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Analysis of road sprint cycling performance

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School of Exercise and Health Sciences

Analysis of Road Sprint Cycling Performance

By

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This thesis is presented for the award of Doctor of Philosophy (Sports Science) from the School of Exercise and Health Sciences; Faculty of Health Engineering and Science; Edith Cowan University, Western Australia

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DECLARATION

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Mamma mia, where do I begin?

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… # ABSTRACT

Sprint cycling ability is a key determinant of road cycling performance, with many races designed specifically for sprinters. The ability to excel in the final sprint is relevant for both individual riders and teams. Despite the importance of sprints within professional road cycling, the characteristics of professional road sprints and sprinters have yet to be extensively described. Thus, the overall objective of the five research studies contained within this doctoral thesis was to describe road cycling sprint performance and improve the general understanding of the physical, technical and tactical factors associated with such performances.

The first two descriptive field studies document the physical and physiological demand of sprint races during actual road cycling competitions. Specifically, Study 1 was designed to quantify the demands of sprinting in the male professional category. Seventeen competitions from six male professional cyclists (mean ± SD: age, 27.0 ± 3.8 y; height, 1.76 ± 0.03 m; weight, 71.7 ± 1.1 kg) who placed Top 5 in professional road races were analysed. Calibrated SRM power meters were used to monitor power output, cadence and heart rate. Data were averaged over the entire race, different durations prior to the sprint (60, 10, 5 and 1 min) and during the actual sprint. Variations in power during the final 10 min of the race were quantified using Exposure Variation Analysis. Power, cadence and heart rate were different between various phases of the race, increasing from 316 ± 43 W, 95 ± 4 rpm and 88 ± 3 % of maximal heart rate in the last 10 min to 487 ± 58 W, 102 ± 6 rpm and 96 ± 2 % of maximal heart rate in the last minute prior to the sprint. The peak power during the sprint was 17.4 ± 1.7 $W \cdot kg^{-1}$. Exposure Variation Analysis revealed a significantly greater number of short duration and high intensity efforts in the final five minutes of the race, compared with the penultimate five minutes ($p=0.01$). These findings quantified the power output requirements associated with high level sprinting in men's professional road cycling and highlighted the need for both aerobic and anaerobic fitness. In Study 2, the characteristics of successful road sprints in professional and under 23 y male cycling races were compared. As in Study 1, Study 2 also described the exercise intensity for the sprinters throughout final 10 min of the race. Nine successful (Top 3) sprints performed by a professional (PRO: 23 y, 1.76 m, 71.8 kg) and an under 23 (U23: 18 y, 1.67 m, 63.2 kg) cyclist sprinter were analysed in this study. No statistical

differences were found between PRO and U23 in the absolute peak power, mean power, duration and total work during the sprint (PRO: 1370 ± 51 W, 1120 ± 33 W, 14.5 ± 2.4 s, 16.2 ± 2.6 KJ; U23: 1318 ± 60 W, 1112 ± 68 W, 12.8 ± 1.1 s, 14.2 ± 1.4 KJ). However, the intensity of the race recorded in the last 10 min prior to the sprint was significantly higher in PRO compared with U23 (4.6 ± 0.3 and 3.7 ± 0.2 $W \cdot kg^{-1}$, respectively). Race duration, total elevation gain (TEG) and mean power were similar between PRO and U23. In conclusion, the physiological demands leading into road sprints (intensity of the last 10 min) were found to be higher in PRO compared to U23 races. Nevertheless, a similar sprint power output (> 2500 $W \cdot A_p^{-1}$ or > 15.5 $W \cdot kg^{-1}$ for approximately 14 s, with a peak power output > 3100 $W \cdot A_p^{-1}$ or > 19 $W \cdot kg^{-1}$; where A_p is Projected Frontal Area) indicates that sprint characteristics may be similar in PRO and U23.

As a result of the findings observed in the first two studies of this thesis, Study 3 was designed to better understand the effects of variable and non-variable exercises that replicate the intensity of the final portion of road competitions on maximal sprint performance. In this laboratory trial, ten internationally competitive male cyclists (age, 20.1 ± 1.3 y; height, 1.81 ± 0.07 m weight, 69.5 ± 4.9 kg; and VO_{2max}, 72.5 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$) performed a 12-s maximal sprint in a rested state and again following: i) 10 min of non-variable cycling, and ii) 10 min of variable cycling. Variable and non-variable trials were conducted in a randomized, crossover fashion. The intensity during the 10 min efforts gradually increased to replicate the pacing observed in final sections of cycling road races. During the variable cycling subjects performed short (2 s) accelerations at 80% of their peak sprint power, every 30 s. Mean power output, cadence and heart rate during the 10 min efforts were similar between conditions (5.3 ± 0.2 $W \cdot kg^{-1}$, 102 ± 1 rpm, and 93 ± 3 %, respectively). Post exercise blood lactate concentration and perceived exertion immediately after exercise were also similar (8.3 ± 1.6 $mmol \cdot L^{-1}$, 15.4 ± 1.3 (6-20 scale), respectively). Peak and mean power output and cadence during the subsequent maximal sprint were not significantly different between the three experimental conditions ($p \geq 0.14$). These results indicate that neither the variable nor the non-variable 10 min efforts performed within this study impaired the sprint performance in elite competitive cyclists.

Due to the importance of the elevation gain variable in road cycling, the fourth study of this thesis was methodological and investigated the consistency of commercially available devices used to measure the TEG during races and training. This chapter was separated in two observational validation studies. Garmin (Forerunner 310XT, Edge 500,

Edge 750 and Edge 800; with and without elevation correction) and SRM (Power Control 7) devices were used to measure TEG over a 15.7 km mountain climb performed on 6 separate occasions (6 devices; Study 4a) and during a 138 km cycling event (164 devices; Study 4b). TEG was significantly different between Garmin and SRM devices ($p<0.05$). The between device variability in TEG was lower when measured with SRMs, compared to Garmin (Study 4a: 0.2 and 1.5%, respectively). The use of the Garmin elevation correction option resulted in a 5-10% increase in the TEG. Thus, while measurements of TEG were relatively consistent within each brand, the measurements differed between SRM and Garmin devices by as much as 3%. Caution should be taken when comparing elevation gain data recorded with different settings or with devices of different brands.

The final study of this thesis was an analysis of technical and tactical factors that influence sprint performance in professional competitions; particular focus was put on the TEG which was a factor identified as a potential cause of fatigue. More specifically, the subject of Study 5 was the highest international ranked professional male road sprint cyclist during the 2008-2011 seasons. Grand Tour sprint stages were classified as WON, LOST, or DROPPED from the front bunch prior to the sprint. Video of 31 stages were analysed for mean speed of the last km, sprint duration, position in the bunch and number of teammates at 60, 30, and 15 s remaining. Race distance, TEG and mean speed of 45 stages were determined. Head-to-head performances against the 2nd to 5th most successful professional sprint cyclists were also reviewed. Within the 52 Grand Tour sprint stages the subject started, he WON 30 (58%), LOST 15 (29%), was DROPPED in 6 (12%) and had one crash. Position in the bunch was closer to the front and the number of team members was significantly higher in WON compared to LOST at 60, 30 and 15 s remaining ($p<0.05$). The sprint duration was not different between WON and LOST (11.3 ± 1.7 and 10.4 ± 3.2 s). TEG was significantly higher in DROPPED (1089 ± 465 m) when compared to WON and LOST (574 ± 394 and 601 ± 423m, $p<0.05$). The ability to finish the race in the front bunch was lower (77%) compared to other successful sprinters (89%). However, the subject was highly successful, winning over 60% of contested stages while his competitors won less than 15%. Findings from Study 5 support the notion that tactical aspects of sprinting are important for performance outcomes.

In conclusion, the general findings of this thesis were as follows: as expected, exercise intensity significantly increases in the last 10 min of relatively flat road races; there is a significantly greater number of short duration and high intensity efforts in the final 5 min of competitive road cycling races when compared with the penultimate 5 min;

sprint duration and peak power output does not differ between PRO and U23 races and is approximately 13 s and 17 $W \cdot kg^{-1}$, respectively; the physiological demands in the 10 min before the sprint are higher in PRO compared to U23 races; neither a variable nor a non-variable 10 min lead up effort appears to impair the sprint performance of elite competitive cyclists; measurements of elevation gain are consistent within devices of the same brand, but differed between brands or when different settings were used; and technical and tactical aspects of road sprinting are related to performance outcomes.

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LIST OF PUBLICATIONS

Five chapters of this thesis have been previously published in, or submitted to, peer reviewed journals. In each of these publications the first author substantially contributed to the design, data collection and analysis. He also wrote the manuscripts, approved their final versions and acted as corresponding author. These publications are outlined below.

Chapter Three

Menaspà P, Quod M, Martin DT, Peiffer J, Abbiss CR. Demands of the sprint finish in professional road cycling. [the Journal of Strength and Conditioning Research. Under review]

Chapter Four

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Chapter Five

Menaspà P, Martin DT, Victor J, Abbiss CR. Maximal sprint power in road cyclists following variable or non-variable high intensity exercise. [International Journal of Sports Medicine. Under review]

Chapter Six

Menaspà P, Impellizzeri FM, Haakonssen E, Abbiss CR, Martin DT. Consistency of commercial devices for measuring elevation gain. *International Journal of Sports Physiology and Performance*. 2014 Sep; 9(5):888-890

Chapter Seven

Menaspà P, Abbiss CR, Martin DT. Performance Analysis of a World Class Sprinter during Cycling Grand Tours. *International Journal of Sports Physiology and Performance.* 2013 May; 8(3):336-40.

Additional publications arising from PhD research

PEER REVIEWED JOURNALS

Abbiss CR, Menaspà P, Villerius V, Martin DT. Invited Commentary: Distribution of Power Output when Establishing a Breakaway in Cycling. *International Journal of Sports Physiology and Performance. 2013 Jul; 8(4):452-5.*

Garvican-Lewis LA, Schumacher YO, Clark SA, Christian R, Menaspà P, Plowman J, Stephens B, Martin DT, Thompson KG, Gore CJ, Ma F. Hemodilution during a two week cycle race at altitude. *Journal of Applied Physiology, online 2014*.

CONFERENCE PROCEEDINGS

Menaspà P, Abbiss CR, Martin DT. *Characteristics of a successful professional road cycling sprinter: a performance analyss case study.* 17th Annual ECSS-Congress, Bruges 2012

Menaspà P, Martin DT, Flyger N, Quod M, Beltemacchi M, Abbiss CR. *Maximal Mean Power of track and road sprint cyclists during World Class races.* 18th Annual ECSS-Congress, Barcelona 2013

Garvican-Lewis LA, Schumacher YO, Clark SA, Christian R, Menaspà P, Plowman J, Woods A, Stephens B, Thompson KG, Ma F, Gore CJ. *Haemodilution in both sea level and altitude natives during a two week cycle race at moderate altitude.* 6th ESSA conference, Adelaide 2014

Menaspà P, Martin DT, Quod M, Abbiss CR. *Elite road cycling sprinters: quantifying the demands of the final hour.* 19th Annual ECSS-Congress, Amsterdam 2014

ONLINE ARTICLES

Ross Tucker. *The profile of a sprint: What does it take to win a sprint stage?* The Science of Sport, 8th July 2014. http://sportsscientists.com/2014/07/profile-sprint-take-win-sprint-stage/

Wesley Stephenson. *Why sprinters are muscly and climbers are wiry.* BBC News Magazine, 18th July 2014. http://www.bbc.com/news/magazine-28363129

CHAPTER ONE INTRODUCTION

1.1 Overview

This doctoral thesis contains five research studies with an underlying focus aimed at describing road sprints in endurance cycling and improving the understanding of factors that influence the sprint performances. Specifically, the purpose of this research was to examine sprints in endurance cycling, with particular focus on the elite and professional categories. The first two of these studies were descriptive, field based studies, aimed at examining and documenting the physiological demand of sprint races during actual professional and Under 23 cycling competitions. Study 3 was a laboratory experimental study aimed at understanding the effects on maximal sprint performance of variable and non-variable exercises that replicate the intensity of the final part of road competitions. The fourth study was methodological and investigated the consistency of commercially available devices used to measure the total elevation gain (TEG) during races and training. Following this, the final study of this thesis was an analysis of technical and tactical factors that influence sprint performance in professional competitions; particular focus was put on the TEG, factor identified as potential cause of fatigue.

1.2 Background

Successful road cycling performance is dictated by a variety of factors, including technique, tactics and the aerobic and anaerobic characteristics of cyclists (66). Based on physiological traits and primary objectives during competition, cyclists have been classified into a number of different specialty groups, including climbers, sprinters, time trialists, all terrain specialists and flat terrain specialists (52, 64, 93, 109). In the past decade there have been several studies describing both the physiological demands of competition and the characteristics of various specialty cycling groups (64, 93). However, these studies have focused primarily on aerobic characteristics of athletes (22, 90) and

associated uphill and/or time trial performances (64, 93). For instance, Lucia and colleagues (64) showed that professional climbers have a lower body mass index and higher maximal oxygen uptake (VO_{2max}) normalized to body mass, when compared with time trial specialists. This area of research has been important in the monitoring of athlete fitness, assessing the effectiveness of various training programs and identifying talent in junior athletes, with relevance to uphill and time trial cycling performance. However, since cycling has traditionally been considered an endurance based aerobic sport, to date few research studies have examined the anaerobic characteristics important to road cycling (33, 34, 89).

Sprint cycling ability is often a key determinant of road cycling performance. In fact, many stages (e.g. approximately 7 out of 21 stages) within each of the grand tours (i.e. Giro d'Italia, Tour de France and Vuelta a Espana) are designed specifically for sprinters, with other races still often decided in bunch sprints or sprints between a few riders. Furthermore, several World Road Championships have been won by a sprint cyclist. It therefore appears that the ability to excel in the final sprint could be highly relevant for individual riders (and team) performances. Indeed, top level sprinters are usually well positioned in the international road cycling seasonal rankings (*www.cqranking.com*). Despite the importance of sprints within professional road cycling, the physiological characteristics of professional road sprinters have yet to be described. To the best of our knowledge, only two research studies describing the physiological characteristics of competitive nonprofessional sprint cyclists have been published (79, 109). In these studies, sprinters showed a higher short term absolute and relative sprint power output but lower aerobic capacity (relative to body mass), when compared with other cycling specialists (i.e. climbers and flat terrain).

Furthermore, the physiological demand of successful professional road sprints is a topic that appears to have only been described once, on a single subject (68). In the mentioned study, Martin and colleagues (68) reported the power output of a single sprint performed by a single cyclist winning a professional road race. In this case study, the cyclist rode at a mean power output of 490 W in the last 3 min and exceeded 600 W for a total of 64 s. The duration of the final sprint was 14 s, while the mean power was 926 W (peak power 1097 W) and the maximal recorded speed was 65 $km \cdot h^{-1}$. Such high power outputs are not far from those ridden by elite pursuit track cyclists (4000 m) and highlight the high physiological load experienced during road sprint cycling.

1.3 Purpose of the Research

The general purpose of the research composing this thesis was to describe road sprint performances, and investigate the factors that may influence the development of fatigue during prolonged cycling. The literature related to the physiological demand of sprint races in professional road cycling is limited. Thus, the purpose of the first study contained within this thesis (Study 1) was to examine and describe the characteristics of the sprint finish over various road competitions in male professional cyclists, with particular focus on the lead up phase and the final sprint. Also, the variability of the power output in the final part of the race was examined with Exposure Variation Analysis (EVA). Following this, the purpose of Study 2 was to describe and compare the power output data recorded during successful road sprints in professional and amateur (U23) male cycling races. Furthermore, a secondary aim of Study 2 was to examine the intensity in the final 10 minutes of race to describe the difficulties that a sprinter has to overcome to be in contention for the sprint. The purpose of Study 3 was to examine the effects of variable and non-variable 10 minutes efforts on the maximal sprint capacity of internationally competitive male cyclists. These trials were performed under laboratory conditions and were set to replicate the intensity of the final part of road competitions. Study 4 was aimed at determining the consistency of several devices typically used for measuring altitude and elevation gain in outdoor activities and sporting events. Finally, the purpose of Study 5 was to examine technical and tactical factors that may influence road sprint performances, such as the TEG during the competitions. A secondary aim of this investigation was to provide a description of the sprint characteristics during Grand Tours in order to extend methodology used for evaluating road sprints. Collectively, this research aims at better understanding the physical, technical and tactical factors that influence road sprint cycling performance. Such information can assist in establishing the basis for selection of successful sprinters, as well as support the advancement of specific training programs and the development of better tactical considerations.

1.4 Research Questions

The research questions asked in this PhD thesis have been separated into five separate studies, as listed below:

1.4.1 Study 1 (chapter 3)

Demands of the sprint finish in professional road cycling

i. What are the characteristics of successful road sprints (e.g. duration, peak and mean power, cadence and speed)?

ii. How intense is the final hour of competition before the sprint?

iii. Does the power output and variability of power increase in the last 5 min of a road race when compared to the penultimate 5 min?

1.4.2 Study 2 (chapter 4)

Physiological demands of road sprinting in professional vs U23 cyclists

i. Do the characteristics of successful road sprints (e.g. duration, peak and mean power) differ between professional and amateur (U23) road cycle races?

ii. Do the physical demands prior to the sprint differ between professional and amateur (U23) road cycle races?

1.4.3 Study 3 (chapter 5)

Maximal sprint power following variable or non-variable high intensity exercise in road cyclists

i. Is sprint power output impaired by the physical demands of exercise occurring in the last 10 min of road competitions?

ii. Does a 10-min variable intensity effort result in greater decrements in subsequent sprint power output, when compared to a non-variable effort of the same intensity?

1.4.4 Study 4 (chapter 6)

Consistency of commercial devices for measuring elevation gain

i. What is the reliability of commercially available devices that are used for measuring elevation gain within cycling?

ii. Is elevation gain consistent between different commercially available devices?

iii. Does correcting for positioning on the software of commercially available devices (i.e. GPS-corrected) influence the reliability of devices?

1.4.5 Study 5 (chapter 7)

Performance analysis of a world class sprinter during cycling grand tours

i. What influence does elevation gain have on success of a professional road sprint cyclist?

ii. Is team support (e.g. number of teammates) associated with successful road sprint performance?

1.5 Definitions of Selected Terms

A_p:	Projected Frontal Area
ADP:	Adenosine diphosphate
ANOVA:	Analysis of variance
ATP:	Adenosine triphosphate
ATP-PC:	Adenosine triphosphate – Phosphocreatine
BMI:	Body Mass Index
CdA:	Aerodynamic drag area
CI:	Confidence intervals
CON:	Fresh condition (Control)
Cr:	Free creatine
CT_{peak}:	Peak crank torque
CV:	Coefficient of variation
ECU:	Edith Cowan University
EMG:	Electromyography
EVA:	Exposure variation analysis
EVA_{SD}:	Standard deviation of the exposure variation analysis matrix
GT:	Grand Tours (Giro d'Italia, Tour de France, Vuelta a Espana)
HC:	Hors Category cycling competition
HR_{max}:	Maximum heart rate
MA:	Musculoarticular
MAP:	Maximal aerobic power
min:	Minute(s)
MMP:	Maximal Mean Power
MVC:	Maximal voluntary contraction
N-VAR:	Non-variable
PAP:	Post activation potentiation
PC7:	Power Control 7 (part of the SRM device)
PCr:	Phosphocreatine
PO:	Power output
PO_{peak}:	Peak power output
PRO:	Professional cyclist(s)
r:	Pearson's product moment correlation coefficient

RCTD:	Rate of Crank Torque Development
rh:	relative humidity
RPE:	Rating of Perceived Exertion
RR:	Road race events
s:	Second(s)
SD:	Standard deviation
SRM:	Schoberer Rad Meßtechnik: A portable power monitoring system for bicycles
STMP:	short term muscle power
TEG:	Total elevation gain
TEM:	Technical error of measurement
TT:	Time trial event
U23:	Under 23 cycling category, according to UCI rules
UCI:	*Union Cycliste Internationale;* International Cycling Union
VAR:	Variable
$\dot{V}O_2$:	Oxygen consumption
$\dot{V}O_{2max}$:	Maximal oxygen consumption
$\dot{V}O_{2peak}$:	Peak oxygen consumption
VT_1:	First ventilation threshold
VT_2:	Second ventilation threshold
WT:	World Tour cycling competition

CHAPTER TWO REVIEW OF LITERATURE

SPRINTING IN ENDURANCE CYCLING

This review of literature provides information relevant to the studies of this PhD thesis. This chapter outlines research that has been observed and reported in peer reviewed manuscripts, relating to the characteristics and demands of road sprint cycling. This review also discusses the energetics of short duration maximal efforts and the effects of prolonged exercise on maximal sprint capacity.

2.1 Introduction

In an attempt to enhance the understanding of cycling performance, physiologists and sport scientists have described characteristics of cyclists (33, 63, 93) and the demands of cycling competitions (94-96, 125, 126). Despite the importance of the final section of competitions (i.e. final sprint) for road cycling performance outcomes only one study has reported data related to this specific aspect of cycling (69). Indeed, to date research into cycling performance has largely focused on time trial and/or uphill performances (2, 15, 31, 86, 106, 124, 125). Several studies have also investigated the physiological characteristics of track sprinters (18, 39, 40, 74, 112). However, the physiological and performance characteristics of road cycling sprints and sprinters have not been the focus of extensive scientific investigation. Therefore, the purpose of this review was to: i) define and describe road cycling sprint performances, ii) describe the energetics of short duration maximal efforts, and iii) highlight the effects of prolonged cycling on short duration maximal cycling efforts.

2.2 Sprinting in cycling

The performances of road cyclists are influenced by many physiological, technical, tactical, psychological and environmental variables (12, 63). When focusing on

physiological aspects associated with performance, cycling is often described as an aerobic activity (22, 84, 90). Nonetheless, anaerobic characteristics are extremely important and the contribution of the anaerobic metabolism is required during the high intensity sections of cycling competitions (33, 34, 89). For instance, anaerobic metabolism is extremely important near the end of road races when more than one cyclist approaches the finish line and a maximal effort (i.e. final sprint) determines the race result.

2.2.1 Definition of sprint

Short duration maximal exercise has been described with different and not always consistent terminology. In a review paper, Girard and colleagues (43) defined the sprint as a brief exercise of duration equal to, or shorter than, 10 s in which the maximal workout intensity (e.g. power) is maintained and does not decrease. In the same review, maximal intensity efforts of longer duration (e.g. lasting 30 s or more) were described as ‘all-out’ exercise where it is possible to measure a decrease in exercise capacity despite maximal intensity effort. In a separate review, Van Praagh and Doré (122) defined short term muscle power (STMP), or peak power, the maximal mechanical power that can be produced in efforts lasting up to 30 s. To date, therefore, the description of a road sprint is not entirely clear. As such, for the purpose of this thesis, sprint refers to the maximal effort done at the end of a road cycling competition in order to be successful over direct competitors. Details on the identification of sprints as they pertain to road cycling are outlined below.

2.2.2 Road cycling and sprints

A road cycling sprint can be measured and defined as the continuous time elapsed between a rapid increase in power output (i.e. begin of the sprint) and an immediate drop of power (i.e. end of the sprint) (Fig. 2.1). This increase in power output represents the rapid acceleration that a cyclist produces in order to reach the finish line before the other competitors. Technically, therefore, a sprint occurs every time two or more cyclists compete to reach the finish line (or, any other “line” such as for *intermediate sprints* or for the *king of the mountain* competitions) before their respective competitor or competitors. However, the focus of this thesis is purely on “bunch sprints”, which are generally different from small group sprints (e.g. less than 10 cyclists in a breakaway).

The definition of bunch sprint is difficult as there are no strict criteria to define the bunch. Generally, a bunch sprint occurs when a large number of competitors (e.g. >20; or, the bigger group of cyclists riding together, named bunch or peloton) reach the finish line together, often at the end of a flat or hilly road race, and the final part of competition is ridden at relatively high speed (e.g. ≥ 50 km·h^{-1}).

To date, only one study has reported the power output recorded in a bunch sprint performed in a professional road cycling competition. Interestingly, the power data were recorded during a successful sprint; however, they were from a single subject and from a single competition. It was found that the duration of the final sprint was 14 s, and the mean power was 926 W (peak power 1097 W), with a maximal recorded speed of 65 km·h^{-1}. Interestingly, the authors also reported the intensity recorded before the sprint. The cyclist rode at an average power output of 490 W in the last 3 minutes and, within that time frame, he exceeded 600 W for a total of 64 s (68). These data appear to be very unique and difficult to evaluate as there are limited data on sprinters previously published. In fact, this may be the first and only published study describing a road sprint performance.

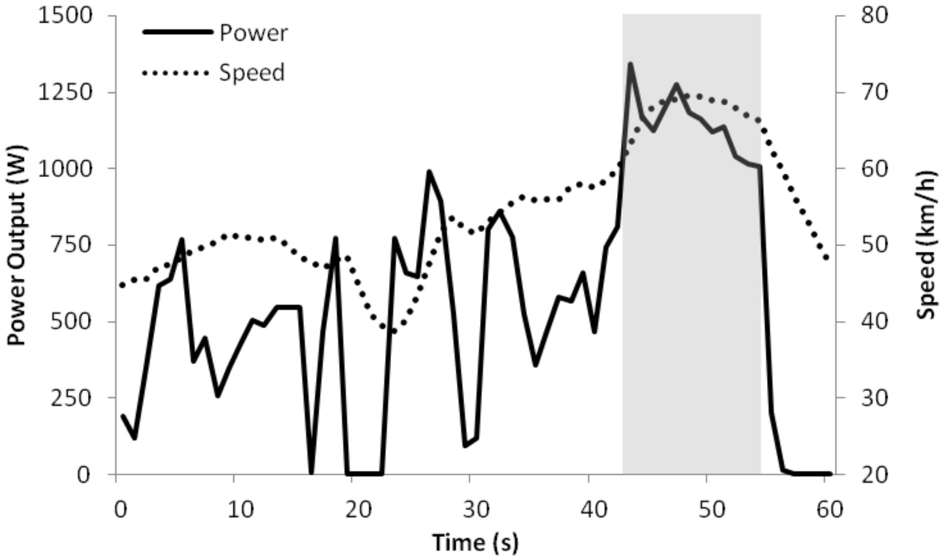

Figure 2.1 Example of power output and speed recorded at the end of a road race. The final sprint is highlighted in grey.

2.2.3 Cycling specialties and road sprinters

Within elite and professional cycling, athletes can be categorized into one of several different specializations. For instance, Padilla and colleagues defined a total of five categories of male road cycling specialists, including uphill riders, flat terrain riders, all terrain riders, time trial specialists, and sprinters (93). Similar categories of specialized riders have also been described in elite women, amateur (Under 23) and junior (Under 19) cyclists (52, 79, 109). Uphill riders, also known as climbers, excel in hilly or mountainous competitions; conversely, sprinters mainly compete for successes in predominantly flat races. Flat terrain riders often have the role to control the race before the climbs or before the final sprint. Among them, the highest performing athletes can win time trial races and they are often described as specialized time trialists. A restricted number of cyclists are capable of succeeding in all kind of terrains and for this reason they are named all-terrain riders. Despite competing in the same races and over the same courses, the anthropometric and physiological characteristic of various specialty cyclists can significantly differ. For instance, climbers are shorter and have lighter weight, while time trialists are taller and heavier (33, 63, 64). Padilla and colleagues (93) showed that climbers were significantly lighter than all the other cyclists, they also had higher frontal area to body mass ratio (i.e. aerodynamic disadvantage) when compared to flat specialists and time trialists. The abovementioned results highlight the climbers' advantage while riding uphill, as well as the disadvantage on flat terrains whereby air resistance is the main resistance to overcome (93). Other studies have also confirmed that flat specialists and time trialists are significantly taller and heavier than climbers (63, 109). Anecdotal observations would suggest that road sprinters may have a broader range of body sizes when compared to other specialists, however, the extremely limited published data do not allow a conclusion to be drawn in this regard.

Not only the anthropometric but also the physiological data related to specialized road sprinters are currently lacking within the literature. Such limited information pertaining to the characteristics of successful road sprinters is likely to be due to the limited number of road sprinters per team (e.g. 1 or 2 in a team of 25-30 cyclists), and thus in the overall peloton. As such, physiological and anthropometric characteristics of elite road sprinters have, to date, only been reported within a single study by Sallet and colleagues (109). In their study four cyclists were categorised as sprinters. These cyclists were 20.2 ± 2.6 y, 1.76 ± 0.02 m tall and weighed 67.3 ± 2.5 kg. Sprinters were

significantly younger than uphill and flat terrain cyclists (23.6 ± 3.6 y and 23.5 ± 3.87 y, respectively). Stature and body weight of the sprinters weren't statistically different from stature and weight of the other specialists (overall mean ± SD: 1.79 ± 0.05 m and 69.7 ± 1.7 kg). The reported body fat was 8.2 ± 2.3 %, similar to the 8.6 ± 1.7 % reported for the other groups (30). The sprinters' maximal oxygen uptake was 71.8 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$, with a maximal aerobic power of 428 ± 33 W, corresponding to 6.3 ± 0.3 $W \cdot kg^{-1}$. The overall mean for the study participants were a maximal oxygen consumption of 74.6 ± 6.5 $mL \cdot kg^{-1} \cdot min^{-1}$, maximal aerobic power of 452 ± 39 W, corresponding to 6.5 ± 0.5 $W \cdot kg^{-1}$. None of the above mentioned parameters were significantly different when sprinters were compared with the other specialty groups. The sprinters gross mechanical efficiency was 25.4 ± 1.4 %, similar to the overall mean of 25.1 ± 2.5 %. The sprinters reached a maximal peak power of 1279 ± 74 W during a 30 s all-out test, which corresponds to 19.0 ± 1.1 $W \cdot kg^{-1}$; the maximal power was found to be significantly higher in sprinters when compared to uphill, flat terrain and all-terrain riders (15.5 ± 1.5, 16.7 ± 1.5 and 15.7 ± 1.8 $W \cdot kg^{-1}$, respectively).

Published data on anthropometric and physiological characteristics of road sprinters do not reveal unique attributes compared to other categories of specialised cyclists, with the exclusion of peak power expressed in relation to body weight. Whether this was due to the limited sample size (only four road sprinters were part of the study) or to minimal differences between categories is not possible to determine. Further research investigating these aspects is warranted.

2.2.4 Literature on cycling track sprint

Road sprinters are not the only sprinters within the sport of cycling. Indeed, track cyclists that specialise in sprint events are also known as sprinters. Despite similarities in the terminology used to describe these cyclists, track and road sprinters are extremely different athletes. It is likely that the main reason for the differences among these athletes is due to the significant differences in the task demands of road and track cycling competitions. However, what both the sprinter categories have in common is their ability to produce relatively high power output for short periods of time, when compared to other cyclists competing in the same setting. In practical terms, road sprinters are "faster" (or,

more powerful over short distances) than the average road cyclist, and similarly track sprinters are “faster” than the average track cyclist.

To date, considerably more research has focused on the track (aka velodrome) sprinter, when compared with road sprinting. Indeed, a number of research groups have reported the anthropometric and physiological characteristics of specialised track sprinters along with the specific demands of competition (27, 40, 68). Due to the track sprinters' extreme specialization they can be described as the most powerful competitive cyclists, which make their characteristics of interests for this literature review. Indeed, their absolute short term muscle power can be considered as the highest power output that can be achieved on a bicycle. Dorel and colleagues (27) analysed the performances of 12 French track sprinters (including gold medallists at World Championships and Olympic Games). The participants were 24.3 ± 3.9 years old, their stature was 1.81 ± 0.04 m and their body mass was 83 ± 5 kg. The body fat was estimated in 11 ± 2 % (29). In this study, the cyclists' peak power was 1600 ± 116 W, corresponding to 19.3 ± 1.3 $W \cdot kg^{-1}$. The optimal cadence (i.e. the cadence at which maximal sprint power occurred) was 130 ± 5 rpm, with a maximal torque of 236 ± 19 Nm. In a different study, a maximum power of 1792 ± 156 W was found in Australian elite sprinter cyclists, equal to 20.8 $W \cdot kg^{-1}$. Data were recorded while the cyclists were sprinting on the track (40). The seven Australian male sprinters were 1.80 ± 0.3 m and 86 ± 6 kg. Their optimal cadence was 129 ± 9 rpm, with a maximal torque of 266 ± 13 Nm. No differences were found by Gardner and colleagues (40) between parameters recorded in laboratory versus field (i.e. track) conditions.

Track sprinters are generally considered the most powerful competitive cyclists within all disciplines of the sport of cycling (i.e. road, track, BMX, MTB and cyclo-cross). Similarly, road sprinters are considered the most powerful cyclists in the professional road cycling peloton making comparisons between these two specialities interesting. Due to different anthropometric characteristics (i.e. track sprinters have bigger body sizes compared to road sprinters, thus higher lower limb muscle masses) track sprinters can produce considerably higher absolute peak power outputs than road sprinters (peak power: ≥ 1600 W and ~1100, respectively) (27, 40, 69). Such differences appear largely due to differences in muscle mass characteristics. Indeed, despite limited published data, it seems that when accounting for body weight track and road sprint cyclists appear much more comparable. Supporting this, similarities in the relative peak

power outputs of track and road sprinters were also found in a pilot study by Menaspà and colleagues (77).

2.3 Physiology of sprinting in cycling

2.3.1 Energetics of high intensity cycling exercise

While road cycling is typically described as an aerobic activity (22, 84, 90), research on the physiological demands of competitions indicates that both anaerobic and aerobic metabolism are extremely important to performance (13, 33). Given that road competitions last several hours, the main contribution to energy supply comes from the aerobic metabolism; however, road cycling could, at least in part, be assimilated to intermittent sport events (or multiple sprint sports) in which several short and high intensity efforts are repeated (4). Exercise associated with repeated high intensity or maximal effort of short duration is regulated by complex energetics. The energy to produce work at muscular level is obtained by the adenosine triphosphate (ATP) hydrolysis in adenosine diphosphate (ADP) and inorganic phosphate (P_i), but this source of energy is only available for a few seconds (38, 97). For exercises of duration up to 10 s, the human body relies heavily on phosphocreatine (PCr), with a reaction that produces ATP and creatine (Cr) (11). This energy production pathway is one of the major contributors during the final sprint of road cycling competitions (120). However, during the high intensity phases of road races in which several efforts last more than 5-10 s, ATP supply becomes more reliant on anaerobic glycolysis (42, 54). The current understanding of intermittent exercises strongly depends on research examining performance and physiology during repeated sprints. Noteworthy, studies clearly show the importance of the aerobic metabolism during sprinting, even for efforts as short as 6 s (42). Indeed, it has been shown that approximately 9% of the energy used during the first 6 s of a 30 s maximal sprint comes from aerobic metabolism (97). Research also indicates that when maximal sprints are repeated, oxygen uptake (VO_2) kinetics are improved supporting additional reliance on aerobic energy yielding systems. When sprints are repeated before VO_2 returns to resting levels, the oxygen uptake will be elevated during the following sprints (38, 44). The higher VO_2 during recovery (or, low intensity cycling) allows

restoration of homeostasis via replenishment of oxygen saturation of myoglobin, resynthesis of PCr, lactate metabolism and removal of intracellular P_i (10, 37).

During high intensity intermittent exercise, metabolic pathways are required to both fuel muscular contractions and restore homeostasis (9). Due to the high intensity nature of the final sections of road racing, anaerobic glycolysis and aerobic metabolisms are likely to be the main pathways responsible for ATP supply leading into the final sprint. This is important since ATP supply is the major limitation to the production of maximal power in sprints that occur at the end of road cycling competitions.

2.3.2 Factors affecting cycling sprint exercise

Several factors can positively or negatively influence sprint exercise performance, including energy availability and metabolic pathways, neuromuscular fatigue and biomechanical variables. As previously reported, ATP supply is extremely important in the ability to generate high power outputs. According to the energy supply model a failure to provide sufficient ATP will cause fatigue (87). Nonetheless, in the energy depletion model fatigue during high intensity sprint exercise occurs when the levels of PCr are almost completely depleted (46). Thus, these models attribute fatigue to inadequate supply or depletion of substrates (1). Although energetic models provide an explanation for the development of fatigue in cycling, there are other theories to explain fatigue. The neuromuscular fatigue model attributes fatigue to the muscle functionality, in particular to functions involved with excitation, recruitment and contraction of muscles (7, 80, 115). Neuromuscular fatigue can be described as the inability to maintain a certain level of strength (or power); this reduced capacity after prolonged cycling is a result of both central and peripheral mechanisms (5, 59, 60, 116). According to the neuromuscular fatigue model there are three different points along the neuromuscular pathway where the decrease in muscle activation and contraction could originate (1). However, it is beyond the scope of this literature review to provide detail regarding the mechanistic aspects of neuromuscular fatigue. Numerous biomechanical aspects are also important to sprint exercise performance. In fact, it has been shown that the ability to produce a high peak power output (PO_{peak}) and peak crank torque (CT_{peak}) are important determinants that contribute to achieve superior cycling sprint performances (27, 40). In this context, crank length and cadence may be important variables that, when appropriately adjusted, can

contribute to enhance sprint performances (22, 32, 85). Watsford and colleagues suggested that musculoarticular (MA) stiffness is a contributor factor in sprint cycling, and due to its link with the rate of crank torque development (RCTD), MA stiffness may increase the sprint performance (127). These results are supported by research conducted by Ditroilo and colleagues who report reduction in MA stiffness of the quadriceps after a fatiguing cycling exercise (26). The authors also observed reductions in PO_{peak}, CT_{peak} and $RCTD_{peak}$ due to changes in neuromuscular properties. These results suggest that a training modality which helps in maintaining MA stiffness could assist in maintaining, or improving, sprint performances in fatigued conditions.

While some aspects of fatigue related mechanisms are yet to be fully understood, it's clear that cycling sprint exercise can be influenced by numerous metabolic, neuromuscular and biomechanical mechanisms.

2.4 Effects of prolonged cycling exercise

During prolonged exercise fatigue is associated with metabolic alterations and impairment of muscular strength (1, 24, 59, 108, 114). The latter could be due to impairment of excitation-contraction coupling (8, 72). Maximal Voluntary Contractions (MVC) have been extensively used in exercise physiology research to investigate the effect of prolonged cycling (or exercise in general) on muscle contractile functions (i.e. neuromuscular fatigue). Another valid method of assessing the effect of prolonged cycling exercise is the evaluation of changes in whole-body power output. The change within these variables following relevant cycling related exercise tasks is outlined below.

2.4.1 Peak torque of isometric and isokinetic force

Isometric MVC has been used in several studies to evaluate the effect of prolonged exercise on neuromuscular functions. Sahlin and Seger (108) assessed the quadriceps strength during and after prolonged time to exhaustion cycling exercise. With exercise intensity at 75% of the estimated VO_{2max}, the authors observed a 9% decrease in strength after only 5 minutes of exercise. After 40 minutes of cycling the isometric MVC was 82% of the pre exercise value, and it further decreased to 66% at exhaustion. This research is noteworthy because of the short period of time between the beginning of the

exercise and the measure of strength loss. Other authors have also found similar decrements in isometric MVC (~ 30%) after prolonged cycling exercise to exhaustion (intensity above 70% of the VO_{2max}). These studies also found that at 20 and 30 minutes post exercise the MVC is only partially recovered (14, 100). Some authors have reported significant decrements in MVC torque only after hours of cycling exercise. For example, Vallier and colleagues showed that prolonged cycling reduced the isometric MVC of trained cyclists and triathletes only after the 3rd hour of exercise at 60% of their VO_{2max} (121). Interestingly, Lepers and colleagues reported significant reduction of isometric MVC after two or more hours of cycling at intensity below the 65% of the maximal aerobic power output (MAP). However, results showed that other indicators of fatigue (i.e. excitability and central drive) where only impaired in the final part of the 5-hour ride (58, 59). Collectively, these results are interesting because road sprints occur at the end of several hours of cycling exercise. Contrasting results were found by Decorte and colleagues (24). Indeed, measures of contractile function (e.g. maximal rates of force development and time to peak force) were significantly impaired at the beginning of exercise yet voluntary activation (i.e. EMG amplitude) increased near the end of the exercise (24). A possible explanation of the increased central motor drive could be a compensatory mechanism to account for the reduced muscle functionality and attempt to maintain the required exercise demands.

Investigators have also examined on the effects of prolonged cycling on peak isokinetic force during concentric and/or eccentric contractions. Research has shown reductions of isokinetic MVCs ranging between 11 and 26% after prolonged cycling (58, 108). Lepers and colleagues also showed that riding at the freely chosen cadence does not help in preserving the muscle strength of the leg extensors muscles (60). This result suggests that in road cycling the use of different gears in an attempt to preserve the muscle functionality is unlikely to be a successful strategy.

In conclusion, prolonged intense exercise can cause neuromuscular fatigue, both at peripheral and central level. The impairment in muscle function could result in a reduction in maximal sprint capacity after hours of road cycling.

2.4.2 Whole-body power output

While the assessment of muscle fatigue in isolated muscle (e.g. quadriceps) may be ideal to investigate the fatigue mechanism *in vivo*, whole-body power output is a more

appropriate measure of performance. However, the literature investigating the effects of prolonged cycling exercise on whole-body PO_{peak} is limited. Moreover, only few studies have reported the time course of fatigue. Marcora and Staiano (67) evaluated the time course of fatigue measuring maximal sprint power at different stages of time to exhaustion cycling efforts. In their study, once the time to exhaustion was known, the subjects rode at the same intensity and performed maximal sprints after 25%, 50% and 75% of that time. As expected, the authors found a decrement in the maximal sprint power toward the end of the effort and overall, comparing pre and post exercise maximal sprints, the power output was reduced by about 30%. However, between 50 and the 75% of the time to exhaustion the maximal sprint power did not change significantly. Thus, these results highlight that in certain situations, and despite increased fatigue, whole-body sprint power output can be maintained. McIntyre and colleagues (73) have also recently studied the effects of a time to exhaustion exercise on whole-body power output. In their study, participants rode subsequent 20 minutes stages at 70% of VO_{2peak}, with 30 s maximal test at the end of each step (plus ~ 6 minutes recovery to collect data). As expected, at exhaustion the peak power output was reduced (19%); however, none of the subjects had a decline in peak power output after the first cycling stage. Even more interestingly, after 1 or 2 stages, the authors found that 50% of the subjects had either "potentiated or unchanged" sprint power. Finally, Del Coso and colleagues (25) used maximal cycling sprints as performance outcome while comparing the effects of different exercise modalities; in particular the endurance trained cyclists rode three different intermittent protocols, keeping the average intensity of 50% of the second ventilatory threshold for a total of 24 minutes. Surprisingly, the maximal sprint power produced by the participants was not impaired in any of the three conditions. The above mentioned studies indicate that well-conditioned cyclists can endure a variety of different types of endurance exercise (including intense bursts) for prolonged periods possibly without impairing maximal sprint performances.

2.5 Summary and Conclusion

Sprinting in endurance sports is widespread and directly influences performance outcomes, however, the individuals that specialise in endurance sprinting have received

very little attention from sport scientists. It is possible that the endurance sprint has been evaluated but thus far published research on this topic is scarce.

The available literature describing the anthropometric and physiological characteristics of track and road cycling sprinters indicates that these athletes are unique in many ways (35, 74). The demands of competitions between the track and the road sprint are greatly different: track sprint competitions last generally less than one minute, and the real maximal efforts usually last around 10 s; while road cycling competitions ending with a sprint are generally longer than 4 hours, and the final sprints usually last about 12-14 s. Also due to these reasons, track sprinters have a different body type: they are quite heavy and possess a relatively large proportion of muscle mass, while road sprinters are lighter and maintain less muscle mass, especially in the upper body (35, 74).

To date, only one study reported cycling power output data collected in the field from a successful road sprint. This lack of basic information does not allow to do further studies investigating relevant aspects of this kind of performances, such as the effect of fatigue on sprint power after prolonged exercise. Also, training studies that may try to increase the sprinters' performances are limited by the fact that the determinants of road cycling sprints have not been described. Physiological studies investigating the metabolic contribution of different energetic systems to efforts of different duration allow understanding the mechanisms involved in generating force, thus power output during maximal cycling.

The fatiguing effects of prolonged cycling exercise have been repeatedly reported in literature. Maximal voluntary contractions, both in isometric and isokinetic conditions, are impaired after exercise. The impairment varies based on duration and intensity of the exercise. Whole-body power output is likely to be the best measure to evaluate the fatiguing effect of prolonged exercise on sport performances. Multiple studies reported the loss of maximal power production (i.e. short term power output, or sprint power) during or after prolonged cycling. The biggest impairment in performance generally occurs at time to exhaustion. However, some studies have clearly shown that certain types of cycling exercise, despite being intense, do not impair sprint performance. Research examining the endurance sprinter can be of interest for a number of reasons including: 1) performance review, 2) talent identification, 3) construction of appropriate training programs, and 4) unique insights into manifestations of fatigue and related physiology.

CHAPTER THREE

DEMANDS OF THE SPRINT FINISH IN PROFESSIONAL ROAD CYCLING

3.1 Abstract

The aim of this study was to quantify the demands of sprinting in male professional road cycling competitions. It was conducted in the field in order to maximise the ecological validity of the results. Seventeen performance files from 6 male professional cyclists (age, 27.0 ± 3.8 y; height, 1.76 ± 0.03 m; weight, 71.7 ± 1.1 kg) who placed top 5 in professional road cycling races were analysed. SRM power meters were used to monitor power output, cadence and heart rate. Data were averaged over the entire race, different durations prior to the sprint (60, 10, 5 and 1 min) and during the actual sprint. Variations in power during the final 10 min of the race were quantified using EVA. Power, cadence and heart rate were statistically different between different phases of the race, increasing from 316 ± 43 W, 95 ± 4 rpm and 88 ± 3 % of maximal heart rate in the last 10 min to 487 ± 58 W, 102 ± 6 rpm and 96 ± 2 % of maximal heart rate in the last min of the race. Peak power during the sprint was 17.4 ± 1.7 $W \cdot kg^{-1}$. EVA revealed a significantly greater number of short duration high intensity efforts in the final 5 min of the race, compared with the penultimate 5 min. These findings quantify the power output requirements associated with high level sprinting in men's professional road cycling and highlight the need for both aerobic and anaerobic fitness.

3.2 Introduction

Sprinting is the act of accelerating toward the end of a competition in order to reach the finish line in front of other competitors. Sprinting is an important aspect of road cycling, with approximately one third of grand tours stages (i.e. Tour de France, Giro d'Italia, and Vuelta a España) finishing in a sprint. Furthermore, several high profile

one day races are specifically designed for sprinters. Despite the importance of sprinting to the overcomes of a race and the high number of sprint finishes within professional road cycling, the number of sprint cycling specialists is limited (75). Indeed, cycling teams typically only have one or two designated sprinters, making research on such athletes difficult. As an example, Padilla and colleagues described the characteristics of different types of professional road cycling specialists (93). Despite listing five categories of road cycling specialists (i.e. uphill riders, flat terrain riders, all terrain riders, time trial specialists and sprinters), their study only examined four groups without presenting data on sprinters. In a similar study, Sallet and colleagues identified only four sprinters out of a total of 71 cyclists (109). Likewise, the current literature describing the demands of professional road sprints is extremely limited with one study presenting data from a single cyclist (69).

The majority of research that has examined the physiological characteristics and demands of road cycling have focused on uphill and time trial performances (64, 86, 93). Of these studies, performance has largely been explored and quantified by reporting data averaged over entire stages or large sections of a race (103, 123, 125). A contemporary modelling approach used to evaluate the stochastic nature of road cycling is EVA (4). This method of analysis has been used to describe variation in power output during cycling in a variety of cycling events (4) and under various environmental conditions (99). EVA may be useful for providing insights into the demands of road cycling sprinting whereby power output continually changes due to several technical and tactical factors. Indeed, the lead up to the sprint (i.e. lead up phase: the final 10 min prior to the sprint) could be considered the most crucial part of sprint competitions. In this phase the race intensity may dramatically increase as cyclists attempt to find the best position within the peloton. Prior to the sprint, team support is also considered an important factor presumably because it enables efficient positioning in the bunch, thus decreasing both the intensity and number of efforts ridden prior to the sprint finish (71). However, to the best of our knowledge, there are no published studies providing a detailed analysis of the variability in power output for sprinters competing in road races finishing with a bunch sprint. Therefore, the aim of this study was to examine and describe the characteristics of the sprint finish over various road competitions in male professional cyclists, with particular focus on the lead up phase and the final sprint.

3.3 Methods

The study was observational, and was conducted in the field in order to maximize the ecological validity of the results.

3.3.1 Subject

Race data from six male professional sprint cyclists (age, 27.0 ± 3.8 y; height, 1.76 ± 0.03 m; weight, 71.7 ± 1.1 kg) were collected during seventeen professional road races finished with a bunch sprint. At the time of the study, all subjects were specialised sprinters, competing for a UCI WorldTour professional team. Cyclists were classified as sprinters when their best performances were achieved in relatively flat competitions finishing at high speed and against a relatively large number of competitors (75). As a selection criterion, only races in which the subjects finished in the top 5 were included in this study. The races analysed involved 4 first, 4 second, 4 third, 4 fourth and 1 fifth places. The analysed sprints were performed in World Tours (WT; n=7), Hors Category (HC; n=6), and Category 1 (n=4) competitions. The subjects provided written informed consent to participate in this study, which was approved by Edith Cowan University's Human Research Ethics Committee, in the spirit of the Helsinki Declaration.

3.3.2 Procedures

Power output, cadence, speed, heart rate and elevation gain were recorded at 1 Hz using SRM powermeters mounted on the subjects' bikes (PC7, SRM Training System, Jülich, Germany). The "automatic zero" setting was selected on the SRM PC7 according to the manufacturer recommendation. The accuracy and consistency of power and elevation gain data recorded with SRM devices have been previously reported (3, 76). Race files were uploaded online with the web based service TrainingPeaks, then downloaded and analysed using the WKO+ 3.0 software (Peaksware LLC, Lafayette, CO, USA) or Microsoft Excel (EVA; described below). Power output (W and $W \cdot kg^{-1}$), cadence, percentage of maximal heart rate (% HRmax) and TEG were averaged over the entire race. Furthermore, in order to gain an understanding of the lead up phase and overall sprint performance, data were also analysed in the 60, 10, 5 and 1 min prior to the sprint. During the actual sprint, the duration and speed of the final effort were also measured. The sprint was defined

using the SRM data and measured as the continuous time elapsed between the rapid increase in power output (i.e. beginning of the sprint) and the immediate drop of power (i.e. end of the sprint).

EVA was used to provide a detailed analysis of the variations in power output during the penultimate and final 5 min of the race. EVA has been previously utilized in road cycling to describe the total time and the "acute" time spent at different intensities (4). The total time was defined as the overall time spent in a predetermined intensity zone, while the "acute" time referred to the duration for which power output was continuously within a zone. The intensity zones were determined arbitrarily and defined as power to body mass ratio ($W \cdot kg^{-1}$) in order to allow comparisons among different cyclists and to provide useful information to the readers. In fact, the aim of the study was to describe road sprint finishes and the demands of competition, not the subjective intensity of the subjects to this investigation. Increments of 3.33 $W \cdot kg^{-1}$ were used to define intensity zones, resulting in a total of five zones (see Fig. 3.1).

Finally, to correspond to previous research, the length of time of the acute bands was split into the following zones: from 0 to 1.875, 1.875-3.75, 3.75-7.5, 7.5-15 and >15 s (4, 98). EVA results are expressed as a tridimensional distribution. The standard deviation of the EVA matrix was determined to provide an indication of variability in power output (4, 99).

3.3.3 Statistical Analysis

Results are presented as mean ± standard deviation (range). Dependent variables (power, cadence, % HRmax, TEG, speed) were compared between different competition's phases (race, 60, 10, 5 and 1 min prior to the sprint) using a one-way analysis of variance (ANOVA). The EVA_{SD} matrix were calculated and compared using a paired T-test (penultimate 5 min vs last 5 min) in order to evaluate the variation in power output in the final part of the race before the sprint. A greater standard deviation indicates higher variability with intensity. The time spent at high intensity (> 6.6 $W \cdot kg^{-1}$) for short period of time (< 3.8 s) was also compared using a paired T-test. Relationships between individual EVA_{SD} and race outcomes were evaluated via correlation data analysis. Significance was set at $p \leq 0.05$.

3.4 Results

Power output, cadence, % HRmax, TEG and speed over the entire race and in the final 60 min are summarized in Table 3.1. Power, cadence, % HRmax, TEG and speed were statistically different among different races' phases ($P<0.001$).

Table 3.1 Characteristics of professional sprint races; mean ± SD (range).

	RACE	60 min before sprint	10 min before sprint	5 min before sprint	1 min before sprint
Power (W) [a]	200±27 (155-256)	233±33 (180-287)	316±43 (231-424)	363±38 (273-438)	487±58 (409-593)
Cadence (rpm) [a]	87±4 (80-91)	89±4 (82-96)	95±4 (84-104)	96±5 (84-105)	102±6 (91-113)
HR (%HR_{max}) [a]	70.9±6.7 (58.4-79.0)	77.3±5.8 (66.2-88.9)	87.6±3.2 (81.7-92.2)	91.4±2.5 (86.4-94.8)	95.6±1.7 (90.4-97.9)
TEG (m) [a]	1101±725 (144-2397)	218±192 (0-581)	27±37 (0-152)	15±19 (0-59)	3±6 (0-25)
Speed ($km \cdot h^{-1}$) [a #]	41.0±2.2 (37.1-45.4)	45.4±2.9 (41.2-50.1)	50.5±3.3 (46.1-56.4)	52.1±4.1 (44.1-60.3)	55.4±4.7 (45.7-61.9)

[a] Significantly different among competition's phases ($P<0.001$)
n = 15 races

Figure 3.1 shows the mean EVA plots. The EVA_{SD} was not statistically different between the penultimate 5 min and last 5 min of competitions (15.3 and 13.6, respectively). The time spent at high intensity (> 6.6 W·kg^{-1}) for short period of time (<3.8 s) was different between the penultimate and last 5 min, with 36 ± 17 (11-70) and 70 ± 14 (41-88) s, respectively (P=0.010) (Fig. 3.1, black bars). No correlation was found between the individual EVA_{SD} and race outcome (R^2 = 0.009).

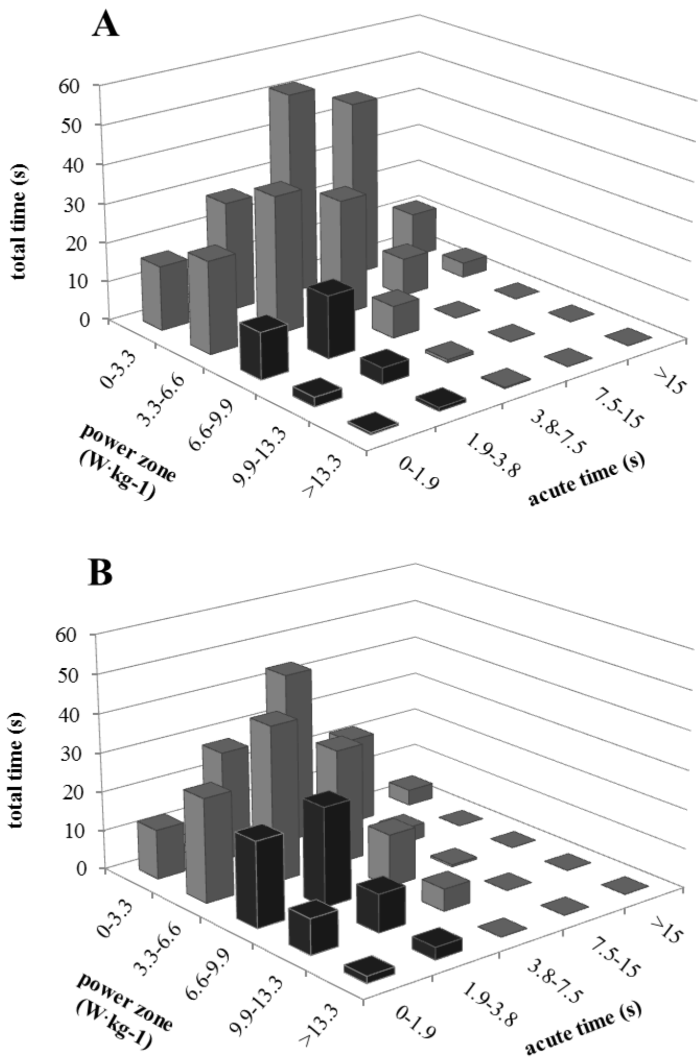

Figure 3.1 Exposure variation analysis of the penultimate 5 min (A), and last 5 min (B) of competition prior to the sprint. In black the time spent in short duration and high intensity efforts.

Mean and peak values during the sprints are reported in Table 3.2. Sprint duration was 13.2 ± 2.3 s (9.0-17.0 s). The HRmax recorded during the sprints was 192 ± 7 bpm (175-206 bpm), corresponding to 99 ± 1% (96.0-100%) of the HRmax recorded during the races.

Table 3.2 Characteristics of road sprints in professional competitions; mean ± SD (range).

	Whole sprint	Peak data
Power (W)	1020±77 (865-1140)	1248±122 (989-1443)
Power ($W \cdot kg^{-1}$)	14.2±1.1 (12.2-15.8)	17.4±1.7 (13.9-20.0)
Cadence (rpm)	110±5 (100-117)	114±5 (102-121)
Speed ($km \cdot h^{-1}$) #	63.9±3.8 (53.7-69.1)	66.1±3.4 (57.1-70.6)

n = 15 races

3.5 Discussion

The aim of this study was to examine the characteristics of the sprint finish in professional road cycling competitions, thus describing the physiological demands of road sprints. The main findings of this study were that: i) when approaching the

finish line the intensity gradually increased, with an mean power output of 487 W, heart rates of 95% HRmax and cadence of 102 rpm in the last minute prior to the sprint; ii) the last 10 min of racing was stochastic in nature with about twice as many short, high intensity efforts in the last 5 min when compared with the penultimate 5 min and; iii) during the final sprint the peak power was 17.4 $W \cdot kg^{-1}$, with a peak cadence of 114 rpm and a peak speed of 66 $km \cdot h^{-1}$.

Within the present study both external (i.e. power output) and internal (i.e. heart rate) load were 10% higher in the last 60 min of race when compared with the intensity over the entire race. The race intensity continued to increase with a power output in the final 10 min of race similar to the one previously reported in a pilot study examining professional road sprint competitions (316 and 332 W, respectively) (78). In the 5 min prior to the sprint the heart rate was 91% of HRmax, indicating that the sprinters were riding at intensity close to their lactate threshold (28). Indeed, although data on the physiological characteristics of the subjects in this study is not available, the 363 W produced in the 5 min prior to the sprint are very similar to the 356 W previously reported to be the anaerobic threshold of professional road sprinters (109). Interestingly, the highest 5 min power to mass ratio observed in this study was 6.1 $W \cdot kg^{-1}$, which is only 8% lower than the estimated 6.6 $W \cdot kg^{-1}$ required for a 4 min (20% shorter) world record pace team pursuit event (111). These results highlight the high intensities that are required by professional road sprinters in the final kilometers of a race in order to be in contention for the sprint finish.

Associated with the very high power outputs and speeds observed in the final kilometres of the race is the variability in intensity, which is likely to be as important to sprint performance. Indeed, many important tactical and technical factors are likely to influence the variability in power output, including team support, position within the peloton, cornering and the need to rapidly accelerate. Furthermore, it has been previously shown that team support during the last minute of the lead-up to the sprint is an important factor in road sprint performance (75). In this study it was suggested that team support allows sprinters to be protected from the wind and sudden changes in speed, allowing them to conserve energies (75). However, it was not possible to provide power data as power was not monitored in the study. Within the present study EVA was used to quantify the variability in power output in the final 10 min of the races. While examination of the entire EVA matrix did not highlight significant differences between the penultimate and final 5 min of the race,

closer analysis indicated that twice as many high intensity, short duration efforts (i.e. >6.6 W·kg^{-1} and <3.8 s) were evident in the last 5 min, compared with the penultimate 5 min (Fig. 3.1, black bars). Unfortunately, it is unclear from the present study whether this increase in the variability of power output was associated with technical and tactical factors, such as a decrease in number of team members supporting the sprinter, a decrease in the total number of riders, changes in the race profile (i.e. corners or elevation) or the slight increase in speed (50.5 km·h^{-1} to 52.1 km·h^{-1}; Tab. 3.1). Regardless, these findings are important in understanding the physical demands of professional road sprinting and will potentially assist in selecting cyclists and developing training programs for athletes who specialise in sprinting.

Results of the present study indicate that the cyclists produce high power outputs during the sprint finish. The mean and peak power observed during the sprint in the present study (1020 W and 1248 W, respectively; Tab. 3.2) are somewhat similar to those previously published within case studies on professional sprinters (e.g. mean, 926 and 1120 W; peak 1097 W and 1370 W) (69, 78). Likewise, the peak speed observed in this study (66.1 km·h^{-1}) is similar to that observed by Martin and colleagues (65 km·h^{-1}) (69). While such high power outputs indicate the importance of anaerobic metabolism to successful road sprint performance, no significant relationship was observed between performance (i.e. race results) and sprint power output. This observation is probably because many other factors are important to sprint performance, such as aerodynamics, position and tactics. Indeed, position in the bunch has already been shown to be important for successful sprint performances (75). Further research examining multiple riders within the same sprinting ability may assist in better understanding the tactical and technical factors that influence the relationship between sprint power output and performance.

Despite the high power outputs observed here, the maximal sprint capacity of these athletes is considerably lower than those previously reported in track sprinters (i.e. ~21 W·kg^{-1}) (40). These differences are reasonable given the vastly different characteristics of road and track sprint races. Indeed, prior to the sprint, road sprint cyclists are required to cycle for prolonged periods at moderate intensities. Within the present study, the mean power output over the entire race was 2.8 W·kg^{-1}, which is higher than previously reported in flat races (2.0±0.4 W·kg^{-1}) (125), but slightly lower than reported in a stage race (3.1±0.2 W·kg^{-1}) (123). A major factor

influencing the mean power output throughout the stage is the TEG. A large range in the TEG was observed in the races analysed in this study (i.e. 144 to 2397 m), with the mean (i.e. 1100 m) being considerably higher than that previously reported in a case study of an extremely successful professional sprinter (~600 m) (75). Clearly, the climbing ability of different sprinters could be diverse and, as such, the elevation change throughout a race is likely to have considerable influences on sprint performance. It's noteworthy to consider that the distribution of the elevation gain along the race course is likely to be of great importance to the race outcomes. As a matter of fact, in this study no sprints occurred when the elevation gain was above 580 m in the last 60 min. Such data is important as it gives an indication of the climbing ability that could be required by sprinters in order to reach the finish line and be in contention to sprint. From a practical point of view, these data contribute to highlight the importance of aerobic fitness in road sprint cycling and could have significant influences on training prescription and/or the selection of sprinters for particular races.

In conclusion, despite the small number of successful road sprinters, a relatively high number of road sprints from high level professional cyclists were examined in this investigation. The results of the present study indicate that the physical demands of road sprint cycling are unique. In fact, in order to be in contention for the sprint cyclists are required to ride for prolonged periods (~4 h) at moderate intensities (2.8 $W \cdot kg^{-1}$) with varying elevation gain (up to 580 $m \cdot h^{-1}$ of vertical ascension rate in the 60 min prior to the sprint). The final 5 min of the race could be extremely demanding due to the combination of very high intensity and significant variability in power output. Indeed, the final 5 min of the race contained about twice as many short duration, high intensity efforts as the penultimate 5 min. Top 5 finishers observed in this study produced mean power outputs of 14.2 $W \cdot kg^{-1}$ for 13 s during the sprints, reaching peak powers of 17.4 $W \cdot kg^{-1}$. These data provide important information regarding the physical demands of professional road sprinting and thus may aid in the identification of talent, in training prescription, and in the selection of teams or athletes for specific road races.

CHAPTER FOUR

PHYSIOLOGICAL DEMANDS OF ROAD SPRINTING IN PROFESSIONAL VS U23 CYCLISTS

4.1 Abstract

This study described and compared the power output (absolute, relative to body weight and relative to frontal area) recorded during successful road sprints in professional and under 23 men's cycling races. The study also described the exercise intensity and requirements of sprinters throughout final 10 min of the race. Nine successful (top 3) sprints performed by a professional (PRO: 23 y old, 1.76 m, 71.8 kg) and an under 23 (U23: 18 y old, 1.67 m, 63.2 kg) cyclist sprinter were analysed in this study. No statistical differences were found in absolute peak and mean power, duration and total work (PRO: 1370 ± 51 W, 1120 ± 33 W, 14.5 ± 2.4 s, 16.2 ± 2.6 KJ; U23: 1318 ± 60 W, 1112 ± 68 W, 12.8 ± 1.1 s, 14.2 ± 1.4 KJ). However, the mean power output relative to body weight and relative to projected frontal area (A_p) was lower in PRO compared to U23 (15.6 ± 0.4 and 17.4 ± 1.1 $W \cdot kg^{-1}$; and 2533 ± 76 and 2740 ± 169 $W \cdot A_p^{-1}$, respectively). The intensity of the race recorded in the last 10 min prior to the sprint was significantly higher in PRO than U23 (4.6 ± 0.3 and 3.7 ± 0.2 $W \cdot kg^{-1}$, respectively). The races duration, TEG and mean power were similar between PRO and U23. In conclusion, the physiological demands leading into road sprinting (intensity of the last 10 min) were found to be higher in PRO compared to U23 races; however, a similar sprint power output (> 2500 $W \cdot A_p^{-1}$ or > 15.5 $W \cdot kg^{-1}$ for approximately 14 s, with a peak power output > 3100 $W \cdot A_p^{-1}$ or > 19 $W \cdot kg^{-1}$) indicates that sprint characteristics may be somewhat similar between PRO or U23 races. Further research is warranted in order to better understand physiological and tactical aspects important to road sprint cycling.

4.2 Introduction

Several studies have described and compared the anthropometric and physiological characteristics of cyclists from various disciplines, specialties and levels of competition (65, 83). Generally, these studies have examined the cyclists' aerobic characteristics, with few studies reporting performance in efforts with durations relevant to sprinting (i.e. ≤ 30 s). Interestingly, similar absolute (W) and relative ($W \cdot kg^{-1}$) power outputs have been reported between high and low level male junior cyclists (79), and between under 23 and professional male cyclists (109), during laboratory based sprint tests (i.e. 5 to 30 s duration). However, these tests were performed with subjects that were not exclusively sprint specialists and under laboratory and not race conditions.

Despite the frequency of sprints in road cycling (e.g. ~7 out of 21 stages within Grand Tours) limited scientific research is available, with only a single study reporting the power output of a cyclist in a professional road sprint (69). Moreover, in road cycling the number of successful sprinters is somehow limited (e.g. 1 or 2 riders out of 30 per team). These factors, together with the complexity of road sprinting, may be the reason for the lack of scientific research describing the physiological demands of road sprinting. As such, little is known on the characteristics and performance demands of successful road sprinting. To date, a considerably greater body of literature has examined sprint performance during track cycling. While it has been suggested that maximal power may be a predictor of sprint performance, Dorel and colleagues (27) found that mean sprint speed during track cycling was not correlated with maximal power output (in W or $W \cdot kg^{-1}$) but instead significantly correlated with power output relative to the cyclists frontal area ($r = 0.75$, $p = 0.01$).

To the best of our knowledge, no study has examined the sprint power output of road cyclists competing at different levels of competition, or reported the sprint power output in relation to frontal area. Thus, in order to better understand the physiological demands of road sprinting, the main aim of this study was to describe and compare the power data (absolute, relative to body weight and projected frontal area) recorded during successful road sprints in professional and U23 male cycling races. Moreover, a secondary aim of this study was to examine the intensity in the

final 10 min of the race to describe the difficulties that a sprinter has to overcome to be in contention for the sprint.

It was hypothesised that the sprint power output relative to frontal area will be similar between successful professional and U23 sprints; however the intensity in the final kilometres of the race will be higher in professional road competitions.

4.3 Methods

The study was a retrospective observational study. The study was conducted in the field in order to maximize the ecological validity of the results.

4.3.1 Subjects

The subjects of this investigation were a male professional cyclist, competing for a UCI World Tour team in his fourth year as a professional cyclist (PRO: age, 23 y; height, 1.76 m; weight, 71.8 kg; VO_{2max}, 72.5 $ml \cdot kg^{-1} \cdot min^{-1}$) and a male non-professional cyclist competing at International level for his first year in the UCI Under 23 category (U23: age, 18 y; height, 1.67 m; weight, 63.2 kg; VO_{2max}, 70.3 $ml \cdot kg^{-1} \cdot min^{-1}$). The subjects were successful road cycling sprinters and the performances analysed in this study included at least 3 winning sprints for each rider, in their respective categories. The subjects provided written informed consent to participate in this study, which was approved by a University Human Research Ethics Committee. The study meets the international ethical standards described by Harriss and Atkinson (48).

4.3.2 Procedures

Performance data of the cyclists over an entire road cycling season have been collected. Only flat or hilly races, finishing at high speed and with a relatively high number of contenders (i.e. bunch sprint) have been considered for this study. Furthermore, only events where subjects finished within the top 3 positions have been analysed. As such, a total of nine sprint performances have been analysed (PRO n: 4, U23 n: 5).

Power output and elevation gain were recorded at 1 Hz using SRM powermeters mounted on the subjects' bikes (PC7, SRM Training System, Jülich, Germany). As suggested by the manufacturer the "automatic zero" setting was turn on the SRM PC7 powermeters. The accuracy and reliability of the SRM powermeters have been previously reported (3, 41). Race files were uploaded online with the web based service TrainingPeaks, then downloaded and analysed using the WKO+ 3.0 software (Peaksware LLC, Lafayette, CO, USA).

The peak and mean power output, sprint duration and total work were determined for each sprint. Sprint power data were presented as absolute (W), relative to body weight ($W \cdot kg^{-1}$) and relative to projected frontal area ($W \cdot A_p^{-1}$). The power output of the cyclists in the 1, 5 and 10 min prior to each sprint were also determined. In order to describe the external load, power data were presented as absolute (W), relative to body weight ($W \cdot kg^{-1}$), and percentage of the subjects' maximal mean power for 60 minutes (%MMP_{60}) (101). Also, total time, mean power (W and $W \cdot kg^{-1}$) and TEG of the races were recorded (PC7, SRM Training System, Jülich, Germany).

The projected frontal area (A_p) of the cyclists has been calculated using digital pictures, as previously done in track sprint cycling research (27). A modified version of the method described by Heil (49) was used. Briefly, frontal photographs of the sprinting cyclists were used to determine the area of the rider and bike and calculated in $pixels^2$ using a computer based photograph analysis software (Adobe Photoshop 12.0, Adobe System Inc, San Jose, CA, USA). The height of the front wheel was calculated in pixels and used to convert pixels into meters based upon a wheel's height of 0.668m (700c wheel with 23mm tyre). Two pictures for each cyclist were utilized, and the mean A_p was used for the analysis (PRO, 0.442 m^2; U23, 0.406 m^2).

4.3.3 Statistical Analysis

Sprint data were compared between PRO and U23 using a one-way ANOVA on each dependent variable which met the parametric assumptions. When parametric assumptions were not met, an independent samples Mann-Whitney U test was used to compare categories. The exercise intensity in the 10 min prior to the sprint was compared using a two-way ANOVA (2 categories x 3 times). When a significant F-value was found, Bonferroni's *post hoc* test was applied. Critical level of

significance was established at $P<0.05$. As per the study above, results are presented as mean ± SD.

4.4 Results

Table 4.1 reports the sprint parameters for PRO and U23. No statistical differences were found in absolute peak and mean power, duration and total work. The peak and mean power output relative to body weight was higher in the U23 compared to the PRO sprinter. Likewise, mean power output relative to projected frontal area was higher in the U23 compared with the PRO.

Table 4.1 Peak and mean sprint power, sprint duration and total work in successful PRO and U23 sprints.

	PRO (n: 4)	U23 (n: 5)	*P*
Peak Power (W)	1370 ± 51	1318 ± 60	P=0.214
Peak Power ($W \cdot kg^{-1}$) [a]	19.1 ± 0.7	20.6 ± 1.0	P=0.034
Peak Power ($W \cdot A_p^{-1}$)	3098 ± 116	3246 ± 148	P=0.148
Mean Power (W)	1120 ± 33	1112 ± 68	P=0.905
Mean Power ($W \cdot kg^{-1}$) [a]	15.6 ± 0.4	17.4 ± 1.1	P=0.016
Mean Power ($W \cdot A_p^{-1}$) [a]	2533 ± 76	2740 ± 169	P=0.016
Sprint Duration (s)	14.5 ± 2.4	12.8 ± 1.1	P=0.194
Work (J)	16220 ± 2645	14221 ± 1364	P=0.183

[a] $P<0.05$

Power outputs in the 10 min prior to the sprint are showed in Table 4.2. Power output, presented as absolute, relative to body weight and %MMP60, were all significantly higher in PRO than U23. The race intensity prior to the sprint was higher in the final minute compared to the final 5 and 10 min. However, no interactions between categories and time were found.

Table 4.2 Physiological demands of road sprint competitions, before the sprints.

	PRO [a]			U23		
Time (min) [b]	1	5	10	1	5	10
Power (W)	450±40	376±28	332±23	385±27	270±26	237±14
Power to weight ($W \cdot kg^{-1}$)	6.3±0.6	5.2±0.4	4.6±0.3	6.0±0.4	4.2±0.4	3.7±0.2
$\%MMP_{60}$	138±13	116±9	102±7	141±10	99±10	87±5

[a] Significantly different from U23 (P<0.001); PRO>U23

[b] Significantly different between times (P≤0.001); 1>5>10

Total time, mean power (W and $W \cdot kg^{-1}$) and TEG of the races were not statistically different between categories: 228 ± 47 min, 213 ± 29 W, 3.0 ± 0.4 $W \cdot kg^{-1}$ and 1295 ± 664 m for the PRO; and 239 ± 11 min, 186 ± 14 W, 2.9±0.2 $W \cdot kg^{-1}$ and 1038 ± 204 m for the U23.

4.5 Discussion

The purpose of this study was to describe and compare performances in professional and U23 successful male road sprints. The main findings from this study were that: i) the power output (absolute, relative to body weight and relative to frontal area) and total work recorded in successful PRO sprints were similar to successful U23 sprints and, ii) the race intensity (absolute and relative power output) in the 10 min leading into the sprint was higher in PRO compared with U23 races.

Contrary to our hypothesis, the results from the present study indicate that a number of sprint parameters (i.e. scaled to body weight and frontal area) were

actually higher in the U23 than in the PRO. Whether this was due to the different body size of the subjects (9 cm and ~9 kg) or to the relatively higher performance level of the U23 sprinter is unclear. However, the aim of the study was to describe the power output necessary to be successful in these categories, as such the data presented here remains relevant in regard to the scope of the study. In particular, the present examination shows that producing a power output > 2500 $W \cdot A_p^{-1}$ (or > 15.5 $W \cdot kg^{-1}$) for approximately 14 s, with a peak power output > 3100 $W \cdot A_p^{-1}$ (or > 19 $W \cdot kg^{-1}$), can potentially lead to a successful sprint in both the professional and U23 categories. Indeed, previously published data has shown that a professional sprint can be won with an even lower peak (~15.2 $W \cdot kg^{-1}$) and mean power output (~12.9 $W \cdot kg^{-1}$) over similar duration (14 s) (69). Similarities in power output between the professional and U23 cyclists observed in this study support previous research that has found no difference in 30 s all-out laboratory sprint performance of professional and U23 cyclists (16.0 ± 1.6 and 16.6 ± 1.9 $W \cdot kg^{-1}$, respectively) (109). These laboratory based power outputs are somewhat higher than those observed in this field study and possibly reflect the fact that in road cycling the sprint occurs after hours (> 4 h) of riding and following a prolonged period of high intensity cycling as showed in the present study (Tab. 4.2).

Interestingly, the relative intensities in the 10 min leading into the finish were higher in the professional races compared with the U23 races. It should be noted that numerous factors may influence a cyclists power output prior to and during a sprint, including physiological characteristics, race dynamics, gradient of the road, wind speed, team support and the ability of the cyclists to position themselves within the bunch appropriately. Indeed, it has recently shown that performances of world class sprint cyclists are related to the team support and the cyclists position within the bunch (75). As such, it is unclear from the present study if technical and tactical factors influenced the power output, relative intensities and performances of cyclists within this study. Irrespectively, the overall intensity of the events analysed in this study (3.0 ± 0.4 $W \cdot kg^{-1}$ and 2.9 ± 0.2 $W \cdot kg^{-1}$ for PRO and U23, respectively) were higher than those recorded in professional flat races (2.0 ± 0.4 $W \cdot kg^{-1}$) (125), but similar to the one previously reported in a professional road stage race, with both flat and mountainous stages (3.1 ± 0.2 $W \cdot kg^{-1}$) (123).

Calculating sprint power output relative to a cyclist's projected frontal area, as in the present study, is likely to be extremely important to sprint cycling

performance. However, it was unfortunately not possible within this study to accurately determine other factors that may influence the calculated sprinters' aerodynamic drag, including air density, wind strength and direction (70). Moreover, other variables such as the bike position (standing or seated) and the position in the bunch (front position or drafting) can influence the aerodynamic drag area (69). Further research examining the importance and methods of determining road sprint cycling power output relative to projected frontal area and aerodynamic drag area is warranted.

A limitation of the present examination is the small number of sprints performed by two single PRO and U23 riders. However, it's worth mentioning that there are very few specialist sprinters in the entire peloton with approximately only one or two per team. Furthermore, the number of races throughout a season whereby these sprinters may be in contention to sprint and ultimately achieve a successful outcome is limited. Considering that all analysed files were from successful sprint performances with professional and U23 events, the data presented here are of great value when it comes to describing the physiological demands and characteristics of successful sprints.

As practical applications, describing and understanding the characteristics important to successful road sprinting will assist professionals, coaches, researchers, and athletes in training program development, talent identification and physical load monitoring. Moreover, examining the physical requirements of sprinters in the final kilometres prior to the race finish will assist in a better of understanding the physiological characteristics important to successful cycling performance. Awareness that a given rider has the physiological capability to win a road sprint, allows them or their team to focus on other aspects that may be important to success, such as the technical and tactical aspects of road sprinting (e.g. team support) or improving climbing ability to ensure the sprinter reaches the finish line with the main group.

In conclusion, this study showed that the physiological demands of male road sprinting in professional races are higher compared to U23 races, in particular the power output in the final part of the race, prior to the sprint. However, a similar sprint power output can theoretically allow a cyclist to win a bunch sprint in either PRO or U23 races.

CHAPTER FIVE

MAXIMAL SPRINT POWER FOLLOWING VARIABLE OR NON-VARIABLE HIGH INTENSITY EXERCISE IN ROAD CYCLISTS

5.1 Abstract

This study compared the sprint performance of professional cyclists following 10 min of variable or non-variable high intensity cycling with sprint performance in a rested state. Ten internationally competitive male cyclists (mean ± SD: 20.1 ± 1.3 y, 1.81 ± 0.07 m, 69.5 ± 4.9 kg, and 72.5 ± 4.4 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$) performed a 12 s maximal sprint in a rested state and following two conditions: i) 10 min of non-variable cycling, and ii) 10 min of variable cycling. The intensity during the 10 min efforts gradually increased to replicate power output previously observed in the final section of cycling road races for this calibre of road cyclist. During the variable cycling subjects performed short (2 s) accelerations at 80% of their sprint peak power, every 30 s. Mean power output, cadence and heart rate during the 10 min efforts were similar between conditions (5.3 ± 0.2 $W{\cdot}kg^{-1}$, 102 ± 1 rpm, and 93 ± 3 % HRmax). Post exercise blood lactate concentration and sessional perceived exertion were also similar (8.3 ± 1.6 $mmol{\cdot}L^{-1}$, 15.4 ± 1.3 (6-20 scale)). Peak and mean power output and cadence during the subsequent maximal sprint were not different between the three experimental conditions ($p \geq 0.14$). In conclusion, this study showed that within the intensity limits introduced in this protocol that neither the variable nor the non-variable 10 min efforts impaired sprint performance in elite competitive cyclists.

5.2 Introduction

Road sprint cyclists are unique athletes that specialise in producing maximal power output following several hours of cycling. The final section of races, known as lead up phase, is particularly intense as cycling teams aim to place their sprinter in the best possible position for the finish. Indeed, intensity in the final 10 km of a race typically increases during which several important tactical decisions are made (71). In professional races ending with a bunch sprint the power output is often variable and can increase from approximately 3 $W \cdot kg^{-1}$ to more than 6 $W \cdot kg^{-1}$ during the last minute prior to the sprint (78). The high intensity cycling prior to the sprint may impair cycling power output during maximal efforts (67, 73, 117). To the best of our knowledge, no studies have examined the effect of a task specific effort similar to the lead up phase typical of road races on a maximal cycling sprint performance.

Team support and good position in the bunch during the lead up phase are associated with successful performance in the sprint (71). For instance, it has been previously shown in a world class road sprinter that the position in the bunch was closer to the front, and the number of team members supporting the sprinter was higher in races won than lost (75). Team support may assist sprint performance by allowing a smoother and more even distribution of power output in the lead up phase of the race. Conversely, when unsupported the sprinter is required to fight for position within the bunch of cyclists (i.e. peloton), thereby resulting in a variable and intermittent distribution of power output, possibly compromising sprint performance. Indeed, rapid accelerations and high intensity efforts are likely to result in greater recruitment of type II muscle fibres and reliance on anaerobic metabolism, thereby compromising the final sprint performance. However, in addition to high anaerobic capacities, road sprint cyclists are also known to have very high aerobic fitness and thus they may be able to rapidly recover from such variable intensity exercise.

While previous research has compared the physiological effects of constant versus variable intensity exercise (62, 118), we are unaware of any studies that have examined the influence of such exercise on maximal sprint cycling power output. Furthermore, to the best of our knowledge none of the abovementioned studies involved elite cyclists. Therefore, the aim of this study was to examine the effects of variable and non-variable lead up efforts on the maximal sprint capacity of

internationally competitive male cyclists. It was hypothesised that a variable lead up would result in greater decrements in performance when compared with a non-variable lead up effort.

5.3 Methods

5.3.1 Subjects

Ten internationally competitive male cyclists (age, 20.1 ± 1.3 y; height, 1.81 ± 0.07 m; weight, 69.5 ± 4.9 kg; VO_{2peak}, 72.5 ± 4.4 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in this study. The subjects are classifiable as professional cyclists or "performance level 5", accordingly to the Guidelines to Classify Subject Groups in Sport-Science Research (23). The cyclists provided written informed consent to participate in the study, which was approved by the University Human Research Ethics Committee in accordance with of the Declaration of Helsinki.

5.3.2 Procedures

The subjects visited the laboratory on 5 separate occasions. All the visits were separated by at least 48 h and were completed within two weeks. The subjects were asked to avoid intense exercise for 24 h prior to each visit. During all testing sessions the temperature of the physiology laboratory was between 20-23°C and relative humidity was between 45-60%.

During the first visit to the laboratory the cyclists performed an incremental cycling test to exhaustion. In the following two sessions subjects were familiarised with the sprints and lead up efforts. During the remaining two sessions subjects then performed the two experimental trials in a randomised and counter-balanced order. During these trials maximal sprint capacity was assessed in a rested/fresh state (CON) and then following 10 min of either variable or non-variable cycling (described below).

5.3.2.1 Incremental cycling test

Subjects performed an incremental cycling test to exhaustion on an electronically braked cycle ergometer (Lode Excalibur, Groninger, The Netherlands),

fitted with the cyclist's own pedal system and adjusted to replicate their individual riding position. The test started at 100 W and increased by 50 W every 5 min until volitional exhaustion. The cyclists self-selected a cadence between 90 and 100 for the duration of the test. Heart rate (Polar S710, Polar Electro, Kempele, Finland) was recorded in the final 30 s of each step, and oxygen consumption was measured throughout the test using a customised gas analysis system (Australian Institute of Sport, Canberra, Australia). Calibration of this system has been described by Saunders and colleagues (110). The peak power output for the incremental test was calculated using the formula of Kuipers and colleagues (57). VO_{2peak} was determined as the two highest consecutive 30 s samples.

5.3.2.2 Experimental exercise sessions

Every experimental session was preceded by a standardised 15 min warm-up. The warm-up intensity was set at 100 W and the cyclists were requested to do 2 short accelerations during the warm-up. During the experimental sessions subjects performed a maximal 12 s effort prior to and immediately following 10 min of either variable or non-variable cycling. Subjects then repeated this protocol on the same day separated by 15 min recovery. Thus during each of the two experimental sessions each subject completed two maximal sprints in a rested condition and two sprints following the 10 min lead up phase. The lead up efforts and sprints were completed on a custom built wind-braked ergometer (AIS, Canberra, Australia) adjusted to replicate the individual riders' positions, and fitted with the cyclists' own pedals. The ergometer consisted of a stainless steel frame that supported a 15 kg flywheel with 18 fan blades to provide air resistance. The mass of the wheel and gearing system were designed to replicate the kinetic energy and crank inertial load typical of road cycling (101). Cyclists accelerated the flywheel via an intermediate drive; the gearing system was adjusted by the researcher in order to provide the adequate cadence and intensity.

During the 12 s sprint cyclists were asked to perform a 'maximal sprint, as if sprinting for a road race victory'. During all sprints the ergometer's resistance was manually adjusted so that they started at the same power output and cadence. During the sprints the cyclists were allowed to remain seated or sprint "out of the saddle". Strong verbal encouragement was provided to subjects during all sprints. Technical error of measurement (TEM) in our laboratory, for peak and mean sprint power after

exercise, were 2.2 and 2.1%, respectively (unpublished data). The 12 s sprint was designed to replicate the sprint duration observed in professional road cycling sprints (69, 75).

The variable and non-variable lead up phases were matched for total work (i.e. mean power output). Both the variable and non-variable lead up phases progressively increased in intensity to simulate the demands observed in the final 10 min of road races ending in a sprint (78). The intensity started at 3 W·kg^{-1} and 95 rpm and progressively increased to ~4 W·kg^{-1} (100 rpm) during the first nine minutes, and ~5 W·kg^{-1} during the 10th minute (Fig. 5.1). The familiarization sessions (days 2 and 3) were used to fine tune the individual targeted power output in order to ensure that subjects rode the last minute at intensity above 92% of their maximal heart rate. The cyclists were verbally instructed and reminded about their targeted power output and cadence every 30 s during the lead up phase. Every 30 s during the variable condition subjects performed an acceleration. During these accelerations subjects were asked to do 3 complete pedal strokes (less than 2 s in duration) with the goal of reaching a power output equivalent to 80% of the peak power measured during the fresh maximal sprints in day 2 and 3. (Fig. 5.1, B). The mean peak power reached during the accelerations was 12.1 ± 1.3 W·kg^{-1}.

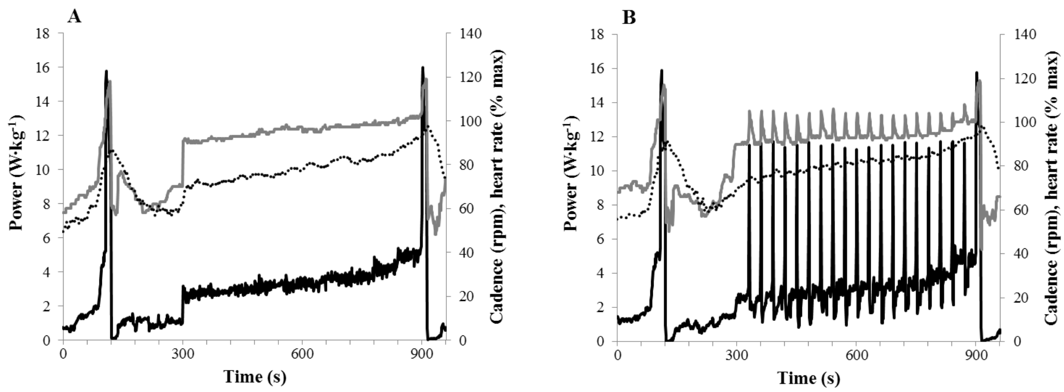

Figure 5.1 Example of the experimental conditions within this study: A) sprint in fresh condition followed by non-variable lead up and sprint, B) sprint in fresh condition followed by variable lead up and sprint. Power (black line), cadence (grey line), and heart rate (dotted line).

Throughout the lead up phase and the sprints power output, cadence and heart rate were recorded at a sampling rate of 1 Hz with a SRM power meter fitted to the crank of the ergometer (SRM PowerControl V; Schoberer Rad Messtechnik, Germany). The SRM was calibrated prior to data collection and the zero offset was checked prior to each test as per the manufacturer guidelines (3). Lactate concentration was measured from a sample of fresh blood collected from the subjects' fingertip, with a portable analyser (Lactate Pro, Arkray, Shiga, Japan), 48 s following the sprint (i.e. 1 min following the lead up efforts).

After each sprint the cyclists were asked to rate the effort they gave on a 0 to 100% scale by answering the question: "How much did you give?" Thirty minutes following each session subjects were also asked to rate the intensity of the session utilizing a modified perception of effort scale (36). The subjects were familiar with the use of the scales prior to the experimental trials.

5.3.3 Statistical Analysis

To confirm that subjects were able to maintain the required intensity (and total work) during the lead up phase, dependant variables (i.e. mean power output, mean heart rate, lactate and session RPE) were compared between the variable and non-variable conditions using a one-way ANOVA. Analysis was completed on the entire 10 min effort and on the last minute of data prior to the sprint. Sprint performance (i.e. peak and mean power output and cadence) was compared between conditions (CON, variable and non-variable conditions) using a one-way ANOVA (JMP Pro 10, Cary, North Carolina). Statistical significance was set at $P \leq 0.05$.

Sprint data from the three conditions were analysed using the magnitude-based inference approach recommended for studies in sports medicine and exercise science (51, 128). A specifically designed spreadsheet (available at newstats.org/xCombineGroups.xls) was used to determine the clinical significance of each treatment. Uncertainty in the effect was expressed as 95% confidence limits. Magnitude of the effects were interpreted using thresholds of 0.2, 0.6, 1.2 and >2.0 for small, moderate, large and very large, respectively. The smallest worthwhile value was determined by multiplying the between subject SD by Cohen's value of the smallest worthwhile effect of 0.2. In circumstances where the chance (%) of the

true value of the statistic being > 25% likely to be beneficial or harmful, a practical interpretation of risk is given. The effect was deemed unclear if its confidence interval overlapped the threshold for substantiveness (e.g. if the effect could be substantially positive and negative, or beneficial and harmful).

5.4 Results

As expected no statistical differences were observed in mean power output, cadence, mean heart rate, lactate and session RPE between the variable and non-variable cycling exercises. In particular, the mean parameters for the lead up efforts were: power output 3.78 ± 0.07 and 3.74 ± 0.08 W·kg^{-1}, cadence 96.6 ± 0.7 and 96.2 ± 0.8 rpm, % HRmax 82.0 ± 3.5 and 83.4 ± 4.6, lactate 8.2 ± 1.3 and 8.4 ± 1.9 mmol·L^{-1}·min^{-1}, and RPE 15.1 ± 1.2 and 15.7 ± 1.3 for the non-variable and variable conditions, respectively ($P \geq 0.11$). Similarly, during the last 60 s prior to the sprint there were no differences between non-variable and variable conditions: 5.34 ± 0.17 and 5.30 ± 0.17 W·kg^{-1}, 101.5 ± 1.1 and 101.6 ± 1.2 rpm, and 92.3 ± 2.3 and 93.4 ± 3.4 % HRmax, respectively ($P \geq 0.25$).

Sprint results in rested condition and following the variable and non-variable protocols are summarized in Table 5.1. Peak and mean power output and peak and mean cadence were not different between the three conditions (CON, variable and non-variable). There was no difference in the cyclists' effort during the sprints, with subjects *giving* 97.2 ± 5.4, 98.7 ± 3.1, and 98.9 ± 3.1 % in the CON, variable and non-variable condition, respectively ($P=0.260$).

Table 5.1 Mean ± SD [95% CI] sprint parameters observed in fresh (CON), variable (VAR) and non-variable (N-VAR) cycling.

					Chances (% and qualitative) of positive/trivial/negative outcome compared to CON	
	CON	VAR	N-VAR	P value	VAR	N-VAR
Peak power ($W \cdot kg^{-1}$)	15.2±2.0 [14.5, 15.8]	16.0±1.5 [15.3, 16.8]	16.0±2.1 [15.0, 16.9]	0.168	34/66/0 possibly beneficial	36/64/0 possibly beneficial
Mean power ($W \cdot kg^{-1}$)	13.1±1.5 [12.6, 13.6]	13.8±1.5 [13.1, 14.5]	13.8±1.5 [13.0, 14.5]	0.142	24/76/0 likely trivial	25/75/0 likely trivial
Peak cadence (rpm)	118.9±3.5 [117.8, 120.0]	118.1±3.4 [116.4, 119.8]	118.4±3.1 [116.9, 119.9]	0.660	4/54/42 possibly trivial	5/66/29 unclear
Mean cadence (rpm)	114.9±3.1 [113.9, 115.9]	114.5±3.1 [113.0, 115.9]	114.9±3.2 [113.4, 116.4]	0.851	5/71/24 possibly trivial	13/74/13 possibly trivial

[a] P<0.05

5.5 Discussion

The primary findings in this study were: i) 10 min of cycling, designed to simulate the lead up phase prior to a cycling road race sprint, did not impair the sprint performance in elite cyclists; and ii) there were no differences in the sprint power output after an either variable or non-variable 10 min effort.

Despite the moderate to high intensity of the variable and non-variable cycling exercises in the present study (10 min at ~82-83% HRmax), neither condition had a negative effect on the cycling sprint power. These results are somewhat surprising and in contrast to previously published studies which have reported the detrimental effects of intense exercise on maximal cycling sprint performance (67, 73, 117). However, a main difference between the present study and previous research is the performance level of recruited subjects. Within the present study we recruited well trained internationally competitive cyclists classifiable as 'performance level 5', or professional, according to the Guidelines to Classify Subjects Groups in Sport-Science Research, while the participants of the abovementioned studies were active male cyclists or rugby players with a mean VO_{2peak} below 56 $mL \cdot kg^{-1} \cdot min^{-1}$, which places them in the lower "performance level 3" (23). Furthermore, the exercise protocol (i.e. intensity and duration) within the present protocol differs to previous research thereby impacting on the comparability of results.

The intensity and duration of the 10 min cycling bout in the present study was developed to replicate the physical demands experienced by cyclists during the final lead up phase of professional road cycle races (78). As such, the similar power outputs observed during the sprints both prior to and following the efforts indicate that the high intensity nature of the lead up phase itself has limited influence on sprint ability, at least within such trained cyclists. It is possible that during such short duration exercise (10 min) the maintenance of performance is associated with an increase in central drive to overcome the progressive development of peripheral fatigue. Indeed, it has previously been observed during high intensity cycling of slightly higher intensity (90% of Pmax) but shorter duration (5:49 min:s) that peripheral fatigue occurs early in the exercise task (60% of time to exhaustion) and is associated with a progressive increase in voluntary activation towards the end of the

task (91). Furthermore, McIntyre and colleagues (73) found that 50% of their participants “had either potentiated or unchanged” sprint power output following prolonged cycling exercise (20 min at 70% of VO_{2peak}, with 30 s maximal test, plus ~6 min recovery). Interestingly, the majority of the studies which have observed a decline in sprint performance following exercise have typically involved prolonged exercise at high intensities. For instance, Theurel and colleagues (117) found a difference in the maximal power ridden by trained cyclists and triathletes after 30 min of exercise at 75% of the maximal aerobic power ($p<0.05$). It is therefore plausible that the prolonged exercise duration of typical road cycling events has a great influence on sprint performance than the physical demands of the lead up phase per se.

It has previously been shown that the number of team members in the final part of competition before the sprint effects the sprinter’s performance. This scenario could result in a smoother/less variable distribution of the power output, due to the fact that the sprinter is riding in a protected position. Therefore, in addition to examining the overall effects of high intensity exercise on sprint performances, this study also investigated possible differences induced by variable and non-variable exercise. Results from this study indicate that the variable distribution of power output during the 10 min before the sprint has little influence on sprint performance, at least in these cyclists and over duration/intensities that aimed to replicate the lead up phase typical of road races. Research has, to date, studied the effects of constant versus variable cycling exercises focusing on physiological parameters and whole-body exercise performance. For example, it was found that the magnitude of central and peripheral fatigue was similar towards the end of 30 min of constant (75% of the maximal aerobic power) and variable (up to ± 15% of mean power output) cycling trials in well trained triathletes (61). Del Coso and colleagues (25) used maximal cycling sprints while comparing the effects of three differently variable exercises. The participants rode for 24 minutes at a mean power output corresponding to 50% of the second ventilatory threshold’s power, with three different power variation ranges. The maximal sprint power produced by endurance trained cyclists was not impaired in any of the three variable conditions. In fact, the maximal sprint power was 1620 ± 160 W power prior to the exercise, and 1590 ± 204, 1606 ± 177, and 1582 ± 170 W after exercises with low, moderate and high intensity variations, respectively ($p\geq0.12$). Interestingly, after the highly variable protocol the blood

lactate concentration was 11.3 ± 1.5 mmol·L^{-1}, thus even higher than the 8.4 ± 1.9 mmol·L^{-1} reached with the variable lead up effort in the present study, however the maximal sprint performance was not different than in the pre exercise condition (p=0.12). The abovementioned studies confirm the present investigation's findings: certain type of variable exercises, despite being intense, do not increase fatigue and do not impair short term power output, especially in highly trained endurance cyclists. Whether similar results would be observed following 4 to 6 hours of road cycling, and or with different power variability remains to be established, and may be the subject of future studies.

Noticeably, a study evaluating performances in senior soccer players found higher repeated jump parameters in the post match, versus the pre match condition. The authors suggested that "an acute bout of intense exercise has an arousing effect that counteracts fatigue effects" (19). Similarly, in our study the 10 min exercise had a possibly beneficial effect on the sprint peak power output. It is possible to speculate that in highly competitive cyclists the lead up efforts used to simulate race conditions had a similar arousing effect, allowing them to maintain or slightly increase the sprint ability.

Further research using different magnitude of the power variability, aiming at better understanding what kind of exercise impairs the maximal sprint performance is recommended.

In conclusion, this study showed that neither variable nor non-variable lead up efforts (designed to replicate the final part of road races) impaired cycling sprint parameters in elite competitive cyclists. Considering the demonstrated positive effect of team support on successfulness of road sprints, this study's results suggest that the importance of the team during the lead up phase could be more related to technical and tactical factors (e.g. good positioning), instead of to save energies. As a practical application, coaches and professional cyclists should consider to use the team mainly to better position the sprinter, rather than to protect him from speed variations.

CHAPTER SIX

CONSISTENCY OF COMMERCIAL DEVICES FOR MEASURING ELEVATION GAIN

6.1 Abstract

The aim of this study was to determine the consistency of commercially available devices used for measuring elevation gain in outdoor activities and sports.
Two separate observational validation studies were conducted. Garmin (Forerunner 310XT, Edge 500, Edge 750 and Edge 800; with and without elevation correction) and SRM (Power Control 7) devices were used to measure TEG over a 15.7 km mountain climb performed on 6 separate occasions (6 devices; Study 4a) and during a 138 km cycling event (164 devices; Study 4b).
TEG was significantly different between the Garmin and SRM devices ($p<0.05$). The between devices variability in TEG was lower when measured with the SRM, compared with the Garmin devices (Study 4a: 0.2 and 1.5%, respectively). The use of the Garmin elevation correction option resulted in a 5 to 10% increase in the TEG. While measurements of TEG were relatively consistent within each brand, the measurements differed between the SRM and Garmin devices by as much as 3%. Caution should be taken when comparing elevation gain data recorded with different settings or with devices of different brands.

6.2 Introduction

Commercially available microtechnology devices are widely used to monitor physical activity and sport (6, 56). For many outdoor activities (e.g. cycling, hiking, cross-country skiing) the vertical distance travelled (i.e. elevation gain) contributes significantly to the total physical load (47, 82). As a result, TEG is a key factor influencing the outcome of competition. Scientists, coaches and athletes often use TEG data to monitor, quantify, reproduce and/or plan training and competition loads. Commercially available devices calculate elevation change using barometric altimeters and/or Global Positioning Systems (GPS) to determine elevation. Despite the importance of the elevation gain when monitoring physical activity and sport performance (75, 81), the consistency of commercially available devices has to our knowledge not been established. Therefore, the aim of this study was to determine the consistency of several devices typically used for measuring elevation and elevation gain in outdoor activities and sporting events.

6.3 Methods

Two separate studies were performed to assess the variability in measurements of TEG within and between 6 devices over a relatively short distance (Study 4a), and between 188 devices over a long distance (Study 4b).

6.3.2 Procedures

6.3.2.1 Variability of TEG within and between devices

In the first study (4a), a total of six separate devices were used to measure the TEG over a 15.7 km mountain climb performed on six separate occasions. Two Edge 800, one Edge 500, one Forerunner 310XT (Garmin International, Olathe, KS, USA), and two SRM Power Control 7 (Schoberer Rad Mebtechnik, Julich, Germany) were mounted on the roof rack of a car which travelled up the 15.7 km long climb in Varese (Italy) at a mean speed of 32 ± 2 $km \cdot h^{-1}$, on six separate occasions. In order to simulate everyday use, the six trials were performed at different times of the day and with different weather conditions (Kestrel 4200; Nielsen Kellerman, Boothwyn, PA)

(temperature range: 10.9 - 24.3 °C; humidity range: 55.0 - 98.8%; pressure range: 660 - 745 mmHg). The 'smart recording' option, which varies the recording rate based on changes of speed, direction and elevation, was used with the Garmin devices as, based on the manufacturer's recommendation, this increases the storage capacity. The Edge devices (500 and 800) and the SRM use a barometric altimeter to determine elevation, whereas the Forerunner 310XT relies only on GPS. All devices were switched on 20-30 min prior to data acquisition. The data from the Garmin devices were uploaded to the Garmin Connect website (http://connect.garmin.com) and then analysed both with and without the 'elevation correction' option. Using elevation correction, the geographic coordinates of the GPS (latitude and longitude) are cross referenced and corrected to the elevation data obtained from professional surveys (description provided by the manufacturer, http://connect.garmin.com).

6.3.2.2 Variability of TEG during a cycling competition

In the second study (Study 4b), data were collected during an actual recreational cycling event. This study used a retrospective, observational design and used online, publically available information. The study presented low risk to subjects, therefore written informed consent was not obtained. As outlined in the Australian National Statement on Ethical Conduct in Human Research the requirement for informed consent may be waived in such circumstances. This study was approved by Edith Cowan University's Human Research Ethics Committee, in the spirit of the Helsinki Declaration.

Data were collected from 188 road cyclists who completed the 138 km course of the renowned Italian granfondo, Maratona Dles Dolomites (Badia, BZ, Italy) on July 10th, 2011. All subjects in this study used a Garmin GPS device during the event. The subjects then uploaded and shared their files on the Garmin Connect website (http://connect.garmin.com). For inclusion, all GPS data had to follow the road course (be superposable on the map of the actual course). For this reason, 24 files were excluded (the start or finish point was at a distance > 0.3 km from the start or finish lines). A total of 164 files from three different Garmin devices (Edge 500, n=85; Edge 705, n=44; and Edge 800, n=35), were included for analysis. All the devices used in this investigation have a barometric altimeter. All files were analysed

without elevation correction, since this is displayed as a default for Garmin devices with a barometric altimeter (as suggested by the manufacturer).

6.3.3 Statistical Analysis

In study 4a, within and between devices variability of the TEG over the six climbs was determined. In study 4a, between devices variability of the TEG was determined for each device model. Variability in TEG was assessed by examining the mean, range and standard deviation. Measures of centrality and spread are presented as mean ± SD. The TEG from both study 4a and study 4b was compared between devices using a one-way ANOVA. Where a significant effect was observed, a Bonferonni post hoc analysis was performed. Statistical tests were conducted using IBM SPSS Statistics version 19.0 (Chicago IL, USA). Significance was set at $P \leq 0.05$.

6.4 Results

The TEG measured by two Garmin devices was significantly higher than both SRM devices (Tab. 6.1). TEG was not significantly different among the Garmin devices with the same setting (i.e. with or without elevation correction). However, elevation correction significantly increased the TEG ($P>0.05$; Tab. 6.1).

Table 6.1 TEG recorded during a 15.7 km climb performed on six separate occasions.

	Total Elevation Gain (m) Mean ± SD (range)
SRM 1	816 ± 8 (20)
SRM 2	815 ± 8 (22)
Without Elevation Correction	
Garmin Forerunner 310XT	853 ± 30[a] (77)
Garmin Edge 500	828 ± 5 (13)
Garmin Edge 800a	858 ± 17[a] (41)
Garmin Edge 800b	832 ± 13 (36)
With Elevation Correction	
Garmin Forerunner 310XT	897 ± 26[ab] (65)
Garmin Edge 500	910 ± 10[ab] (26)
Garmin Edge 800 1	912 ± 13[ab] (35)
Garmin Edge 800 2	908 ± 19[ab] (50)

[a] $P<0.05$, significantly different to both SRM devices; [b] $P<0.05$, significantly different to same device without elevation correction

The within device variability of TEG was slightly lower when measured with the SRM devices, compared with the Garmin devices (1.0 and 1.9%, respectively). The within device variability of TEG measured with the Garmin devices was similar both with and without elevation correction (Tab. 6.1). The between devices variability was lower when measured with the SRM, compared with the Garmin devices (SRM: 0.2%, Study 4a; Garmin: 1.5 and 3.6%, Study 4a and 4b, respectively). In Study 4b, the variability of TEG of each GPS device as measured by the standard deviation was relatively low (Fig. 6.1). All three Garmin devices had a large range in the TEG (Fig. 6.1).

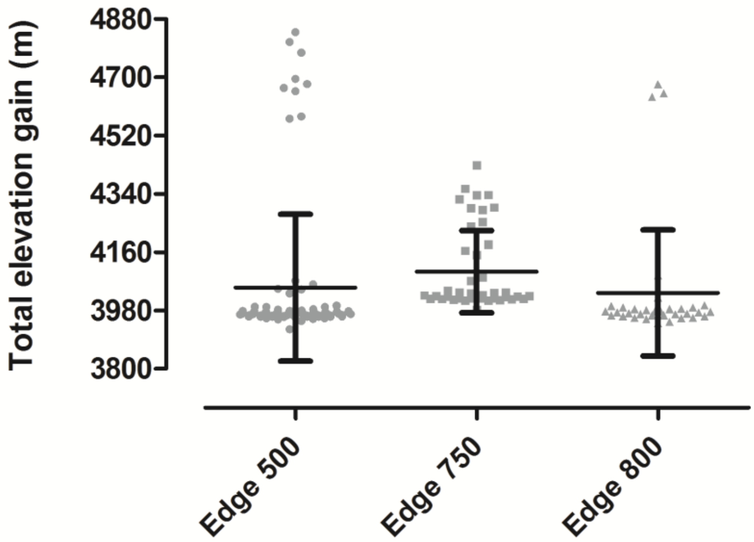

Figure 6.1 TEG of subjects competing in the Maratona Dles Dolomites while using a Garmin Edge 500 (n=85), Edge 750 (n=44), or Edge 800 (n=35).

6.5 Discussion

Measurements of elevation change are meaningful in determining the physical load experienced during physical activities or sporting activities (47, 75, 81). As such, a number of devices and methods have been established in order to determine changes in elevation during outdoor activities. Results of this study indicate that while measurements of elevation are relatively consistent within each model, the measurements differ considerably between the different brands examined (SRM and Garmin). Indeed, the between devices variability of the TEG measured with Garmin devices in Studies 5a and 5b were within 1.5 to 3.6%, respectively (Tab. 6.1 and Fig. 6.1), while the between devices variability of the TEG measured with the two SRM devices in Study 4a was within 0.2 % (Tab. 6.1). However, measurements of TEG were up to 3% greater in Garmin devices (without elevation correction) compared to SRM devices (Tab. 6.1). These results suggest that measurements of TEG may be comparable between athletes using devices of the same brand and with the same settings (e.g. elevation correction).

Within both studies a relatively small number of devices either over or under estimated the TEG. Indeed, the TEG measured by different Garmin 500 devices ranged by as much as 917 m during the 138 km Maratona Dles Dolomites. Nevertheless, over the 4000 m of climbing during this event the majority of values measured by each of the Garmin devices were within a range of approximately 150 m.

While we observed similarities in TEG measurements between all Garmin devices with the same settings, the use of elevation correction resulted in a 5 to 10% (50 to 80 m) increase in measurements of TEG over a 15.7 km climb (Tab. 6.1). Interestingly, this change also resulted in the TEG measured with the Garmin devices being approximately 11% greater than that measured with the SRM devices. Such differences in TEG are likely to have a meaningful influence on the estimates of physiological load experienced by athletes, especially when exercising over longer mountainous course profiles. Manufactures of Garmin devices indicate that use of elevation correction improves the accuracy of elevation measurements by cross-referencing the position of the GPS device with accurate survey data. However, since the aim of this study was to assess the consistency of the elevation change, this study

cannot confirm that the elevation correction actually improved the accuracy of elevation data.

Further research assessing the accuracy of these devices is needed in order to assess these claims and establish the best method for determining physical load during such outdoor sporting activities. Irrespectively, the results of the present study indicate that caution should be taken to ensure consistency in the use or non-use of elevation correction when comparing the elevation profile of various courses. Due to the high reliability of GPS devices to measure position within a horizontal plane (20, 45, 53), cross-referencing elevation based on the position of the GPS is likely to improve the reliability of instantaneous measurements of elevation. However, the use of elevation correction did not decrease the within devices variability in relative measurements of the TEG, which was lower for the SRM, compared with all Garmin devices in this study (Tab. 6.1). These results are important since it is the TEG, rather than the absolute altitude, which is most meaningful for determining the physical load experienced by athletes.

While this study has provided initial insight into the consistency of these devices, future research should further investigate the accuracy of commercially available devices to determine absolute altitude and elevation changes.

As practical applications arising from these studies, researchers, coaches and athletes who measure TEG to plan and/or analyse training and race loads should avoid comparing data collected with devices of different brands. Moreover, when using devices of the same brand, it is strongly recommended that settings are consistent. Comparing the elevation gain measured using different devices or settings may result in unreliable measurements of physical load.

In conclusion, the results of the present study indicate that measurements of TEG are relatively consistent within devices of the same brand (SRM and Garmin) when the same setting is used (e.g. elevation correction). However, measurements of TEG differed considerably between brands. Furthermore, Garmin’s elevation correction setting, which cross-references altitude based on the position of the GPS, significantly increased the measurements of elevation gain.

CHAPTER SEVEN

PERFORMANCE ANALYSIS OF A WORLD CLASS SPRINTER DURING CYCLING GRAND TOURS

7.1 Abstract

This investigation describes the sprint performances of the highest international ranked professional male road sprint cyclist during 2008-2011 Grand Tours. Sprint stages were classified as WON, LOST or DROPPED from the front bunch prior to the sprint. Thirty-one stages were video analysed for mean speed of the last km, sprint duration, position in the bunch and number of teammates at 60, 30, and 15 s remaining, Race distance, TEG and mean speed of 45 stages were determined. Head-to-head performances against the 2nd-5th most successful professional sprint cyclists were also reviewed. In the 52 Grand Tour sprint stages the subject started he WON 30 (58%), LOST 15 (29%), was DROPPED 6 (12%) and had one crash. Position in the bunch was closer to the front and the number of team members was significantly higher in WON compared to LOST at 60, 30 and 15 s remaining ($P<0.05$). The sprint duration was not different between WON and LOST (11.3 ± 1.7 and 10.4 ± 3.2 s). TEG was significantly higher in DROPPED (1089 ± 465 m) compared to WON and LOST (574 ± 394 and 601 ± 423m, $P<0.05$). The ability to finish the race with the front bunch was lower (77%) compared with other successful sprinters (89%). However, the subject was highly successful; winning over 60% of contested stages, while his competitors won less than 15%. This investigation explores methodology that can be used to describe important aspects of road sprint cycling and supports the concept that tactical aspects of sprinting can relate to performance outcomes.

7.2 Introduction

Road cycling sprint performance is influenced by a variety of factors, including individual and team tactics, technique and the physiological characteristics of the cyclist. Road sprinters have the distinctive ability to excel in mainly flat cycling competitions (84, 93), in which the final sprints are initiated from high speed (69). Within professional cycling the sprinters often make up a very small proportion of the team (e.g. 2 out of 30 riders). This factor, together with the complexity of road sprinting, may be the reason for the lack of scientific research detailing the characteristics important to successful road sprinting. Indeed, several studies have described the physiological demands of competition and the characteristics of other specialty cycling groups, including time trialists, climbers and off road cyclists (52, 64, 93, 109). Further a number of studies have examined the physiological characteristics of track sprinters (27, 39, 40). However, we are currently aware of only one study that has provided a detailed description of road sprint cycling performance, and this study was on a single cyclist performing a single sprint (69).

There is little, if any, research describing the tactical approach adopted by road sprint cyclists. Bullock and colleagues (17) have examined bunch position in World Class short track speed skaters and observed unique positioning strategies in winners over three different race distances. Similar to cyclists, speed skaters gain an advantage by drafting but also face the disadvantage of passing a competitor as they approach the finish (107). It is possible that a similar evaluation of sprint cycling could be useful for understanding performance.

Sprints are an extremely important aspect of professional road cycling. In fact, many stages (e.g. ~7 out of 21) within each of the Grand Tours (i.e. Giro d'Italia, Tour de France and Vuelta a Espana) are designed specifically for sprinters. Noticeably, among professional road sprinters only a few are able to win Grand Tour stages, and even less can win repeatedly. For example, examination of the sprint results within recent Grand Tours (2008-2011) indicates that 79 stages (out of 252 total stages, 31%) were won by only 24 sprinters. Interestingly, 5 sprinters won 54 stages of which one sprinter won 30 stages. Due to his outstanding results, this cyclist has been selected as the primary subject of the present investigation. The aim of this investigation is to provide a detailed description of the sprint performances of

a professional world-class sprinter during Grand Tours in order to extend methodology used for evaluating road sprints. A secondary aim is to compare performances of this cyclist against his closest rivals in order to identify key factors that may influence sprint performance.

7.3 Methods

This study incorporates a single case study longitudinal design evaluating data retrospectively. Performance data were publically available and this research project was approved by a University Human Research Ethics Committee. The authors of the present manuscript do not have any potential conflicts of interest.

7.3.1 Subject

The subject in this investigation was a professional road cyclist (age, 26 y; height, 1.75 m; weight, 69 kg; BMI, 22.5 $kg \cdot m^{-2}$) specialising in sprints. At the time of investigation, and in the previous three cycling seasons, this cyclist was ranked as the highest international professional male sprinter according to a specific international ranking (cqranking.com).

7.3.2 Procedures

Performance data and videos from Grand Tours between 2008 and 2011 were taken from online public access websites and official race results. All the Grand Tour stages won by specialist sprinters were analysed and the subject’s race results were classified as rate of victory and defeat per participation. For the purpose of this investigation, cyclists have been classified as sprinters when their best performances were achieved in relatively flat competitions finishing at high speed (e.g. last km at an mean speed of ~60 $km \cdot h^{-1}$) and against a relatively large number of competitors. Sprint stages were classified into those in which the subject won or lost the sprint, or was dropped prior to the sprint (i.e. WON, LOST and DROPPED). In order to determine tactical differences between stages WON and LOST, video footage of 31 stages were also analysed for the subject’s position in the bunch and the number of teammates in front of the subject at 60, 30 and 15 s remaining, mean speed of the last km and sprint duration. Sprint duration has been defined as the amount of time

elapsed between the moment in which the subject started to sprint (i.e. moved off the wheel in front and often began sprinting out of the saddle) to the finish line. Moreover, race distance, TEG and mean speed of 45 stages were determined in order to establish a relationship with stages WON, LOST and DROPPED. The TEG has been calculated using the altitude data presented in the altimetric profile maps. Based on the number of wins in Grand Tour stages the second to fifth most successful sprinters during the period under investigation have also been identified; they won 7, 6, 6 and 5 stages, respectively. The performances of these cyclists have been compared to the subject's performances to provide a descriptive head-to-head analysis. When performing head-to-head comparisons, only stages performed by both subjects have been compared. In the sprint comparison, sprinters have been considered in contention for the sprint when they both finished in the top 20 for the stage.

7.3.3 Statistical Analysis

The mean speed of the last km and the sprint duration were compared between stages WON and LOST using independent sample t-tests. Dependant variables (i.e. stage distance, TEG and mean speed) were compared between stages WON, LOST and DROPPED using a one-way ANOVA. Distance from the front of the bunch and number of team mates at 60s, 30s and 15s of the race remaining were compared between WON and LOST using a mixed model ANOVA. Where significant effect was observed Fisher's LSD test was performed. Where violations of assumptions of sphericity where observed, the degrees of freedom were corrected using Greenhouse-Geisser or Huynh-Feldt corrections where appropriate. Critical level of significance was established at $P<0.05$. Results are presented as mean ± SD.

7.4 Results

The cyclist in this study became professional at the age of 22, winning 75 professional road races at the end of the 2011 cycling season. This cyclist has twice won the general point classification in a Grand Tour. In his professional career he has completed 79 ± 9 professional races·year^{-1}, riding approximately 12000 kilometers·year^{-1} (only in races). The 2nd to 5th competitors rode a mean of 80 ± 10

races·year^{-1} and also raced over approximately 12000 kilometers·year^{-1} (cqranking.com).

In the four cycling season analysed, the subject started nine Grand Tours (i.e. 3 x Giro d'Italia, 4 x Tour de France and 2 x Vuelta a Espana) and finished a total of 52 stages (out of 79 won by sprinters). The cyclist WON 58% (n= 30), LOST 29% (n= 15), was DROPPED on 12% (n= 6) of these stages and in one stage he was involved in a sprint accident. There was no significant difference in the mean speed of the last km (P= 0.51) or the sprint duration (P= 0.33; Tab. 7.1) between WON and LOST. The subject's position in the bunch and the number of teammates at 60, 30 and 15 s were significantly different between WON and LOST stages (P< 0.05; Tab. 7.1).

Table 7.1 Mean speed, sprint duration, position in the bunch and number of teammates of the subject determined from video analysis of won and lost sprints (n=31).

	Mean speed in last km ($km \cdot h^{-1}$)	Sprint duration (s)	Position from the front of the bunch			Number of teammates in front of the subject		
			60 s to the finish	30 s to the finish	15 s to the finish	60 s to the finish	30 s to the finish	15 s to the finish
WON (n:19)	60.6 ± 4.2	11.3 ± 1.7	6 ± 2 [a]	3 ± 1 [a]	2 ± 0 [a]	2 ± 1 [b]	1 ± 1 [a]	1 ± 1 [b]
LOST (n:12)	59.6 ± 4.2	10.4 ± 3.2 #	9 ± 5	8 ± 5	5 ± 4	0 ± 1	1 ± 1	0 ± 1

[a] Significantly different ($P < 0.05$) from lost sprints

[b] Significantly different ($P < 0.001$) from lost sprints

n=9

In DROPPED stages, TEG was significantly higher than both WON and LOST (P<0.01 and P=0.02; Tab. 7.2). TEG for WON and LOST was not significantly different (P=0.85). Stage length and mean speed were not different between WON, LOST and DROPPED (P=0.49 and P=0.85; Tab. 7.2).

Table 7.2 Distance, TEG and mean speed of stages the subject WON, LOST and was DROPPED prior to the finish (n=45).

	Stage distance (km)	TEG (m)	Mean speed ($km \cdot h^{-1}$)
WON (n:28)	179 ± 30	574 ± 394 [a]	41.9 ± 2.5
LOST (n:11)	173 ± 39	601 ± 423 [a]	41.8 ± 2.1
DROPPED (n:6)	193 ± 28	1089 ± 465	42.4 ± 2.0

[a] Significantly different (P < 0.05) from dropped stages

Table 7.3 shows the performances during head-to-head competitions between the subject and his closest competitors. The cyclist’s ability to reach the finish line to be in contention for the sprint (sprint chances) was lower when compared with the four other successful sprinters (77% vs a mean of 89%). However, the subject won over 60% of stages in which he was in contention to sprint (win ability), while his competitors won less than 15%.

Table 7.3 Performance of the subject relative to the 2nd and 5th most successful competitors.

	2nd		3rd		4th		5th	
Number of stages with subject	39		139		92		104	
Number of sprint stages with subject	11		57		39		44	
	S	C	S	C	S	C	S	C
Sprint chances (number of sprint stages in the top 20)	8	11	51	49	28	35	33	35
Sprint chances (% of sprint stages in top 20)	73	100	89	86	72	90	75	80
Wins	6	1	29	5	17	8	19	5
Win/sprint ability (victories relative to sprint chances %)	75	9	57	10	61	23	58	14

Note: only stages competed by both the subject and competitor have been compared
S= Subject; C= Competitor

7.5 Discussion

The purpose of this study was to examine the race results of a professional world-class sprinter performing in Grand Tours in order to explore methodology and identify key factors responsible for winning sprint performances. Our case study reveals methodology that can be used to evaluate tactical aspects of road cycling sprint finishes and documents that bunch position and team work is associated with successful outcomes. In addition, data collected from a highly successful sprint cyclist indicates that in addition to team support and position in the bunch, stage characteristics (e.g. TEG) can influence overall sprint performance.

Despite his young age the cyclist examined is one of the most successful sprinters in the history of cycling (http://www.cyclingnews.com/features/the-top-ten-sprinters-of-all-time). At the time of this investigation, this subject won 58% of the Grand Tour sprint stages that he completed. Whereas previous case studies describe physiological characteristics of cyclists that have repeatedly won Grand Tours (21, 92), our investigation focused on a road sprint cyclist and tactical aspects of his winning performances.

It is well accepted that team tactics are extremely important for winning a sprint finish in cycling; however, we are unaware of research that has directly examined the implementation, execution and success of team tactics during a sprint finish in a Grand Tour. Within road cycling, teammates or team members of a sprinter will often lead the cyclist through the final kilometers of the event in order to allow the sprinter to conserve energy and be well positioned for the final sprint. Broker and colleagues (16) characterised the effect of drafting in team pursuit cyclists riding at $60km{\cdot}h^{-1}$ on a velodrome, a speed that is relevant to the road sprint lead out. For team pursuit cyclists the power output required to ride at $60km{\cdot}h^{-1}$ was reduced by 29% while riding in second position, and by 36% while riding in third position. Martin and colleagues (69) have also used a theoretical model to explored the relevance of drafting in road sprint cycling, showing that a cyclist sprinting from the second position can win by 1 m when compared to other strategies. Video analysis in the present study indicates that in stages resulting in a win, this subject had strong team support, as indicated by the presence of 1-2 teammates leading the subject out at 60 s from the finish (i.e. approximately the last km). Typically, this team support was maintained until the final 15 s where one teammate was still in front of the subject in stages resulting in a win. This team organization may be responsible for the subject's positioning and smooth progression through the bunch in the last minute of each stage. Indeed, the subject in this investigation was significantly better placed at 60 s from the finish in the stages that resulting in a win, compared with stages resulting in a loss (i.e. in 5^{th} to 6^{th} vs. 9^{th} to10^{th} position). Furthermore, the subject rarely had teammates in front of him in the last 60 s (approximately 1km) of the race in the stages that resulted in a loss. These results highlight the significant importance of team tactics in successful road sprint performance. Further research adopting the novel methodology utilised in this study is needed in order to examine the importance of team tactics to other professional

sprint cyclists and in other aspects of road cycling (i.e. hill climbing). Such research may provide valuable information on the importance of team support to different professional cyclists performing various road cycling tasks. Indeed, some professional sprinters appear to have the ability to excel in the road cycling sprint with little team support.

We have adopted a performance analysis technique that is similar to the approach published by Bullock and colleagues (17) who have examined bunch position in elite short track speed skating. Similar to Bullock's observations with skaters, it appears that position within the lead bunch over the final kilometre of the race is important to sprint cycling performance. If the sprint cyclist is too far back or too close to the front the odds of winning are diminished. More specifically, we observed that the winning sprints never occurred if the cyclist was more than nine positions back from the front of the race at 60 s remaining. The ideal position in the peloton towards the end of the race for sprinters appears to be somewhere between 2^{nd} to 9^{th} behind the leader and could be influenced by terrain and technical aspects of the race (narrow roads, turns, etc.).

Road sprint cycling performance is a unique cycling discipline requiring cyclists to have high aerobic and anaerobic capacity (22, 34, 88). Improving strength and anaerobic capacity may improve sprint performance (104, 105), however, within some stages of Grand Tours sprinters are required to cycle over high mountain passes in order to reach the finish line (103). The ability to win such stages, some of which may last more than 7 hours, requires high aerobic qualities (i.e. maximal oxygen uptake and metabolic thresholds). Within this study there was a significant difference in the TEG between stages in which the subject was dropped during the stage (1089 ± 465m) and stages in which the cyclist was in contention for the sprint (582 ± 397 m). The influence of elevation on race dynamics is not only important to the sprinters but the entire peloton. Indeed, we observed a logarithmic correlation (R^2: 0.53), between the TEG of stages and the number of riders that reach the finish line in the first main bunch (data not shown). In particular, 70% of the stages with less than 1000 m of TEG finished with a sprint. Only 20% of the stages with a TEG between 1000 and 2000 m finished with a sprint, and none of the stages with a TEG over 2000 m has been won by a specialised sprinter. The performance of a sprinter during Grand Tours is therefore highly dependent on not only sprint capacity but also other physiological attributes related to hill climbing capacity. Supporting this, the cyclist

in the present study had less sprint chances than his most successful competitors presumably due to lower hill climbing capabilities (i.e. aerobic capacity). However, if he made it to the finish line in the leading group this cyclist was much more likely to succeed in the final sprint winning over 60% of the stages he was in contention to sprint. These differences occurred despite the number of races completed and total kilometers cycled during competitions being similar between the cyclist in this study and his closest rivals. Such results highlight the fact that physiological characteristics might be different among the various speciality sprinters. Future researches aiming to classify and describe different kind of sprinters (e.g. flat or hilly terrain sprinters, long or short sprint sprinters) is recommended. Knowing the sprinters' climbing ability (sprint chances) and their likelihood to succeed in the sprint (win ability), together with a careful evaluation of the rivals' characteristics, may be important in development of training programs or the selection of events that may best suit particular athletes. Noticeably, external factors other than TEG, such as the position of the elevation gain within a stage, are of extreme importance to race dynamics. Despite this, data from this study provides some indication of the influence race profile has on outcomes of the event. Additional valid methods to describe the elevation gain and altimetric profile of road cycling events therefore appear important when describing stage characteristics. With such data it will be possible to analyse the whole race and different sections of competition in order to improve the understanding of technical and tactical issues relevant for race outcomes.

In practical terms, this case study outlines methodology that can be used by sport scientist to quantify key aspects of road sprint cycling. Results showed that positioning in the bunch appears to influence the probability of winning, thus athletes may benefit by team support or training to position themselves wisely. Sprinters with good climbing ability will get more opportunities to sprint, compared to relatively poor climbers, and possibly get a chance to sprint against a less competitive field because others sprinters (i.e. flat terrain sprinters) are dropped prior to the finish. However, training choice (i.e. to improve the climbing ability or the sprint ability) should be guided by a careful evaluation of the characteristics (sprint chances and win ability) of the cyclist and the cyclist's competitors.

In conclusion, this study has examined the race results of a professional world class sprinter performing in Grand tours. The results of this study indicate that the position of this cyclist in the peloton/bunch and the number of teammates leading

into the finish are important factors in stage racing sprint performance. Furthermore, compared with his closest competitors, this subject was less likely to reach the finish line in the leading group during stages that contained a high TEG. However, when arriving at the finish line in the leading group this cyclist was considerably more successful than his closest competitors.

CHAPTER EIGHT

GENERAL DISCUSSION

Sprint ability is a key determinant of success in the majority of endurance road cycling events. Indeed, several races or stages during Grand Tours are specifically designed for sprinters. Despite the importance of this aspect within the sport of cycling, there is little research examining the characteristics of road sprints. To date, basic information describing the characteristics of the final sprint, such as duration and intensity, is limited. Likewise, little is known about the physical demands of the lead up to successful sprint finishes (i.e. last 10 minutes of competitions). As such, the training techniques and strategies to best prepare road sprinters for competition are not well understood, and cannot be evidence based. Thus, the main purpose of this thesis was to document and examine the physiological demands of sprinting in the highly trained endurance road cyclist. A secondary aim was to better understand technical and tactical factors influencing road sprint performance. By increasing our knowledge concerning these themes this research aids in providing greater insight into optimal sprint performance. The major findings from this thesis were that: i) when approaching the finish line the race intensity gradually increased, with a mean power output of 487 W, heart rates of 95% HRmax and cadence of 102 rpm in the last minute prior to the sprint; the last 10 min of racing were stochastic in nature with approximately twice as many short, high intensity efforts in the last 5 min when compared with the penultimate 5 min; during the final sprint the peak power was ~17.5 $W \cdot kg^{-1}$, with a peak cadence of ~115 rpm and a peak speed of ~66 $km \cdot h^{-1}$; ii) the power output and total work recorded in successful PRO sprints were similar to the one recorded in successful U23 sprints; however, the race intensity in the 10 min leading into the sprint was higher in PRO compared with U23 races; iii) ten min of cycling designed to simulate the lead up phase prior to the final sprint did not impair the sprint performance of elite cyclists and there were no differences in the sprint power output after an either variable or

non-variable 10 min lead up effort; iv) elevation gain data measured with commercial devices could be relatively consistent; however, measurements differ considerably among devices of different brands, or with different settings; v) the position in the bunch and the number of teammates in the final 10 min of races are important factors for road sprint performances and sprinters with good climbing ability have more opportunities to sprint against a less competitive field than sprinters with relatively poor climbing ability.

Understanding the physiological demands of competition is a key factor in the development of training and competition strategies that would potentially produce optimal performances. Due to the lack of research related to road cycling sprints, Study 1 and 2 of this thesis were descriptive studies aiming at showing both the final sprint characteristics, and the characteristics of the part of competition preceding the actual sprint. Study 1 confirmed the hypothesis that professional sprinters produce high power outputs during the sprint finish. In particular, the mean and peak powers observed during the sprints were 1020 ± 77 W and 1248 ± 122 W, respectively. These data, similarly to sprint data from Study 2 of this thesis, were comparable to those previously published by Martin and colleagues in a case study on a professional sprinter, who produced a mean power of 926 W and a peak power of 1097 W (69). Also the sprint duration (13.2 ± 2.3 s) and the peak speed (66.1 ± 3.4 $km \cdot h^{-1}$) observed in Study 1 were similar to the 14 s and 65 $km \cdot h^{-1}$ previously reported (69). Interestingly, within Study 2, it was also found that the professional cyclist did not produce a higher sprint power output when compared to a U23 cyclist. Noteworthy, producing a power output > 2500 $W \cdot A_p^{-1}$ (or > 15.5 $W \cdot kg^{-1}$) for approximately 14 s, with a peak power output > 3100 $W \cdot A_p^{-1}$ (or > 19 $W \cdot kg^{-1}$) led to successful sprints in both the categories. Despite the high power outputs reported in Study 1 and 2, the sprint capacity of road sprinters is considerably lower when compared to track sprinters (i.e. peak power: < 1300 W and > 1600 W, respectively) (40). The difference in the power output necessary to be a high level track or road sprinter is explicable due to the different characteristics of road and track sprint races. Indeed, road cyclists are required to race for prolonged periods (i.e. > 4 hours) at moderate intensity, and what’s more they have to ride at high and highly variable intensity in the very last part of the competition prior to the sprint; conversely, track sprinters’ races only last few seconds. In particular, Study 1 showed that both external (i.e. power output) and internal (i.e. heart rate) load were 10% higher in the

last 60 min of race when compared with the average intensity over the entire race. The race intensity continued to increase in the final 10 min of race and in the 5 min prior to the sprint the heart rate was 91% of HRmax, indicating that the sprinters were riding at intensity close to their lactate threshold (28). Interestingly, the highest 5 min power to mass ratio observed in Study 1 corresponds to 6.1 $W \cdot kg^{-1}$, which is only 8% lower than the estimated 6.6 $W \cdot kg^{-1}$ required for a 4 min (20% shorter in duration) team pursuit performance (111). Study 2 also focused on the differences between races' intensities in professional and U23 cycling. As hypothesized, the relative intensities in the final part of competitions were higher in the professional races, when compared to the U23 races. It should be noted that numerous factors may influence a cyclists' power output prior to and during a sprint, including physiological characteristics, race dynamics, gradient of the road, wind speed, team support and the ability of the cyclists to appropriately position themselves within the bunch. As such, it is unclear if technical and tactical factors influenced the power output in Study 2. Irrespectively, the overall intensity of the events analysed in the study (3.0 ± 0.4 $W \cdot kg^{-1}$ and 2.9 ± 0.2 $W \cdot kg^{-1}$ for PRO and U23, respectively) were higher than those recorded in professional flat races (2.0 ± 0.4 $W \cdot kg^{-1}$) (125) but similar to the one previously reported in a professional road stage race with both flat and mountainous stages (3.1 ± 0.2 $W \cdot kg^{-1}$) (123). Finally, the variability of power output within the final 10 min of races was analysed using the EVA technique. The results showed that twice as many high intensity and short duration efforts were ridden in the last 5 min, compared with the penultimate 5 min (Fig. 3.1, black bars). Finally, Study 2 and 5 of this thesis highlighted how the amount of climbing ridden during races could be another factor contributing to increase the fatigue prior to the final sprint. In this regard it is noteworthy to consider that the distribution of the elevation gain along the race course is likely to be of great importance to the race outcomes. Describing and understanding the characteristics important to successful road sprinting can assist researchers and coaches in training planning, talent identification and physical load monitoring. Examining the physical requirements of sprinters in the final kilometres prior to the race finish helps to gain a better understanding of the physiological characteristics important to successful cycling performance. Awareness that a given rider has the physiological capability to win a road sprint could potentially allow him (or his team) to focus on other aspects that may be important to success, such as the technical and tactical aspects of road

sprinting, or improving the climbing ability to ensure that the sprinter can reach the finish line with the main group.

After having reported some factors that can cause fatigue prior to the final sprint (i.e. race intensity, power output variability, amount of climbing) and considering that fatigue resulting from intense exercise could influence sprint capacity, Study 3 was designed to assess this specific aspect. In the development of the exercise protocols for Study 3 the race intensities reported in Studies 1 and 2 were used. In brief, Study 3 was a laboratory experimental design aimed at understanding the effects of variable and non-variable exercises that replicate the intensity of the final part of road competitions on maximal sprint performance (78). Despite the moderate to high intensity of the variable and non-variable cycling exercises in the study, neither condition had a negative effect on the cycling sprint power. The results were somehow surprising and in contrast with some previously published studies which have reported the detrimental effects of intense exercise on maximal cycling sprint performance (67, 73, 117); however, the literature there are also studies showing a conservation of sprint power after cycling exercise (25, 55). One of the differences between Study 3 of this thesis and other researches is the performance level of the recruited participants. In fact, the participants of Study 3 were highly trained internationally competitive cyclists while the subjects of the studies in which sprint performances decreased were active male cyclists or rugby players with a mean VO_{2peak} below 56 $mL \cdot kg^{-1} \cdot min^{-1}$. Considering the importance of aerobic fitness (i.e. high VO_{2max}) to high intensity cycling exercises (38, 42, 97) it's possible that the conservation of the sprint ability in Study 3 was partially due to the very high aerobic fitness level of the participants. Furthermore, the exercise protocol (i.e. intensity and duration) used in Study 3 differed from the ones used in previous researches thereby impacting on the comparability of results. As a matter of fact, the exercise protocols used in studies reporting a decline in maximal sprint performance were rides longer than 40 minutes at intensity above 75% of the VO2max, or time to exhaustion exercises (67, 73, 117). Actually, a few researches focusing on the time course of fatigue, despite adopting diverse exercises modalities, showed unchanged maximal short term power output after prolonged cycling exercise (25, 55, 67, 73). Cycling exercise can cause fatigue; however, exercise can also elicit a phenomenon called post activation potentiation (PAP). PAP corresponds to an acute enhancement of the muscular performances due to the muscle contractile history (119). PAP is

generally induced by maximal or near maximal voluntary contractions and it's particularly effective in endurance exercises involving speed and power (50, 102). As such, endurance sprint cycling performance could theoretically be positively influenced by potentiation-inducing exercises. Another possible explanation for the maintenance of maximal performances near the end of the exercise could be an increased voluntary activation (i.e. central drive) to contrast the rise of peripheral fatigue (24, 91). Results from Study 3 indicate that the variable distribution of power output during the 10 min before the sprint had little influence on sprint performance, at least in high level competitive cyclists and over duration/intensities that aimed to replicate the lead up phase typical of road races. Similar results were found by Del Coso and colleagues (25) who used maximal cycling sprints while comparing the effects of three differently variable exercises. The participants rode for 24 minutes at a set intensity but with three different power variation ranges. The maximal sprint power produced by the endurance trained cyclists was not impaired in any of the three conditions. Potentially the prolonged exercise duration of typical road cycling events (e.g. > 4 hours) has a greater influence on sprint performance than the physical demands of the lead up phase per se (e.g. ~10 minutes). Overall, it is possible to speculate that the 10 min exercise protocol used with highly competitive cyclists in Study 3 had a beneficial effect on the sprint peak power output, allowing them to maintain the sprint ability. The above mentioned studies confirm the plausibility of the present investigation's findings: certain types of variable exercises, despite being intense, do not impair short term power output, especially in highly trained endurance cyclists.

Study 2 took into account the elevation variable, reporting a large range of TEG in the analysed races (i.e. from 144 to 2397 m). Theoretically, the climbing ability of different sprinters could be diverse and, as such, the elevation change throughout a race is likely to have considerable influences on sprint performance. The influence of elevation on race dynamics is not only important to the sprinters but to the entire peloton. Indeed, a logarithmic correlation (R^2: 0.53) was observed between the TEG of stages and the number of riders that reach the finish line in the first bunch (Fig. 8.1) (75).

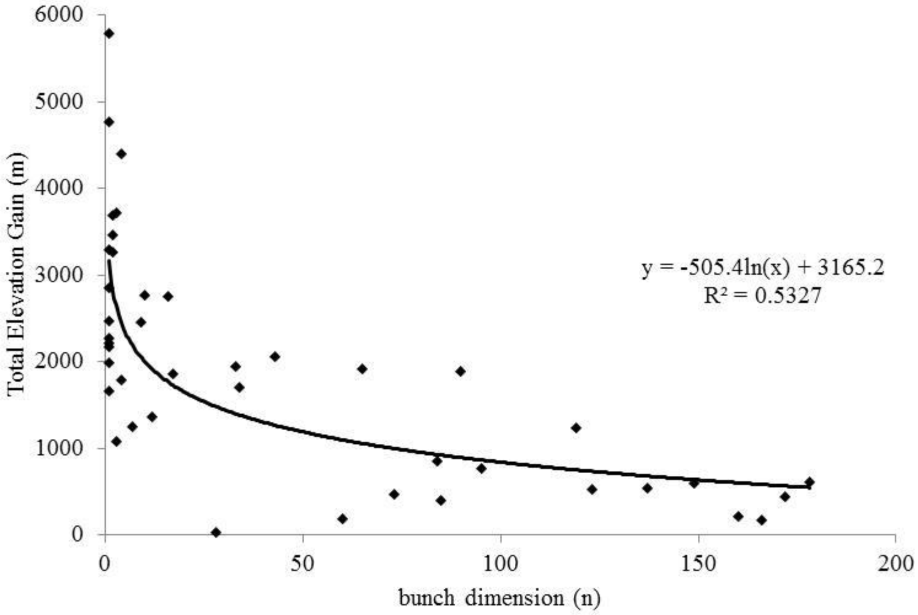

Figure 8.1 Logarithmic correlation between the stages' TEG and the bunch dimension.

In Study 5 the TEG was calculated using altitude data presented in altimetric profile maps; however, alternative and valid methods to describe the elevation gain and the altimetric profile of road cycling events are of practical importance in order to collect valid training and races data on a daily basis. For this reason, Study 4 evaluated several commercially available devices commonly used to measure altitude and elevation gain in cycling and outdoor sports in general. Results of the study indicated that while measurements of elevation were relatively consistent within each device, the measurements differed considerably between the different brands examined (SRM and Garmin). Within both Studies 4a and 4b a relatively small number of devices either over or under estimated the TEG. Indeed, the TEG measured by different Garmin 500 devices ranged by as much as 917 m during the 138 km Maratona Dles Dolomites. Nevertheless, over the 4000 m of climbing during the cycling event the majority of values measured by each of the Garmin devices was within a range of approximately 150 m. While we observed similarities in TEG measurements between all Garmin devices with the same settings, the use of

elevation correction resulted in a 5 to 10% (50 to 80 m) increase in measurements of TEG over a 15.7 km climb (Tab. 7.1). Interestingly, this change resulted with the TEG measured with the Garmin devices being approximately 11% greater than the TEG measured with the SRM devices. Such differences may be relevant to the race results, in fact the TEG influences the size of the bunch reaching the final sprint (i.e. likelihood to have a sprint) as showed in Fig. 8.1. Also, differences in the TEG are likely to have a meaningful influence on the estimates of physiological load experienced by athletes, especially when exercising over longer mountainous course profiles. Thus, comparing the elevation gain measured using different devices or settings may result in unreliable measurements of physical load and must be avoided.

After having reported the consistency of devices used to measure the elevation gain in Study 4, Study 5 evaluated the importance of the elevation gain for sprint performances. Also, some technical and tactical aspects of road sprinting were analysed in Study 5 of this thesis. In fact, an important remark from Study 2 was that no significant relationships were observed between performance (i.e. race results) and sprint power outputs (i.e. mean or peak, absolute or relative). This observation is probably due to the many variables that actively contribute to sprint performance, such as aerodynamics, position in the bunch and tactics. For this reason, position in the bunch, number of teammates and total elevation gain of stages were evaluated to see if there were relationships between these variables and successful or unsuccessful competitions (75). Results of Study 5 revealed that the subject was significantly better placed 60 s before reaching the finish line in the stages that resulted in a win, compared to stages resulting in a loss. Furthermore, the subject rarely had teammates in front of him in the last 60 s of the race (i.e. approximately last km) in the stages that resulted in a loss. Similar to Bullock and colleagues' observations with skaters (17), it appears that position in the bunch over the final section of competition is relevant to sprint cycling performance. In fact, Study 5 clearly showed that if the sprinter was too far back (or too close to the front too early), the odds of winning were diminished. Considering the demonstrated positive effect of team support on successfulness of road sprints (Study 5), the results from Study 3 (i.e. intensity of the last 10 minutes did not impair sprint performance) might suggest that the team support during the lead up phase should be more focused on technical and tactical factors (e.g. good positioning) instead of on saving energy. As a practical application, coaches and professional cyclists could consider to use the team mainly

to better position their sprinter, rather than to protect him from speed variations. Road sprint cycling performance is a unique cycling discipline requiring cyclists to have high aerobic and anaerobic capacity (22, 34, 88). During some stages of Grand Tours sprinters are required to cycle over high mountain passes in order to reach the finish line (103). The ability to win such stages, some of which may last more than 7 hours, requires high aerobic qualities (i.e. maximal oxygen uptake and metabolic thresholds). In Study 5 there was a significant difference in the TEG between stages in which the subject was dropped during the race (1089 ± 465 m) and stages in which the cyclist was in contention for the sprint (582 ± 397 m). Thus, data collected in Study 5 indicated that in addition to team support and position in the bunch, stage characteristics can influence the sprinter's performance. Moreover, sprinters with good climbing ability could have more opportunities to sprint, compared to relatively poor climbers, and possibly get a chance to sprint against a less competitive field because other sprinters are dropped prior to the finish. However, training choice (i.e. to improve climbing ability vs sprinting ability) should be guided by a careful evaluation of the characteristics (sprint chances and win ability) of both the cyclist and the cyclist's competitors.

8.1 Directions for Future Research

The general findings from the studies conducted in this thesis are as follows: i) exercise intensity significantly increased in the last 10 min of road races; sprint duration was 13.2 ± 2.3 s and peak power was 17.4 ± 1.7 $W \cdot kg^{-1}$; there was a significantly greater number of short duration and high intensity efforts in the final 5 min of the race, compared with the penultimate 5 min; ii) the physiological demands of competitions were higher in PRO compared to U23 races, despite a similar sprint duration and power output in the two categories; iii) neither the variable nor the non-variable 10 min lead up efforts impaired the sprint performance in elite competitive cyclists; iv) measurements of elevation gain were consistent within devices of the same brand, but differed between brands or when different settings were used; v) technical and tactical aspects of road sprinting are related to performance outcomes.

While these novel findings make a significant contribution to the current body of literature, the results of this thesis also highlight potential areas for future

research. Studies 1 and 2 of this thesis showed similar sprint data, with regard to sprint duration and power output. Data were also consistent with the only previously published case study (69). However, when compared to other specialties such as time trialing, or riding uphill, the sample was still limited to a relatively small number of cyclists. Furthermore, all the sprinters involved in these studies were of relatively similar body sizes. For these reasons further research examining successful road sprints is warranted in order to confirm the results from these studies with a bigger sample size.

Study 2 of this thesis examined the power output in relation to body shape. In particular, as previously done in track cycling sprint, the ratio between power output and frontal area (27). However, the best indicator of the aerodynamic characteristics of a cyclist is the aerodynamic drag area (CdA). Thus, future research is needed to better understand the real contribution of all the variable that contribute to the cyclist's speed; realistically, a combination of extremely high power and efficient aerodynamic position on the bike. Ideally, this research will be an integration of laboratory data (e.g. from wind tunnel testing) and field data (i.e. calculated considering air density, wind speed and direction).

In Study 1 no correlations were found between power data and race results. One of the reasons could be the fact that all the analysed files were recorded in different competitions. In order to better understand tactical and technical factors that influence the relationship between sprint power output and performance, further research examining multiple riders with similar sprint ability and competing in the same race would be recommended.

Study 3 evaluated the effect of different exercises on the sprint ability. Results indicate that neither the variable nor the non-variable exercise significantly impaired the sprint performance. Although the results of Study 3 are partially supported by some previous research, they were unexpected, in particular due to the intensity and the specificity of the exercise modality. Further research should therefore examine the effect of fatiguing exercise with a different magnitude of power variability, and with shorter recovery periods in between high intensity accelerations. Furthermore, the Critical Power and W' model (113) could be applied in order to better understand what kind of exercise impairs the road sprint performance. Finally, the laboratory efforts used in Study 3 only lasted 10 minutes.

Whether similar results would have be observed following 4 to 6 hours of road cycling remains to be established, and may be the subject of future studies.

Due to the relevance of elevation gain measurements, Study 4 of this thesis evaluated the consistency of commonly used devices that measure altitude and elevation gain. Results showed that elevation correction (i.e. cross-referencing elevation based on the position of the GPS to improve the validity of measurements of altitude) did not decrease the within devices variability in relative measurements of the TEG. So, while Study 4 has provided initial insight into the consistency of these devices, future research should further investigate the accuracy of commercially available devices and the effect of elevation correction on the validity of the measure.

In this thesis, Study 5 analysed some key technical and tactical variables affecting road sprint results. The results highlighted the significant importance of team tactics and team support for successful road sprint performance. However, the study was done on a single subject. Further research adopting the novel methodology presented in Study 5 is recommended in order to confirm the importance of team tactics to other professional sprint cyclists, and possibly in other aspects of road cycling (i.e. hill climbing). Indeed, these further studies might reveal that some professional sprinters may have the ability to excel in road cycling sprints with little, or potentially without, team support. In this case, studies investigating in depth other characteristics (e.g. skills acquisition, cognitive traits, etc) of the sprinters would be warranted.

Both Study 2 and 5 of this thesis described the TEG of stages. As expected, results suggested that different sprinters have different climbing abilities. Future researches aiming at classifying and describing different kind of sprinters (e.g. flat- or hilly- terrain sprinters, long- or short- sprint sprinters) is recommended. Knowing the sprinters' climbing ability (sprint chances) and their likelihood to succeed in the sprint (win ability), together with a careful evaluation of the rivals' characteristics, may be important in development of specific training programs, or in the selection of events that may best suit certain athletes.

8.2 Conclusion

The main findings from the studies of this thesis were that: i) exercise intensity significantly increased to a highly variable high intensity in the last part of road competitions; sprint duration was 13.2 ± 2.3 s and mean sprint power was 14.2 ± 1.1 $W \cdot kg^{-1}$; ii) the physiological demands of competitions were higher in PRO compared to U23 races, despite similar sprint characteristics in the two categories; iii) neither the variable nor the non-variable 10 min efforts impaired the sprint performance in elite competitive cyclists; iv) measurements of elevation gain were consistent within devices of the same brand used with the same settings; v) technical and tactical aspects of road sprinting are related to performance outcomes.

Collectively then, the studies of this thesis have shown that road sprint performances depend on the ability to produce a high power output for a duration of approximately 10-15 s. Interestingly, in high level cyclists an intense 10 minute effort itself (either with variable and non-variable power output) does not impair sprint performance. To be successful in the professional category it's fundamental to have high fitness level in order to be able to sustain the significant increase in race intensity that occurs when approaching the finish line, after several hours of exercise. In particular, the ten minutes prior to the sprint appear to be of critical importance for a few reasons: i) increase in race intensity, ii) increase in power output variability, iii) technical and tactical variables. In fact, technical and tactical variables are significantly related with race results. Similarly, the amount of climbing characterising a cycling competition has an impact on the likelihood of a sprint finish, and on the individual chances that a sprinter will be in the main bunch to contest the final sprint. Researchers, coaches and athletes interested in the measure of elevation gain should avoid comparing data collected with devices of different brands, especially if the settings are not consistent. Research confirming and expanding some of the results of this thesis and further examining the mechanisms responsible for fatigue is necessary in order to gain a greater understanding of road sprint performances.

CHAPTER NINE REFERENCES

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CHAPTER TEN APPENDICIES

A Photo of subjects winning bunch sprints in the PRO (A) and U23 (B) categories (Study 1 and 2)

B Photos during data collection for Study 1 and 2. Team support in the field (A), checking devices' slope during stage racing (B) and collecting race data (C) (Study 1 and 2)

C Photos of subjects performing laboratory testing: maximal oxygen uptake (A), warm-up before the 10 minutes and sprint effort (B) (Study 3)

D Photos from Study 4a, Varese (A), location of analysed devices during data collection (B) (Study 4a)

E Screenshot from a congress presentation illustrating methods for Study 5

F Ethics approval for PhD – ECU Human Research Ethics Committee

G Document of information letter to participants for PhD research

H Document of informed consent for PhD research

I Copy of publication from Chapter 4 (Study 2; pg 1)

J Copy of publication from Chapter 6 (Study 4; web page)

K Copy of publication from Chapter 7 (Study 5; pg 1)

L Screenshot from an article/interview published on the Science of Sport website

M Screenshot from an article/interview published on the BBC News Magazine website

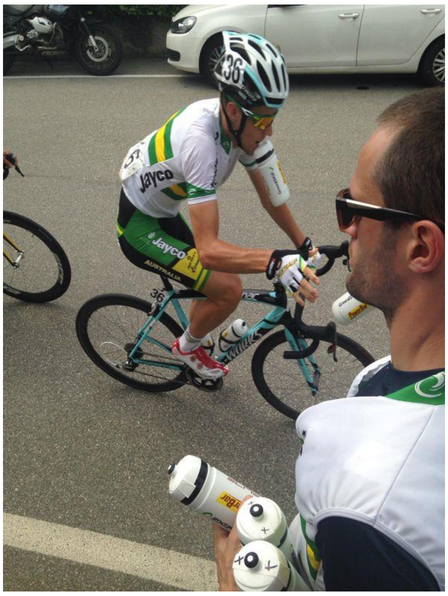
Appendix A

(A)

(B)

Appendix B

(A)



(B)

(C)

Appendix C

(A)

(B)

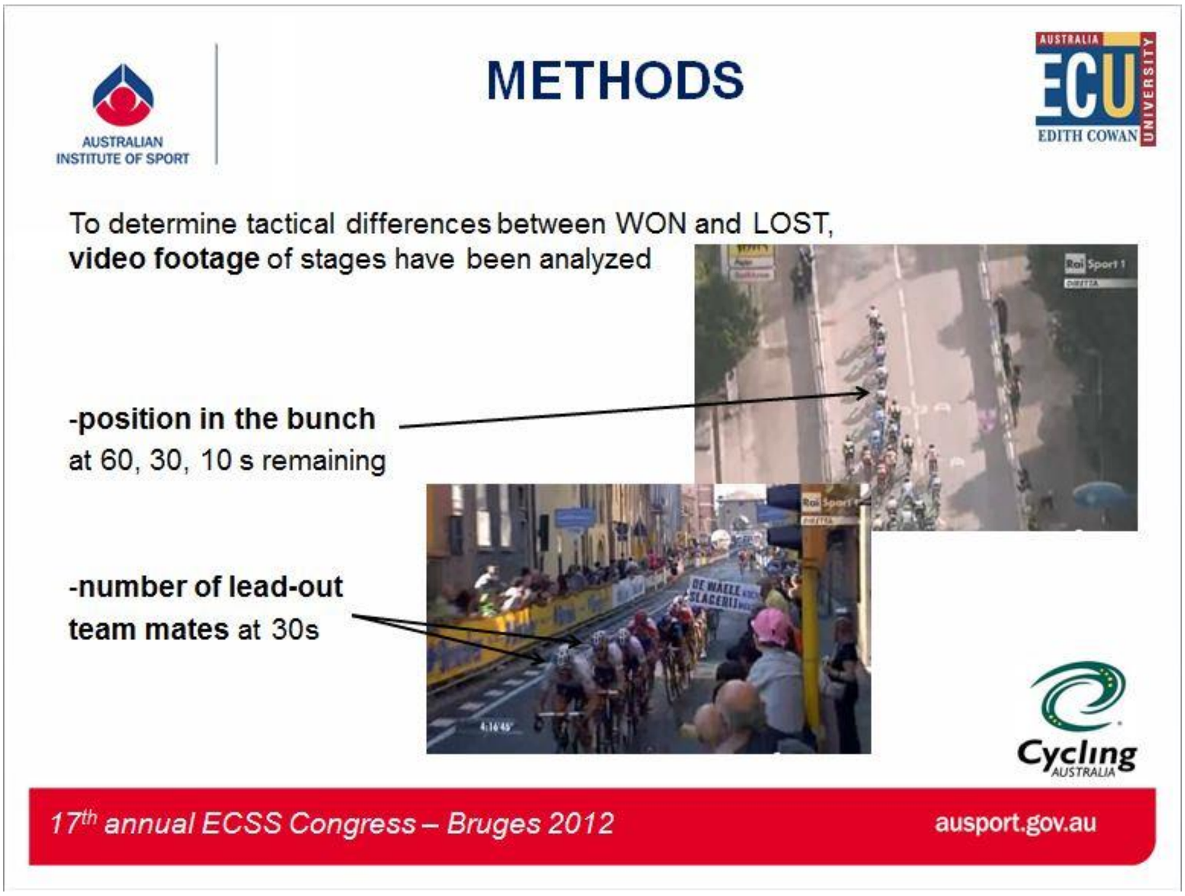
Appendix D

(A)

(B)

Appendix E

(A)


METHODS
AUSTRALIAN INSTITUTE OF SPORT
AUSTRALIA ECU EDITH COWAN UNIVERSITY
To determine tactical differences between WON and LOST, video footage of stages have been analyzed
-position in the bunch
at 60, 30, 10 s remaining
-number of lead-out team mates at 30s
Cycling AUSTRALIA
17th annual ECSS Congress – Bruges 2012
ausport.gov.au

Appendix F

Research Ethics <research.ethics@ecu.edu.au> Fri, May 18, 2012 at 3:54 AM
To: "pmenaspa@our.ecu.edu.au" <pmenaspa@our.ecu.edu.au>, "paolomenaspa@gmail.com" <paolomenaspa@gmail.com>
Cc: Chris ABBISS <c.abbiss@ecu.edu.au>, Greg HAFF <g.haff@ecu.edu.au>, "david.martin@ausport.gov.au" <david.martin@ausport.gov.au>, "franco.impellizzeri@gmail.com" <franco.impellizzeri@gmail.com>, Research Assessments <researchassessments@ecu.edu.au>

Dear Paolo

Project 8061 MENASPA'

Physiological Aspects of Sprinting in Endurance Cycling

Student Number: 10243978

The ECU Human Research Ethics Committee (HREC) has reviewed your application and has granted ethics approval for your research project. In granting approval, the HREC has determined that the research project meets the requirements of the *National Statement on Ethical Conduct in Human Research*.

The approval period is from 16 May 2012 to 31 December 2013.

The Research Assessments Team has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Please feel free to contact me if you require any further information.

Regards

Kim

Kim Gifkins

Research Ethics Officer

Appendix G

Information Letter to Participants

Title of the project

"Anthropometric and physiological characteristics of road sprinters. Physiological demands of road sprints"

Description of the research project

This research study is being conducted as part of Paolo Menaspa's PhD.
The aim of this study is to describe the anthropometric and physiological characteristic of road sprinters and the physiological demands of road sprints. The parameters collected in the laboratory will describe the sprinter's physiological and anthropometrical characteristics. The data recorded in the field will describe the demands of competitions. Length, duration and cumulative elevation gain of every race performed by each cyclist for the duration of the study will be monitored. Also, power output, cadence, heart rate and speed data will be collected over the last 30 km of each event, using SRM power meters, which will be fitted to each cyclist's bike.

You have been selected as a potential participant in this project because you are a healthy, male cyclist aged between 20 and 40 years old. You have been selected by way of personal contact with one of the investigators, because you are a professional cyclist.

As a participant in this study, you will be involved in a number of laboratory testings, moreover monitoring of your performance (i.e. power output, speed and cadence) in professional cycling races will be conducted over the competitive season. All testing will be conducted under supervision at the exercise physiology laboratory of the Australian Institute of Sport (Canberra) or at the exercise physiology laboratory at the AIS European Training Centre (Gavirate, Italy). As a participant in this study, you will undergo a complete anthropometric assessment, perform an incremental cycle test to exhaustion, and perform a sprint test for the assessment of anaerobic physiological characteristics. These laboratory evaluations will be done in one single day. Testing sessions will last approximately 4 hours in duration.

During this testing session you will have your body composition determined using dual energy x-ray absorption, have a 5 µl blood sample taken from a fingertip. Blood samples will be conducted by a qualified researcher and will be used to determine your blood lactate concentrations during an incremental exercise. The incremental cycling tests will start at a relatively light intensity and every 5 minutes the intensity will be increased until you have reached your maximal aerobic capacity. This test typically lasts 30-40 min with the total duration depending on your fitness. The testing session will last approximately 4 hours, from the very beginning to the end.

During testing session:

- Your heart rate will be monitored continuously with a personal heart rate monitor
- Inspired and expired gases will be continuously monitored
- You will be asked periodically about your perceived exertion
- Blood samples will be taken from your fingertip: approximately 5 µl of blood will be collected from the finger tip, within each sample. The number of samples will be between 4 and 7, depending on the physiological characteristics of each subject. A trained and qualified technician will perform all blood collection procedures.

During the maximal exercise tests and training it is possible that you may experience fatigue and muscle

soreness.

You will benefit from participating in this study through a better understanding of your own fatigue during such exercises. Where possible you will also be provided with information regarding your physiology.

The current study design has been approved by the ECU Human Research Ethics Committee.

Confidentiality of information

The information collected in this study will be used to prepare a scientific report to be published in an academic journal. The information will only be available to Dr. Paolo Menaspa' and his team of researchers. Your personal data will be assigned an identification code, such that only those people directly involved in collecting information for the study will be able to recognise which person the information pertains to. The information collected in this study will be stored under file in the Australian Institute of Sport for a period of 5 years. After the study has finished the information collected during the course of the study will be destroyed.

Results of the research study

The data collected in this study will be summarised as average data for all participants. There will be no individual data presented, which means that your personal information cannot be identified. The data will be presented at conferences and as a scientific report to be published in an academic journal. If you request it, you will receive a summary of your own personal information and a group summary explaining the findings of the study.

Voluntary participation

Your participation in this study is entirely voluntary. No explanation or justification is needed if you choose not to participate.

Withdrawing consent to participate

You are free to withdraw your consent to further involvement in the research project at any time. If you choose to withdraw, you have the right to request that any personal information collected up to that point in the study is returned to you without question.

Questions and/or further information

If you have any questions or require any further information about the research project, please contact Paolo Menaspa' on +61 429 072885 or email: paolomenaspa@gmail.com

Researchers and Contact details

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Independent contact person

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Committee
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

If you are interested in taking part in this study, then please read and sign the Informed Consent document and return it to Paolo Menaspa' in person or by post at the address provided at the beginning of this letter.

Appendix H

Informed Consent Document

Title of the project

"Anthropometric and physiological characteristics of road sprinters. Physiological demands of road sprints."

Researchers and Contact details

Paolo Menaspa'

School of Exercise, Biomedical and Health Sciences

Edith Cowan University

School of Exercise, Biomedical and Health Sciences

270 Joondalup Drive

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Phone +61 429 072885

Statement indicating consent to participate

I confirm the following:

- I have been provided with a copy of the *Information Letter*, explaining the research study
- I have read and understood the information provided
- I have been given the opportunity to ask questions and I have had any questions answered to my satisfaction
- I am aware that if I have any additional questions I can contact the research team
- I understand that participation in the research project will involve:
  - 1 day of laboratory testing (anthropometric, aerobic and anaerobic characteristics)
  - Maximal cycling tests performed on the laboratory
  - Blood samples taken from fingertip for lactate measurements
  - Measurements of heart rate, oxygen consumption and perceived exertion
  - Measurements of length, duration and cumulative elevation gain of every race performed for the duration of the study
  - Measurement of power output, cadence, heart rate and speed data using a SRM power meter, which will be fitted to my bicycle

- I understand that my information provided will be kept confidential, and that my identity will not be disclosed without consent
- I understand that the information provided will only be used for the purposes of this research project, and I understand how the information is to be used
- I understands that I am free to withdraw from further participation at any time, without explanation or penalty
- I freely agree to participate in the project

Signed .... **Name**.. **Date**..............

Signed by member of research team ....

Appendix I

J Sci Cycling. Vol. 2(2), 35-39

RESEARCH ARTICLE

Open Access

Physiological demands of road sprinting in professional and U23 cycling. A pilot study

Paolo Menaspà[1,2,3], Marc Quod[4], David T Martin[1,2,3], James Victor[3] & Chris R Abbiss[1]

Abstract

This pilot study described and compared the power output (absolute, relative to body weight and relative to frontal area) recorded during successful road sprints in professional and under 23 men's cycling races. The study also described the exercise intensity and requirements of sprinters throughout final 10 min of the race. Nine successful (top 3) sprints performed by a professional (PRO: 23 y old, 1.76 m, 71.8 kg) and an under 23 (U23: 18 y old, 1.67 m, 63.2 kg) cyclist sprinter were analysed in this study. No statistical differences were found in absolute peak and average sprint power (PRO: 1370±51 W and 1120±33 W; U23: 1318±60 W and 1112±68 W). The average power output relative to body weight and to projected frontal area (A_p) was lower in PRO than U23 (15.6±0.4 and 17.4±1.1 $W \cdot kg^{-1}$; and 2533±76 and 2740±169 $W \cdot A_p^{-1}$, respectively) (*P*=0.016). The intensity of the last 10 min prior to the sprint was significantly higher in PRO than U23 (4.6±0.3 and 3.7±0.2 $W \cdot kg^{-1}$, respectively) (*P*<0.05). Races duration, total elevation gain and average power were similar between PRO and U23. In conclusion, the physiological demands leading into road sprinting (intensity of the last 10 min) were found to be higher in PRO compared to U23 races; however, a similar sprint power output (>2500 $W \cdot A_p^{-1}$ or >15.5 $W \cdot kg^{-1}$ for approximately 14 s, with a peak power output >3100 $W \cdot A_p^{-1}$ or >19 $W \cdot kg^{-1}$) indicates that sprint characteristics may be somewhat similar between PRO or U23 races. Further research is warranted in order to better understand physiological and tactical aspects important to road sprint cycling.

Keywords: anaerobic, sprint, cycling, performance, racing, male

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Introduction

Several studies have described and compared the anthropometric and physiological characteristics of cyclists from various disciplines, specialties and levels of competition (Lucia et al. 1998; Moseley et al. 2004). Generally, these studies have examined the cyclists' aerobic characteristics, with few studies reporting performance in efforts with durations relevant to sprinting (i.e. ≤ 30 s). Interestingly, similar absolute (W) and relative ($W \cdot kg^{-1}$) power outputs have been reported between high and low level male junior cyclists (Menaspà et al. 2012), and between under 23 and professional male cyclists (Sallet et al. 2006), during laboratory based sprint tests (i.e. 5 to 30 s duration). However, these tests were performed with participants that were not exclusively sprint specialists and under laboratory and not race conditions.

Despite the frequency of sprints in road cycling (e.g. ~7 out of 21 stages within Grand Tours) limited scientific research is available, with only one study reporting the power output of a single cyclist winning one race (Martin et al. 2007). Moreover, in road cycling the number of successful sprinters is somehow limited (e.g. 1 or 2 riders out of 30 per team). These factors, together with the complexity of road sprinting, may be the reason for the lack of scientific research describing the physiological demands of road sprinting. In fact, little is known on the characteristics and performance demands of road sprinting. Thus, research on road sprinting is novel, nevertheless logistically difficult to study with a sample. Still, considering that successful sprinters must produce a minimum amount of power to defeat their opponents, even just limited data can illustrate successful performances.

To date, a considerably greater body of literature has examined sprint performance during track cycling. While it has been suggested that maximal power may be a predictor of sprint performance, Dorel at al. (2005) found that average sprint speed during track cycling was not correlated with maximal power output (in W or $W \cdot kg^{-1}$) but instead significantly correlated with power output relative to the cyclists frontal area ($r = 0.75$, $p = 0.01$).

To the best of our knowledge, no study has examined the sprint power output of road cyclists competing at different levels of competition, or reported the sprint power output in relation to frontal area. Thus, in order to better understand the physiological demands of road sprinting, the main aim of this study was to describe and compare the power data (absolute, relative to body weight and projected frontal area) recorded during successful road sprints in professional and U23 male

Appendix J

IJSPP Volume 9, Issue 5, September

Brief Reports

Consistency of Commercial Devices for Measuring Elevation Gain

2014, 9, 888 – 890

http://dx.doi.org/10.1123/IJSPP.2013-0232

Purpose: To determine the consistency of commercially available devices used for measuring elevation gain in outdoor activities and sports. ***Methods***: Two separate observational validation studies were conducted. Garmin (Forerunner 310XT, Edge 500, Edge 750, and Edge 800; with and without elevation correction) and SRM (Power Control 7) devices were used to measure total elevation gain (TEG) over a 15.7-km mountain climb performed on 6 separate occasions (6 devices; study 1) and during a 138-km cycling event (164 devices; study 2). ***Results***: TEG was significantly different between the Garmin and SRM devices ($P < .05$). The between-devices variability in TEG was lower when measured with the SRM than with the Garmin devices (study 1: 0.2% and 1.5%, respectively). The use of the Garmin elevation-correction option resulted in a 5–10% increase in the TEG. ***Conclusions***: While measurements of TEG were relatively consistent within each brand, the measurements differed between the SRM and Garmin devices by as much as 3%. Caution should be taken when comparing elevation-gain data recorded with different settings or with devices of different brands.

Keywords: reliability, GPS, cycling, outdoor activity, total elevation

Authors: Paolo Menaspà, Franco M. Impellizzeri, Eric C. Haakonssen, David T. Martin, Chris R. Abbiss

Appendix K

International Journal of Sports Physiology and Performance, 2013, 8, 336-340

INTERNATIONAL JOURNAL OF
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www.IJSPP-Journal.com
CASE STUDY

Performance Analysis of a World-Class Sprinter During Cycling Grand Tours

Paolo Menaspà, Chris R. Abbiss, and David T. Martin

This investigation describes the sprint performances of the highest internationally ranked professional male road sprint cyclist during the 2008–2011 Grand Tours. Sprint stages were classified as won, lost, or dropped from the front bunch before the sprint. Thirty-one stages were video-analyzed for average speed of the last km, sprint duration, position in the bunch, and number of teammates at 60, 30, and 15 s remaining. Race distance, total elevation gain (TEG), and average speed of 45 stages were determined. Head-to-head performances against the 2nd–5th most successful professional sprint cyclists were also reviewed. In the 52 Grand Tour sprint stages the subject started, he won 30 (58%), lost 15 (29%), was dropped in 6 (12%), and had 1 crash. Position in the bunch was closer to the front and the number of team members was significantly higher in won than in lost at 60, 30, and 15 s remaining ($P < .05$). The sprint duration was not different between won and lost (11.3 ± 1.7 and 10.4 ± 3.2 s). TEG was significantly higher in dropped (1089 ± 465 m) than in won and lost (574 ± 394 and 601 ± 423 m, $P < .05$). The ability to finish the race with the front bunch was lower (77%) than that of other successful sprinters (89%). However, the subject was highly successful, winning over 60% of contested stages, while his competitors won less than 15%. This investigation explores methodology that can be used to describe important aspects of road sprint cycling and supports the concept that tactical aspects of sprinting can relate to performance outcomes.

Keywords: total elevation gain, competition analysis, Tour de France, drafting, winning strategy

Road-cycling sprint performance is influenced by a variety of factors including individual and team tactics, technique, and the physiological characteristics of the cyclist. Road sprinters have the distinctive ability to excel in mainly flat cycling competitions,[1,2] in which the final sprints are initiated from high speed.[3] In professional cycling the sprinters often make up a very small proportion of the team (eg, 2 out of 30 riders). This factor, together with the complexity of road sprinting, may be the reason for the lack of scientific research detailing the characteristics important to successful road sprinting. Indeed, several studies have described the physiological demands of competition and the characteristics of other specialty cycling groups, including time trialists, climbers, and off-road cyclists.[1,4-6] Furthermore, a number of studies have examined the physiological characteristics of track sprinters.[7-9] However, we are currently aware of only 1 study that provides a detailed description of road sprint-cycling performance, and that study was on a single cyclist performing a single sprint.[3]

There has been little, if any, research describing the tactical approach adopted by road sprint cyclists. Bullock et al[10] examined bunch position in World Class short-track speed skaters and observed unique positioning strategies in winners over 3 different race distances. Similar to cyclists, speed skaters gain an advantage by drafting but also face the disadvantage of passing a competitor as they approach the finish.[11] It is possible that a similar evaluation of sprint cycling could be useful for understanding performance.

Sprints are an extremely important aspect of professional road cycling. In fact, many stages (eg, ~7 out of 21) in each of the Grand Tours (ie, Giro d'Italia, Tour de France, and Vuelta a España) are designed specifically for sprinters. Noticeably, among professional road sprinters, only a few are able to win Grand Tour stages, and even fewer can win repeatedly. For example, examination of the sprint results in recent Grand Tours (2008–2011) indicates that 79 stages (of 252 total stages, 31%) were won by only 24 sprinters. Five sprinters won 54 stages of which 1 sprinter won 30 stages. Due to his outstanding results, this cyclist was selected as the primary subject of the current investigation. The aim of this investigation was to provide a detailed description of the sprint performances of a professional world-class sprinter during Grand Tours to extend methodology used for evaluating road sprints. A secondary aim was to compare performances of this cyclist against those of his closest rivals to identify key factors that may influence sprint performance.

Menaspà and Abbiss are with the School of Exercise and Health Sciences, Edith Cowan University, Perth, Australia. Martin is with Sports Science Sports Medicine, Australian Institute of Sport, Canberra, Australia.

Appendix L

THE SCIENCE OF SPORT

Welcome to the Science of Sport where w
level of analysis you will not find anywhere

Be it doping in sport, hot topics like **Caster S**
dehydration myth, we try to translate the s
performance. Consider a donation if you like

The profile of a sprint: What does it take to win a sprint stage?

08 Jul 2014 Posted by **Ross**

Category: **2014 Tour de France**, **Cycling Physiology**

What does it take to win a sprint stage in the Tour de France?

A picture says a thousand words, so let's begin the answer with a trip on a professional sprinter's bicycle. This is John Degenkolb finishing second in Stage 1 of this year's Tour of California (he's beaten by Mark Cavendish, who you see first at 0:50 and then catch a glimpse of on his right at the very end).

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Fast, frantic, and furious.

But the physiology and the power output that goes into producing that is really interesting too. Not something I've covered here much in the past, my focus has normally been on the mountains where the yellow jersey is won and lost. But today, and for this week, it's about the green jersey, and the fastest men in the Tour.

As luck would have it, I was chairing a session at the recent European College of Sports Sciences meeting in Amsterdam, and up to present comes **Paolo Menaspa, who is studying this exact question**. We discussed it afterwards, and he agreed to help me put together an explanation of some of the hidden aspects of a professional cycling sprint.

So here is Paolo's expert viewpoint (indented and dark grey if you want to read uninterrupted!), with some comment and added explanation woven in from me.

Appendix M

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NEWS MAGAZINE

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18 July 2014 Last updated at 23:17

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Why sprinters are muscly and climbers are wiry

By Wesley Stephenson
BBC News

As the Tour de France heads for the mountains the sprinters will start to take a back seat. Don't expect the likes of Marcel Kittel and Andre Greipel to win any stages up there. This is the territory of riders like Vincenzo Nibali and Joaquim Rodriguez.

To look at them, they're as different as flat and jumps racehorses. The sprinters are packed full of muscle while the *grimpeurs* (climbers) are lithe, almost skeletal figures.

But the Alps and the Pyrenees look pretty mean, and often require 30-40 minutes of solid climbing. You would think a bit of muscle would come in handy, so why do climbers do better with less of it - and why do those muscly sprinters struggle with the gradient?

Before answering that question, let's look more closely at their physiques. According to Paolo Menaspa, a physiologist and cycling coach studying at the Australian Institute of Sport, the key factor is body mass index, or BMI. (To calculate BMI you divide someone's weight in kilos by their height in metres squared.)

In today's Magazine

Remembering Ben Bradlee

Tales from the India Office

How safe is mouldy food to eat?

The man who magically made maths fun