to be an important contributing factor to success in DH. The conclusions drawn from the current study stand as a platform for future research to be based on to allow a more comprehensive understanding into this exciting sport.

Chapter Seven – Further Discussion For Future Research

Fatigue During a DH Race Run

Downhill is an intermittent activity made up of short duration (~ 5-seconds) efforts and periods of pedalling only make up < 45 % of total runtime. The greatest speed generation and power output is seen at the start of the DH run. It is widely accepted that energy during short-duration maximal exercise is derived from anaerobic pathways resulting in lactate formation and phosphocreatine degradation (Gaitanos *et al.,* 1993). Course dependant, the rider will be called upon to generate power at intermittent periods of the race run and future research may want to investigate the effects of fatigue during DH racing. Specifically of interest; the effect (and magnitude) of fatigue on the intermittent periods of pedalling efforts during the run. Many studies have investigated the muscle metabolism and ability to re-produce power in response to short-duration maximal exercise (Bogdanis *et al.,* 1995; Gaitanos *et al., 1993*; Balsom *et al.,* 1992; McCartney *et al., 1986*). The present study measured PPO during maximal sprints of a duration specific to DH (6-seconds), however, due to sufficient rest (5 minutes in the present study) in between bouts, the effects of fatigue on PPO and MPO of repeated sprint efforts could not be determined. Gaitanos *et al.,* (1993), conducted a study which measured PPO and MPO from ten, 6-second sprints separated by 30-second rest. They saw a decrease in both PPO and MPO as the sprints progressed however; it was not until the fourth sprint that this decrease became significant. Depending on DH course duration, the end of the race may see MPO and PPO significantly decreased. Gaitanos *et al* (1993), reported that after the 5th sprint, a 12.6 % and 15.9 % decrease in MPO and PPO, respectively. This study may suggest a similar fatigue pattern (if not greater, due to the shorter rests and terrain) may be observed during DH mountain biking and future research may wish to look at the effects of fatigue to allow efficient and optimal power production throughout the race. The current study also identified the influential effects of impacts (Chapter Four) experienced through downhill racing. Future research may wish to investigate this area further and determine the effect impacts and vibrations experienced during DH have on fatigue.

Standing Riding Position

Rider position has been subject to a number of studies in the past and conclusions suggest it to have a direct effect on cycling efficiency (Millet *et al.,* 2002). Downhill mountain bikers have a unique riding position in that they do not sit down at any point during the race. The rider stands on the pedals regardless of periods of pedalling or non-pedalling. Observations of athletes in seated and standing cycling positions in laboratory and field settings have identified they may produce different outputs (Wilson *et al.,* 2009). Further investigation into Downhill mountain bike riding position may therefore be an interesting avenue for future research. Studies showed that during moderate intensity cycling, standing position showed a greater VO_2 response than when in the seated position (Tanaka *et al.,* 1996; Ryschon and Stray-Gundersen, 1991). The extra work of the upper body muscles in the standing position may account for this observation. Heart rate response to DH riding showed high mean HRs (91 ± 11 % HR_{max}) and perhaps the standing position and upper body work (including isometric contractions to absorb terrain) have a role in this. There are studies however, which show no difference in VO_2 response when the rider is sitting or standing (Wilson *et al.,* 2009; Millet *et al*, 2002). These studies investigate rider positions during higher intensity exercise (> 70 % VO_{2max}) and therefore are perhaps more applicable to the intensities of DH. However, it is very important to note, all studies look at the physiology of cycling on a flat or uphill gradient and thus, results are not comparable to the effects of standing positions for the downhill riders. A future investigation into the physiological response during downhill riding would be of use to DH athletes and coaches to give them a specific and relevant insight to the demands of the standing position riders adopt.

Braking Pattern and Line Choice

Although not discussed in great detail, the importance of the technical skills of DH riders have been highlighted in the current study. The terrain of a DH course is highly changeable and the ability of the rider to navigate the bicycle at speed during technical areas of the course is important for performance. Cycling downhill at speed, places a high demand on effective decision making in terms of optimal line selection, braking and duration, for performance. This may be influenced by a number of factors and the rider must balance the competitive risks and the risk of injury effectively. An un-published study from our University (Westbury *et al.,* personal communication, 19 March 2010) investigated decision-making and line choice in response to downhill running. They determined that line choice was based around finding firm terrain which increased their confidence to accelerate. Furthermore, risk of injury and fatigue were also dominant factors in line choice and despite the runner finding and covering optimal line choice/ terrain, fatigue may override the decision to accelerate. This study can be applied to downhill cycling, however, the speed of decision-making process must be quicker due to the higher speeds travelled by the DH cyclists. Future studies may aim to determine a framework for decision making in DH cycling and gain insight into the braking pattern in particularly technical sections and would thus generate an understanding of the psychological demands of the sport and may aid in mental preparation for competition.

Caffeine

Caffeinated energy drinks are readily available at DH competitions and often large energy drink companies sponsor the events and supply prizes. Many riders drink caffeinated drinks prior to competing and whether the athletes themselves are aware of the effects of caffeine on their performance is unlikely. There are now many studies that examine the effects of caffeine on performance and it is accepted that caffeine can be used as an ergogenic aid to improve performance (McNaughton *et al.,* 2008; Flinn *et al.,*1990). The effects of caffeine have been shown to have a positive effect on performance by increasing time to exhaustion when taken before and during exercise. Caffeine has also been reported to have mood elevating effect, increase alertness and concentration. It may be these effects that have particular significance in relation to DH mountain biking for decision-making (Ivy *et al.,* 2009). Whilst many studies investigate the effects of caffeine on endurance performance (Ivy *et al.,* 2009; McNaughton *et al.,* 2008; Flinn *et al.,* 1990) however Woolf *et al.,* (2008) examined the effects of a moderate dose of caffeine on anaerobic performance. They determined a significantly greater PPO during a Wingate test after caffeine ingestion. This may have implications in peak power generation at the start of the DH race. The high availability of caffeine-based drinks at DH events and the possible positive effects on DH performance should direct future investigations.

Measurements of Power Output in the Field

The current study planned to measure power output during the field-based assessments however, with the advancement in the DH bicycles, SRM cranks cannot be fitted onto the rig. Other power measuring devices (e.g. Power Tap, Polar® S710) were determined inappropriate and as such, SRM cranks are the most realistic way of measuring power during DH mountain biking. Currently, the bottom bracket it too wide for the axel of the crank to fit the rig, perhaps, with the correct resources, this problem could be overcome to allow measurements of power output, cadence and speed to be measured during DH mountain biking.

REFERENCES

Achten J and Jeukendrup A (2003). "Heart Rate Monitoring: Applications and Limitations." *Sports Medicine* **33**(7): 517-538.

Adrados C, Girard I, Gendner J and Janeau G. (2002). "Global Positioning System (GPS) location accuracy improvement due to Selective Availability removal." *Comptes Rendus Biologies* **325**(2): 165-170.

Astrand P and Rhyming I (1954). "A monogram for calculation of aerobic capacity from pulse rate during submaximal work." *Journal of Applied Physiology* **7**: 218-221.

Atkinson G, Davison R, Jeukendrup A and Passfield L. (2003). "Science and cycling: current knowledge and future directions for research." *Journal of Sports Sciences* **21**(9): 767-787.

Axelrod J and Reisine T (1984). "Stress hormones: their interaction and regulation." *Science* **224**(4648): 452-459.

Balmer J, Davison R, Coleman D and Bird S (2000). "A comparison of power output recorded by an SRM powercrank and Kingcycle test rig." *Journal of Sports Sciences* **18**(1): 27.

Balmer J, Bird S, Davison R, Doherty M and Smith P. (2004). "Mechanically braked Wingate powers: agreement between SRM, corrected and conventional methods of measurement." *Journal of Sports Sciences* **22**(7): 661-667.

Balsom P, Seger J, Sjodin B and Ekblom B (1992). "Physiological responses to maximal intensity intermittent exercise." European *Journal of Applied Physiology and Occupational Physiology **65**(2): 144-149.*

Baron R (2001). "Aerobic and anaerobic power characteristics of off-road cyclists." *Medicine & Science in Sports & Exercise* **33**(8): 1387-1393.

Bassett D and Howley E (2000). "Limiting factors for maximum oxygen uptake and determinants of endurance performance*." Medicine & Science in Sports & Exercise* **32**(1): 70-84.

Bentley D, Wilson G and Davie A. (1998). "Correlations between peak power output, muscular strength and cycle time trial performance in triathletes." *Journal of Sports Medicine & Physical Fitness* **38**(3): 201-207.

Berry M, Dunn C, Edwards D, Pittman C (1993). "The effects of a mountain bike suspension system on metabolic energy expenditure." *Cycling Sci.* Spring: 8-13.

Bertucci W, Duc S, Pernin J and Grappe F . (2005). "Validity and Reliability of the PowerTap Mobile Cycling Powermeter when Compared with the SRM Device." *International Journal of Sports Medicine* **26**(10): 868-873.

Bogdanis G, Nevill M, Boobis L, Lakomy H and Nevill A (1995). Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man.*Journal of Physiology* **482**.(2): 467-480

Bruggemann G, Morlock M, Zatsiorsky V (1997). Analysis of the Bobsled and Men’s Luge events at the XVII Olympic Winter Games in Lillehammer. *Journal of Applied Biomechanics* **13**(1): 98-108.

Coutts A and Duffield R. "Validity and reliability of GPS devices for measuring movement demands of team sports." Journal of Science and Medicine in Sport **In Press, Corrected Proof**.

Coyle E (1999). "Physiological determinants of endurance exercise performance." *Journal of Science and Medicine in Sport* **2**(3): 181-189.

Craig N and Norton K (2001). "Characteristics of track cycling" *Sports Medicine* **31**(7): 457-468.

Cyclist, I. U. (1/01/08, 1/1/08). "UCI CYCLING REGULATIONS; PART 4 MOUNTAIN BIKE RACES." Retrieved 10/11/08, from http://www.uci.ch/Modules/BUILTIN/getObject.asp?MenuId=MTkzNg&ObjTypeCode=FILE&type=FILE&id=34424&.

Davies C. and Sandstrom E (1989). "Maximal mechanical power output and capacity of cyclists and young adults*." European Journal of Applied Physiology and Occupational Physiology* **58**(8): 838-844.

Davison R, Balmer J, Morgan G, Coleman D and Bird S (2000). "The reliability of power output recorded during a maximal aerobic power test using an SRM powercrank and Kingcycle test rig." *Journal of Sports Sciences* **18**(1): 29.

Dawson B, Hopkinson R, Appleby B, Stewart G and Roberts C (2004). "Player movement patterns and game activities in the Australian Football League." *Journal of Science & Medicine in Sport* **7**(3): 278-291.

de Konning J, Thomas J, Berger M, Groot G, van Ingen Schenau (1995). "The start in speed skating: from running to gliding." *Medicine & Science in Sports & Exercise* **27**(12): 1703-1708.

de Koning J, Bobbert M and Foster C (1999). "Determination of optimal pacing strategy in track cycling with an energy flow model." *Journal of Science and Medicine in* Sport **2**(3): 266-277.

Deurenberg P, Pieters J and Hautvast J (1990). "The assessment of the body fat percentage by skinfold thickness measurements in childhood and young adolescence." *British Journal of Nutrition* **63** (02): 293-303.

Dorel S, Bourdin M, van Praagh E, Lacour J and Hautier (2003). "Influence of two pedaling rate conditions on mechanical output and physiological responses during all-out intermittent exercise." *European Journal of Applied Physiology* **89**(2): 157-165.

Duc S, Villerius V, Bertucci W and Grappe F. (2007). "Validity and Reproducibility of the Ergomo Pro Power Meter Compared With the SRM and Powertap Power Meters." *International Journal of Sports Physiology & Performance* **2**(3): 270-281.

Duma S, Manoogian S, Bussone W, Brolinson G, Goforth M, Donnenwerth J, Greenwald, Chu J, Crisco J, (2005). Analysis of Real-time head accelerations in Collegiate Football Players. *Clinical Journal Sports Medicine* **15** (1): 3-8.

Edgecomb S. and Norton K (2006). "Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian football." *Journal of Science & Medicine in Sport* **9**(1-2): 25-32.

Eston R, Rowlands A, Charlesworth S, Davies A and Hoppitt T (2005). "Prediction of DXA-determined whole body fat from skinfolds: importance of including skinfolds from the thigh and calf in young, healthy men and women." *Eur J Clin Nutr* **59**(5): 695-702.

Faria E, Parker D and Faria I (2005). "The Science of Cycling: Physiology and Training. Part 1." *Sports Medicine* **35**(4): 285-312.

Faria E, Parker D and Faria I (2005). "The Science of Cycling: Factors Affecting Performance. Part 2." *Sports Medicine* **35**(4): 313-337.

Finn J, Maxwell B and Withers R (2000). "Air-braked Cycle Ergometers: Validity of the Correction Factor for Barometric Pressure*." Int J Sports Med* **21**(07): 488-491.

Flinn S, Gregory J and Davies T (1990). "Caffeine Ingestion Prior to Incremental Cycling to Exhaustion in Recreational Cyclists." *Int J Sports Med* **11**(03): 188-193.

Foley J, Bird S and White J (1989). "Anthropometric comparison of cyclists from different events." *British Journal of Sports Medicine* **23**(1): 30-33.

Foss M. and Keteyian S (1998). Fox's physiological basis for exercise and sport. 6th ed. New York; United States, McGraw-Hill.

Foss O and Hallen J (2005). "Cadence and performance in elite cyclists." *European Journal of Applied Physiology* **93**(4): 453-462.

Gaitanos G, Williams C, Boobis L and Brooks S (1993). Human muscle metabolism during intermittent maximal exercise. *J Appl Physiol* **75**: 712-719.

Gardner A, Stephens S, Martin D, Lawton E, Lee H and Jenkins D (2004). "Accuracy of SRM and power tap power monitoring systems for bicycling." *Medicine & Science in Sports & Exercise* **36**(7): 1252-1258.

Gnehm P, Reichenbach S, Altpeter E, Widmer H and Hoppler H (1997). Influence of different racing positions on metabolic cost in elite cyclists. *Med. Sci. Sports Exerc.* **29**:818–823.

Godsen R, Carroll T, Stone S *(*1991). How well does the Polar Vantage XL heart rate monitor estimate actual heart rate? *Medicine & Science in Sports & Exercise* **23**(Suppl): 14.

Goodie J, Larkin K, Schauss S (2000). Validation of the polar heart rate monitor for assessing heart rate during physical and mental stress. *J Psychophysiol* **14**:159–64.

Gregory J, Johns D and Walls J (2007). "Relative Vs Absolute physiological measures as predictors of mountain bike cross-country race performance." *Journal of Strength & Conditioning Research* **21**(1): 17-22.

Hansen E, Jensen K and Pedersen P (2006). "Performance following prolonged sub-maximal cycling at optimal versus freely chosen pedal rate." *European Journal of Applied Physiology* **98**(3): 227-233.

Hawley J and Noakes T(1992). "Peak power output predicts maximal oxygen uptake and performance time in trained cyclists." *European Journal of Applied Physiology & Occupational Physiology* **65**(1): 79-83.

Heil D, Wilcox A and Quinn C. (1995). "Cardiorespiratory responses to seat-tube angle variation during steady-state cycling." *Medicine & Science in Sports & Exercise* **27**(5): 730-735.

Hopkins W, Schabort E and Hawley J (2001). "Reliability of Power in Physical Performance Tests." *Sports Medicine* **31**(3): 211-234.

Hultman E and Sjöholm H (1983). Electromyogram, force and relaxation time during and after continuous electrical stimulation of human skeletal muscle in situ. *The Journal of Physiology*, **339**: 33-40.

Hurst H and Atkins S (2006). "Power output of field-based Downhill Mountain biking." *Journal of Sports Sciences* **24**(10): 1047-1053.

Impellizzeri F, Sassi A, Rodriguez-Alonso M, Mognoni P and Marcora S (2002). "Exercise intensity during off-road cycling competitions." *Medicine & Science in Sports & Exercise* **34**(11): 1808-1813.

Impellizzeri F, Rampinini E, Sassi A, Mohnoni P and Marcora S (2005). "Physiological correlates to off-road cycling performance." *Journal of Sports Sciences* **23**(1): 41-47.
Impellizzeri F and Marcora S (2007). "The Physiology of Mountain Biking." *Sports Medicine* **37**(1): 59-71.

Ivy J, Kammer L, Ding Z, Wang B, Bernard J, Liao Y and Hwang J (2009). "Improved Cycling Time-Trial Performance After Ingestion of a Caffeine Energy Drink." *International Journal of Sport Nutrition & Exercise Metabolism* **19**(1): 61-78.

Jackson A and Pollock M (1978). "Generalized equations for predicting body density of men." *British Journal of Nutrition* **40**: 497-504.

Jacobs I, Tesch P, Bar-Or O, Karlsson J and Dotan R (1983). "Lactate in human skeletal muscle after 10 and 30 s of supramaximal exercise." *J Appl Physiol* **55**(2): 365-367.

Jeukendrup, A. and A. Van Diemen (1998). "Heart rate monitoring during training and competition in cyclists." *Journal of Sports Sciences* **16**: 91-99.

Jeukendrup A, Craig N and Hawley J (2000). "The bioenergetics of world class cycling." *Journal of Science and Medicine in Sport* **3**(4): 414-433.

Jones D, Rutherford O and Parker D (1989). "Physiological changes in skeletal muscle as a result of strength training." *Experimental Physiology* **74**(3): 233-256.

Karchin A and Hull M (2002). "Experimental Optimization of Pivot Point Height for Swing-Arm Type Rear Suspensions in Off-Road Bicycles." *Journal of Biomechanical Engineering* **124**(1): 101-106.

Kohler G and Boutellier U (2005). "The generalized force–velocity relationship explains why the preferred pedaling rate of cyclists exceeds the most efficient one." *European Journal of Applied Physiology* **94**(1): 188-195.

Kronisch R and Pfeiffer R (2002). "Mountain Biking Injuries: An Update." *Sports Medicine* **32**(8): 523-537.

Kyle C (1988). The mechanics and aerodynamics of cycling. In Medical and scientific aspects of cycling, *Human Kinetics*, p.235-251. United States.

Larsson P (2003). "Global Positioning System and Sport-Specific Testing." *Sports Medicine* **33**(15): 1093-1101.

Larsson P and Henriksson-Larsen K (2001). "The use of dGPS and simultaneous metabolic measurements during orienteering." *Medicine & Science in Sports & Exercise* **33**(11): 1919-1924.

Lawton E, Martin D and Lee H (1999). Validation of SRM power cranks using dynamic calibration. Fifth IOC World Congress; Oct 31-Nov 5; Sydney. Sydney: International Olympic Committee: 199

Lee H, Martin D, Anson J, Grundy D and Hahn A (2002). "Physiological characteristics of successful mountain bikers and professional road cyclists." *Journal of Sports Sciences* **20**(12): 1001-1008.

Leger L and Thivierge H (1988). "Heart rate monitors: validity, stability, and functionality." *Physician & Sports Medicine* **16**(5): 143-146; 148-149; 151.

Levy M and Smith G (2005). "Effectiveness of vibration damping with bicycle suspension systems." *Sports Engineering* **8**(2): 99-106.

Lucia A, Hoyos J and Chicharro J (2001). "Physiology of professional road cycling." *Sports Medicine* **31**(5): 325-337.

Lucia A., Pardo J, Durantez A, Hoyos J and Chicharro J (1998). "Physiological differences between professional and elite road cyclists." *International Journal of Sports Medicine* **19**(5): 342-348.

MacIntosh B, Neptune R and Horton J (2000). "Cadence, power, and muscle activation in cycle ergometry." *Medicine & Science in Sports & Exercise* **32**(7): 1281-1287.

MacRae H, Hise K and Allen P (2000). "Effects of front and dual suspension mountain bike systems on uphill cycling performance" *Medicine & Science in Sports & Exercise* **32**(7): 1276-1280.

Marsh A and Martin P (1993). "The association between cycling experience and preferred and most economical cadences." *Medicine & Science in Sports & Exercise* **25**(11): 1269-1274.

Martin J, Milliken D, Cobb J, McFadden K and Coggan A (1998). "Validation of a Mathematical Model for Road Cycling Power." *Journal of Applied Biomechanics* **14**(3): 276.

Mastroianni G, Zupan M, Chuba D, Berger R and Wile A (2000). "Voluntary pacing and energy cost of off-road cycling and running." *Applied Ergonomics* **31**(5): 479-485.

Maxwell B, Withers R, Ilsley A, Wakim M, Woodds G and Day L (1998). "Dynamic calibration of mechanically, air- and electromagnetically braked cycle ergometers." *European Journal of Applied Physiology & Occupational Physiology* **78**(4): 346-352.

McCartney N, Heigenhauser G and Jones N, et al. (1983). "Power output and fatigue of human muscle in maximal cycling exercise." *J Appl Physiol* **55**(1): 218-224.

McCartney N, Spriet L, Heigenhauser G, Kowalchuk J, Sutton J and Jones N (1986). "Muscle power and metabolism in maximal intermittent exercise." *J Appl Physiol* **60**(4): 1164-1169.

McNaughton L, Lovell R, Siegler J, Midgley A, Sandstrom M and Bentley D (2008). "The Effects of Caffeine Ingestion on Time Trial Cycling Performance." *International Journal of Sports Physiology & Performance* **3**(2): 157-163.

Millet G, Tronche C, Fuster N and Candau R (2002). "Level ground and uphill cycling efficiency in seated and standing positions." *Medicine & Science in Sports & Exercise* **34**(10): 1645-1652.

Millet G, Tronche C, Fuster N, Bentley D and Candau R (2003). "Validity and Reliability of the PolarÂ® S710 Mobile Cycling Powermeter." *Int J Sports Med* **24**(03): 156-161.

Mujika I and Padilla S (2001). "Physiological and performance characteristics of male professional road cyclists." *Sports Medicine* **31**(7): 479-487.

Nielens H and Lejeune T (2004). "Bicycle shock absorption systems and energy expended by the cyclist." *Sports Medicine* **34**(2): 71-80.

Nishii T, Umemura Y and Kitagawa K (2004). "Full suspension mountain bike improves off-road cycling performance." *Journal of Sports Medicine & Physical Fitness* **44**(4): 356-360.

Olds T, Norton K, Lowe E, Olive S, Reay F and Ly S(1995). "Modeling road-cycling performance." *Journal of Applied Physiology* **78**(4): 1596-1611.

Padilla S, Mujika I, Orbananos J and Angulo F (2000). "Exercise intensity during competition time trials in professional road cycling." *Medicine & Science in Sports & Exercise* **32**(4): 850-856.

Padilla S, Mujika I, Orbananos J, Santisteban J, Angulo F, Jose Goiriena J (2001). "Exercise intensity and load during mass-start stage races in professional road cycling" *Medicine & Science in Sports & Exercise* **33**(5): 796-802.

Palmer G, Noakes T and Hawley J (1997). "Effects of steady-state versus stochastic exercise on subsequent cycling performance." *Medicine & Science in Sports & Exercise* **29**(5): 684-687.

Paton C and Hopkins W (2001). "Tests of cycling performance." *Sports Medicine* **31**(7): 489-496.

Paton C and Hopkins W (2006). "Ergometer Error and Biological Variation in Power Output in a Performance Test with Three Cycle Ergometers." International Journal of Sports Medicine **27**(6): 444-447.

Pino J, Martinez-Santos R, Moreno M and Padilla, C (2007). Automatic analysis of football games using GPS on real time. *J Sports Sci Med* **6**(Suppl 10): 9.

Platzer H, Raschner C and Patterson C (2009). Performance determining physiological factors in the luge start. *Journal of Sports Sciences* **27** (3): 221-226.

Pollock M, Gaesser G, Butcher J, Despres J, Dishman R, Franklin B and Garber C (1998). "American College of Sports Medicine position stand: the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults." *Medicine & Science in Sports & Exercise* **30**(6): 975-991.

Reilly J, Wilson J and Durnin J (1995). "Determination of body composition from skinfold thickness: a validation study." *Archives of Disease in Childhood* **73**(4): 305-310.

Ryschon T and Stray-Gundersen J (1991). "The effect of body position on the energy cost of cycling." *Medicine & Science in Sports & Exercise* **23**(8): 949-953.

Sargeant A, Hoinville E and Young A (1981). "Maximum leg force and power output during short-term dynamic exercise." *Journal of Applied Physiology* **51**(5): 1175-1182.

Schutz Y and Herren R (2000). "Assessment of speed of human locomotion using a differential satellite global positioning system. *Medicine & Science in Sports & Exercise* **32**(3): 642-646

Seaward B, Sleamaker R, McAuliffe T and Clapp J (1990). The precision and accuracy of a portable heart rate monitor. *Biomedical Instrumentation and Technology* **24**:37–41,

Seifert J, Luetkemeier M, Spencer M, Miller D and Burke E (1997). "The effects of mountain bike suspension systems on energy expenditure, physical exertion, and time trial performance during mountain bicycling." *International Journal of Sports Medicine* **18**(3): 197-200.

SRM. Retrieved 7/11/08, 2008, from http://srm.de/englisch/prod_srmts_powerm.html.

Stapelfeldt B, Schwirtz A, Schumacher Y and Hillebrecht M (2004). "Workload Demands in Mountain Bike Racing." *International Journal of Sports Medicine* **25**(4): 294-300.

Stone M, Sands W, Carlock J, Callna S, Dickie D, Daigle K, Cotton J, Smith S and Hartman M (2004). "The Importance of Isometric Maximum Strength and Peak Rate-of-Force Development in Sprint Cycling." The Journal of Strength & Conditioning Research **18**(4): 878-884.

Swain D (1994). "The influence of body mass in endurance bicycling. / Influence de la masse corporelle lors d ' epreuves d ' endurance en cyclisme*." Medicine & Science in Sports & Exercise* **26**(1): 58-63.

Takaishi T, Yamamoto T, Ono T, Ito T and Moritani T (1998). "Neuromuscular, metabolic, and kinetic adaptations for skilled pedaling performance in cyclists." Medicine *& Science in Sports & Exercise* **30**(3): 442-449.

Tanaka H, Bassett D, Best S and Barker K (1996). "Seated versus standing cycling in competitive road cyclists: uphill climbing and maximal oxygen uptake." *Canadian Journal of Applied Physiology* **21**(2): 149-154.

Terbizan D, Dolezal B and Albano C (2002). "Validity of seven commercially available heart rate monitors." *Measurement in Physical Education & Exercise Science* **6**(4): 243-247.

Thorstensson A., Grimby G and Karlsson J (1976). "Force-velocity relations and fiber composition in human knee extensor muscles." *J Appl Physiol* **40**(1): 12-16.

Titlestad J, Fairlie-Clarke T, Whittaker A, Davie M, Watt I and Grant S (2006). "Effect of suspension systems on the physiological and psychological responses to sub-maximal biking on simulated smooth and bumpy tracks." *Journal of Sports Sciences* **24**: 125-135.

Too D (1990). "Biomechanics of cycling and factors affecting performance." *Sports Medicine* **10**(5): 286-302.

Townshend A, Worringham C, Whittaker A, Davie M, Watt I and Grant S (2008). "Assessment of Speed and Position during Human Locomotion Using Nondifferential GPS." *Medicine & Science in Sports & Exercise* **40**(1): 124-132.

van Ingen Schenau G, de Koning J and de Groot G (1994). "Optimisation of sprinting performance in running, cycling and speed skating." *Sports Medicine* **17**(4): 259-275.

van Soest A and Casius L (2000). "Which factors determine the optimal pedaling rate in sprint cycling?" *Medicine & Science in Sports & Exercise* **32**(11): 1927-1934.

Wang E and Hull M (1997). "A Dynamic System Model of an Off-Road Cyclist." J*ournal of Biomechanical Engineering* **119**(3): 248-253.

Warner S, Shaw J and Dalsky G (2002). "Bone mineral density of competitive male mountain and road cyclists." *BONE* **30**(1): 281-286.

Westbury T. Fast and frugal heuristics and downhill running speed over steep, rough and varied terrain: A preliminary study. (Personal communication, 19 March 2010)

Weyand P, Lin J and Bundle M (2006). "Sprint performance-duration relationships are set by the fractional duration of external force application." *Am J Physiol Regul Integr Comp Physiol* **290**(3): R758-765.

Wilber R, Zawadzki K, Kearney J, Shannon M and Disalvo D (1997). "Physiological profiles of elite off-road and road cyclists." *Medicine & Science in Sports & Exercise* **29**(8): 1090-1094.

Wilmore J, Constable S, Stanforth P Buono M, Tsao Y, Lowdon B, Ratliff R and Frederick B (1982). Mechanical and physiological calibration of four cycle ergometers. *Med Sci Sports Exerc*; **14**: 322-5

Wilson R, Snyder A and Dorman J (2009). "Analysis of Seated and Standing Triple Wingate Tests." *The Journal of Strength & Conditioning Research* **23**(3): 868-873

Witte T and Wilson A (2004). "Accuracy of non-differential GPS for the determination of speed over ground." *Journal of Biomechanics* **37**(12): 1891-1898.

Woolf K, Bidwell W and Carlson A (2008). "The Effect of Caffeine as an Ergogenic Aid in Anaerobic Exercise." *International Journal of Sport Nutrition & Exercise Metabolism* **18**(4): 412-429.

Zanoletti C, Torre A, Merati G, Rampinini and Impellizzeri F (2006). Relationship between push phase and final race time in Skeleton performance. *Journal of Strength and Conditioning Research* **20** (3): 579-583.

Internet Resources

Figure 2.4. http://gpsports.com/gpsports_website/index.php?category=6 &page=19
(Accessed - 05/05/2009).

Figure 2.5.Picture image from: http://content.answers.com/main/content/im
g/oxford/Oxford_Body/019852403x.g-and-g-suit.1.jpg. (Accessed: 05/05/2010).

Figure 3.9. Adapted Imagine from www.quintic.com/education/case_studies/power.htm
(Accessed - 24.03.2010)

Bibliography

Bird S, Davison R (1997). Physiological testing guidelines (British Association of Sport and Exercise Sciences, Leeds), 3rd ed.

Burke E. High tech cycling. Illinois: Human Kinetics; 1996.

Carter J and Heath B (1990). Somatotyping - Development and Applications. Cambridge, UK: Cambridge Univ. 1990 Press, p. 374.

Garrett and Kirkendall (2000). Exercise and Sports Sciences. England Lippincott Williams & Wilkins p 31-52.

Norton K. (1996). Anthropometric estimation of body fat. In *Anthropometrica* (edited by K. Norton, and T. Olds), pp. 171± 198. Sydney, NSW: University of New South Wales Press.

McArdle W and Katch V (2007). Exercise Physiology: Energy, Nutrition and Human Performance. Baltimore, Lippincott Williams & Wilkins.

Wilmore J, Costill D. Physiology of sport and exercise. Champaign (IL): Human Kinetics, 1994

Smith Jr. S, Allen J, Blair S, Bonow R, Brass L, Fonarow G, Grundy S, Hiratzka L, Jones D, Krumholz H, Mosca L, Psaternak R, Pearson T, Pfeffer M and Taubert K. AHA/ACC guidelines for secondary prevention for patients with coronary and other atherosclerotic vascular disease: 2006 update endorsed by the National Heart, Lung, and Blood Institute J Am Coll Cardiol 2006; 47:2130-2139.

APPENDICES

LIST OF ABBREVIATIONS

DH	Downhill mountain biking
dGPS	Differentiated GPS
DOP	Dilution of precision
GPS	Global Positioning System
HR	Heart rate
HRM	Heart rate monitor
ISAK	International Society for the Advancement of Kinanthropometry
LOC	Loss of consciousness
MAP	Maximal aerobic power
MPO	Mean power output
PO	Power output
PPO	Peak power output
SA	Selective availability
s.f	skinfold
SRM	Schoberer Rad Meβtechnik
TT	Time trial
UCI	Union Cycliste Internationale
VO_2	Rate of oxygen uptake
VO_{2max}	Maximal oxygen uptake
XC	Cross country mountain biking

GLOSSARY OF TERMS

Acceleration	The rate of change of velocity with respect to magnitude or direction.
Anthropometry	The measurement of the size and proportion of the human body.
Cadence	The number of revolutions of the crank per minute (rpm).
Correlation	The degree to which two or more attributes or measures show a tendency to vary together.
Downhill	A sub-discipline of mountain biking.
G-force	The g-force associated with an object is its acceleration relative to free fall.
GPS	Global positioning systems are a space-based navigation system that provides location and time information in all weather, at all times when there is an unobstructed line of sight.
Physiology	The branch of science concerned with the functioning organism including all physical and chemical processes.
Power	Work accomplished per unit of time, expressed in watts (W).
PPO	The maximal power output reached in a unit of time (W).

EDINBURGH NAPIER UNIVERSITY

Faculty of Health, Life and Social Sciences

Participant Information

TITLE OF PROJECT:
The physiological demands of Downhill Mountain biking.

INVITATION TO TAKE PART IN A RESEARCH STUDY:
You are being invited to take part in a research project, which will assess the physiological demands of Downhill Mountain biking.

For this study, you will be asked to participate in two testing sessions;

- A lab-based session will take place in the Performance laboratory at the Merchiston campus of Edinburgh Napier University. This session will allow familiarisation with the equipment prior to body composition measures, consisting of various limb length, breadth and circumferences measures and skinfold measures. You will then be asked to complete six, 6 second maximal sprints, with adequate rest periods in between. The aim of this test is to assess your power characteristics and to determine an optimal cadence for producing peak power. Duration of this session will be between 2 and 2.5 hours. You should expect to feel physically tired at the end of the session.
- A field-based session will take place at Innerleithen. You will be asked to perform a minimum of 3 runs of this track, which will be timed. You will be asked to wear a heart rate monitor and a GPS unit to monitor speed, distance, altitude and force.

Following the test and only if you attend all sessions, you will receive an individual report, detailing your results and the impact they may have on you Downhill performance.

This study will benefit you by providing you will a detailed account of your fitness specific to your sport. In addition, the study will allow us to investigate the physiological demands of Downhill mountain biking, information that is currently unavailable. The overall aim will be to gain information to allow riders and their coaches to devise specific training programmes to improve overall Downhill performance.

PARTICIPATION AND TERMINATION:
Participation in this study is voluntary. You may terminate your participation in this study at any time, without explanation.

RISKS:
We ask that you complete a medical questionnaire prior to participation. While you will experience physical discomfort as a result of working at high intensities, there are no known risks of this study over and above this activity as a hobby.

CONFIDENTIALITY:
The data collected from this study will be held in confidence and only members of the research team will have access to it. If the research is published, you will not be individually identifiable. The data will be destroyed upon the completion of the project.

FURTHER INFORMATION: contact **Suzi Hadden.** Email: s.hadden@napier.ac.uk Tel: 0773 051 0262

EDINBURGH NAPIER UNIVERSITY

Faculty of Health, Life and Social Sciences

Participant Consent Form

TITLE OF PROJECT:

The Physiological Demands of Downhill Mountain Biking.

CONSENT:

By signing below you are agreeing that you have read and understood the Information Sheet and that you agree to take part in the research project.

You are agreeing that your data may be used for research purposes on the understanding that your data will not be individually identifiable and that the data will be destroyed upon completion of the project.

____

Participant's printed name

________________________________ ______________________

Participant's signature *Date*

________________________________ ____________________________

Parent/ Guardian's signature (if under 18) *Date*

________________________________ ____________________________

Printed Name of Person Obtaining Consent *Signature of Person Obtaining Consent*

FOR FURTHER INFORMATION ABOUT THIS STUDY: Suzi Hadden (s.hadden@napier.ac.uk) will be glad to answer your questions about this study.

Anthropometric Profile

Name1					
Name 2					
Country					
Ethnicity					
Sex (male=1, female=2)					
Sport	**DH MTB**				
Date of Measurement					
Date of Birth				**3rd**	
Measure	**1**	**2**	**3**	**Measure?**	
Body mass				###	###
Stretch stature				###	###
Sitting Height				###	###
Triceps sf				###	###
Subscapular sf				###	###
Biceps sf				###	###
Iliac Crest sf				###	###
Supraspinale sf				###	###
Abdominal sf				###	###
Front Thigh sf				###	###
Medial Calf sf				###	###
Arm girth relaxed				###	###
Arm girth flexed and tensed				###	###
Forearm Girth				###	###
Wrist Girth				###	###
Waist girth (min.)				###	###
Gluteal girth (max.)				###	###
Thigh (1cm dist glut)				###	###
Mid Thigh				###	###
Calf girth (max.)				###	###
Acromiale-radiale				###	###
Radiale-stylon				###	###
Midstylon-dactylion				###	###
Iliospinale b ht				###	###
Trochanterion b ht				###	###
Trochanterion-tibiale laterale				###	###
Tibiale laterale ht				###	###
Tibiale mediale-syphyrion tibiale				###	###
Foot length				###	###
Humerus breadth (biepicondylar)				###	###
Femur breadth (biepicondylar)				###	###

IDENTIFICATION OF ANATOMICAL LANDMARKS

Landmarks are identifiable skeletal points which mostly lie close to the surface of the skin and allow identification of the exact location of a measurement site or soft tissue site (e.g. limb girth or length, skinfold site).

Acromiale: The point on the superior aspect of the most lateral part of the acromion border. *Necessary for: tricep skinfold, bicep skinfold, arm girth (relaxed and tensed), acromiale-radiale length.*

Radiale: The point at the proximal and lateral border of the head of the radius. *Necessary for: tricep skinfold, bicep skinfold, arm girth (relaxed and tensed), acromiale-radiale length, radiale-stylon.*

Stylion (radiale): The most distal point on the lateral margin of the styloid process of the radius.
Necessary for: wrist girth, midstylion-dactylion length.

Subscapulare: The under-most tip of the inferior angle of the scapula.
Necessary for: subscapula skinfold.

Iliocristale: The point on the iliac crest where a line drawn from the mid-axilla, on the longitudinal axis of the body meets the ilium.
Necessary for: iliac crest skinfold, supraspinale skinfold.

Iliospinale: The most inferior or under-most part of the tip of the anterior superior iliac spine.
Necessary for: supraspinale skinfold, iliospinale-box height.

Trochanterion: The most superior point on the greater trochanter of the femur. *Necessary for: trochanterion-box height, trochanterion-tibilale laterale length.*

Tibiale-laterale: the superior point on the lateral border of the head of the tibia.

Necessary for: trochanterion-tibiale laterale length, tibiale laterale height.

Tibiale-mediale: The most superior point on the medial border of the head of the tibia.

Necessary for: tibiale mediale-sphyrion tibiale length.

Sphyrion-tibiale: The most distal tip of the medial malleoulus.

Necessary for: tibiale mediale-sphyrion tibiale length.

SPRINT TEST PROTOCOL

Name: ______________________ **Height:** ______________
DOB: ______________________ **Weight:** __________
Date: ______________________

Warm Up

		RESISTANCE (W)	CADENCE (rpm)
5 minutes		100W	85-90
	2.30	100W	120-130
	3.30	100W	120-131

Start Test

			CADENCE (rpm)	Test Order	
Sprint 1	SPRINT	6 seconds			Hyperbolic Mode
	Active Rest 1	30 seconds	0 W		Mean:
	Passive Rest 1	4.30 minutes	N/A		Peak:
Sprint 2	SPRINT	6 seconds	60		
	Active Rest 2	30 seconds	0 W		Mean:
	Passive Rest 2	4.30 minutes	N/A		Peak:
Sprint 3	SPRINT	6 seconds	80		Mean:
	Active Rest 3	30 seconds	0 W		Peak:
	Passive Rest 3	4.30 minutes	N/A		
Sprint 4	SPRINT	6 seconds	100		Mean:
	Active Rest 4	30 seconds	0 W		Peak:
	Passive Rest 4	4.30 minutes	N/A		
Sprint 5	SPRINT	6 seconds	120		Mean:
	Active Rest 5	30 seconds	0 W		
	Passive Rest 5	4.30 minutes	N/A		Peak:
Sprint 6	SPRINT	6 seconds	140		Mean:
					Peak:

Cooldown

Time	Cadence (rpm)	Revs	Torque	Cadence (RAD)	Power (w)	Power ($W \cdot kg^{-1}$)
0.005	74.07	0	14.4878	7.77735181	112.677	1.16282

Cumulative Time	Time (s)	Heart Rate	% HR max	Distance (m)	Speed (km.hr^{-1})	Speed Zone
0.01	74.07	2.2	14.3746	7.77735	111.797	1.15373
0.015	74.07	4.4	14.4878	7.77735	112.677	1.16282
0.02	74.07	6.7	14.5444	7.77735	113.117	1.16736
0.025	74.07	8.9	14.4312	7.77735	112.237	1.15827
0.03	74.07	11.1	14.4878	7.77735	112.677	1.16282
0.035	74.07	13.3	14.601	7.77735	113.557	1.1719
0.04	74.07	15.6	14.5444	7.77735	113.117	1.16736
0.045	74.07	17.8	14.7142	7.77735	114.438	1.18099
0.05	74.07	20	14.9406	7.77735	116.198	1.19915
0.055	74.07	22.2	15.6763	7.77735	121.92	1.2582
0.06	74.07	24.4	15.5631	7.77735	121.04	1.24912
0.065	74.07	26.7	16.412	7.77735	127.642	1.31725
0.07	74.07	28.9	17.3175	7.77735	134.684	1.38993
0.075	74.07	31.1	18.4493	7.77735	143.487	1.48077
0.08	74.07	33.3	20.5433	7.77735	159.772	1.64884
0.085	74.07	35.6	23.0334	7.77735	179.139	1.8487
0.09	74.07	37.8	25.9762	7.77735	202.026	2.08489
0.095	74.07	40	29.7114	7.77735	231.076	2.38468
0.1	74.07	42.2	33.5031	7.77735	260.565	2.68901
0.105	74.07	44.4	37.5778	7.77735	292.256	3.01606
0.11	74.07	46.7	43.4635	7.77735	338.031	3.48845
0.115	74.07	48.9	47.9909	7.77735	373.242	3.85183
0.12	74.07	51.1	54.1596	7.77735	421.218	4.34694
0.125	74.07	53.3	60.8376	7.77735	473.155	4.88292
0.13	74.07	55.6	68.0249	7.77735	529.053	5.45979
0.135	74.07	57.8	76.2309	7.77735	592.874	6.11841
0.14	74.07	60	85.0594	7.77735	661.537	6.82701
0.145	74.07	62.2	94.1709	7.77735	732.4	7.55831
0.15	74.07	64.4	103.962	7.77735	808.545	8.34412
0.155	74.07	66.7	114.092	7.77735	887.331	9.15718
0.16	74.07	68.9	124.505	7.77735	968.317	9.99296
0.165	74.07	71.1	137.182	7.77735	1066.91	11.0104
0.17	74.07	73.3	146.067	7.77735	1136.01	11.7236
0.175	74.07	75.6	158.8	7.77735	1235.04	12.7456
0.18	74.07	77.8	173.345	7.77735	1348.16	13.9129
0.185	74.07	80	186.587	7.77735	1451.16	14.9758
0.19	74.07	82.2	196.378	7.77735	1527.3	15.7616
0.195	74.07	84.4	204.358	7.77735	1589.36	16.4021
0.2	74.07	86.7	211.488	7.77735	1644.82	16.9744
0.205	74.07	88.9	217.204	7.77735	1689.27	17.4332
0.21	74.07	91.1	220.996	7.77735	1718.76	17.7375
0.215	74.07	93.3	225.127	7.77735	1750.89	18.0691
0.22	74.07	95.6	230.956	7.77735	1796.23	18.5369
0.225	74.07	97.8	229.145	7.77735	1782.14	18.3916
0.23	74.07	100	229.768	7.77735	1786.99	18.4415

00:00:00	0	116	60.10362694	0	0	1
00:00:00	0.2	116	60.10362694	0	1.791	1
00:00:01	0.4	116	60.10362694	0.2	4.495	1
00:00:01	0.6	116	60.10362694	0.5	5.502	2
00:00:01	0.8	116	60.10362694	0.8	6.773	2
00:00:01	1	116	60.10362694	1.2	7.558	2
00:00:01	1.2	117	60.62176166	1.7	9.049	2
00:00:02	1.4	117	60.62176166	2.3	11.558	3
00:00:02	1.6	117	60.62176166	3	13.014	3
00:00:02	1.8	118	61.13989637	3.7	14.192	3
00:00:02	2	118	61.13989637	4.5	15.74	4
00:00:02	2.2	119	61.65803109	5.5	17.837	4
00:00:03	2.4	119	61.65803109	6.5	19.087	4
00:00:03	2.6	120	62.1761658	7.6	19.953	4
00:00:03	2.8	120	62.1761658	8.7	21.004	5
00:00:03	3	120	62.1761658	10	24.487	5
00:00:03	3.2	121	62.69430052	11.4	25.787	5
00:00:04	3.4	121	62.69430052	12.8	26.33	5
00:00:04	3.6	122	63.21243523	14.3	27.712	5
00:00:04	3.8	123	63.73056995	15.8	26.884	5
00:00:04	4	123	63.73056995	17.4	27.337	5
00:00:04	4.2	124	64.24870466	18.9	28.328	5
00:00:05	4.4	124	64.24870466	20.6	31.273	5
00:00:05	4.6	125	64.76683938	22.3	31.297	5
00:00:05	4.8	126	65.28497409	24	31.86	5
00:00:05	5	126	65.28497409	25.8	32.486	5
00:00:05	5.2	127	65.80310881	27.6	32.655	5
00:00:06	5.4	128	66.32124352	29.5	32.836	5
00:00:06	5.6	128	66.32124352	31.3	33.077	5
00:00:06	5.8	129	66.83937824	33.1	33.162	5
00:00:06	6	129	66.83937824	35	33.481	5

The relationship between relative PPO and thigh girth (1 cm dist)

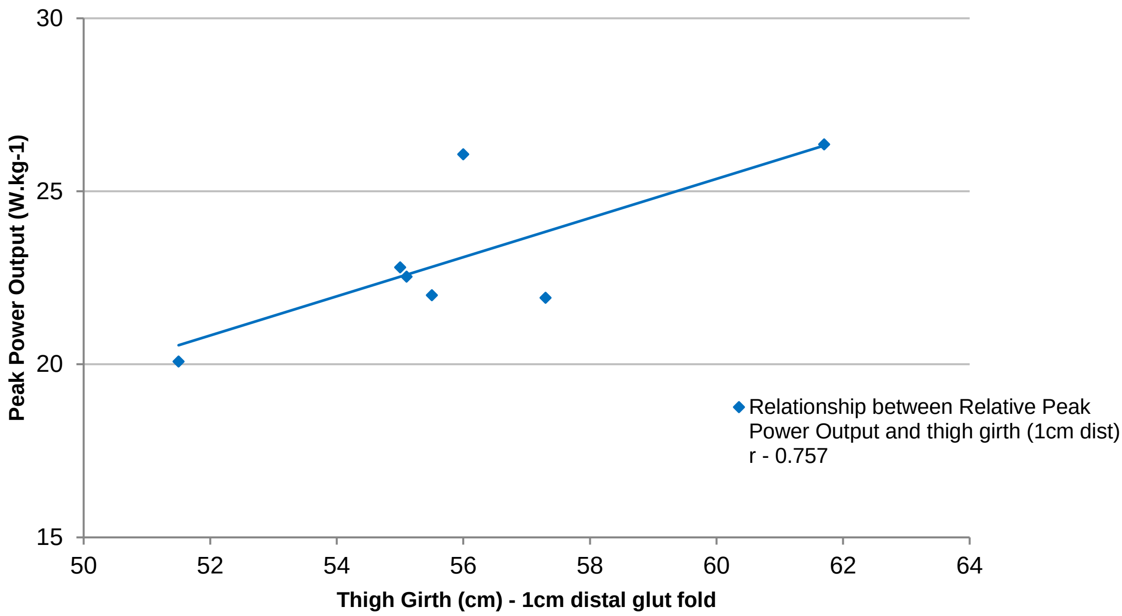


Figure. The significant positive correlation between relative PPO ($W{\cdot}kg^{-1}$) and thigh girth (1cm distal of gluteal fold). P = 0.049, r = 0.76.

GPS Reliability Study

Introduction

The physiological testing of an athlete is an integral component of their training and preparation for competition. Whilst it is important to test in a controlled, laboratory setting, often the athletes' true, sport-specific performance is unable to be mimicked and therefore limits the useful information that can be extracted from the data collected. Field-testing measures sport-specific performance and provides a plethora of useful data impossible to gain from a restricted laboratory setting. However, with field-testing, there are many external factors which are hard to control for, thus making it difficult to achieve standardised conditions required for valid results (e.g. air-resistance, environmental conditions).

The continual acceleration and deceleration experienced during the course of a Downhill track means it is very difficult to measure important speed characteristics of the sport. Previous field-based studies testing across a range of sports, used the time taken to travel a known distance to measure speed (Coutts and Duffield, 2008) or used equipment such as timing gates (Townshend *et al.,* 2008) This, however, will only provide a mean speed, which is of little use when determining the 'real' speed characteristics of a Downhill mountain biker during a race, due to the constant changes in speed. The introduction of global positioning system (GPS) in the 1990's may provide a solution to this problem when monitoring Downhill mountain biking, allowing speed, distance and location data to be collected in real time.

A number of studies (Pino *et al*., 2007; Edgecomb and Norton, 2006; Dawson *et al.,* 2004; Petersen *et al*., 2004; Larsson and Henriksson-Larsen, 2001) aimed specifically to assess the use of GPS in the sports performance context, using it with sports such as Australian Football, soccer, cross country skiing and hockey.

The aim of the current study was to assess the hypothesis that GPS was an accurate and reliable method of determining speed during cycling. Two experiments were conducted to investigate this hypothesis. A road trial compared speed and distance measures from two GPS units (SPI-Pro, GPS Sports) against the SRM powermeter (Schoberer Rad Messtechnik) (Paton and Hopkins, 2001) to determine the reliability. The intra-reliability between the two GPS units was also investigated during the road trial (Experiment 2).

Materials and Methods

Materials and Equipment

This study used a commercially available wireless 5 Hz (sample rate of 5 per second) GPS receiver (SPI Pro, GPSports). The receiver is small and light in size (48 mm x 20 mm x 87 mm and 76 g respectively). Information recorded included: time, position (latitude, longitude, altitude), distance travelled (m), speed ($km.hr^{-1}$), distance (m), number of satellites in use and acceleration information such as impacts, accelerations and decelerations (up to 400 Hz) are also recoded. All data was logged using the GPS software (Team AMS, GPSports).

A road bicycle was fitted with an SRM powermeter (Schoberer Rad Messtechnik). The power crank is mounted onto the bike instead of the normal crank/chain-ring combination and recorded at 1-second intervals. The signal is transmitted to a receiver mounted on the handlebars, which stores the sessions data e.g. speed ($km.hr^{-1}$), total distance covered (km), cadence (rpm) and power output (W). The data was logged using SRM software (SRMWin).

Experiment 1: GPS Vs. SRM powermeter

The aim of this experiment was to assess the reliability of the GPS for measuring speed and distance compared to the Gold Standard SRM powermeter system (for measuring power). A trained cyclist completed several laps of a straight course (3.0 km, with a change in elevation of 44 m) and was instructed to include a series of periods of rapid changes in speed. The speed and distance were recorded by two GPS receivers (located in the jersey pockets of the rider) and the SRM powermeter and the full trial and six splits were analysed.

Experiment 2: GPS Intra-reliability

Using the same path as Experiment 1, intra-reliability of the GPS was assessed. The speed and distance recorded were compared during six splits and during the full trial, to determine whether the performance measures were significantly related.

Statistics

The SRM powermeter sampled once per second in comparison to the GPS which sampled 5 times per second. Averaging formulas in Excel (Microsoft 2007) were used to allow the SRM and GPS to be overlaid and comparisons to be made. Paired t-tests and Pearsons Product Moment correlations were run using SPSS statistical package (version SPSS14). Significance was set at $p < 0.05$.

Results

Experiment 1: GPS Vs. SRM powermeter.

The SRM powermeter recorded total distance travelled as 34.020 km in comparison to GPS 1 and 3, which recorded 32.772 km and 32.773 km respectively. Table x.1 displays the distances measured for each split. There was no significant difference ($p > 0.05$) between the SRM distances and distances recorded by either of the GPS systems (SRM vs. GPS1, $p = 0.175$; SRM vs. GPS3, $p = 0.180$, from t-tests). Speed recorded by the SRM powermeter was significantly different ($p = 0.000$) to the speed recorded by GPS 1 and GPS 3, with GPS units underestimating the speed recorded by the SRM powermeter (Figure x.1). Peak and mean speeds ($km.hr^{-1}$) for six splits also showed the GPS systems to record a significantly different speed to the SRM powermeter (Table x.2 and Figure x.2).

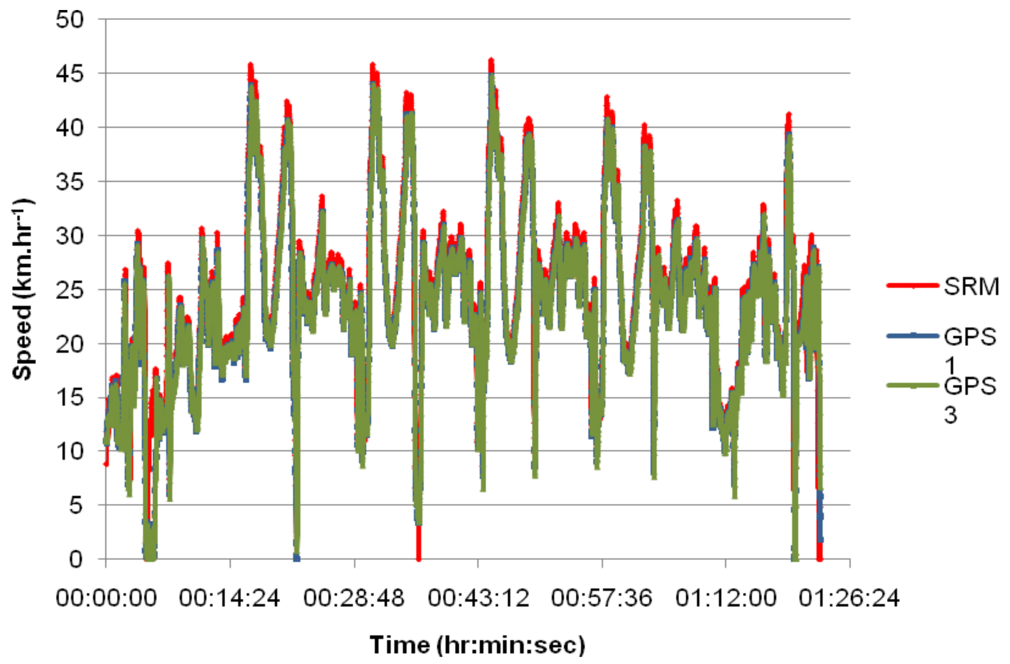


Figure x.1. Speed recorded during the full road trial from the GPS and SRM powermeter. The speed recorded by the SRM was significantly different to the speeds measured by the GPS units ($p = 0.000$ for both). The speed recorded by the GPS units were not significantly different from each other ($p = 0.485$).

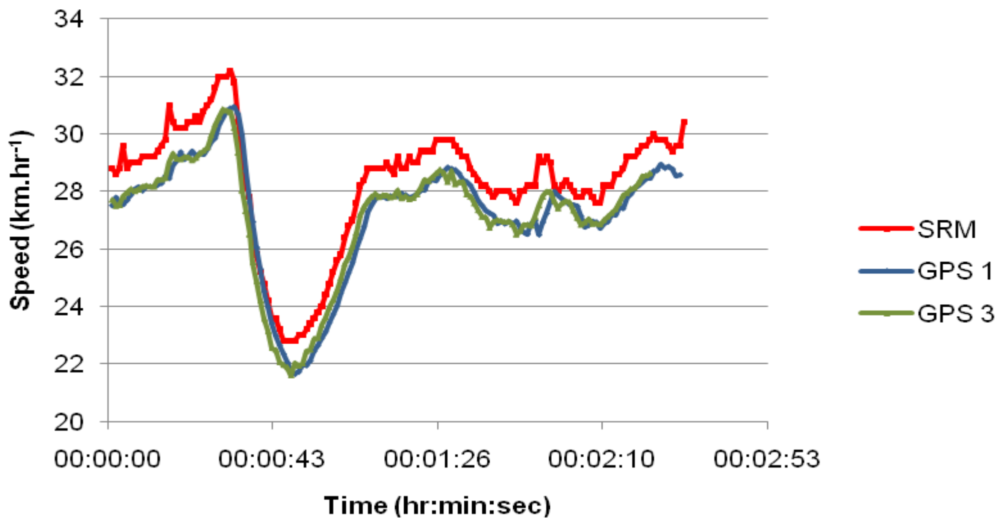


Figure x.2. Speed recorded during the third split from the SRM powermeter and the GPS units. The speed recorded by the SRM was not significantly related to the speed recorded by GPS 1 or 3 ($p = 0.000$ for both). Speed recorded by the two GPS units were significantly related ($p = 0.747$).

Table x.1. There was no significant difference between the distances measured by the SRM powermeter and either of the GPS systems or between the two GPS units ($p > 0.05$).

	SRM Powermeter	**GPS 1**	**GPS 3**	**Mean**	**± SD**
Performance Variable					
Distance (km)					
Full	34.020	32.772	32.773	33.19	0.72
Split 1	1.13	1.06	1.05	1.08	0.04
Split 2	1.04	1.01	1.01	1.02	0.02
Split 3	1.12	1.01	1.05	1.06	0.06
Split 4	1.04	1.02	1.02	1.03	0.01
Split 5	1.12	1.04	1.04	1.07	0.05
Split 6	1.04	1.02	1.02	1.03	0.01

Experiment 2: GPS Intra-reliability

For the six splits measured, there was no significant difference in speed ($p > 0.05$) between the two GPS units for four of the splits. Paired t-tests showed the full session to have a p value of 0.485; split 1 p= 0.476; split 2 p = 0.818; split 3 p = 0.54; split 4 p = 0.818. Speed during split 5 and 6 were significantly different (p = 0.000 and p = 0.02 respectively). When the speeds were displayed as mean and peak values ($km.hr^{-1}$) all speeds measured were highly significantly related to each other (p = 0.000). The distance measured by the two GPS systems were not significantly different from each other and values can be seen in Table x.1 ($p > 0.05$).

Table x.2. Mean and peak speeds from the SRM powermeter, GPS1 and GPS 3, during six splits.

	SRM Powermeter	**GPS 1**	**GPS 3**
Performance Variable			
Speed ($km.hr^{-1}$)			
Split 1 mean	27.64	26.62	26.60
peak	33.60	32.20	32.14
Split 2 mean	21.42	20.67	20.88
peak	45.80	43.97	43.93
Split 3 mean	28.28	27.23	27.13
peak	32.20	31.00	30.85
Split 4 mean	29.22	28.12	28.17
peak	46.20	44.80	44.17
Split 5 mean	28.16	27.15	27.08
peak	33.00	31.67	31.90
Split 6 mean	22.04	21.08	21.35
peak	42.80	40.64	40.76

Discussion

The reliability of GPS has been subject to many studies (Coutts and Duffield, 2008; Townshend *et al.,* 2008; Pino *et al*., 2007; Larsson, 2003). To date, this is the first investigation into the reliability of GPS with specific interest in using GPS to measure characteristics of Downhill mountain bike performance.

We concluded that GPS systems accurately measured distance travelled (Table x.1). This is in agreement with other studies which have also investigated the reliability of GPS systems (Coutts and Duffield, 2008; Townshend *et al.,* 2007; Edgecomb and Norton, 2006). When measured on a clear road trial (Experiment 1), the GPS showed a trend to underestimate distance in comparison to the SRM powermeter but this was not a significant difference (Table x.1). As the SRM is measuring at 1Hz and GPS at 5Hz you might expect that GPS would be more accurate. SRM is taking distance off the turning wheel which can also be prone to differences caused by tyre pressure. In addition, results showed a strong correlation ($r = 1.00$, $p = 0.000$) between the distance measured by GPS1 and GPS3 (Experiment 2), suggesting that intra-GPS reliability is high when measuring cycling performance characteristics on the road.

Much of the existing literature suggests that GPS offers an accurate estimation of speed and displacement (Townshend *et al.,* 2007) and the present study tends to agree with this. We determined that GPS systems (GPS 1 and GPS 3) significantly underestimated speed ($p = 0.000$) compared to an SRM powermeter during a road trial. However, it may be the SRM accuracy called in to question rather that the GPS as discussed in the previous paragraph. Figure x.1 shows that although the speed recorded by the GPS and the SRM follow a similar profile, the GPS consistently underestimated the speed. For four of the six splits measures, there was no significant difference in the speed recorded by the two different GPS units ($p > 0.05$) during the road trial. When the speed values were presented as peak and mean values, there was no significant difference ($p < 0.001$) in speeds across the 6 splits recorded from the two GPS units.

The study results suggest that GPS can be used as a reliable measure of distance travelled (Table x.1) when cycling. Furthermore, speed characteristics of cycling can also be obtained reliably (Table x.2) by use of GPS unit measuring 5 Hz (SPI-Pro, GPSports).

SDA SERIES: FORT WILLIAM, RACE ANALYSIS PILOT

Introduction

Downhill mountain biking is an exciting cycling sport that requires the athlete to skilfully manoeuvre a technically and physically demanding descending course. The terrain is made up of a succession of challenging jumps, drops and berms (cambered corners). Riders can descend between 300 and 600 metres during a course of ~2.5 km and the race will usually last between 2 and 5 minutes. Each course has its own variety of terrain, with some courses requiring more pedalling and others placing more emphasis on technical ability. The conclusions from the current study (Chapter Four and Five may be course dependant and the main aim of this small Pilot was to gain a race profile from another course during the Scottish Championships (Fort William, 17th May 2009). This course was also used during a World Cup event in June 2009 and thus both DH courses used in this study (Study Two and SDA Pilot) are high profile and recognised DH courses. The pilot also aimed to assess the practicality and efficacy of using GPS elite (SPI-Pro, GPSports) in determining kinematic characteristics of a downhill race.

Methods

Two trained males (aged 23 and 26 years) performed two timed runs of the Fort William DH course; the first being their seeded run and the second their final placing run. Heart rate was recorded every 5 seconds by a downloadable heart rate monitor (Polar Electro, UK). The belt strap was worn around the chest and a watch worn on the preferred wrist. One GPS receiver (SPI Elite, GPSports) measured time (minutes) speed ($km.hr^{-1}$), distance travelled (m) and impacts (g) every second. The GPS unit was attached to the top of the riders back, using duct tape to secure it to the body. The course (Figure xi.1) is described as ‘Fast and Rocky’ as it descends down off Aonach Mor. It is then composed of big rocky straights, bus stops, tight bermed corners, rock gardens, exposed hillside, slab rock, forest single track, tight gullies and big jumps before the rider drops down the wall and into the finish. Race day course conditions were dry and the riders were familiar with the run due to the allocated practice time the day before. Riders and their bicycles were transported to the start line via a gondola and an official marshal started the race.

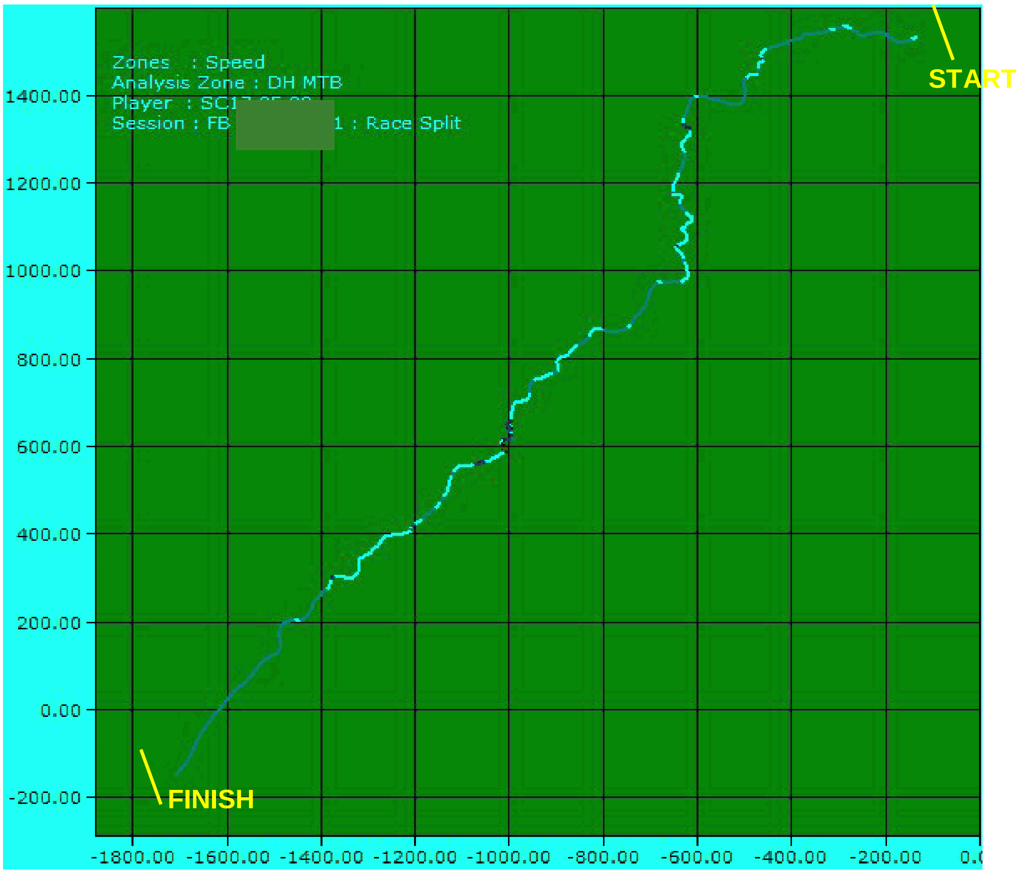


Figure xi.1. Schematic of the course profile of the Downhill course used for field-testing. Colours indicate the Speed zones (described in Chapter 4).

Statistical Analysis

Raw GPS data was exported from GPSports software to Excel (Microsoft Office 2007) for analysis. Descriptive statistics such as mean, minimum and peak speed were generated using Excel formulas. Participant SC 1 crashed during the run, thus all data was omitted for analysis. The group for the pilot was too small (n = 3) to compare means (paired t-tests) against the Study Two group however, graphs have been generated to show visually the differences between the race characteristics of the two DH courses.

Results

Full run time (seconds) is shown for each individual along with mean, minimum and peak speeds ($km.hr^{-1}$) for the individuals race run in Table xi.1. Group means are 327 ± 17 seconds, 31.7 ± 0.9 $km.hr^{-1}$, 8.3 ± 2.6 $km.hr^{-1}$ and 62.8 ± 2.2 $km.hr^{-1}$ for total run duration (seconds), mean, minimum and peak speeds ($km.hr^{-1}$) respectively.

Table xi.1. Full race time (seconds), distance (m), mean, minimum and peak speeds for the run ($km.hr^{-1}$). Group means (± SD) shown. Note that SC 1 crashed during the run.

Participant	**Run Time (s)**	**Distance (m)**	**Mean Speed ($km.hr^{-1}$)**	**Min Speed ($km.hr^{-1}$)**	**Peak Speed ($km.hr^{-1}$)**	**Mean HR (bpm)**	**Peak HR (bpm)**
SC 1 *	369	2949.3	28.5	0.0	63.5	174	191
SC 2	307	2914.2	32.8	10.7	64.8	183	197
SC 3	335	2930.0	31.2	5.6	60.4	190	198
SC 4	339	2921.0	31.2	8.7	63.3	189	200
Mean	327	2921.7	31.7	8.3	62.8	187	198
± *SD*	17	7.9	0.9	2.6	2.2	4	2

Run characteristics (duration, distance, elevation, heart rate) for Study Two and for the SDA Pilot and the differences are shown in Table xi.2.

Table xi.2. Race characteristics for Study Two (Innerleithen) and SDA Pilot (Fort William) and the difference between the course.

Race Characteristic	Study Two	SDA Pilot	Difference
Run Duration (s)	178.6	327	252.8
Course Distance (m)	1223.4	2936.5	1713.1
Starting Elevation (m)	461	661	200
Finishing Elevation (m)	143	106	37
Total Decent (m)	318	555	237
Mean HR (% HR_{max})	91	98	7

An example of the course and heart rate (bpm) profile for the Fort William course is shown in Figure xi.2. Speed characteristics (mean, minimum and peak speeds ($km.hr^{-1}$)) of each run (Innerleithen and Fort William) are detailed in Table xi.1. Table xi.2 details further characteristics of interest.

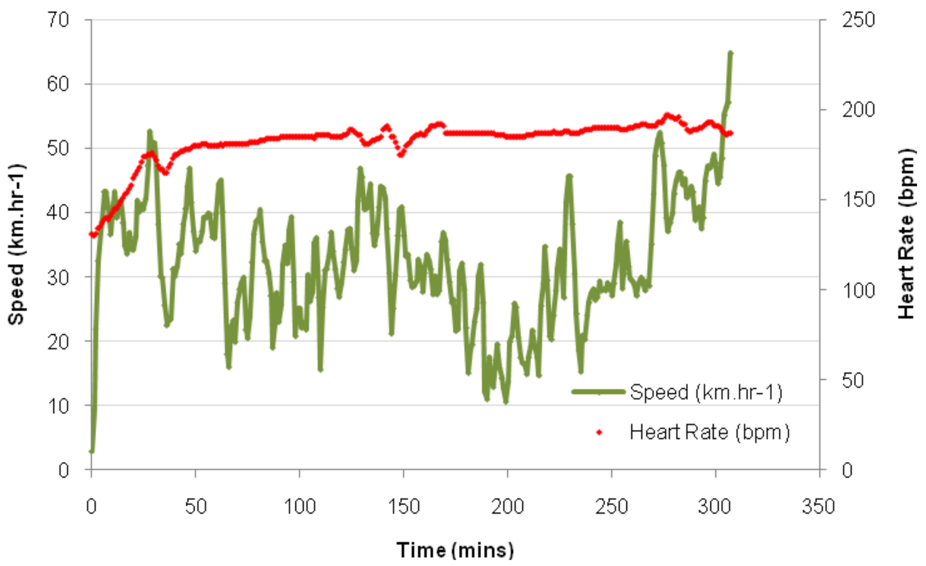


Figure xi.2. Example of speed and heart rate profile of the race run. Heart rate expressed in bpm.

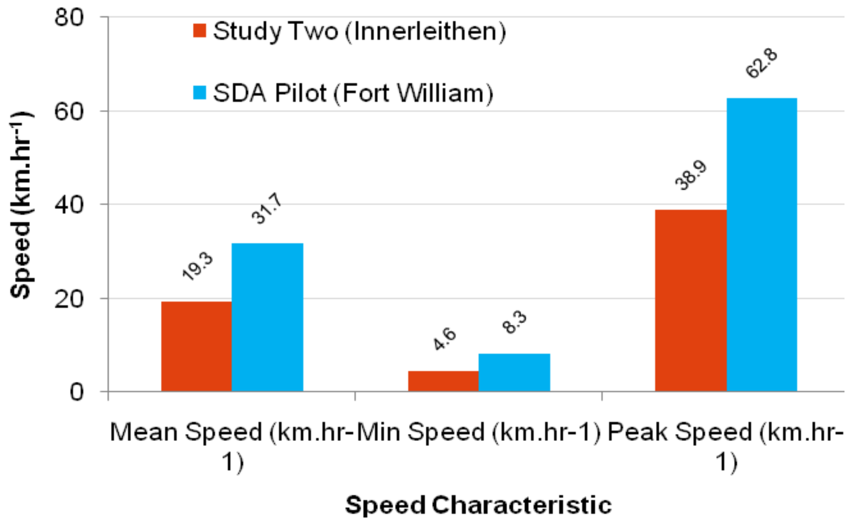


Figure xi.3. Graph showing the difference in speed characteristics between the two courses.

Discussion

Chapter Four and Five discuss factors which influence Downhill mountain bike performance during the National Championship course at Innerleithen, Scotland. It was concluded that performance during the first 15-seconds of the run had a positive impact on overall race performance. Furthermore, it was identified that performance during the technical section of the course (course Section 4) was also important for performance, with the ability to carry and maintain speed into the technical terrain influential in this. When analysis investigated the relationship between the DH athletes physiological attributes such as peak power output (PPO) and time to peak PO and whether they had an impact on performance, it was concluded that they did indeed have a positive effect on the race start. Thus, the study was able to conclude that whilst technical skills are important for performance, training should also aim to improve power characteristics, specifically anaerobic PPO and time to peak PO. Having identified this however, it was also noted that due to the variety of DH courses, these conclusions may be course dependant and more investigations into DH courses should be undertaken.

The SDA Pilot study aimed to identify race characteristics during a Scottish Championships race (Fort William, Scotland) and highlight how different DH courses can be. Furthermore, this pilot aimed to assess the practicality and efficiency of using GPS elite (GPSports, Australia) in determining kinematic characteristics of a Downhill race. The World Cup course in Fort William, Scotland, is described as one of the longest courses on the DH circuit and GPS data details course distance to be 2936.5 m with a total decent of 555 m. This is significantly greater that the National Championships course (Innerleithen, Scotland) on both accounts (1223.4 m and 318 m, respectively) and this is also reflected in the longer run durations (327 seconds and 179 seconds). Further investigations show the Fort William course to be faster. Mean, minimum and peak speeds were all faster than the Innerleithen course (greater by: 12.4 $km.hr^{-1}$, 3.7 $km.hr^{-1}$ and 23.9 $km.hr^{-1}$, respectively). This may suggest that the Fort William course relied less on technical skills, however, a larger subject group during the pilot testing would have been beneficial to be able to identify statistical differences in the race profiles.

Conclusions

As mentioned, the aim of the SDA Pilot study was to emphasise the varying natures and therefore demands of different DH courses (2009 SDA Series/ World Cup course, Fort William and 2009 National Championships course, Innerleithen). Differences in course distance, durations and speed profiles demonstrated the differing natures of the two courses. Whilst successful performance on the Innerleithen course may be more dependent on technical ability, performance on the Fort William course may depend largely on physical fitness. The Fort William course is one of the longest on the DH circuit (~ 5 minutes) and the speed profile identifies it to be a fast course (mean speed: 31.7 ± 0.9 $km.hr^{-1}$; peak speed: 62.8 ± 2.6 $km.hr^{-1}$. As such, the ability to perform at this pace for the longer duration may depend on the fitness of the aerobic system and rider strength and thus, preparation should be tailored towards training these systems to aim for optimal performance. The data obtained from the pilot study could also conclude that the use of GPS in elite Downhill mountain biking is an easy and efficient method of obtaining kinematic characteristics of DH cycling.

The SDA Pilot identifies and emphasises the requirement for further studies on Downhill mountain biking and analysis of the different courses used on the circuit. Only then can the true demands of the sport be recognised and optimal preparation for performance achieved.

NATIONAL CHAMPIONSHIPS PRACTICE DAY

Table xii.1, xii.2 and xii.3 detail GPS data from three athletes, showing movement patterns from the Practice day of the National Championships, Innerleithen, 2009. The practice day occurs the day before the race day and further research may be interested in identifying the demands of practice and whether this may affect performance on race day. The tables depict the durations of the Uplift, the push to the start (riders push their own bicycle from where the Uplift drops them, uphill to the start line), Practice run duration and Downtime (between finish and start of next practice run).

Table xii.1.

NC Practice Participant 1 — ***Durations (mins)***

Practice Run	Uplift	Push to Start	Practice Run	Downtime	Section Practice
1	47.3	11.28	8.13	9.07	Section 4
2	35.24	7.26	10.1	44.29	Section 1
3	36.12	9.52	6.38	21.21	Sections 2 and 4
4			*GPS battery died*		

Table xii.2.

NC Practice Participant 2 ***Durations (mins)***

Practice Run	Uplift	Push to Start	DH Run	Downtime	Section Practice
1	51.45	6.05	13.35	33.02	Sections 2 and 4
2	35.24	7.31	14.57	39.03	Sections 1 and 4
3	36.12	9.23	7.07	21.17	Section 4
4			*GPS battery died*		

Table xii.3.

NC Practice Participant 3 ***Durations (mins)***

Practice Run	Uplift	Push to Start	DH Run	Downtime	Section Practice
1	59.25	11.25	6.02	22.51	Sections 2 and 4
2	38.03	5.06	11.00	*No Data*	Sections 3 and 4
3			*No GPS for this practice*		
4	31.24	14.30	11.58	End	Sections 1, 4 and 5