An Examination of the Factors Determining the Performance of Cyclists in Elite Competitions

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

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ABSTRACT

A key objective of sports performance research is to provide team managers, coaches, and athletes seeking to improve performance with information on the attributes that contribute to or predict overall success, yet the determinants of performance in actual competition remain an under-examined and under-theorised field. The focus of this thesis is an exploration of these determinants, particularly in the more complex races that permit opponent interaction.

The rationale and theoretical framework for the thesis is outlined in Chapter 1, where I explain how it is underpinned by concepts from ecological dynamics, utilising a sequential explanatory mixed-methods research approach, first to quantify the changes in cyclist performance in increasingly complex racing environments, followed by a qualitative investigation to explain and elaborate on the potential mechanisms underpinning these changes. In the initial quantitative analyses (Chapters 2 and 3), linear mixed modelling of race results was used to examine changes in the variability and predictability of elite track cyclists' performances between solo time trials and race events involving direct interaction with competitors. In Chapter 2, cyclists' performances in the three solo time-trials and three mass-start race events that comprise the overall Omnium competition were investigated. The reproducibility of performance in the mass-start events was lower than in the solo events. In Chapter 3, Match Sprint tournaments provided performance measures in a qualifying time trial and subsequent head-to-head racing. Qualifying time-trial performance largely determined success in head-to-head racing, but there was evidence of unknown factors modifying cyclists' chances of success. In Chapter 4, a systematic narrative review was undertaken, in which published findings on the determinants of cyclists' behaviours and chances of success in elite competition were collated and synthesised. Key findings were grouped and used to shape a conceptual framework of the determinants of performance. A qualitative research approach was adopted for Chapters 5 and 6, wherein semi-structured interviews with 15 elite cyclists from three racing disciplines were used to explore potential factors underpinning the results in Chapters 2, 3 and 4. Transcribed text of the interviews was examined using thematic inductive content analysis to develop initial themes, which were cross-validated with results from Chapter 4. Chapter 5 focused on the changes in the perceptions and practices of cyclists between solo time trials and race events with direct interaction between opponents. In Chapter 6, other themes of the thematic content analysis are combined with results from each prior study to propose an initial systems model of elite cycling performance, summarising the dimensions, features and mechanisms identified throughout this thesis. Final concluding statements, including the practical applications, limitations and possible future directions of this work are made in Chapter 7.

In this thesis, I have demonstrated the advantages of combining research techniques and drawing on research across a range of scientific disciplines in order to enrich our understanding of competitive performance in some cycling disciplines. Research on competitive performance in

other sports characterised by complex environments could benefit from this mixed-methods approach.

STUDENT DECLARATION

I, Kathryn E Phillips, declare that the PhD thesis by Publication entitled ‘An Examination of the Factors Determining the Performances of Cyclists in Elite Competition’ is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature: [redacted] Date: 16.07.2020

DETAILS OF INCLUDED PAPERS

Chapter	Paper Title	Publication Status	Publication Title and Details
Chapter 2	Performance Relationships in Timed and Mass-Start Events for Elite Omnium Cyclists	Published	Phillips, K.E., & Hopkins, W.G. (2017) in the International Journal of Sports Physiology and Performance, 12 (5), 628-633 Impact Factor: 4.0
Chapter 3	Factors Affecting Cyclists' Chances of Success in Match-Sprint Tournaments.	Published	Phillips, K.E., & Hopkins, W.G. (2019) in International Journal of Sports Physiology and Performance, 14 (4), 472-477 Impact Factor: 4.0
Chapter 4	Determinants of Cycling Performance: a Review of the Dimensions and Features Regulating Performance in Elite Cycling Competitions.	Published	Phillips, K.E., & Hopkins, W.G. (2020) in Sports Medicine Open, 6 (23), 1-18 Impact Factor: 3.1
Chapter 5	The Influence of Opponents in Elite Cycling Races: a Qualitative Analysis.	Currently under review	Phillips, K.E., Corban, R.C., & Hopkins, W.G. submitted to Psychology of Sport and Exercise Impact Factor: 2.096
Chapter 6	An Empirical Study and Initial Systems Model of the Features Influencing Competition Performances of Elite Cyclists	Unsubmitted but proposed to be submitted	Phillips, K.E., Hopkins, W.G., & Corban, R.C.

Declaration by: Kathryn Elizabeth Phillips

Signature: [redacted]

Date: 14/07/2020

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In the first instance I must thank my principal supervisor, Will Hopkins, for the extraordinary amount of time and patience he offered me throughout this process. I knew you would be a hard task master, Will. I knew you would critique my work thoroughly. Your reputation preceded you. What nobody told me was the sheer privilege it would be to be supervised by you. I am enormously grateful. I will never be able to repay you for the extent of your mentorship these past years and the time you have poured into me. I can only hope that over the course of my career I might have the opportunity to do the same for others.

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Thirdly, to those within the cycling industry that I have had the privilege of working with, it has been a joy to work alongside you. I learned an enormous amount from you all and you collectively ignited a passion for this sport that remains to this day. I remain a passionate advocate of sport and this work only furthers my desire to see it done well.

I also wish to thank those who encouraged me to undertake this journey and who continued to provide inspiration that it could be done. Rita, Sian, Paul, Damian, and Jono, thank you for your advice and encouragement. Knowing you had successfully walked this path helped enormously when the going got tough.

Finally, to my long-suffering friends and family. Thank you. When all is said and done, you lot are all that truly matter. Thank you for continuing to ask if I was finished yet, even when that was met with a less than favourable response. Thank you for the support.

Mum & Dad, there are no words. I am so blessed to be loved and supported by you both. I hope I can continue to make you proud. Thank you for continuing to tolerate my mad endeavours and your unwavering support. I love you both and I'm so proud to be yours.

Steve, I know you will never read this… but thank you none the less. PhD student came as part of the package, and your patience and understanding as it slowly ate up more and more of my time is so appreciated. Thank you for the kind words, the tough words, the encouragement, the space to get it done, and the bear hugs when it was all too much.

Above all, lead on. Psalm 63.

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LIST OF ABBREVIATIONS

ASO: Amaury Sports Organisation

BMI: body mass index

CL: confidence limit

GC: general classification

ICC: intraclass correlation coefficient

IOC: International Olympic Committee

NSO: national sporting organisation

SD: standard deviation

UCI: Union Cycliste Internationale

ETHICAL APPROVAL

Ethical approval for Chapters 5 and 6 were granted by the Victoria University Human Research Ethics Committee (HREC). The HREC reference for this chapter was:

Application ID: 0000024479
Application Title: Exploring the athlete's viewpoint: the influence of tactics and strategy on performance in cycling races.
Approved on: 01/06/2016

CHAPTER 1:

INTRODUCTION

The overall aim of this doctoral thesis was to advance knowledge about the performance of cyclists in the complex environments that characterise actual competitive racing at the elite level. Although numerous researchers have investigated the factors shaping the performance of elite cyclists, most studies have been conducted in laboratories or other controlled environments that lack contextual relevance. In this thesis I sought to establish how the performances of elite cyclists changed in increasingly complex competition environments and to quantify the extent of these changes, then to identify the features underpinning performance in actual competitive racing, their interactions, and the levels and timescales across which they acted. The sequential explanatory mixed-method design used in this thesis illustrates the benefits of combining quantitative and qualitative approaches to produce a more nuanced understanding of cycling performance in actual competitive racing. My approach corresponds with recent calls for researchers to find more encompassing methodologies that provide holistic explanations of performance and enable the dynamics of the performer-environment relationship to be more adequately captured, assessed, and understood. My objective was to advance knowledge about the performance of cyclists and provide organisations, managers, coaches, and athletes with information to inform better practice.

1.1 Rationale and Significance of the Study

The determinants of success in elite cycling, particularly in races permitting opponent interaction, are not well understood. A majority of elite cycling competitions, as sanctioned by the Union Cycliste Internationale (UCI), are race events, where the interaction permitted between competitors results in behavioural dynamics not evident in time trials. A race refers to any competition where two or more athletes start together and compete against each other for the win. In a race the goal is to cross the finish line before your opponent(s) and direct interaction is typically permitted between competitors. In contrast, the goal in a time-trial is to finish the race distance in the shortest possible time, and interaction between competitors is usually negligible. In elite cycling, the structure of competitions and event formats differ between cycling disciplines and may include solo or team time-trials, single or multi-race competitions, and single or multi-day tournaments. What is more, races can be one-versus-one, mass-start, individual or team format, and take place across a range of distances, locations, surfaces and terrain. The direct interaction permitted between competitors during race events lead to performance dynamics not evident in time trials, as riders constantly adapt to the actions of their opponents and the changing structure of the race environment [1–3].

There is a considerable body of research focused on investigating the factors underpinning the performances of elite cyclists, but the studies have been conducted largely from the perspective of reductionism, where specific components of performance are isolated and examined in laboratories or other controlled environments to reduce the influence of confounding variables. Although the contributions of reductionist research have been considerable, it is unclear how the features known to contribute to the performance of a cyclist in controlled settings also predict performance in actual competitions. The reductionist approach is built on the tacit assumption that, in understanding the behaviour of specific components of a system (here, the cyclist), we are able to build a representation of how the system as a whole will behave [4]. This assumption has been challenged in recent decades, with numerous authors arguing that the sum of the parts does not equal the whole, and that by examining the performance of athletes devoid from real-world context, an incomplete understanding of performance has been formed [5–8].

Notwithstanding the contribution of reductionist research, there is a gap in our knowledge of the factors shaping the performance of elite cyclists in actual competitive racing. In races, cyclists must constantly adapt to the actions of their opponents and the changing structure of the race environment [1–3]. The aerodynamic benefits that can be gained from drafting are one reason amongst many for the behavioural dynamics that emerge, as athletes can greatly reduce the physiological cost of maintaining the same speed by positioning behind the wheel of another rider [9]. Elite athletes are known to adjust their behaviour according to contextual features of the competition environment, and it is the interactions between an athlete, their opponents, and these environmental features that determine their decisions and actions during a race [10,11]. To understand the performance of elite cyclists in actual competition, it is therefore necessary to find methodological approaches that are able to account for modifying effects of these interactions.

Given that the goal of sports performance research is to improve our understanding of the attributes that contribute to, or predict overall success in competitive sporting environments, there are a number of questions that I set out to address in this thesis. First, how well does a cyclist's performance in solo time-trials transfer to performance in the more complex racing events? Secondly, how can we account for the complex interplay between cyclists and their environment? Finally, what are the factors that affect a cyclist's chances of success in actual competitions and how do they interact? The intent is to provide organisations, managers, coaches, and athletes with more accurate information on elite competitive performance that can inform better practice.

1.2 Assessing Performance in Actual Competition

In order to address the first question, of how well a cyclist's performance in solo time-trials transfers to performance in the more complex racing events, I drew on previous research that has provided estimates of performance from measures of elite athletes in competition. An important aspect of analysing the factors affecting athletic performance is to first understand the variability in an athlete's performance from competition to competition in actual events [12].

Without this, we cannot ascertain how well the factors known to influence the performance of athletes in laboratory or controlled field tests actually translate to performance in actual competition [13]. Malcata and Hopkins [12] systematically reviewed research aimed at estimating the within-athlete variability of athletes' competitive performance in a range of different sports, and demonstrated the benefits of statistical analysis of race result data to enable comparison within and between sports and event disciplines. While the variability shown by elite cyclists, and track cyclists in particular, has been reported for athletes competing in time-trial disciplines [14,15], the performance variability of cyclists competing in mass-start events has not been well established. Contrasting the variability shown by cyclists competing in mass-start events with that of the same cyclists competing in time-trial events enabled me to assess the extent to which factors contributing to performance transferred between the different race formats, as presented in Chapters 2 and 3.

In formulating an approach to the second question, of how to account for the interplay between a cyclist and the performance environment, I drew on the results of previous studies that had examined the changes in athletes' behaviour and performance under varying conditions in actual competition. Seifert and colleagues [16] have previously argued the need for athlete behaviour to be examined at different levels of analysis, and for researchers to adopt methodologies that can account for the interactions between an athlete, their opponents, teammates, and the specific constraints of the performance environment. A number of studies have demonstrated the benefits of combining research methods, mixing the findings from both qualitative and quantitative studies to generate a 'more robust analysis' that accounts for the interactions between an individual and their environment [17–20]. One rationale for using a mixed-method approach is that, by comparing the findings from quantitative analyses with those from qualitative analyses, the integration of results acts as a form of triangulation, where the results may concur, contradict, or expand on one another [20,21]. Mixed methods have been used previously in sports performance research [18,22–24]. For example, Brown [18] used a combination of notational analysis and athlete interviews to examine how the positioning of runners changed throughout races before exploring why these runners modified their pacing strategies and competitive tactics. A number of authors advocate that combining quantitative and qualitative approaches can offset the weaknesses of using any single approach, provide stronger and more accurate inferences regarding the research question, improve validity, allow a more 'complete and comprehensive picture of the phenomenon to emerge', assist in theory and instrument development and testing, 'enhance purposeful sampling and case selection' and finally, enhance the generalizability of the findings [25]. In this thesis, findings from the initial quantitative analyses informed the approach taken in the subsequent qualitative studies presented in Chapters 5 and 6. By combining research approaches, my aim was to generate novel insights into the multidimensional and interactive nature of features influencing the performance of cyclists in elite races.

In order to address the final research question, regarding the factors that affect a cyclist's chances of success in actual competitions and how they interact, I first explored what had already been established within the literature. As noted above, research exploring the factors shaping the performance of elite cyclists has been conducted almost exclusively in simulated laboratory experiments or controlled environments, and the results therefore cannot be generalised to actual performance environments due to the lack of representative design [26]. However, a number of studies have explored cyclist performance in actual competitive racing, and these are reviewed in detail in Chapter 4. In summary, the research on racing dynamics in cycling has focused predominantly on road racing (with some studies also in mountain biking, track cycling, and cyclo-cross), using mathematical, physical, physiological, psychological, and sociological approaches. There are various advantageous and disadvantages to the approaches used in these studies, all of which have contributed to our knowledge of particular components of cyclists' performances in competitive racing. However, no single perspective has been able to adequately capture how the various components interact dynamically with one another at varying intensities and across different spatio-temporal scales, or how cyclists adapt and change their behaviour to fit the emerging constraints [27,28]. In part, the failure of these studies to adequately explain performance is due to the complex number of variables that must be accounted for. In a road race there can be upwards of 60 riders competing for the win, combined with a varied course profile and changing environmental influences. As such, using a single research method or technique to explain the behaviour of a complex system produces a limited explanation of performance [29]. A comprehensive and integrated understanding of performance in complex race events remains at large, something I have attempted to rectify in Chapter 6.

1.3 Theoretical Framework and Research Objectives

1.3.1 Paradigmatic Assumptions

The research questions addressed in this thesis grew from discussions with people in the cycling industry regarding the lack of knowledge on what predicts a cyclist's chances of success in the more complex racing disciplines, and regarding how to appropriately train cyclists for these events. As a researcher who had spent a significant period of time working as a practitioner within the sport and seeking answers to real world problems, certain ontological and epistemological positions fit better with my world view and therefore the theoretical framework of this thesis. Ontology is concerned with how we understand the world and the assumptions we make about the nature of reality, while epistemology concerns the assumptions that underpin our attempts to construct and attain knowledge [30,31]. Ontological and epistemological assumptions inform how we determine what constitutes a valid and worthwhile research question and the methodology and methods that enable us to obtain and generate knowledge in the area.

The research in this thesis is situated within the ontological assumptions of critical realism, which lies somewhere between the realist and relativist positions [31]. At one end of the spectrum, realism assumes that an objective truth exists and can be accessed by the use of appropriate application of research techniques, while at the other end, relativism assumes that there are multiple constructed realities rather than an objective truth, and that knowledge is socially constructed and bonded to the researcher's position [31,32]. Situated somewhere in between, critical realism provides a stance that is more compatible with the aims of this thesis and my position as a research-practitioner, recognising that an objective reality exists independently of human understanding (realist ontology), while also acknowledging that people's experiences and interpretations of reality provide a foundation for knowledge (relativist epistemology) [31,33].

At an epistemological level, the philosophical stance of critical realism means that there is no obligation for a researcher to adopt any single methodology, because in order to 'get beneath the surface' and explain why things are the way they are, different theoretical lenses should be employed [34]. Critical realists typically take a stratified approach to understanding, valuing both empirical observations, which allow us to be more confident about what we think exists [35], whilst also recognising the existence and effects of unobservable entities [34,35]. Consequently, critical realism allows for a pragmatic approach toward the selection of research methods, and 'is compatible with the essential methodological characteristics of both qualitative and quantitative research, [promoting] communication and cooperation between the two' [36]. The complex, context-dependent and emergent nature of causality can thereby be captured, which fits with my intention in undertaking this project to first understand the nature of reality (the observable changes in performance in complex racing environments), before also seeking to explore individuals' experiences of that reality (the unobservable mechanisms generating the performance changes).

1.3.2 Theoretical Framework

The intent of this project was to establish how the performances of elite cyclists change in increasingly complex competition environments, to quantify the extent of these changes, and then to identify the features underpinning performance in actual competitive racing. With respect to the latter, a key principle of critical realism is the nature of causality, which is positioned as 'complex, context-dependent' and 'characterised by emergence' [32,35]. Within the sports performance literature, this principle is compatible with complex-systems theory and the ecological-dynamics framework, which position athletes and sports teams as complex adaptive systems that self-regulate according to the context they operate within and whose behaviour is an emergent property of their interactions with the surrounding environment [16,27,37–39]. Levy [40] defines a complex system as 'one whose component parts interact with sufficient intricacy that they cannot be predicted by standard linear equations; so many variables are at work in the system that its overall behaviour can only be understood as an emergent consequence of the holistic sum of all the myriad behaviours embedded within'. In keeping with the ontological and epistemological assumptions of critical realism, ecological dynamics provides a multi-dimensional theoretical framework that is appropriate for the study of athletes and sports teams as complex systems, and allows for an integrated explanation of athlete behaviour encompassing numerous scientific disciplines [16]. Seifert et al. [16] outline three main pillars of ecological dynamics: first, that causality in a complex system shows elements of non-linearity; secondly, emphasis is placed not only on observable phenomena, but also on the way athletes experience and make sense of their environment; and finally, a recognition that athletes' behaviours are coupled with information from the environment and their interactions with it [16,38]. In order to improve our understanding of the unobservable entities and mediating mechanisms shaping the observable performances of cyclists in actual competitive racing, a methodology was required that enabled me to determine 'how athletes operated relative to a diverse set of interrelated physical, cognitive, psychosocial, environmental, and wider systemic influences' [41]. Correspondingly, the methodology I adopted for this thesis corresponds with the assumptions of critical realism and the principles of ecological dynamics, allowing me to adopt multiple approaches in my search for a more holistic explanation of cycling performance.

1.3.3 Methodology

A sequential explanatory mixed-methods research approach was adopted, consisting of a quantitative, qualitative and integrative phase, with the goal of enhancing the quality and rigor of the thesis. Utilising this approach enabled me to explore the research questions from several angles and use the findings of the initial studies to guide the design and analyses of subsequent studies. By gathering multiple types of data (race results, findings from other researchers, interviews) across three different cycling disciplines, I was able to reduce the biases that would arise from using a single data source [42] or from investigating performance in a single cycling discipline. An outline of each phase, the order in which the studies were undertaken, and the key procedures and outputs from each, are presented in Figure 1.1.

In the quantitative phase, official race results for the Omnium and Match Sprint disciplines of track cycling at Olympic and UCI tournaments were collated. The goal of this phase was to quantify the changes in cyclists' performances in increasingly complex racing environments. The competition format of Match Sprint and Omnium tournaments enabled us to statistically analyse the changes in cyclists' performances between event disciplines where they competed solo and more complex event disciplines in which direct interaction was permitted between competitors. Linear mixed modelling of race results was used to examine changes in the variability and predictability of elite track cyclists' performances between these disciplines. In Chapter 2, I explored the relationships between cyclists' performances in the events that comprise the Omnium, in which up to 24 cyclists compete across two days in three solo time trials and three mass-start race events. In Chapter 3, I explored cyclists' performances in the Match Sprint, in which cyclists first complete a qualifying time trial, with the top 24 proceeding to compete in numerous rounds of head-to-head racing.

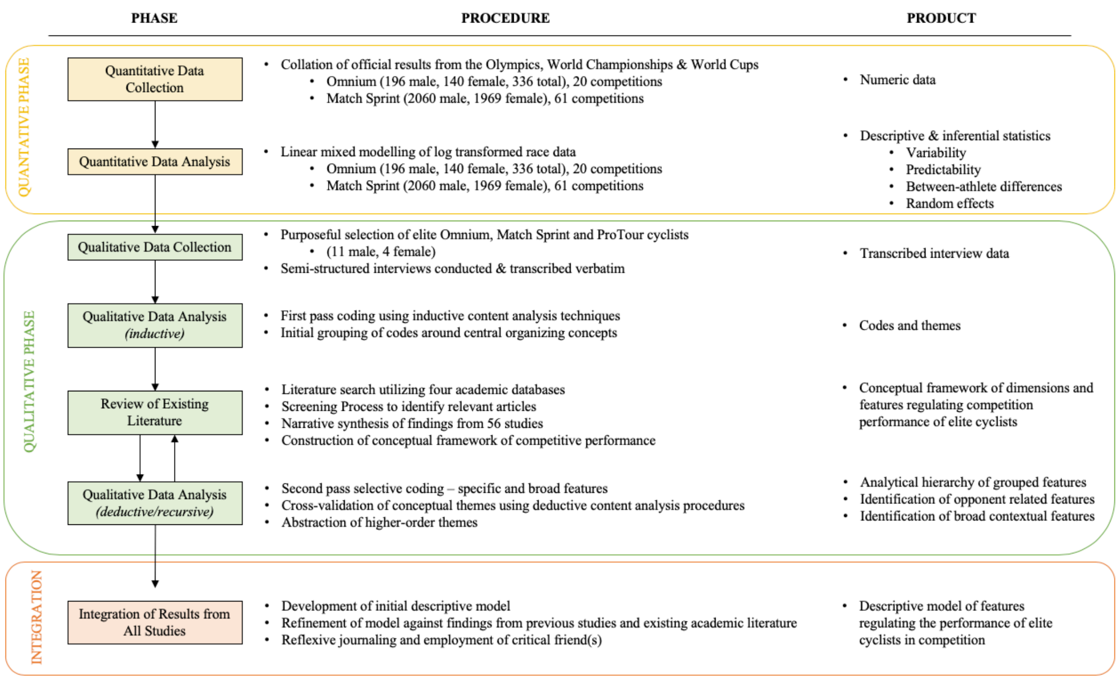

Figure 1.1: Visual Representation of the Sequential Explanatory Mixed-Methods Design Used in This Thesis, Indicating the Procedures and Product of Each Phase and the Sequence in Which They Were Undertaken. Adapted From Ivankova et al. [20]

In the qualitative phase of the project, I conducted and analysed the data from semi-structured interviews with 15 elite cyclists, to explore and explain the statistical results from the first phase of the thesis. Transcribed text of the interviews was first examined using inductive content analysis to construct initial codes and themes, which were then cross-validated with results from the systematic narrative review that forms Chapter 4. In this review, published findings on the determinants of cyclists' behaviours and chances of success in elite competition were collated and synthesised. Key findings were grouped and used to shape a conceptual framework of the determinants of performance. At this point of the PhD, I returned to the interview data, conducting a second pass of selective coding to identify the changes in the perceptions and practices of cyclists between solo time trials and race events, and to identify broader contextual features cyclists referred to in their discussions of performance. The process of abstracting the initial codes and themes into higher-order themes and dimensions was a recursive one, where I moved repeatedly through inductive analyses and deductive analyses until coherence was achieved between the data, the literature, and our interpretations. In Chapter 5, I have focused on the effects of interpersonal competition on cyclists' performances in racing events. Chapter 6 forms the integrative phase, where additional emergent themes identified in the second part of the thematic content analysis of the interviews are integrated with results from each prior study to propose an initial systems model of elite cycling performance, summarising the dimensions, features and mechanisms identified throughout this thesis. In order to enhance the quality and rigor of the developed model, I sought the perspectives of other skilled experts, who acted as 'critical friends' [43] to challenge the conceptual work and my interpretation of the data.

1.3.4 Scope of the Thesis

While the thesis is centred on examining the factors determining the performance of cyclists in elite competitions, there were limitations to the number of cycling disciplines that could be included. Three racing disciplines (Match Sprint, Omnium and ProTour cycling) were selected for several reasons. First, to answer the first research question, we required data from actual competitions that would enable us to examine how cyclists' performances changed between solo time-trials and more complex racing events. The Match Sprint and Omnium competitions provided a number of advantages: the cyclists are required to perform at least one solo time trial during the tournament and enter into competitive racing against one another; the tournaments occurred indoors on standardised tracks and across set racing distances; the race events in each of these disciplines provided a spectrum of complexity due to the number of opponents present in the race; and detailed race results were available in the public domain.

A database of ProTour results was collated during the course of the PhD, with the intent to include a quantitative analysis of predictability of the team performances that characterise this discipline. However, at that stage the first two quantitative analyses had already demonstrated that solo time-trial performance did not adequately explain performance in more-complex events, and I reasoned that my time would be better spent on the qualitative and integrative phases of the thesis. ProTour athletes were included into the qualitative phase to increase the relevance of the research findings beyond the specialised discipline of track cycling and to provide insights into yet another increase in complexity, as these events often incorporate over 100 competitors and include team components.

1.4 Thesis Structure

In this first chapter, the intent is to provide an overall understanding of the thesis, including the rationale and significance of the research, underlying theoretical framework, research objectives, and methodological approach. The subsequent chapters consist of published manuscripts (Chapters 2, 3 and 4), a manuscript submitted for publication (Chapter 5), and a manuscript in preparation for publication, awaiting feedback from 'critical friends' (Chapter 6). In keeping with the sequential explanatory design, the chapters are presented in the order in which they were undertaken, beginning with the quantitative phase, bridged by the review of literature and followed by the qualitative work. In Chapter 7 I provide a summary of the findings, the limitations of the work, and the key theoretical and applied contributions of the thesis. An overview of each chapter is presented in Figure 1.2.

CHAPTER ONE - INTRODUCTION

- **Rationale:** the importance of understanding what shapes the performance of elite cyclists in actual competition
- **Theoretical Framework:** paradigmatic assumptions, theoretical framework, methodology, scope of thesis
- **Thesis Structure:** overall sequence of studies

CHAPTER TWO - PERFORMANCE IN SOLO-TIMED AND MULTI-OPPONENT RACES

- **Published Paper:** Performance Relationships In Timed And Mass-start Events For Elite Omnium Cyclists.
- **Rationale:** exploring the extent to which solo performance transfers to performance in races against multiple opponents
- **Research Approach:** quantitative - linear mixed modelling of Omnium cyclists race results

CHAPTER THREE - PERFORMANCE IN SOLO-TIMED AND SINGLE-OPPONENT RACES

- **Published Paper:** Factors Affecting Cyclists' Chances of Success in Match-Sprint Tournaments.
- **Rationale:** to further understanding of the variability of elite performers competing against one opponent in a tournament setting
- **Research Approach:** quantitative - linear mixed modelling of Match Sprint cyclists racing results

CHAPTER FOUR - SYSTEMATIC NARRATIVE LITERATURE REVIEW

- **Published Paper:** Determinants of Cycling Performance: a Review of the Dimensions and Features Regulating Performance in Elite Cycling Competitions
- **Rationale:** to synthesize the existing academic literature exploring the determinants of cycling performance in actual competition
- **Research Approach:** systematic narrative review

CHAPTER FIVE – PERFORMANCE CHANGES IN THE PRESENCE OF OPPONENTS

- **Submitted Manuscript:** The Influence of Opponents in Elite Cycling Races: A Qualitative Analysis
- **Rationale:** to explore elite cyclists' perceptions of, and differences between, the factors determining success in solo-timed and racing events
- **Research Approach:** qualitative – semi-structured interviews & thematic analysis

CHAPTER SIX - THE INFLUENCE OF BROADER CONTEXTUAL FEATURES ON PERFORMANCE

- **Draft Manuscript:** An Empirical Study and Initial Systems Model of the Features Influencing Competition Performances of Elite Cyclists
- **Rationale:** to explore the features and dimensions athletes perceive to influence their chances of success in complex racing environments
- **Research Approach:** qualitative – semi-structured interviews & thematic analysis

CHAPTER SEVEN - DISCUSSION & CONCLUSIONS

- **Contribution to Field:** development of an initial systems model to describe breadth of factors determining the performances of elite cyclists in complex race events, and demonstrated potential of benefits of adopting mixed-methods approach to characterise performance in complex environments
- **Practical applications:** the descriptive model presents a more holistic understanding of the determinants of elite cycling performance in complex racing events that challenges traditional research and training paradigms and should promote those seeking to improve cyclist performance to:
  - *Better understand and mange the constraints on elite performers across multiple dimensions*
  - *Consider appropriate methods for improving a cyclist's skills, particularly in the domain of proficiency*
  - *Work in collaboration with experts in other disciplines in order to build a more nuanced understanding of sporting performance*

Figure 1.2: Overview of Thesis Structure, Outlined with Summary Titles and Detailing the Publication Status, Full Manuscript Title, Rationale, and Research Approach for Each Chapter.

CHAPTER 2:

PERFORMANCE IN SOLO-TIMED AND MULTI-OPPONENT RACES

This chapter comprises the following paper accepted for publication at International Journal of Sports Physiology and Performance: Phillips, K. E., & Hopkins, W. G. (2017). Performance relationships in timed and mass-start events for elite Omnium cyclists. *International Journal of Sports Physiology and Performance.* 12 (5). 628-633

2.1 Overview

Purpose To explore the extent to which factors that determine performance transfer within and between time-trial and mass-start events in the track-cycling Omnium. *Methods* Official finish rank in the three time-trial events, in the three mass-start events, and in the competition overall were collated in 20 international Omnium competitions between 2010 and 2014 for 196 male and 140 female cyclists. Linear mixed modelling of the log-transformed finish time for the time-trial events and of log-transformed finish rank for all events and final rank provided estimates of within-athlete race-to-race changes in performance and average between-athlete differences across a season. These estimates were converted to various correlations representing relationships within and between the various events and final rank. *Results* Intraclass correlation coefficients, representing race-to-race reproducibility of performance, were similar whether derived from finish rank or finish time for the time-trial events. Log-transformed finish ranks are therefore a suitable measure to assess and compare performance in time-trial and mass-start events. Omnium cyclists were more predictable in their performances from race-to-race in the timed events, while reduced predictability was observed in mass-start events. Inter-event correlations indicated stronger links in performance between the timed disciplines, while performance in any of the mass-start events had only a slight positive relationship with performance in the other mass-start events and little or no relationship with the timed events. *Conclusions* Further investigation is warranted to determine whether factors related to performance in mass-start events can be identified to improve reproducibility or whether variability in performance results from random chance.

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DECLARATION OF CO-AUTHORSHIP AND CO-CONTRIBUTION: PAPERS INCORPORATED IN THESIS

This declaration is to be completed for each conjointly authored publication and placed at the beginning of the thesis chapter in which the publication appears.

1. PUBLICATION DETAILS (to be completed by the candidate)

Title of Paper: Performance Relationships in Timed and Mass Start Events for Elite Omnium Cyclists

Surname: Phillips | First name: Kathryn

Institute: Institute for Health and Sport | Candidate's Contribution (%): 85

Status:

Accepted and in press: ☐ Date:

Published: ☑ Date: Jan 2017

2. CANDIDATE DECLARATION

I declare that the publication above meets the requirements to be included in the thesis as outlined in the HDR Policy and related Procedures – policy.vu.edu.au.

[redacted] | 14/07/2020

Signature **Date**

3. CO-AUTHOR(S) DECLARATION

In the case of the above publication, the following authors contributed to the work as follows:

The undersigned certify that:

1. They meet criteria for authorship in that they have participated in the conception, execution or interpretation of at least that part of the publication in their field of expertise;

2. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

3. There are no other authors of the publication according to these criteria;

4. Potential conflicts of interest have been disclosed to a) granting bodies, b) the editor or publisher of journals or other publications, and c) the head of the responsible academic unit; and

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2.2 Introduction

Researchers have predominantly adopted a reductionist approach to explore the factors related to achieving success in cycling, isolating and testing the components of performance in simplified environments (lab-based tests or time-trial disciplines) in order to reduce the influence of confounding variables [44–46]. The majority of cycling events on the UCI international race calendar are mass-start events, but there is limited understanding of how the factors known to contribute to cycling performance in time-trial or lab-based tests transfer to performance in mass-start cycling [5–8]. Unlike time-based events in which athletes compete independently to complete the race-distance in the shortest possible time, in mass-start racing the time taken to complete the race distance is inconsequential; rather, all competitors start *en masse* with the goal simply being to better your opponents. The complexity of mass-start events, characterised in particular by the direct interaction permitted between opponents, results in behavioural dynamics not evident in time-trials as riders adapt to the actions of their opponents and the changing structure of the race environment [1–3].

Establishing the variability in performance of elite athletes from competition to competition is important in order to provide thresholds for assessing the effects of changes in performance [47]. Comparing measures of variability shown by elite performers in differing events can also provide insights into the factors affecting performance, such as race dynamics, power output, environment, and skill [12]. While the variability shown by elite cyclists, and track cyclists in particular, has been reported for athletes competing in time-trial disciplines, the performance variability of cyclists competing in mass-start events has not been well established. Contrasting the variability shown by cyclists competing in mass-start events with that of the same cyclists competing in time-trial events should enable us to assess the extent to which factors contributing to performance transfer between the different race formats.

We present here the relationships in elite cyclists performance in the six events and overall competition of the track-cycling Omnium. This Olympic discipline provides a natural platform from which to compare cycling performance across time-trial and mass-start events. In an Omnium competition up to 24 riders compete in six track events across two days, with riders awarded points according to their finish rank in each event. Of the six events in which the riders compete, three events are time-focused (flying lap, individual pursuit, time-trial) and three are mass-start events (points race, scratch race, elimination). Our aim is to present statistical methods for assessing performance variability in sports with mass-start racing formats where finish rank is the only available measure of performance. Furthermore, by analysing the performance relationships within and between Omnium events we aim to identify the extent to which the factors that determine performance in one event transfer or predict performance in the others.

2.3 Methods

Official results of cyclists competing in UCI World Cup, World Championship, and Olympic Omnium competitions were collated across four racing seasons (2010-2014), incorporating the results of 336 riders (196 male, 140 female) in 20 elite international competitions. Due to rule changes by the UCI in 2010 and again in 2014 that altered the structure of the competition, only results from the 2010-2014 seasons have been included. In order to calculate within-athlete variability analyses were restricted to include only those athletes who had competed in more than one competition across a racing season. A season rank was generated for each athlete by combining their finish ranks in all events and competitions within a season. Male and female data were analysed separately.

Finish time for the time-trial events, finish rank for all events, and final rank were used to provide estimates of within-athlete race-to-race changes in performance and average between-athlete differences across a season. All data were log-transformed prior to analysis to more accurately reflect what occurs in elite athletic performance [48]. A mixed-linear modelling procedure (Proc Mixed) in the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC) was used to analyse the log-transformed data. Athlete identity and the residual were the only random effects in each model, to estimate respectively athlete ability and within-athlete variability from competition to competition. Competition identity was included as a fixed effect to adjust for any environmental effects in the analyses of time-trial times and for any differences in mean calibre of athlete in the analyses of ranks. Coefficients of variation were calculated to estimate the within-athlete race-to-race variability and between-athlete differences in mean rank (or time) across a season. Intraclass correlation coefficients (ICC) were calculated to indicate the predictability of athlete performance, determined from the variability an athlete showed in their performances across multiple competitions in a given season. Thresholds to evaluate the ICCs were set at 0.99, 0.90, 0.75, 0.50, and 0.20 to denote respectively, extremely high, very high, high, moderate, and low reliability [49].

Various correlation coefficients were generated to assess the relationships among the six events comprising the Omnium, and between these events and final rank. Observed correlations provided an indication of the relationships in any given competition, within-athlete correlations provided an indication of the relationships among events for any given athlete during a single competition, and between-athlete correlations provided an indication of whether athletes who on average performed strongly in certain events tended on average to also do well in other events across the season. The scale of magnitudes used to interpret population correlations (0.1 through 0.9 for small through extremely high [48]) does not apply to measures of competitive performance of solo athletes. However, the effect of linear covariates can be evaluated as the magnitude of the effect of a difference of 2 standard deviations (SD) of the covariate on the dependent variable [48]. The correlations between event finish rank and final rank were therefore converted to the effect of a 2-SD difference in event finish rank on final rank; the magnitude of the resulting difference in final rank was then interpreted using thresholds previously shown to be effective in evaluating differences between elite athletes: 0.3, 0.9, 1.6, 2.5, and 4.0 of the within-season race-to-race within-athlete log of the rank, denoting small, moderate, large, very large and extremely large changes respectively [12,48,50]. The magnitude of the correlations among the events could not be evaluated. To provide an indication of uncertainty in all estimates confidence limits were set at 90%.

The aim of the analyses was to investigate relationships between performance between events within and between competitions within a competitive season. To simplify what were already complex analyses, athletes who competed across multiple seasons were treated as independent individuals, and the relationships were investigated by pooling the data from all the seasons. The apparent number of athletes was therefore larger than the actual number, so confidence limits in ± form for between-subject CV and for correlations were adjusted by multiplying by √[(apparent number)/(true number)].

2.4 Results

The data presented in the following section are derived from analysis of the top-24 season-ranked cyclists. UCI regulations restrict the number of competitors in any given Omnium competition to a maximum of 24 riders, which also represents the cut-off point for qualification to the World Championships. This enabled us to derive estimates of variability that represented athletes with medal winning capability and reduce bias arising from inclusion of weaker athletes. The apparent numbers of male and female athletes in the analyses were 60 and 63 respectively, whereas the true numbers were 43 and 35. The correction factors applied to the confidence intervals provided by the mixed model were therefore 1.18 and 1.34 respectively. A comparison of within-athlete variability and intraclass correlation coefficients calculated using event finish rank or event finish time (time-trial events only) is shown in Table 2.1. Despite the marked difference in within-athlete variability across these two performance measures there was general agreement in the intraclass correlation coefficients within each event.

The race-to-race variability, between athlete-differences, and predictability in event finish rank and final rank for males and females are shown in Table 2.2. Both male and female athletes showed lower values of race-to-race variability, larger between-athlete differences, and higher values of predictability in the timed events in comparison to the mass-start events. Male athletes showed greater variability from race-to-race in final rank in comparison to the females, although only small differences were evident between the sexes in variability of event finish rank from race-to-race. For both males and females the largest between-athlete differences were observed in the individual pursuit, and the smallest in the scratch race. A slight negative CV in the scratch race amongst the women indicated no real differences between athletes in this event. The similarities in between-athlete differences in event finish rank between the sexes were not reflected in final rank, with between-athlete differences in final rank for the women greater than that of the men. Higher values of predictability were evident in event finish rank in the timed events in comparison to the mass-start events for both sexes. Despite no consistent differences in predictability observed between the sexes in event finish ranks, predictability in final rank was much higher for the women in comparison to the men.

Table 2.1: Comparison of Within-Athlete Variability (CV) and Intraclass Coefficient Coefficients (ICCs) Calculated Using Event-Finish Rank or Event-Finish Time for the Top 24 Season-Ranked Male and Female Omnium Athletes across Four International Racing Seasons (2010-2014) in the Time-Trial Events

Event	Coefficient of Variation (%)				Intraclass correlation coefficient			
	Men		Women		Men		Women	
	Rank	Time	Rank	Time	Rank	Time	Rank	Time
Flying Lap	68	1.6	72	1.8	.62	.73	.55	.76
Individual Pursuit	68	1.5	44	2.4	.65	.59	.82	.85
Time Trial	67	1.4	54	2.0	.61	.65	.73	.84

Note: 90 % confidence limits for CV of ranks: men, ±10-11 %; women, ±6-10 %. 90% confidence limits for CV of times: men, ±0.3-0.5 %; women, ±03-0.4 %. 90% confidence limits for ICC of ranks: men, ±0.13-0.14; women, ±0.08-0.16. 90% confidence limits for ICC of times: men, ±0.12-0.29; women, ±0.12-0.15

Table 2.2: Coefficient of Variation and Intraclass Correlation Coefficients in Finish Rank for the Top 24 Season-Ranked Male and Female Omnium Athletes (2010-2014), Indicating Variability and Predictability in Performance from Race-To-Race in Each of the Six Events Comprising the Omnium and in Final Rank

Event	Coefficient of variation				Intraclass correlation coefficient [c]	
	Within-athlete (%)[a]		Between-athlete (%)[b]			
	Men	Women	Men	Women	Men	Women
Time-trial						
Flying lap	68	72	94	83	0.62	0.55
Individual pursuit	68	44	102	118	0.65	0.82
Time-trial	67	54	90	104	0.61	0.73
Mass-start						
Points race	110	107	65	49	0.32	0.23
Elimination	94	87	70	89	0.39	0.51
Scratch race	112	136	32	-9	0.12	-0.01
Final Rank	109	64	50	99	0.23	0.66

Note: [a] 90% confidence limits: men, ±10 to ±19 %; women, ±6 to ±21 %. [b] 90% confidence limits: men, ±27 to ±40 %; women, ±28 to ±38 %. [c] 90% confidence limits: men, ±0.13 to ±0.18, women, ±0.08 to ±0.17

Relationships between the six events and final rank are presented in Table 2.3. The correlations representing the effect of a difference in event finish rank on final rank observed in any given competition ranged in magnitude from small to moderate in the men, and moderate to large in the women. The correlations among the six events observed in any given competition are not shown but ranged as follows: among the timed events, men 0.17 to 0.68, women 0.34 to 0.56; among the mass-start events, men 0.04 to 0.21, women -0.03 to 0.23; and between the timed and mass-start events, men -0.17 to 0.21, women -0.14 to 0.32. For both sexes the strongest positive correlations were found between the flying lap and the time trial (men 0.68, women 0.56), while the most negative correlations were between the points race and the flying lap for the men (-0.17), and between the points race and the time trial for the women (-0.14).

Table 2.3: Correlation Analysis Showing the Observed Effect of Event Finish Rank on Final Rank for the Top 24 Season-Ranked Male and Female Athletes in the Omnium

Gender	Correlation Between Final Rank and Event-Finish Rank					
	Time-trial			Mass-start		
	Flying Lap	Individual Pursuit	Time Trial	Points Race	Elimination	Scratch Race
Men	0.41 small	0.49 moderate	0.61 moderate	0.36 small	0.47 moderate	0.37 small
Women	0.66 large	0.73 large	0.46 moderate	0.36 moderate	0.62 large	0.47 moderate

Note: Uncertainty in all estimates in the order of ±0.18 - ±0.25

Table 2.4: Correlation Analysis of Final Rank and Event Finish Rank for the Top 24 Season-Ranked Male and Female Athletes in the Omnium, Showing the Effect of Finish Rank in Each of the Six Events on the Other Events and on Final Rank

	Time-trial			Mass-start			Final Rank (between)
	Flying Lap	Individual Pursuit	Time Trial	Points Race	Elimination	Scratch Race	
Men							
Time-trial							
Flying Lap		**0.22**	**0.78**	-0.26	0.18	-0.00	0.49
Individual Pursuit	**0.14**		**0.37**	0.20	-0.10	-0.02	0.53
Time Trial	**0.42**	**0.31**		-0.11	0.17	0.03	0.64
Mass-start							
Points Race	-0.04	0.12	0.10		**0.07**	**0.27**	0.33
Elimination	0.04	0.15	0.21	**0.22**		**-0.06**	0.41
Scratch Race	-0.05	0.07	0.19	**0.16**	**0.11**		0.29
Final Rank (within)	0.32	0.48	0.55	0.39	0.55	0.39	
Women							
Time-trial							
Flying Lap		**0.62**	**0.61**	-0.03	0.45	0.00	0.78
Individual Pursuit	**0.11**		**0.42**	0.39	0.52	0.00	0.82
Time Trial	**0.43**	**0.28**		-0.23	0.22	0.00	0.49
Mass-start							
Points Race	0.05	0.16	0.01		**0.31**	**0.00**	0.36
Elimination	0.15	0.07	0.03	**0.19**		**0.00**	0.77
Scratch Race	0.28	0.02	0.22	**-0.07**	**0.15**		0.00
Final Rank (within)	0.43	0.38	0.43	0.43	0.39	0.44	

Note: Values below the diagonal, in white, are for within-athlete comparisons; values above the diagonal, highlighted grey, are for between-athlete comparisons; bold factors are related to each other by event type, i.e., correlations between mass-start to mass-start and time-trial to time-trial events. Uncertainty in all estimates in the order of ±0.18 - ±0.25. Effect magnitudes of changes in within-athlete finish rank on final rank: men, small to moderate; women, all small. Effect magnitudes of changes in between-athlete finish rank on final rank: men, trivial to small; women, trivial and small to extremely large

What we have termed within-athlete correlations in Table 2.4 represent the extent to which a cyclist who performs better than their average in a given event also performs better in another event in the same competition. The correlations tended to be stronger amongst the timed events (men 0.14 to 0.42, women 0.11 to 0.43). Correlations among the mass-start events were lower (men 0.11 to 0.22, women -0.07 to 0.19) and not dissimilar from the correlations between timed and mass-start events (men -0.05 to 0.21, women 0.01 to 0.28). The strongest correlations within an athlete during a given competition were between the time-trial and the flying lap, and between the time-trial and individual pursuit for both sexes.

The between-athlete correlations in Table 2.4 show that across a season athletes who tended to finish well on average in one timed event also tended to do well in the other timed events (men 0.22 to 0.78, women 0.42 to 0.62). Among the mass-start events, the correlations were lower (men -0.06 to 0.27, women 0.00 to 0.31). Between mass-start and timed events correlations were low for the men, while for the women, moderate relationships were observed between the elimination and the flying lap and between the elimination and the individual pursuit. Women tended to show higher correlations between event finish rank and final rank than men, except in the scratch race, where no stable differences between female athletes were observed. The magnitude of a change in event finish rank on final rank between opponents ranged from trivial to small in the men, and small to large in women.

2.5 Discussion

The values of race-to-race variability of athlete performance in the current study, calculated using log of the rank for both timed and mass-start disciplines, are much larger than those previously reported for cyclists, which have ranged from 0.3% to 2.9% using time as the performance measure (reviewed by Malcata and Hopkins [12]). In order to provide an effective comparison with previous research the variability of the Omnium athletes was also calculated using event finish time for the three timed disciplines and these values were consistent with those previously reported for track cyclists in time-trial events [14,15]. The high values of within-athlete variability arise from our use of rank as the measure of performance, rather than the usual measures of time, distance, or weight. For example, 100% variability in rank for an athlete in the individual pursuit is equivalent to a doubling or halving of their finish rank from one competition to the next, such as a change from 10th to 5th place. In this example, while the finish rank has halved the corresponding difference in performance time would be at most only a few percent. In order to evaluate the effectiveness of log of the rank as a performance measure, intraclass correlation coefficients (ICC) derived using event finish rank and finish time were compared (Table 2.1). The differences in the ICCs were smaller than the differences in the thresholds for interpreting the magnitude of ICCs. Therefore, the general agreement between measures gave us confidence that the log of the rank provided a trustworthy measure through which to evaluate the variability shown in cyclists' performances in mass-start events. A number of studies of the Omnium and of other sports events have used competition finish rank as the dependent variable to model the performance of athletes, although to the best of our knowledge none has evaluated performance using log of the rank [51–56].

The greater race-to-race variability observed in the mass-start events of the Omnium reflects those previously reported for athletes in other sports characterised by this racing format. Of the studies reviewed by Malcata and Hopkins [12], those conducted on sports with mass-start race formats (track athletics, mountain biking, road cycling, triathlon), showed slightly greater performance variability in finish time on average than those of sports with time-based competition formats (canoe-slalom, canoe-sprint, rowing, skeleton, speed skating, swimming, road cycling time-trial), averaging 1.5% and 1.0% respectively. Paton and Hopkins [15] are the only authors to present data showing an opposite trend, reporting lower values of performance variability for cyclists competing in road races (mass-start) in comparison to individual road time-trials (time-based). The lower variability observed in road-racing can be attributed to the use of finish time as the measure of performance and the bunch-race style that is prevalent, where riders work together to benefit from the drafting effects of riding as a group. Bunch-racing was thought to have an averaging effect on the finish times, with riders that finished in the same bunch awarded the same time, resulting in lower values of variability.

Between-athlete differences provide an indication of the dispersion of performances between athletes, with the smaller between-athlete differences in the final rank of the male athletes suggesting a higher level of competitiveness amongst male athletes in comparison to the women. When the spread of competitive ability between athletes is small, slight variations in performance from one competition to the next are more likely to result in an altered finish rank. Across the six events only minor differences were observed between the sexes, except in the scratch race, where for the females no stable differences between-athletes were observed. For men and women, larger between-athlete differences were evident in the timed events in comparison to the mass-start events, indicating it is easier to discern stable differences in the abilities of athletes across a season in the events in which riders compete individually for the best time.

Measures of predictability (ICC) in the current study indicate that Omnium athletes were more predictable in their performances from race-to-race in the timed events, with the highest values of predictability shown in the individual pursuit and the lowest in the scratch race for both men and women. It is worth noting that the predictability of performance in the mass-start events is not zero, which indicates there is some reproducibility shown by cyclists in these events. Although all events showed relatively similar predictability between the sexes, females were more predictable in final rank from race-to-race in comparison to the men. A tendency for the same females to perform better on average across the events from one competition to the next compared with the men could explain this difference. Such a tendency is apparent in Table 2.4, where the females showed overall higher between-athlete correlations between events and between events and final rank.

Owing to the structure of the scoring system of the Omnium, the relatively similar correlations between final rank and finish rank in each of the six events shown in Table 2.3 is to be expected, as an athlete's final rank is simply the sum of their finish rank in each of the six events. Our observations of the inter-relationships between the six events presented in this table reflect those previously reported by Ofoghi and colleagues [53,56]. Between the six events, those considered by Ofoghi et al., to have similar physiological demands showed the strongest relationships, with the highest correlations between those events requiring sprint capacity (flying lap and time-trial), and between those events favouring endurance (points race and individual pursuit). For the males the scratch race was more strongly correlated with the endurance events, but for the females the scratch race correlated more strongly with the sprint events. The contrast between the sexes reflects the difference in racing styles of men and women at the international level. Scratch races amongst the men tend to be characterised by fast-paced racing with many breakaway attempts, favouring riders with endurance capacity. In contrast women's races are frequently determined by a bunch sprint in the last few laps, which favours riders with strong sprint capacity (KEP, unpublished observations). The low (and sometimes negative) correlations observed between the sprint- and endurance-based events suggests some antagonism exists between the energy systems required for success in these events, where athletes strong in one may have compromised ability in the other.

A novel aspect of this study was the analysis that allowed us to dissect the usual observed correlations between event rank and finish rank into more meaningful within- and between-athlete correlations, as shown in Table 2.4. The within-athlete correlations represent the extent to which a strong performance on any given day in a particular event influenced performance in the other events and in the final rank in that competition. There were stronger links in performance between the timed disciplines for both the men and the women. Performance in any of the mass-start events had only a slight positive relationship with performance in the other mass-start events and little or no relationship with the timed events. In summary, an athlete's form on the day transfers only between the timed events, and therefore the factors that contributed to success in one mass-start event on the day had little contribution to the other events.

The between-athlete correlations in Table 2.4 represent the extent to which an athlete who is consistently well ranked in a given event across a season tended to be well ranked in any of the other events. The patterns were similar to those for the within-athlete correlations, except that the relationships among the timed events tended to be stronger, and for the women, performance in the elimination race showed some relationship with the timed events. Some elements required for performance must therefore transfer between the flying lap, individual pursuit, and elimination race, but otherwise the factors that determine consistent performance in the timed events appear to transfer minimally to the mass-start events. Factors that determine consistent performance in one mass-start event also transfer only minimally to the other mass-start events.

The lack of reproducibility in performance of riders in the mass-start events indicates either there is a large element of chance, or that differences in the race structure such as technical skill requirements, race distance, average speed, or pacing patterns between these events are too great to enable transferability of skills from one to the other. While the lack of transferability between mass-start events could be explained by these differences in race structure, the lack of reproducibility in performance in any particular mass-start event from competition to competition implies the factors that enable an athlete to perform well in one competition are not reproducible skills or abilities. Further research is required to explore what is contributing to the greater variability in mass-start racing.

2.6 Practical Applications

The performance relationships observed between the six disciplines of the track-cycling Omnium and final rank indicate a relatively even contribution of each event to success in the overall competition, requiring athletes to have both strong sprint and endurance capacities. Improving performance in one of the timed events will likely transfer to improvements in the other timed events (and in the elimination race for the females). It is difficult to provide advice on the mass-start events, as riders do not appear to be able to consistently execute the skills or abilities that enable a strong performance from one competition to the next. While our data update previous research, a rule change by the UCI in 2014 means that future analysis will need to address the impact of the new competition structure.

2.7 Conclusions

The reproducibility in performance for elite cyclists competing in the mass-start disciplines of the Omnium is notably lower than in the timed events. Further investigation is warranted to identify whether the lack of reproducibility results from inexorable chance or whether a better understanding of what appears to be random variability would lead to avenues for performance improvement.

CHAPTER 3:

PERFORMANCE IN SOLO-TIMED AND SINGLE-OPPONENT RACES

This chapter comprises the following paper accepted for publication at International Journal of Sports Physiology and Performance: Phillips, K. E., & Hopkins, W. G. (2019). Factors affecting cyclists' chances of success in match-sprint tournaments. *International Journal of Sports Physiology and Performance.* 14 (4). 472-477

3.1 Overview

Purpose: To further the understanding of elite athlete performance in complex race environments by examining the changes in cyclists' performances between solo time trials and head-to-head racing in match-sprint tournaments. *Methods:* Analyses were derived from official results of cyclists in 61 elite international sprint tournaments (2000-2016), incorporating the results of 2060 male and 1969 female head-to-head match races. Linear mixed modelling of log-transformed qualification and finish ranks was used to determine estimates of performance predictability as intraclass correlation coefficients. Correlations between qualifying performance and final tournament rank were also calculated. Chances of winning head-to-head races were estimated adjusting for the difference in the cyclists' qualifying times. All effects were evaluated using magnitude-based inference. *Results:* Minor differences in predictability between qualification time-trial and final tournament rank were suggestive of more competitiveness amongst males in the overall tournament. Performance in the qualification time-trial was strongly correlated with, but not fully indicative of, performance in the overall tournament. Correspondingly, being the faster qualifier had a large positive effect on the chances of winning a head-to-head race, but small substantial differences between riders remained after adjustment for time-trial differentials. *Conclusions:* The present study provides further insight into how real-world competition data can be used to investigate elite-athlete performance in sports where athletes must directly interact with their opponents [57,58]. For elite match-sprint cyclists, qualifying time-trial performance largely determines success in the overall tournament, but there is evidence of a consistent match-race ability that modifies chances of winning head-to-head races.

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I declare that the publication above meets the requirements to be included in the thesis as outlined in the HDR Policy and related Procedures – policy.vu.edu.au.

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3. CO-AUTHOR(S) DECLARATION

In the case of the above publication, the following authors contributed to the work as follows:

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3.2 Introduction

> Skills and tactics play a much greater role in bicycle racing than is generally thought by those outside the sport… even a well-conditioned cyclist will not win if she can't employ a good racing strategy, execute timely tactics and have highly developed bike-handling skills and techniques. [59]

Sports performance research is focused on examining the relationships between attributes that contribute to or predict the overall performance of an athlete or team [60]. Researchers examining performance in elite cycling have predominantly focused on the parameters that influence performance when athletes are competing in the absence of opponents, such as individual time-trials [46,61,62]. While time-trials provide a useful format to investigate and understand the performance of the individual, in most cycling races athletes compete concurrently with their opponents and it is the first athlete to cross the line that wins, regardless of their finish time. The presence of opponents in a first-across-the-line race results in behavioural dynamics not evident in time-trial performances, as riders must constantly adapt to the actions of their opponents and the changing structure of the race environment [1–3,57,63]. Konings and Hettinga [57] demonstrated short-track speed skaters were making tactical pacing decisions in the presence of competitors, securing energetic advantages by adjusting position to draft behind opponents. The factors contributing to the performances of elite cyclists in race environments, including interactions between the cyclists, are not well understood.

In track cycling, match-sprint tournaments consist of a preliminary qualification time trial followed by rounds of head-to-head racing, with the winners of each race proceeding through knockout rounds to reach the final. The qualification time trial is used to seed the riders from fastest to slowest, with (typically) the fastest 24 riders qualifying for the match-race tournament. In qualification, riders complete a flying 200-m time trial, aiming to qualify for the tournament and secure a favourable seeding for the subsequent racing rounds. In the head-to-head races, athletes compete against each other over the 750-m race distance, with the win awarded to the athlete who crosses the finish line first and the winner proceeding through to the subsequent round.

While prior research has identified factors contributing to performance in the qualification time-trial [61,62,65], less is known regarding how these factors predict or transfer to performance in the head-to-head races of the match-sprint tournament. In order to examine the assertions that the fastest athlete does not always win [2,59], we present here a statistical analysis of the relationships between qualification time trial and head-to-head race performances of elite cyclists competing in match-sprint tournaments. Our aim was to further the understanding of elite athlete performance in complex race environments.

3.3 Methods

Official results of cyclists competing in UCI World Cup, World Championship, and Olympic match-sprint tournaments were collated across seventeen racing seasons (2000-2016), incorporating the results of 4029 sprint races (2060 male, 1969 female) in 61 elite international tournaments. Races involving more than two opponents (i.e., repecharges) and those races won or lost due to technicalities (relegation, disqualification) were excluded from the analysis. For all races in each tournament, opponent names, sprint round, individual qualifying times, difference in qualifying times between opponents and race outcome (win/loss) were recorded. Qualification rank and final rank were also recorded for each tournament, with analyses restricted to include only those cyclists who had competed in more than one tournament across a racing season and who had qualified for the head-to-head racing rounds. While upwards of sixty cyclists may enter a tournament, UCI regulations restrict the number of cyclists that qualify for the race rounds to (typically) the top-16 or top-24 based on their flying 200-m qualification times. Restricting our analyses to only include cyclists who had qualified for the match-racing component of the tournaments enabled us to derive estimates of variability that represent cyclists with the capability of competing in head-to-head races at the elite level. Data for males and females were analysed separately.

The first phase of the analysis focused on establishing the typical performance variability shown by elite sprint cyclists from tournament-to-tournament in order to estimate magnitude thresholds for changes in rank (needed in later analyses) and to explore the attributes that contribute to performance [12]. The benefit of using log-transformed performance ranks to assess and compare the variability in athlete performance across different racing modes has been shown previously, in a comparison of time-trial and mass-start race performances of elite omnium cyclists [58]. Estimates of within-athlete tournament-to-tournament changes in performance and average between-athlete differences across a season were calculated from log-transformed qualifying and finish rank data [48] with the mixed linear modelling procedure (Proc Mixed) in the Statistical Analysis System (version 9.4, SAS Institute, Cary, NC). Stable differences in cyclist ability over a season and within-athlete variability from tournament to tournament within the season were estimated, with cyclist identity and the residual as the only random effects in each model. Tournament identity was again included as a fixed effect to adjust for any differences in mean calibre of athlete between tournaments. The predictability of athlete performance was determined by calculating the intraclass correlation coefficient (ICC) representing the expected correlation between the ranks in any two tournaments in the season. Thresholds to evaluate the ICCs were set at 0.99, 0.90, 0.75, 0.50, and 0.20 to denote respectively, extremely high, very high, high, moderate, and low reliability [49].

Observed correlations provided an indication of the relationship between qualification rank and final tournament rank for the cyclists in any given tournament. The magnitudes of the correlations between qualification rank and final rank were assessed as the effect of a 2-SD difference in qualification rank on final rank [48]. The resulting difference in final rank was then interpreted using thresholds: 0.3, 0.9, 1.6, 2.5, and 4.0, which denote small, moderate, large, very large and extremely large differences respectively [12,48,50,58]. To provide an indication of uncertainty in all estimates confidence limits were set at 90%. The observed correlations were initially dissected into within- and between-athlete correlations, as in our study of the relationship between events in the Omnium [58]. However, these correlations did not provide any further insight into the transferability of skill between the two elements of the tournament, due to their lack of independence.

In the final stage of analysis, logistic regression (Proc Glimmix in SAS) was used to examine the effect of the difference between opponent qualification times on the chances of winning a head-to-head race. The dependent variable was the win/loss outcome of each match. Fixed effects in the model were the difference in the log of the qualification time between the cyclist and their opponent (for the mean effect of the time difference), the calendar date of the tournament (to estimate and adjust for mean trend in improvement of performance), and a dummy variable representing riders competing in their home country or home continent (to estimate mean home-country or home-continent advantage; separate analyses). The effect of qualification time was back-transformed to a difference in chances of winning a close match [66], per percent difference in time, and per two standard deviations in time [67]. The effect of tournament experience was expressed as change in chances of winning after three years (almost exactly the mean time cyclists competed). Thresholds for small, moderate, large, very large and extremely large differences were set to 10, 30, 50, 70 and 90 %, or 1, 3, 5, 7 and 9 extra wins every 10 matches [66]. One set of random effects consisted of cyclist identity (to estimate each cyclist's mean match-sprint ability) and cyclist identity interacted with the difference in qualification time (to estimate individual differences in the effect of qualification time differential) and with a dummy variable representing important tournaments (Olympics and World Championships, to estimate individual differences in the effect of tournament prestige). These three effects had an unstructured covariance matrix, to allow for them to be correlated. A second set of uncorrelated random effects consisted of cyclist identity interacted with the following variables: tournament experience (to estimate individual differences in performance trend), season identity (to estimate consistent changes within cyclists between seasons), tournament identity (to estimate consistent changes within cyclists between tournaments), and dummy variables representing home-country and home-continent advantage (to estimate individual differences in these effects). The binomial residual variance allowed for over-dispersion. The random effects were expressed as standard deviations, doubled for assessment of their magnitude [50], then back-transformed to the difference in chances of winning a match.

3.4 Results

The within-athlete variability, between-athlete differences and intraclass correlation coefficients (predictability) in qualification time-trial and final tournament ranks of elite cyclists competing in match-sprint tournaments from 2000-2016 are presented in Table 3.1. Male cyclists showed lower values of variability, larger between-athlete differences, and higher values of predictability in their qualification rank in comparison to their final tournament rank. For the females, little difference was evident in these measures between qualification rank and final tournament rank. Between the sexes, females were slightly less variable, showed larger between athlete differences and slightly higher predictability in both qualification and final tournament ranks from tournament-to-tournament.

Table 3.1: Coefficient of Variation (% CV) and Intraclass Correlation Coefficients (ICC) in Qualification Rank and Final Tournament Rank for all Male and Female Match Sprint Cyclists that Qualified for the Racing Rounds (2000-2016)

	Within-athlete variation (%)		Between-athlete differences (%)		Intraclass correlation	
	Males	**Females**	**Males**	**Females**	**Males**	**Females**
Qualification rank	64	61	87	90	0.62	0.65
Final rank	74	60	77	92	0.51	0.66

Note: Variability and predictability in performance from tournament-to-tournament in qualification time-trial and final tournament rank are shown. Within-athlete variability, 90% confidence limits: men, ±9 %; women, ±10 %. Between-athlete differences, 90% confidence limits: men, ±5 %; women, ±4 %. Intraclass correlation coefficients, 90% confidence limits: men, ±0.05, women, ±0.04

The observed correlations between qualification and tournament finish rank were 0.76 for both males and females. The magnitudes of these correlations, assessed as the effect of a 2SD change, indicated a change in qualification rank had a large effect on final tournament rank in any given tournament for males and females.

Table 3.2 shows that having a faster qualifying time than your opponent in the head-to-head racing rounds had a very large effect on the outcome of a head-to-head race, when evaluated for 2SD of the difference in qualifying time. The table also shows the extra chances of winning for 1% step changes in the difference in qualifying times, to illustrate that even a 1% difference had a small but most likely substantial effect on chances of winning. The random effects representing individual differences in the effect of being the faster qualifier were also examined, but there were trivial individual differences for both male and female cyclists (Table 3.3).

Race experience at the international level did not appear to improve a cyclist's chances of winning a match: over the mean of three years that cyclists competed at World-Cup level and above, there were only trivial changes in the chances of winning an extra match (mean, ±90% confidence limits: males -0.3, ±3.4 %, most likely trivial; females 7.2, ±4.7 %, likely trivial). There were small individual differences in the effect of race experience between cyclists for both sexes (Table 3.3). Racing on a home country track or within their continent did not appear on average to improve a cyclist's chances of winning a match (mean, ±90% confidence limits: home country, males -0.8, ±9.3 %, likely trivial; females -2.1, ±11.7 %, likely trivial; home continent, males 1.2, ±6.3 %, very likely trivial; females 3.0, ±8.5 %, likely trivial). There were large individual differences in the effect of home-country advantage for the males and moderate differences in the effect of home-continent advantage. For the females these effects were unclear, but the observed magnitudes were moderate (Table 3.3).

Table 3.2: The Effect of Being the Faster Qualifier in a Head-to-Head Race on the Outcome of the Head-to-Head Race Expressed as the Extra Chances (%, With ±90% CL) of Winning the Race, for Male and Female Sprint Cyclists (2000-2016).

	1% faster	2% faster	3% faster	4% faster	2 SD faster
Males	25, ±1 ^{S}	48, ±2 ^{M}	65, ±3 ^{L}	78, ±2 ^{VL}	73, ±3 ^{VL}
Females	20, ±1 ^{S}	39, ±2 ^{M}	55, ±2 ^{L}	68, ±2 ^{L}	78, ±3 ^{VL}

Abbreviation: CL, confidence limits. Note: The smallest important effect is 10%, or 1 extra win in every 10 races. 2SD faster was 3.7% and 5.2% for males and females respectively. Effect magnitudes: ^{S}small, ^{M}moderate, ^{L}large, ^{VL}very large. All effects were most likely substantial.

Table 3.3: Random Effects Representing Individual Differences or Changes in the Increased Chances (%, With ±90% CL) of Winning a Head-To-Head Race in a Close Match of Elite Male and Female Match-Sprint Cyclists in Tournaments From 2000-2016

Individual differences or changes	Males	Females
Differences in being 2SD faster in qualification	9, (-3, 13) ^{T}	6, (-4, 9) ^{T}
Differences in 3-y trend of race experience	13, (-10, 21) ^{S}	21, (-6, 30) ^{S}
Differences in home-country advantage	55, (22, 69) ^{L}	47, (-41, 68)
Differences in home-continent advantage	35, (-7, 48) ^{M}	40, (-22, 57)
Differences in important-tournament advantage	8, (-21, 23)	28, (8, 37) ^{S}
Within-athlete between-season changes	0, (-24, 4) ^{T}	25, (14, 32) ^{S}
Within-athlete between-tournament changes	39, (33, 43) ^{M}	40, (33, 45) ^{M}
Remaining individual differences *(match-race ability)*	24, (17, 29) ^{S}	32, (23, 39) ^{M}

Abbreviation: CL, confidence limits. Note: Data were derived by back-transforming twice the SD representing the random effect in logistic regression analysis of win/loss outcome of the races. The smallest important effect is 10%, or 1 extra win in every 10 matches. Magnitudes of clear effects: ^{T}trivial, ^{S}small, ^{M}moderate, ^{L}large.

Small individual differences in the effect of tournament importance on chances of success in head-to-head racing were evident amongst the females (Table 3.3). The individual differences for males were unclear, but the confidence limits indicate that the magnitude could be small and similar to those for the females. Table 3.3 also shows random effects representing individual differences in within-athlete season-to-season and tournament-to-tournament changes in chances of success in head-to-head racing. The between-season changes were small for the females; amongst the males a negative variance was observed, but the confidence interval was consistent with trivial changes. There were moderate individual differences in tournament-to-tournament changes for both sexes. Even after adjustment for fixed and random effects, consistent individual differences were observed between riders in their chances of success. These remaining individual differences are likely indicative of cyclists' match racing abilities and were small in magnitude for the males and borderline small-moderate for the females.

The random effect solutions representing the individual differences in riders' match-race ability across the last three racing seasons (2013/14 to 2015/16) are presented in Table 3.4, indicating the five riders in each sex with the best match-race ability scores. The majority of the cyclists had match-racing ability equivalent to only a trivial effect on winning head-to-head races, but for most of these riders the confidence limits showed that their ability was unclear.

Table 3.4: Match-Race Ability of Individual Riders Derived From the Random Effect Representing Remaining Individual Differences for Male and Female Sprint Cyclists

Top 5 males	Country	Ability %, ±CL	Top 5 females	Country	Ability %, ±CL
Dmitriev	Russia	26, ±15 ^{S}	Vogel	Germany	53, ±23 ^{M}
Kenny	Great Britain	24, ±16 ^{S}	Junhong	China	43, ±25 ^{M}
Levy	Germany	21, ±17 ^{S}	Clair	France	38, ±33 ^{M}
Puerta Z.	Colombia	15, ±17 ^{S}	Lee	Hong Kong	30, ±22 ^{M}
Constable	Australia	13, ±20 ^{S}	Voinova	Russia	26, ±25 ^{S}

Abbreviation: CL, confidence limits. Note: Values are expressed as extra chances (%, with ±90% confidence limits) of winning a head-to-head race in a close match, showing the five best riders across the last three seasons in our data set (2013/14 to 2015/16), where the smallest important effect is 10%, or 1 extra win in every 10 matches. Effect magnitudes: ^{T} trivial, ^{S} small, ^{M} moderate, ^{L} large, ^{VL} very large

3.5 Discussion

3.5.1 Performance Variability

The current study builds on recent research investigating the performance of elite athletes in complex race environments [57,58]. The variability and predictability shown by match-sprint cyclists were of a similar magnitude to those of omnium cyclists, where log-transformed ranks were also used as the performance measure [58]. Across the two studies, there was general agreement in measures of performance variability for cyclists competing in the flying 200-m (sprint) and flying 250-m (omnium) time-trials, providing further evidence of the effectiveness of using log-transformed performance ranks to assess elite athlete performance [58,68]. Log-transformed rank data are particularly useful when researchers wish to compare performances of elite athletes across events, disciplines or codes with differing race structure (e.g., time-trial vs mass-start).

The use of log-transformed rank data enabled us to compare the performances of match-sprint cyclists in the qualification time-trial with performance in the overall tournament. The within-athlete race-to-race variability, between-athlete differences and predictability of qualification time-trial performances were relatively similar for males and females. In their final tournament rankings, males showed greater variability, smaller between athlete differences and reduced predictability compared with the qualification time trial. The greater variability and the smaller between-athlete differences both contribute to the reduced predictability and indicate a higher level of competitiveness in the match-racing component of the tournament. There were negligible differences between qualification time trial and final tournament rankings for the females, resulting in females having higher predictability (less competitiveness) than the males in the final tournament ranking. This finding regarding less competitiveness in females echoes previous research in skeleton, weightlifting, cross-country skiing, mountain biking and track cycling [12,15,51,58].

3.5.2 Effect of Qualification Time Trial on Match-Sprint Racing

The magnitudes of the observed correlations indicate that performance in the qualifying time-trial has a large effect on success in the overall match sprint tournament, although the less than perfect correlations indicate time-trial performance is not fully predictive of final tournament ranking. The format of match sprint tournaments likely contributes to the strength of the observed correlations, with the race draw affording the faster qualifiers an advantage by matching them against slower qualifiers in the initial rounds of head-to-head racing [63]. The elimination of losing riders from the tournament after the first round of racing likely also contributes to these relationships. To account for the effect of qualification position on final tournament rank, logistic regression analyses were used to examine the effect of the difference in opponent qualifying times on the win/loss outcomes of match races.

For male and female match-sprinters, being the faster qualifier strongly increased a cyclist's chances of winning head-to-head races. The high reliability of the qualification time trial indicates that a rider who qualifies faster than their opponent is indeed the faster rider in most head-to-head races. Individual differences in the effect of being the faster qualifier on chances of winning (Table 3.3) were trivial (although for the males, the upper confidence limit was small), indicating that most riders were able to capitalise on the speed differential between riders to the same extent during head-to-head match races.

3.5.3 Other Factors Affecting the Match Sprint

The final stage of analysis enabled us to adjust for the difference in opponent qualifying times and estimate the effect of other factors on the outcome of match sprint races. A cyclist's chances of winning a match race did not appear to improve with increased years of race experience at international level, with a trivial effect observed for both men and women. As it is only the top-24 ranked cyclists (or fewer) following the qualification time-trial who make the cut-off for the race rounds at elite tournaments, cyclists must already be of a certain calibre to qualify for the match-sprint racing. This result reflects a similar finding amongst elite tennis players, where years at the elite level also appeared to have a trivial effect on match outcome [69]. In both instances, qualifying for the tournaments evidently requires athletes to be of a high performance standard before the first match is even played. These results highlight the potential importance of pre-elite developmental years for the development of skills and attributes necessary to compete successfully in head-to-head matches at the elite level [70]. The small individual differences in the effect of race experience for males and females suggest some riders (the up-and-comers) are able to capitalise on their years of race experience to improve their chances of success, while for others (in the twilight of their careers) it appears to reduce their chances.

While the overall effect of tournament location (home country and home continent) was trivial for both sexes, amongst the male cyclists the large individual differences in home-country advantage and moderate differences in home-continent advantage indicate some male cyclists benefit from competing closer to home. These differences were unclear amongst the females, but the moderate observed effects indicate competing in their home-country or home-continent may still provide an advantage for some cyclists. Ovaska and Sumell (2014) found higher ranked tennis players had an advantage when playing at home, noting that the advantage was magnified during close matches at the most prestigious tennis tournaments. The authors concluded that home advantage was greatest when the pressure and rewards of winning a match were high, highlighting a supportive crowd, lack of travel fatigue, acclimatisation and familiarity with the environment as potential mechanisms for the improved performances [71].

The small individual differences in the effect of tournament importance on winning head-to-head races in the women (and potentially in the men) may reflect behavioural and cognitive changes shown to occur in elite performers when the stakes are high [72]. Tennis and chess players have been shown to make strategic decisions regarding their level of effort and risk tolerance according to the expected payoff of winning a match [71,72]. Gonzalez-Diaz and Palacios-Huerta (2016) found the cognitive load on chess players increases at the most prestigious chess tournaments, allowing differences in the cognitive abilities of players to become more evident. These cognitive changes are likely connected to the phenomenon of *choking,* where, given their typical level of expertise, individuals perform more poorly than expected in high pressure situations [73]. In this way, tournament importance appears to be affecting the behaviour of some elite cyclists, likely reflecting changes in cognitive load and skill execution under pressure.

The moderate differences observed between cyclists in their consistent changes in performance from one tournament to the next suggest factors specific to the cyclist at the time of the tournament and to each tournament itself affect the cyclist's chances of winning head-to-head races. Periodisation, used by some athletes to vary the structure of training across a season, with the objective of achieving peak performances at predetermined competitions[74] (usually the World Championships or Olympic Games) could explain these differences. Factors shown to affect match outcomes in other sports may also be affecting cyclists' chances of winning races, including momentum (that in a best-of-three contest the player who wins the previous match will be more likely to win the subsequent match)[69,75], and *palmarès* (record of previous achievements) [69,71]. It may also be that some athletes are able to find a winning strategy or tactic for use at a particular tournament that is less effective at a subsequent tournament due to diminishing returns [76].

The random effect for within-athlete between-season changes is a standard deviation representing the extent to which individual cyclists have good seasons and bad seasons. The standard deviation for the males is negative, but its upper confidence limit indicates that the males changed little from season to season. The females, on the other hand, showed clear small changes from season to season. The stronger competitiveness in the men's field, when combined with the qualification cut-off, implies that a male cyclist having a poor season is more likely to miss the cut and would therefore be excluded from the analysis, giving a biased indication of their seasonal changes in performance. Conversely, because the women's field is less competitive and the between-athlete differences are larger, a female must have a relatively poorer season before she no longer makes the cut for the match racing. The within-athlete between season changes in this sense are probably another manifestation of competitiveness.

The small consistent differences observed between riders after adjustment for random and fixed effects indicates some cyclists have a remaining ability that improves their chances of winning head-to-head races. This 'match-race ability' must reflect the strategic, technical and tactical abilities of these cyclists. Throughout a head-to-head race riders must constantly adapt to the movements and actions of their opponents [77], making tactical decisions under time pressure [60] and manoeuvring at high speed. Previous statistical models have identified the influence of optimal positioning and speed on the probability of winning head-to-head match-sprint races, and the authors have emphasised the independent nature of optimal tactics (i.e., a tactic that is successful for one rider may not be optimal for another) [77]. In match-sprint cycling, some riders are better able to harness these additional elements of performance (whatever they may be) and increase their chances of success during head-to-head match-sprint races.

3.6 Practical Applications

A cyclist's overall performance in a match sprint tournament is largely shaped by their performance in the qualifying time-trial, but additional elements affect the overall outcome of a tournament by modifying cyclists' chances of winning head-to-head matches. Practitioners should consider the factors that contribute to performance in the head-to-head racing rounds, for example by identifying the cyclists who show the highest levels of match-race ability (Table 3.4) and reviewing their match races. Whether their skills and attributes could be instilled into the cyclists with poor match-race ability or whether they need to be developed prior to cyclists reaching the elite level are issues for further investigation.

3.7 Conclusions

The present study provides insights into how real-world competition data can be used to examine the performances of elite athletes, particularly in sports where athletes must directly interact with their opponents [57,58]. In match-sprint cycling, qualifying time-trial performance largely determines success in head-to-head match-sprinting, but there is evidence of other factors that modify chances of winning head-to-head matches, including consistent match-race ability. Identifying and training the attributes contributing to this ability provides a potential avenue for performance enhancement.

CHAPTER 4:

SYSTEMATIC NARRATIVE LITERATURE REVIEW

This chapter comprises the following paper accepted for publication at Sports Medicine Open: Phillips, K. E., & Hopkins, W. G. (2020). Determinants of Cycling Performance: a Review of the Dimensions and Features Regulating Performance in Elite Cycling Competitions**.** *Sports Medicine Open.* 6 (23), 1-18

4.1 Overview

Background A key tenet of sports performance research is to provide coaches and athletes with information to inform better practice, yet the determinants of athletic performance in actual competition remain an under-examined and under-theorised field. In cycling, the effects of contextual factors, presence of and interaction with opponents, environmental conditions, competition structure, and socio-cultural, economic and authoritarian mechanisms on the performance of cyclists are not well understood. *Objectives* To synthesise published findings on the determinants of cyclists' behaviours and chances of success in elite competition. *Methods* Four academic databases were searched for peer-reviewed articles. A total of 44 original research articles and 12 reviews met the inclusion criteria. Key findings were grouped and used to shape a conceptual framework of the determinants of performance. *Results* The determinants of cycling performance were grouped into four dimensions: features related to the individual cyclist, tactical features emerging from the inter-personal dynamics between cyclists, strategic features related to competition format and the race environment, and global features related to societal and organisational constraints. Interactions between these features were also found to shape cyclists' behaviours and chances of success. *Conclusion* Team managers, coaches, and athletes seeking to improve performance should give attention to features related not only to the individual performer, but also to features of the interpersonal, strategic, global dimensions and their interactions.

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This declaration is to be completed for each conjointly authored publication and placed at the beginning of the thesis chapter in which the publication appears.

1. PUBLICATION DETAILS (to be completed by the candidate)

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2. CANDIDATE DECLARATION

I declare that the publication above meets the requirements to be included in the thesis as outlined in the HDR Policy and related Procedures – policy.vu.edu.au.

Signature	Date
[redacted]	14/07/2020

3. CO-AUTHOR(S) DECLARATION

In the case of the above publication, the following authors contributed to the work as follows:

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2. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

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Name(s) of Co-Author(s)	Contribution (%)	Nature of Contribution	Signature	Date
Professor William G. Hopkins	10	Review of manuscript, critique of synthesis, and review of theoretical underpinnings	[redacted]	14/07/2020

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4.2 Introduction

The focus of sports performance research is to provide coaches and athletes with information to inform better practice, yet the dimensions and features shaping the performances of elite athletes in actual competitions remain under-examined and under-theorised [52,78]. In elite cycling, the factors related to achieving success have been investigated predominantly using the traditional reductionist paradigm, where components of performance are isolated and examined in laboratories or solo time trials in order to reduce the influence of confounding variables. The physiological, biomechanical, nutritional, aerodynamic and physical components of elite cycling performance have all been examined from this perspective [44–46,79]. These investigations have identified an extensive number of features governing the performance of individual cyclists, but the interplay between these features is not well understood, and there is still a limited understanding of how cyclists regulate their behaviour in competitive performance environments [5,7,8,80].

In elite cycling, which we define as competitions sanctioned by the UCI, the majority of competitions are race events, where opponents compete simultaneously to be first across the finish line. Characterised by the direct interaction permitted between opponents, race events can range from one-versus-one to mass-start contests and are found in most cycling disciplines (road, track, BMX, cyclo-cross, and mountain biking). The proximity of opponents in racing contests results in behavioural dynamics not evident in solo performances, as riders constantly adapt to the actions of their opponents and the changing structure of the race environment [1–3]. The contextual, temporal and spatial parameters shaping athlete behaviour must be better understood if we are to further our knowledge of the determinants of cycling performance in race events.

In recent decades there has been an increased recognition of the complex interplay between features regulating an athlete's competitive performance and a call for research that takes an integrated approach to the study of athlete behaviour [16,39,81,82]. Seifert and colleagues [16] argued for the need to study athlete behaviour at different levels of analysis, recognising athletes as complex adaptive systems whose behaviour is governed by their interaction with opponents, teammates, and the specific constraints of the performance context. The aim of the current project was to synthesise findings from existing academic literature to build an integrated understanding of the dimensions and features underpinning cyclists' behaviours and chances of success in elite racing.

In the interest of reflexivity (transparency about the perspectives of the authors), the primary author worked within a national elite cycling program for close to a decade. Her experience of the limitations of the existing scientific literature in addressing the complex interrelatedness of elite performance helped shape the design of this study and elements of the interpretation. Professional experience and knowledge provides a valuable lens through which to examine the research [83], and narrative synthesis enables a wide range of research to be systematically reviewed and synthesised [84]. Her co-author has more than 20 years of experience with quantitative assessment of athletic performance.

4.3 Methods

4.3.1 Literature Search

Four academic databases (PubMed, ScienceDirect, SPORTDiscus, Google Scholar) were searched for peer-reviewed articles related to the study of cycling performance in elite competition. Search terms initially included combinations of the following keywords: athlete, bicycling, competition, contest, elite cycling, performance, peloton, professional cycling, road racing, and track cycling. Using the reference lists of these primary identified articles, an additional snowball search was conducted, with further database searches conducted using additional search terms and highly relevant articles added [30]. The terms added were: BMX, cyclo-cross, Giro de Italia, Grand Tour, mountain-biking, road cycling, time-trial, Tour de France, world class, and Vuelta a España. Following this widened search, the titles and abstracts of all articles were reviewed, duplicates removed, and 139 papers identified for potential inclusion.

4.3.2 Inclusion Criteria

Research articles had to meet the following criteria to be eligible for inclusion: analyses were of cyclists at the elite level (those who had performed in competitions sanctioned by the UCI); authors sought to identify and explain the determinants of performance in actual competitions; and articles were published in peer-reviewed journal or books in English with full text available. In total 44 original research and 12 reviews met the inclusion criteria. Of the excluded publications, 41 articles did not examine performance in elite competition, seven were modelling or mathematics papers that were highly theoretical and focused only on the optimisation of time-trial performance; and a further 37 descriptive studies were excluded, as no links were made between the findings and race outcome or chances of success. The studies selected for final inclusion incorporated research with mathematical, physiological, psychological, sociological, management, economic and game theoretical approaches. Thirty-seven research articles focused on the performance of elite cyclists in professional road racing, with a further nine articles focused on track cycling, three on mountain biking, one on cyclo-cross, and six articles examined a mix of cycling disciplines (see Figure 4.1).

4.3.3 Data Extraction and Study Interpretation

A narrative synthesis approach was taken to systematically review the included articles, as this allowed synthesis of findings from multiple studies with considerable heterogeneity in their methods, participants, cycling discipline and theoretical underpinnings. In a preliminary synthesis, the key characteristics of all relevant articles were captured, including: author(s), date, title, discipline of cycling, methodology, competition level, sample size, aim of study, variables used, key findings and conclusions. The key findings from the selected studies were then grouped according to the setting or context of the investigation and according to the nature of the feature(s) being reported (see Table 4.1). These groupings were used to construct a rubric that helped explain the determinants of cycling performance, as presented below. The relationships within and between these groupings were also explored. A standardised risk-of-bias assessment was unable to be conducted due to the heterogeneity in study designs across the included articles, but a critical review of methodological quality is addressed where necessary.

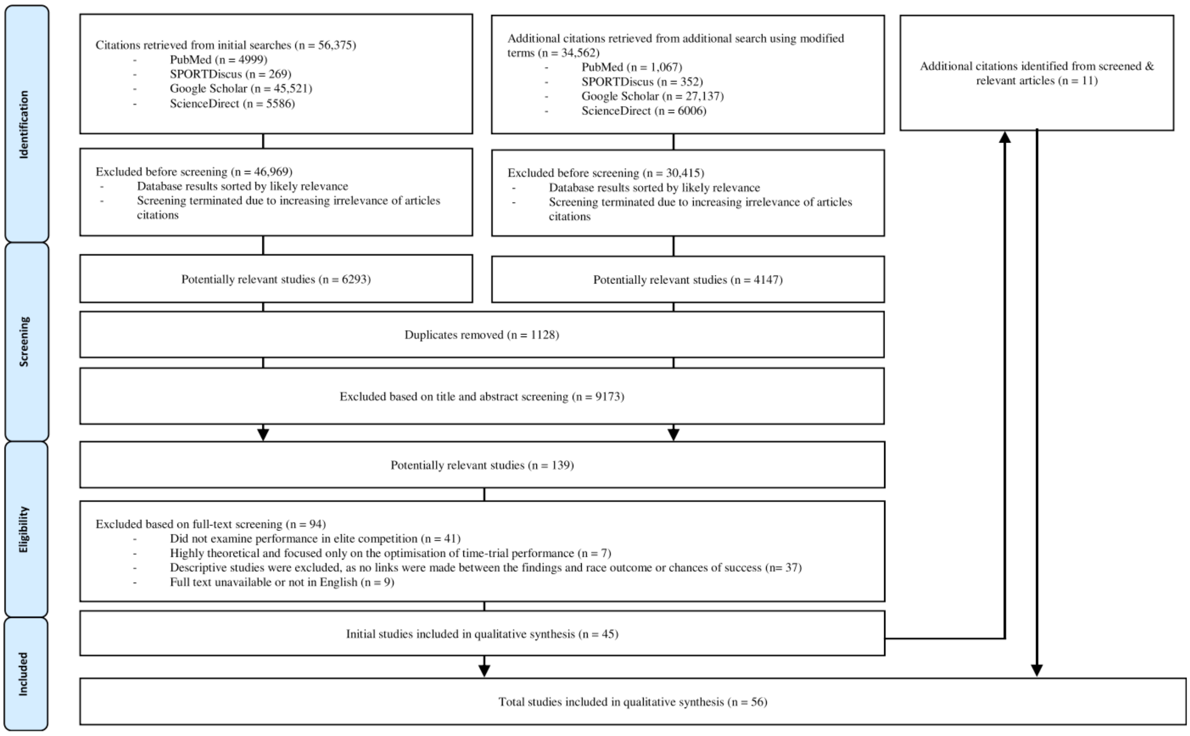

Figure 4.1: Flow Diagram of the Screening Process. See Section 4.3.2 for the Criteria Defining the Initial and Modified Searches

4.4 Results and Discussion

The performances of elite cyclists in competitive elite racing are influenced by features related to the following four dimensions: the individual dimension and features related to the individual cyclist; the tactical dimension and features which emerged from the inter-personal dynamics between performers; the strategic dimension and features related to the competition format and environment; and the global dimension related to societal and organisational features of the sport. An overview of each dimension is presented below, identifying the key features and how these interact to shape cyclists' behaviours and chances of success in elite racing.

4.4.1 The Individual Dimension

Various features have been shown to govern the performance of individual cyclists in elite competitions, including the cyclists' physiological and morphological features, cognitive skills, nationality, aptitude for risk, and physical attractiveness. Research in the field of sport and exercise science has tended to focus at this level of analysis [85].

4.4.1.1 Physiological Features

An individual cyclist's performance has been attributed to their peak and functional power outputs, cardiovascular, pulmonary and other physiological capacities (see [44–46,79,86–89] for comprehensive reviews). In recent decades the contribution of submaximal physiological variables, including cycling economy or efficiency, has also been highlighted [90–93]. Despite extensive study of cyclists' physiological features, the extent to which these predict competitive success in races at the elite level is limited, particularly in mass-start racing [91,94–96]. Impellizzeri and colleagues [97] found only 40% of the variance between international cross-country cyclists' finishing times was explained by differences in physiological characteristics. Chidley and colleagues [89] found that most of the variance in finish times of downhill mountain bikers was explained by skill (r^2 = -0.76), with only a small proportion attributable to physiological variables (anaerobic capacity, r^2 = 0.0; vo2max, r^2 = -0.3). Phillips and Hopkins [57,97 and Chapters 2 and 3] demonstrated the tenuous links between an individual’s physiological features and elite competitive performance, finding that factors determining consistent individual time-trial performance transferred minimally to performance in mass-start or one-vs-one racing. Cyclists must have high levels of physiological fitness to reach the elite level, but at this level there appear to be little differences in their physiological characteristics, and therefore other factors contribute to race outcomes [94,95]. Contextual, temporal and spatial parameters are also known to alter the physiological demands on a cyclist and their association with success. For example, the format and structure of a cycling competition alters the technical skill requirements and physiological demands on a cyclist, predisposing individuals with particular physiological features to be better suited for certain competition formats or races [92,99–104]. These links are highlighted further in section 4.4.3.1.

4.4.1.2 Morphological Features

A cyclist’s height, body weight, muscle size, and fibre composition have been shown to influence performance in specific types of races at the elite level [61,105–108]. Furthermore the morphological characteristics of elite cyclists vary between cycling disciplines [45,86,108,109], consistent with cyclists specialising into particular disciplines or team roles based on their morphology [110]. For example, road cyclists are frequently categorised according to their morphological characteristics as climbers, sprinters, or domestiques. As air resistance is one of

Table 4.1: Key Characteristics of Research Articles Investigating the Performance of Elite Cyclists in Competition, Organised by Level of Analysis and Highlighting the Performance Features Focused on in Each Study

Level of Analysis	**Cycling Discipline**	**Method**	**Subjects and Data**	**Performance Features**
The Individual Dimension				
Lucia et al. 2004 [96]	Road (time-trial)	Empirical analysis	11 professional road cyclists, 3 Tour de France time trial performances over 2 years (1998/1999)	Physiological features
Padilla et al. 1999 [101]	Road cycling	Empirical analysis	24 professional road cyclists	Physiological & morphological features (links to competition features)
Rodriguez-Marroyo et al. 2009 [109]	Road cycling	Empirical analysis	Workload demands on 30 professional road cyclists across 5-day, 8-day, and 21-day stage races (n=10, 5, and 5 respectively) collected over 5 consecutive racing seasons.	Link between: physiological & competition features (links also to team dynamics, team hierarchy)
Impellizzeri et al. 2005 [95]	Mountain biking	Empirical analysis	12 internationally competitive cyclists, competing in one international level mountain bike race	Physiological features (links to competition features)
Impellizzeri et al. 2005 [97]	Mountain biking	Empirical analysis	13 male regional, national and international U23 cross-country mountain bike cyclists competing in a national level cross-country competition	Physiological & additional individual features *(ability/experience level)* (links to competition features)
Chidley et al. 2015 [89]	Mountain biking	Mixed methods	Multiple study project. In study 3: 43 male cyclists ranging from junior, senior, master, expert and elite downhill mountain biking categories	Physiological, cognitive, & additional individual features *(skill, self-confidence)*
Svendsen et al. 2018 [111]	Road cycling	Empirical analysis	Retrospective categorisation of 80 competitive male cyclists, including 9 World Tour cyclists	Physiological & additional individual features (training, race experience)

Moran and Pitsiladis 2017 [112]	Road cycling	Review	Review article	Additional individual features *(genetics & performance)*
Impellizzeri et al. 2008 [108]	Road cycling and mountain biking	Empirical analysis	27 professional female road cyclists and 12 elite female mountain bikers from eight different countries	Morphological & physiological features (links to competition features)
Dorel et al. 2005 [61]	Track cycling	Empirical analysis	12 male elite cyclists competing at National and International level track races	Physiological, morphological & additional individual features (*frontal surface area, optimal pedalling rate*)
Haake et al. 2009 [113]	Track cycling and road cycling	Empirical analysis	World records for the one-hour distance from 1894-1996, and for the 4-km individual pursuit from 1964-1996	Other individual features
Spindler et al. 2018 [114]	Various cycling disciplines	Review	Review article	Cognitive features
The Tactical Dimension				
Waldron et al. 2011 [115]	Track cycling	Empirical analysis	1 single race (24 riders) of international competitive cyclists (World Championship level)	Drafting & interpersonal features
Menaspà et al. 2013 [116]	Road cycling	Empirical analysis	Single-case study longitudinal design, retrospective analysis of one male professional road cyclist in the sprint finishes of 31 grand tour stages from 2008-2011	Drafting features, inter-personal features, team dynamics, competition features
Bossi et al. 2018 [117]	Cyclo-cross	Empirical analysis	329 cyclists (men + women) competing in 5 editions of the UCI World Championships (2012-2016)	Drafting features, competition features (weather)
Hoenigman et al. 2011 [118]	Road cycling	Agent-based modelling	The model ran 1800 trials of various combinations of cyclist strength and best strategy	Drafting & interpersonal features (links to competition features, additional individual features)

Trenchard 2009 [119]	Road cycling	Economic modelling	Theoretical analysis - modelling estimates based on drafting data from prior research	Drafting & interpersonal features *(links to physiological features)*
Trenchard 2015 [120]	Road cycling	Economic modelling	Two test protocols run with various levels of cyclists and adjusted variables	Drafting & interpersonal features (links to physiological features)
Scelles et al. 2017 [121]	Road cycling	Empirical analysis	268 breakaways, over 76 stages, 4 Tour de France events. Results were also bootstrapped.	Interpersonal & contextual features (links to individual dimension, drafting & competition features)
Dilger and Geyer 2009 [1]	Road cycling	Empirical analysis	49 sprint finals in which a small group of cyclists sprinted for the stage win. 26 duels, 13 three-ups, 10 finishes with between four and seven cyclists. 140 riders in total.	Drafting & interpersonal features (*links to individual dimension)*
Moffatt et al. 2014 [77]	Track cycling	Logistic regression models	231 races at 4 UCI World Cup competitions	Drafting, interpersonal, & contextual features
Dwyer et al. 2013 [104]	Track cycling	Machine learning	4 races from World Cup (3) and World Championship (1) events across 1 season, incl. 91 cyclists (66 unique)	Drafting & contextual features
The Strategic Dimension				
Phillips and Hopkins 2017 [58]	Track cycling	Empirical analysis	336 UCI World Cup/World Championship and Olympic level cyclists (196 male, 140 female)	Competition features (links to individual & tactical dimensions)
Lucia et al. 2000 [103]	Road cycling	Empirical analysis	13 professional road cyclists, 8 'climbers' & 6 'time trialists' who had a stage win in a UCI event in the prior two years.	Link between competition features and individual dimension (physiological & morphological features)
Ofoghi et al. 2013 [56]	Track cycling	Machine learning	7 events, all cyclists, mix of 5 & 6 event omniums	Competition features (links to individual dimension)

Ofoghi et al. 2013 [53]	Track cycling	Machine learning	193 male omnium records, 167 female omnium records across 5 & 6 event Omniums	Competition features: competition structure
Ofoghi et al. 2010 [54]	Track cycling	Empirical analysis	96 data records (men) and 75 data records (women) from four competitions, encompassing elite & junior racing at World Championship and National Championship level	Competition features (links to individual dimension)
Filipas et al. 2017 [100]	Road cycling	Empirical analysis	43 professional cyclists who achieved a top 10 pacing in a Grand Tour between 2010-2015	Links between team hierarchy, competition features & competition calendar
Larson and Maxcy 2014 [122]	Road cycling	Empirical analysis	All mass start stages of the three Grand Tours (1985-2010) n=1436	Contextual features (links to authoritarian & interpersonal features)
Rodriquez-Gutierrez 2013 [123]	Road cycling	Empirical analysis	All professional cyclists belonging to the 18 UCI Pro teams in the year 2011. Sample equalled 448 cyclists.	Team features: opportunity (links to morphological features, additional individual features, competition calendar features)
Larson and Maxcy 2013 [124]	Road cycling	Modelling	Expansion of the model of Candelon and Dupuy [85] to incorporate coaching and production functions.	Team features, contextual features (links to authoritarian features, economic features, reward mechanisms)
Cabaud et al. 2015 [125]	Road cycling	Review	Method used on two 2014 Tour de France stages	Objectives & rewards, economic features, reward mechanisms, & interpersonal features
The Societal and Organisational Dimension				
Perneger 2010 [126]	Road cycling	Empirical analysis	5th place Grand Tour finishers from 1990-2009	Strategic dimension: competition features societal dimension: historical features *(links both to subversive behaviours)*
Lippi et al. 2014 [127]	Road cycling	Empirical analysis	Winners of Grand Tours since inception	Strategic dimension: competition features

				societal dimension: historical features *(links both to subversive behaviours)*
Rogge et al. 2013 [128]	Road cycling	Data envelopment analysis	31 cycling teams competing in the Tour de France over the period 2007-2011 (105 observations)	Team features & reward mechanisms, (links to competition & individual features)
Rebeggiani and Tondani 2008 [129]	Road cycling	Empirical analysis	One season of Pro Tour racing data (2005)	Authoritarian & economic features (links to competition features & reward mechanisms)
Aubel et al. 2018 [130]	Road cycling	Discrete time-logit model	Data from 10,551 cyclists in the first three world divisions of cycling from 2005-2016, including 271 sanctioned cyclists	Subversive behaviours (links to authoritarian, economic & reward mechanisms)
Zheng 2016 [131]	Various	Interviews & document Analysis	4 semi-structured interviews with lead Chinese staff + comprehensive document analysis	Authoritarian & economic features
Lodewijkx and Brouwer 2011 [132]	Road cycling	Empirical analysis	Winners of Grand Tours since World War 2	Social mechanisms and subversive behaviours (links to authoritarian, economic, and inter-personal features)
Prinz and Wicker 2016 [133]	Road cycling	Socio-cultural analysis	Longitudinal dataset from Tour de France from 2004-2013 (1542 observations from 598 different cyclists)	Authoritarian features, team features *(links to individual features)*
Mignot 2016 [106]	Road cycling	Review	Theoretical analysis	History & prestige, economic & authoritarian features, competition calendar features
Fink and Smith 2012 [134]	Road cycling	Socio-cultural analysis	Socio-cultural examination of unofficial norms with examples given from previous editions of the Tour de France	Social mechanisms (with links to authoritarian, economic, & reward mechanisms, and subversive behaviours)

Schumacher et al. 2006 [70]	Road & track cycling	Retrospective analysis	Race results of 4432 cyclists from 77 countries who had participated in major elite or junior elite cycling races from 1980 to 2004	Authoritarian features (links to individual features)
Larson and Maxcy 2014 [122]	Road cycling	Empirical analysis	Finishing position and relative times for Top-25 cyclists finishing all mass-start stages of the three Grand Tours from 1985 to 2010 (n=1436)	Authoritarian features (with links to drafting, interpersonal, & economical features)
Brewer 2002 [135]	Road cycling	Review	Review article	Subversive behaviour & authoritarian mechanisms, history & prestige *(links to economical features)*
Multi-Dimensional				
Albert 1991 [136]	Road cycling	Empirical analysis	Various: personal experience from racing, formal interviews with US riders & officials, cycling press & video reports. Senior mens road racing in all instances.	Tactical dimension: drafting, interpersonal & contextual features Societal dimension: social mechanisms & authoritarian features *(all interlinked)*
Van Reeth and Larson 2016 [137]	Road cycling	Various levels	Review: comprehensive book with chapters exploring the various dimensions and features of professional road cycling – predominantly from an sports economics perspective.	Individual dimension: physiological, morphological, cognitive & additional features Tactical dimension: drafting, interpersonal & contextual features Strategic dimension: competition features, calendar effects, objectives, collusion & association, team features. Societal dimension: history & prestige, authoritarian, economical mechanisms, subversive behaviour *(various links)*
Torgler 2007 [105]	Road cycling	Ordered probit and ordinary least squares modelling	Tour de France, full data - 21 teams, 188 cyclists (147 finishers)	Individual dimension: morphological features, experience effects, cultural background effects

				Tactical dimension: teammate effects Strategic dimension: opportunity effects
Mujika and Padilla 2001 [87]	Road cycling	Review	Review article	Individual dimension: physiological, morphological features Strategic dimension: competition features
Netland et al. 2012 [138]	Road cycling	Socio-cultural Analysis	Semi-structured interviews: 9 persons (6 athletes, 3 directors) of Norwegian continental cycling teams. Plus 1 director & 3 cyclists from a different professional team.	Strategic dimension: team features Societal dimension: authoritarian, reward, & social mechanisms
Lucia et al. 2001 [88]	Road cycling	Review	Review article	Individual dimension: physiological, morphological & additional individual features Strategic dimension: competition features (and links to physiological & drafting features) Societal dimension: subversive behaviours (and links to additional individual features)
Martin et al. 2007 [65]	Various disciplines (sprint finishes)	Review	Review article	Individual dimension: physiological features Tactical dimension: drafting features *(links to physiological features)*
Craig and Norton 2001 [45]	Track cycling	Review	Review article	Individual dimension: physiological & morphological features Strategic dimension: competition features *(links to physiological features)*
Santalla et al. 2012 [86]	Road cycling	Review	Review article	Individual features: physiological, morphological & additional individual features

				Strategic dimension: competition features *(links to physiological features)* Societal dimension: history & subversive behaviour features *(links to physiological features)*
Castronovo et al. 2013 [139]	Road cycling	Review	Review article	Individual dimension: physiological & cognitive features Strategic dimension: competition features *(links between these features)*
Menaspa and Abbiss 2017 [140]	Road cycling	Review	Review article	Individual dimension: physiological & morphological features Strategic dimension: competition features *(and the links between these)*

the dominant forces a cyclist must contend with, certain morphological trade-offs occur. Having a greater muscle mass can enable a cyclist to better generate the energy and power required to overcome the drag caused from riding at high speeds on flat surfaces [107] but can also lead to an increased frontal surface area, thereby increasing drag and negatively affecting performance [61]. In the hill and mountain stages of professional road races, when speeds are low, overcoming gravity becomes more important than overcoming drag, and cyclists with low body mass tend to be more successful [101,107]. These and other well-established links between a cyclist's morphology, competition features and chances of success, are detailed further in section 4.4.3.1.

4.4.1.3 Emotional and Cognitive Features

The role of a cyclist's cognitive features in regulating their behaviour and competition performance was highlighted by Spindler and colleagues in a recent review of the psychology of elite cycling [114]. A cyclist's mood, levels of anxiety, self-confidence, ability to manage pain, attentional focus and cognitive function were identified as influencing performance, although the authors noted that the differing aims and objectives of the studies reviewed made it difficult to establish strong support for any particular association. There was tentative evidence that anxiety impairs performance amongst elite male road riders, that implicit beliefs affect decision-making performance, and that pain management is important to achieve success in elite road cycling [114]. There was also some evidence that the sex of a cyclist modified the effect of confidence on performance, and evidence of a difference in cognitive abilities between elite and sub-elite riders [114], but whether these cognitive differences predict success at the elite level remains to be seen. The potential influence of stress, mental fatigue, personality, and an individual's implicit beliefs in regulating their behaviour and competition performance were also highlighted [114].

Larson and Macxy [94] provided further support for the importance of cognitive skills, explaining that cyclists must manage their energy expenditure, effort and pacing, optimize their aerodynamics in relation to their opponents, and make decisions not only in competition but also in training. Castronovo and colleagues [139] explored how cognitive features influence a cyclist's perceived level of exertion and subsequent regulation of effort over the course of a race. Cyclists are known to subjectively distribute their energetic resources across the race to improve their performance, a strategy referred to as pacing [45,141]. Cyclists adjust their pace according to their anticipated and accumulated levels of fatigue, terrain characteristics, race duration, elapsed distance, and competition structure [109,117]. The pacing strategy a cyclist adopts is also known to be affected by the presence and behaviour of their opponents, and there is some evidence of a sex effect [109,117,142]. For example, Bossi and colleagues [117] found male and female cyclo-cross athletes distributed their efforts differently across the course of a race, but were unable to conclude whether this was due to differences in contextual features, such as race length, or psychological differences, such as differences in confidence and risk perception. These studies lend support to the arguments of Seifert et al [16] and Noakes [81] of athletes as complex adaptive systems whose behaviours are governed by the interplay between cognition and action, and who regulate their effort and energy expenditure according to the information available. As noted by Spindler and colleagues [114], there is a need for further research into the psychological factors governing success in elite cycling to improve understanding of the interplay between cognitive function, athlete behaviour and competition performance.

4.4.1.4 Other Individual Features

The effects of nutrition and ergogenic aids on performance have received some attention in the literature [139]. No studies appear to have been performed to establish the efficacy of these strategies in actual competitions.

Performance improvements in solo time-trial events have been attributed to advances in bike technology and aerodynamic positioning [113], but in races where competitors are able to draft, the benefits of technology are much more difficult to quantify. Lippi and colleagues [127] analysed the average speed of Tour de France winners across the decades and attributed some of the improvement to major advances in bike technology from 1926-1970, as well as improvements in training, nutrition and an increasing prevalence of doping across this period (see Section 4.4.4.5). The stabilisation of average speeds of Tour de France winners in recent decades is thought to be a result of reaching a ceiling in improvements in training and bike technology, as well as improvements in anti-doping measures. Notably, the improvements in cycling performance attributed (in part) to advances in bike technology by Haake [113] and Lippe et al. [127], occurred over several decades, whereas most athletes competing against each other in any particular race or competition are likely to have access to technological developments at roughly the same time. As such, differences in bike technology in races with multiple opponents are unlikely to be of a magnitude that differentiates between cyclists' chances of success within a particular race.

Nationality or regional origin has been shown to influence performance and chances of success, with riders and teams seemingly more willing to take risks or expend effort when races hold some kind of national significance or are located closer to their country of origin [105] (see also Section 4.4.4.6). In downhill mountain biking skill level had a positive effect on a rider's self-confidence and their subsequent performance, but no significant relationship was found between performance and past experience, or performance and access to quality equipment [89]. Similarly, in track and road cycling, increased elite competitive cycling experience did not correlate with better performance [58,105], but increased competition exposure in the *developmental years* was more predictive of future success than physiological measures for road cyclists at World Tour level [111]. There is also some evidence to suggest a male cyclist's physical attractiveness, masculinity and likeability is linked to performance and chances of success in professional road cycling [94,143]. A cyclist's willingness to abide by the social norms that govern interactions between riders in the peloton can also influence their likelihood of success [118] (see Section

4.4.4.4). Finally, there is some evidence that an individual must have the right genetic make-up to succeed in elite cycling by responding appropriately to training stimuli [112]. Lack of consistent findings across these features means these results are suggestive of an effect rather than conclusive, and more research is required to establish the robustness of these findings and the magnitudes of their effects on the performance of elite cyclists in race events.

4.4.2 The Tactical Dimension

In competitions where opponents are able to interact, riders continually adapt to the actions of opponents and the changing race environment [57,98,144,145]. The tactical dimension refers to features arising from this interaction between competitors and the actions they take in response to what is occurring. Understanding the effects of inter-personal dynamics on cyclists' behavioural and tactical decisions is important if we are to make sense of their performances in events other than solo time trials.

4.4.2.1 Drafting Features: Pacing, Positioning and the Emergence of Pelotons

In race events, the presence of other cyclists enables drafting to occur, whereby a cyclist can reduce the energy cost of maintaining a particular speed by riding in the slipstream of other cyclists [9,65,119,146]. By working together and taking turns to ride in the lead position, the energetic benefits of drafting allow a group of cyclists to sustain a speed greater than a cyclist could sustain riding alone [9]. The term *peloton* describes a group of cyclists who ride as a pack or bunch, a form of cooperative behaviour that emerges due to the energetic benefits provided by drafting [110]. The drag experienced by cyclists in the mid to rear positions of large pelotons (~120 riders) is ~5 to 10% of that experienced by an isolated cyclist riding at the same speed, and ~16% of that experienced by the cyclist leading the peloton (who experiences a reduction in drag due to the 'upstream' flow disturbance caused by the mass of riders following behind) [147]. Positions towards the rear of the peloton provide greater energetic savings, but are tactically disadvantageous, as the risk of collisions increases and it is harder to manoeuvre past opponents when nearing the finish line, or to respond to or launch attacks (whereby riders attempt to break away from the front of the main peloton and ride in advance of their opponents despite the higher energetic cost) [106,147]. Consequently, cyclists tend to compete for the drafting and positional resources available, and effective use of these two resources has been shown to affect a cyclist's chances of success in racing [119]. In the Elimination, a mass-start race in the track-cycling Omnium, the most successful cyclists were shown to be those who rode towards the front of the peloton (tactically advantageous) and in positions lower on the track (energetically advantageous) throughout the race [104]. Menaspà and colleagues [116] presented a case study of a Tour de France rider who was able to improve his chances of success in the final sprint by spending less energy through effective positioning and drafting during the earlier stages of the race. In cyclo-cross, top-ranked cyclists expended more energy in the initial laps of a race in order to gain a positional advantage over their opponents, after which they settled into a more sustainable pace for the remaining laps [117].

4.4.2.2 Interpersonal Features: 'Coopetition', Cooperation, and Defection

While riding in a peloton reduces the overall energy cost of maintaining a certain speed, it can also narrow the gap between cyclists' physiological capacities [119]. A weaker cyclist who optimises use of the drafting resource through effective positioning could theoretically beat a stronger opponent who did not position well or regulate their energy expenditure as effectively [110]. As a result, a cyclist's best course of action during a race is dependent on their individual characteristics (see Section 4.4.1), opponent characteristics and actions, contextual features of the race, and the options available to them [106,121]. To gain a positional advantage over their opponent(s), some cyclists will launch an attack and attempt to ride in advance of their opponent(s) [115,118,121]. Attacking cyclists often form into smaller groups termed 'breakaways', electing to share positional and drafting resources in order to reduce the energetic cost of staying ahead of the main peloton. The degree of cooperation displayed in a breakaway group appears to be influenced by the size and physiological heterogeneity of the riders in the group, with cooperation increasing as the breakaway group size decreases and the physiological disparity narrows amongst the riders [119]. If a cyclist in the breakaway refuses to cooperate in sharing the drafting resource with their opponent(s), the likelihood of the other riders defecting (not sharing in the workload) also increases, and the breakaway is likely to fail [118]. A number of researchers have used game theory to characterise the dilemma cyclists face between cooperating, attacking, or defecting [110,121,137]. Mignot [110] characterised the dilemma as a zero-sum sequential-move game, where the optimal timing of an attack or breakaway attempt is the point at which delaying for any longer reduces the cyclist's chances of winning the race. The option to cooperate, attack or defect has also been characterised as a prisoner's dilemma, where each cyclist has an incentive to be the first to defect [121,137].

4.4.2.3 The Influence of Contextual Factors on Race Dynamics

Modelling work from a number of authors has highlighted how contextual features alter the best choice of action for a cyclist, breakaway group or peloton during a race and the influence of these features on the chances of a cyclist's or breakaway's success [3,118]. For example, as the speed of the peloton increases and riders approach their maximal sustainable power, drafting becomes a more valuable resource. In contrast, when the finish line is approaching or the peloton encounters crosswinds (where the formation of echelons can cause splits in the field), increased value is placed on the more forward positions [120]. Olds [3] found that breakaway-group size, chase-group size, gradient, and remaining race distance all affected the velocity, time to exhaustion, and critical gap size a breakaway group needed to succeed. Agent-based modelling by Hoenigman and colleagues [118] indicated that stronger cyclists seem to benefit from adopting a strategy of cooperation, while weaker cyclists appear to be better off defecting. On a practical level, the influence of contextual factors on a rider's best choice of action was demonstrated by the analyses of Moffatt and colleagues [77], who showed that distance to finish, physiological differences, and relative rider positioning during a race influenced the likely outcome of head-to-head match sprints in track cycling. In a similar analysis of sprint finishes of Tour de France stages, cyclists' chances of winning were linked to the distance remaining, the number of teammates still riding in support, and the positioning of the cyclist in the final meters of the race [1]. In stage races, the chances of a breakaway succeeding were also dependent on the threat it posed to the leader in the general classification (overall cumulative position) and whether the energy expenditure required to chase down the breakaway was deemed supportable by the cyclists in the main peloton [121]. For example, if the next stage of the race was perceived to be tough, the riders often considered it more prudent to save their energy than catch the breakaway.

4.4.2.4 Team Dynamics

In professional road cycling, a cyclist's overall performance is influenced by the skills and attributes of their teammates, as most riders work to improve their team leader's chances of success rather than their own [105,106,129]. While an individual is awarded the win, their efforts are often aided by the work of teammates, who provide drafting and positional assistance to allow the team leader to conserve energy for the most crucial moments of the race [105,106,129]. Torgler [105] applied theories from labour economics to examine productivity in professional road cycling teams, finding that an individual cyclist's performance suffered if they were in a team of high performers, as that rider was expected to sacrifice their own chances of success in order to improve the chances of their teammate(s). For the team leader, the benefit of having teammates in support was also demonstrated by Menaspa and colleagues [116], who found the chances of a cyclist winning a sprint stage of a Grand Tour increased when they had teammates providing a non-competitive drafting benefit during the last 60 seconds of the race. Features of team dynamics at the strategic level are explored in Section 4.4.3.5.

4.4.3 The Strategic Dimension

Strategic features refer to elements of the competition or race environment that shape the decisions of a cyclist, team, or organisation before the competition begins and set their actions within a wider context [6]. Cycling differs from most sporting competition in that the features and format of cycling races are heterogeneous, with competition structures, course distances, routes and terrain differing from race-to-race. The multiple-prize reward structure in professional road cycling adds further complexity to the race environment, leading to the emergence of efficiency, non-competitive behaviour, and occasionally, the formation of tacit alliances and collusion between riders.

4.4.3.1 Competition Features: Terrain, Environment, and Competition Structure

The format and structure of a cycling competition alters the technical-skill requirements and physiological characteristics associated with optimal performance, predisposing riders with particular characteristics to be better suited for certain competition formats or races [92,99–104]. Cycling competitions may consist of a single race or be multi-race, single day or multi-day competitions; take a mass-start, one-versus-one, individual or team format; take place indoors, outdoors, in purpose built facilities, off-road, on road, or on purpose built tracks; and run across a range of surfaces and terrain [129]. Numerous studies have explored the attributes required for success across the various formats of cycling competition, demonstrating that each presents different metabolic, physical, physiological, technical and cognitive stressors on an individual [45,86,87,89,95–97,103,104,108]. In this sense, the attributes required for optimal performance in any particular cycling discipline, event, or race are highly dependent on the competition features. Cyclists therefore tend to specialise into particular disciplines that suit their characteristics and improve their likelihood of success, as detailed in Section 4.4.1.2.

The structure of a competition has also been shown to alter the physiological characteristics associated with success [54,140]. Rodriquez-Marroyo and colleagues [109] demonstrated the impact of competition structure on performance, detailing the changes in the workload demands on professional cyclists across 5-, 8-, and 21-day stage races. Adjustments to the format of the Omnium, a two-day competition in track cycling, have also shown the effect of competition structure on performance, with the addition of the elimination event altering the type of rider likely to do well in the overall competition [53]. Course route, commonly referred to as the *parcours* in road cycling, also influences cyclist performance. For example, race distance and difficulty and location of technical features (such as the inclusion of cobblestone sections, or position, gradient and number of hill climbs) all alter the physiological and technical demands on a rider [101]. While the competition format and route are fixed in advance, environmental (e.g., weather) conditions can also alter performance and likelihood of success. Wind and rain in particular can alter the value of the drafting and positional resources, altering the perceived risk associated with particular racing strategies and the way cyclists elect to expend their energy [K.E. Phillips, unpublished observations].

4.4.3.2 Competition Calendar Effects: the Emergence of Efficiency and Non-Competitive Behaviour

Competition features have been shown not only to influence the *type* of cyclists likely to succeed, but the *way* cyclists compete, particularly in competitions consisting of a series of races, such as the Match Sprint, Keirin, and Omnium tournaments in track cycling, and multi-day stage racing in road cycling. In multi-race or multi-stage contests, cyclists must balance their desired goals against the efforts required to achieve them, resulting in the emergence of strategies related to efficiency, whereby riders seek to optimise performance across a series of races to secure a larger objective [125]. For example, road cyclists aiming to win the general classification in a multi-day stage race often adopt conservative racing strategies in the early stages, saving energy for the critical moments of the competition [110]. The potential payoffs of using a strategy of efficiency have been shown in the track cycling Omnium, where a cyclist aiming for the overall title is able to finish as low as 6th place in one of the events and still be in contention for the overall title [53]. The importance of efficiency in multi-stage cycling races can also lead to the emergence of non-competitive behaviour, where cyclists who are unlikely to win a race or secure a high ranking in the various classifications have a higher incentive to abandon the race, should it not go as they planned [105]. Abandoning a race is a rational way for a cyclist to conserve energy, reducing the cost of the current effort to protect performance in future events [105].

4.4.3.3 The Influence of Objectives: Incentives and Rewards

The diversity of racing objectives amongst cyclists presents a unique challenge for researchers seeking to understand the performance of individual cyclists in real-world competition, namely that numerous competitors may deliberately withhold their best efforts [125]. Instead, riders may be motivated by objectives that have nothing to do with winning a particular race or stage [125]. For example, elite track cyclists have discussed employing conservative racing strategies, taking less risks, and seeking only to finish above a certain rank in order to secure a qualification spot for a more prestigious race, such as the Olympic Games (K.E. Phillips, unpublished observations). In professional road cycling, the multiple-prize structure of the competition shapes cyclists' goals and thereby influences their choice of action in any given race or stage [110]. Cyclists may be focused on securing a classification title (e.g., general, mountain, points, young rider) or focused on gaining TV exposure for sponsors or their personal brand by being in the breakaway group at the front of the race [125].

An individual's or team's *perception* of their chances of success in a competition is known to influence their selection of race objective, affecting their selection of racing strategy and willingness to expend effort. For example, professional road cycling teams have been shown to adjust their objectives depending on the characteristics of the riders in a given event, stage, or competition [128]. A team may also elect to adjust their objective mid-competition, seeking a secondary prize (such as a stage win or other classification) owing to an early injury, change in leadership, crashes, or a change in their perceived chances of success [125].

4.4.3.4 Collusion and Association

Race outcomes in cycling are sometimes influenced by collusion, when opponents deliberately cooperate, form tacit alliances, or swap monetary compensation in return for assistance in achieving a goal [129,135]. The cooperation seen between opponents in cycling (as referred to in Section 4.4.3.2) is an interesting case study for game theorists, as cooperation violates the implicit assumptions of the zero-sum game (one side wins, one side loses) that characterises most sporting competitions [110]. In cycling, one competitor may 'carry' another competitor, even to the point of helping the other to win, with the goal of securing a larger objective [136]. Unlike in many other sports, conflict and association exist together in cycling.

> On one hand, the theme of individualism reflects the unambiguous aspects of conflict, emphasizing individual or team effort that occurs within the framework of the basic rules and results in a win or loss. On the other hand, a theme of collectivism has emerged, reflecting some of the situational particularities of the sport that require an association between opponents, called 'drafting'. Albert [135 p.133]

Riders have been known to collude or 'fix' the outcome of races, offering some compensation in return for the assistance of other riders [106,135]. Mignot [106] uses the example of Miguel Indurain and Claudio Chiappucci in the 13th stage of the 1991 Tour de France to illustrate fixing, where Indurain allowed Chiappucci to win the stage on the premise that he contributed to the workload of the breakaway group, helping ensure the group stayed clear of the main peloton and enabling Indurain to achieve his aim securing a classification jersey.

4.4.3.5 Team Hierarchy: Opportunity

Researchers seeking to examine the performance of cyclists in real-world competition must also understand that a rider's performance may depend on whether they are given the opportunity to race for the win. Professional road cyclists who are not team leaders often have two conflicting goals: seeking to contribute to their team success while on a secondary level aiming to contribute to their own personal success and career longevity [148]. Professional road cycling teams may consist of up to 30 riders, with only eight or nine of these riders permitted to start in Grand Tours, and entries are also limited in other ProTour events. Team management will normally select a team and a 'lead' rider based on the characteristics of their riders relevant for the race features and importance [100]. Team leaders are generally more successful than other cyclists across a racing season, but whether this is due to the team leader's superior individual characteristics or because they benefit from the work of their teammates is unclear [148]. Cyclists riding in support of their team leader (termed 'domestiques') have little incentive to continue racing once they have fulfilled their expected duties. Domestiques are known to 'sit up' once they have executed their support task(s), no longer seeking to remain competitive and only seeking to finish the race within the time cut-off to ensure they are permitted to start the following stage [K.E. Phillips, unpublished observations].

4.4.4 The Global Dimension

Elite cycling competitions take place within a complex social and organisational setting, where economic, socio-cultural, and historical forces shape behaviour and decisions made by governing bodies, race organisers, cycling teams, and the cyclists themselves [149]. Researchers in the fields of economics, management and sociology have provided some insight into how organizational changes and reforms, largely driven by attempts to improve the globalisation and professionalism of the sport, have impacted the performance of cyclists in recent decades [135,137,138,148–150]. To date, authors have focused almost exclusively on male professional road cycling.

4.4.4.1 Economic Features: Revenue Generation, TV Rights, Sponsorship

Various authors have explored the economic drivers of male professional road racing, detailing how the competing interests of multiple stakeholders shape the structure of professional racing and influence the competitive pressures on teams and riders [135,137,149]. As the primary governing body, the UCI formulates (and adapts) the rules of racing, regulates the classification of races and points ranking systems, and issues racing licenses to teams and riders. Organisational changes and reforms over the decades, designed by the UCI to improve the globalisation and professionalism of the sport, have led to major changes in racing behaviour by cyclists and their teams (see Section 4.4.4.2) [149]. Race organisers also play a key role in shaping the structure of professional road racing, with many of the most prestigious events controlled by private corporations such as the Amaury Sports Organisation (ASO) [149]. Race organisers are known to alter the design of a race route to ensure high competitive intensity between riders, with the aim of increasing spectator interest to generate revenue, attract sponsors and secure interest in the purchasing of TV rights [125,151,152]. External stakeholders, such as team sponsors and the media, also have a strong interest in ensuring the attractiveness of the contest, driven by a desire to increase TV viewership and ensure brand visibility [125]. As professional race teams are funded almost entirely from sponsorship, team managers have a strong incentive to promote sponsors' visibility during a race and deliver race results, in order to ensure the ongoing financial viability of a team [149]. For riders, professional race contracts are often short, and while riders can participate in races only as part of a team, there is also a strong incentive for individual cyclists to perform well in order to secure a contract [124]. Aubel [130] argues there is a potential link between the economic position of a team or rider and the doping, reporting sanctioned riders were 5.8 times more likely to have experienced career interruptions or 61% more likely to have had multiple team changes (see Section 4.4.4.5).

Similar economic drivers of revenue generation via spectator engagement appear to be responsible for reforms made to other disciplines of cycling, namely BMX and track cycling (see Section 4.4.4.2). For example, the removal of the solo time-trial events from the Olympic track-cycling program and introduction of the two-day multi-race Omnium competition were seen as a reflection of the UCI and International Olympic Committees (IOC) desire to deliver more engaging and tightly fought contests for spectators [56].

4.4.4.2 Authoritarian Features: Governing Bodies and Race Organizers

Governing bodies and race organisers are known to implement changes to the regulations of cycling competitions in attempts to improve the competitive intensity of racing and thereby increase public interest in cycling [106,125]. Reforms made to rules and racing regulations over the decades have allowed researchers to observe and analyse the subsequent changes in racing behaviour and performance [122,131,149].

A particularly influential reform was the introduction of a ranking system by the UCI in 1984, which was designed in part to increase competition and reduce collusion amongst professional road racing riders and teams [129]. UCI ranking points had a major influence on the way teams and riders prepared and raced [125,129,135,149]. In races that had traditionally been fixed or used for training, teams became competitive, needing to accumulate ranking points across a wider number of races throughout the competitive season to gain entry to the more prestigious events [135,149]. A secondary aim of the UCI was to globalise cycling, and the ranking system ensured teams competed in races outside of Europe, the traditional stronghold of the sport [125]. Brewer [135] described how the increase in competitiveness resulted in an effective lengthening of the competitive racing season and modified the pressures on teams and riders. For example, team managers were compelled to build a squad of cyclists capable of success across a wider range of races, rather than the more traditional method of structuring a team around the support of one key rider for the more prestigious event(s) [135]. For the cyclists, a higher expectation to perform well in races across the full competitive season increased the pressure to remain in top physical condition, driving advances in training techniques and technology, as well as inadvertently encouraging subversive behaviours such as doping [129,135] (see Section 4.4.4.5).

Another influential reform was the introduction of a ban by the UCI on the use of radio technology in some professional road races from 2011-2015, which was also seen as an attempt to improve the competitive intensity of the sport and prevent racing from becoming too predictable [122]. Larson and Maxcy [122] found the change in information flow caused by the radio ban affected race structure and outcome, although they could not determine conclusively whether changes in the likelihood of breakaway success were due to absence of radio communications or changes in the cycling sub-culture across the period examined (see Section 4.4.4.4). As a side note, the authors found the use of radio technology and likelihood of breakaway success were strongly modified by terrain variables (see Section 4.4.3.1).

Within a particular country, the regulations of national sporting organisations (NSO) impact the development, recruitment, and performances of elite cyclists. For example, Zheng [131] provided an interesting commentary on the relative underperformance of Chinese cyclists in Olympic and UCI ProTour cycling events, suggesting the under-representation of Chinese cyclists was due to organisational elements of the Chinese sporting system. In comparison, a strong talent development program within the Australian national system was apparently responsible for a 50% increase in the conversion rate of junior world championship athletes to success in the senior divisions [70].

4.4.4.3 Reward Mechanisms: Multiple Prize Incentives

The introduction of secondary prizes in the Tour de France by the ASO is an example of reward mechanisms used to encourage cyclists to compete and create a dynamic spectacle that will draw public interest [106,138]. Secondary prizes, such as time bonuses, intermediate sprints, and combative rider prizes, provide an incentive to cyclists who are not in contention for the overall win, by presenting them with opportunities to gain ranking points or media exposure while adding to spectator interest [152]. As riders vying for overall win in multi-day stage races are likely to adopt strategies of energy conservation and non-competitiveness in the early or flat stages, secondary prizes help maintain a level of competitive intensity by incentivising the other riders.

Formal rules and regulations can also inadvertently provide a disincentive for teams and riders to compete. Rebeggiani and Tondani [129] outlined how the UCI inadvertently encouraged non-competitive behaviour from professional teams across the racing season by restricting the total number of professional road teams in the UCI ProTour, thereby making it a closed league. Without the risk of relegation to a lower league, teams were concentrating their best efforts on races organised in their sponsors' home countries or on only a few other races each season. The authors argued the UCI would better achieve their aim of improving the competitive intensity of racing by opening the league and increasing the number of ProTour teams, thereby providing an incentive to compete in races teams may otherwise not target. The UCI has adopted a version of this recommendation in recent years [153].

4.4.4.4 Social Mechanisms: Unofficial Norms and Peloton Sub-Culture

In addition to the formal rules governing the competition, a cyclist’s behaviour and decisions are constrained by unofficial norms or social mechanisms that exist within the peloton [136,138]. Unofficial norms emerge when it is beneficial for race participants to enforce a subset of social rules, driven by a collective desire to ensure the profitability of the sport [134]. Unofficial norms dictate the shared expectations of how cyclists should behave within the peloton and individuals who do not abide by these social expectations are subjected to sanctions by other members of the peloton [134,138]. For example, if a race favourite or race leader should suffer a mechanical issue, the unofficial norm dictates that the other cyclists should not make use of the opportunity to benefit themselves by making an attacking move [110,134]. Cyclists who disobey this norm are often punished by the peloton, who collectively refuse to cooperate with the ‘defector’, denying them camera exposure (e.g., by chasing down any breakaway attempt), and in more extreme cases, by physically interfering with the defectors’ ability to ride [134]. Albert [136] conducted a sociological examination of the peloton to explore the influence of social dynamics on the performance of cyclists in road races, seeking to understand why riders share the lead, why a peloton may allow a breakaway to form, and why some breakaways succeed when others fail. The author concluded that using formal rules to explain the constraints on cyclist behaviour is insufficient to capture the experienced reality of the sport, arguing that the informal social norms must be considered if we are to understand racing behaviour. Fink and Smith [134] built on this work by examining the unofficial norms that govern behaviour in elite road cycling and by explaining how these norms affect the profitability of the Tour de France for race organisers and maintain the attractiveness of the event for spectators.

4.4.4.5 Subversive Behaviours: the Prevalence of Doping

Cycling has been characterised by numerous doping scandals and the phenomenon of doping, and its effects on cycling have been examined from a number of angles [126,127,130,132,135]. The prevalence of subversive behaviour amongst cyclists and team management, where the anti-doping regulations of governing bodies were deliberately ignored or actively flouted, is becoming evident as those formerly involved in the industry reveal the actions they took to avoid detection [e.g. 154]. The influence of doping on the performance of elite cyclists is difficult to quantify, because there is no accurate way of knowing who doped, to what extent, and when [152]. To examine the potential influence of doping on race performance and assess the effectiveness of anti-doping measures, some researchers have used secondary measures of performance, such as changes in the average speed of Grand Tour winners across the decades [126,127]. The decrease (or plateau) in average speed of Grand Tour winners since the early 2000's has been attributed to strengthened anti-doping measures [127,155], but changes in the socio-cultural environment in which riders compete provide equally plausible explanations [132,135]. Such changes include modification of team structure, sponsorship, inter-team dynamics, and rider preparation [132,135,149].

Fink and Smith [134] outlined how the challenges associated with monitoring and preventing doping amongst cyclists at an organisational level resulted in specific social norms developing amongst teams and riders. As doping behaviours were not able to be observed directly, cyclists were uncertain who was doping, so the 'clean' cyclists could not collectively monitor and punish those using illicit substances [135]. Instead, a social norm known within the sport as the *omerta* developed, where organisers and riders both accepted doping was prevalent, but the established social norm was not to discuss it publicly, in order to protect the sport and the revenue it generated [134,135]. Economists have used game theory to explain how teams and riders rationalised doping, where the economic and financial benefits of improved performance, along with prohibitively high sanctioning costs, resulted in a Nash equilibrium in which it was most profitable for all cyclists to dope [134,152]. Brewer [135] drew links between authoritarian, reward, and social mechanisms and the increasing incentive to dope, particularly for teams at risk of losing sponsorship or for riders at risk of not securing an ongoing professional contract. Aubel et al [130] found a higher risk of doping amongst cyclists who began their professional careers before 2005, but noted the reasons for the declining number of sanctioned riders since 2005 were ambiguous. The reduction could be due to improved anti-doping measures, including the introduction of the biological passport in 2008, changes to the structure of the WorldTour, changes to the socio-cultural norms of the peloton, or 'improvements' in the doping practices of teams and athletes making the use of banned performance enhancing substances harder to detect.

4.4.4.6 History and Prestige

Brewer [135] and Mignot [106] provided thorough overviews of the history of professional road cycling and explored how changes in global mechanisms across the decades have led to changes in rider performance. As outlined in Sections 4.4.4.1 to 4.4.4.5, changes made by governing bodies aimed at increasing the commercialisation and globalisation of the sport altered the pressures on team managers and riders, leading to changes in team organisation and rider preparation, fostering changes in the social dynamics of the sport, and inadvertently resulting in the rationalisation of doping practices. The growth of commercial sponsors led to increased professionalism, enabling riders to increasingly specialise as the racing calendar gradually increased in length and intensity [135]. Furthermore, the roster of team riders shifted from being organised around the support of a single team leader to an organisation of sub-teams that trained for peak performance in specific races or Grand Tours [106]. Team managers started selecting and organising sub-groups of riders from their team roster for success in particular races, targeting either a Grand Tour, the Classics (Milan-San Remo, Tour of Flanders, Paris-Roubaix, Liège-Bastogne-Liège, and Tour of Lombardy), or races with regional or national significance [106]. Top cyclists and their support riders then adjust their training and periodisation to peak for these particular events [129,151]. While evidence of improvements in cyclist performance due to race prestige remains predominantly anecdotal, teams certainly appear to place increased importance on performance in particular races and tours [106,135]. In professional road cycling the Tour de France remains the most prestigious competition, while in other cycling disciplines the World Championships are considered the most prestigious event in non-Olympic years [106].

4.4.4.7 Other Societal and Organisational Features

The preceding sections of this review have dealt with performance of individual cyclists. There are only a few cycling disciplines where team performance is of interest, and in professional road cycling there has been only one publication addressing the determinants of team performance. Prinz and Wicker [133] applied concepts from management research and labour markets to assess the effect of team composition on the performance of professional road cycling teams in the Tour de France. Having a diverse range of tenure (length of time in team) was positively associated with team performance, which the authors suggested was due to internal competition for selection between team riders raising performance standards or preventing stagnation in those with longer careers. Age diversity of team riders had a positive (albeit non-significant) effect on performance, while diversity in nationality and language had little effect. Another explanation for these relationships is that early-career riders will join any team, but as their performance improves they are likely to move to teams where they have more opportunities. Prinz and Wicker also found that a wide range of body mass index (BMI) scores was linked to poorer team performance, likely due to overall performance indices favouring hill climbers, who generally have lower BMI. Previous Tour de France participation and previous stage wins were not significantly related to team performance, but the number of riders finishing the Tour de France did matter, which likely reflects the sharing of workload between team members. The authors concluded that team managers seeking team success needed to consider the composition of their teams, selecting riders capable of finishing the race and with a diverse range of tenure [133].

4.5 Limitations

As outlined in Section 4.3.2, a narrative-synthesis approach was used to systematically review the selected articles and formulate dimensions and features. Of the articles that met the inclusion criteria, a majority analysed the competition performances of road cyclists, and in particular, male professional road cyclists. Consequently, some of the dimensions and features identified in this article are based on research in a single cycling discipline (see Table 4.1 for detail). There may also be factors affecting performance of cyclists that are being used in competition but that have not been the subject of published research; for example, teams who have developed new ergogenic aids or improvements in technology are unlikely to publish their findings. Finally, several features known to enhance cyclists' performance in non-competition settings have received limited attention in this review, because the extent of their implementation and effects in actual competitions are unknown.

4.6 Conclusions

The aim of the current study was to improve our understanding of how performance emerges in elite cycling competitions, with a particular focus on the effects of contextual factors, presence of and interaction with opponents, environmental conditions, competition structure, and socio-cultural, economic and authoritarian mechanisms. The challenges associated with modelling the performance of cyclists in the complex environments that define cycling racing become evident when the features and dimensions influencing race performance are collated. In particular, there are limitations in using a traditional reductionist approach to understanding the performance of cyclists in elite racing. Sports performance research needs to be holistic, idiographic and take a process-oriented approach that emphasises the analysis of emergent patterns of coordination and control underpinning performance [5,39,156–158]. Moving forward, the challenge is for sports performance researchers to find methodologies and techniques that enable elements of performance to be considered in concert rather than in isolation, and for the complex interplay and interactions between dimensions and features of racing to be better understood. We must search for data collection and analysis techniques that allow us to adequately account for and explain the interactions and mechanisms underpinning successful cycling performance in racing contests [5–8,155,159]. For example, ecological dynamics provides a multi-dimensional theoretical framework that allows for an integrated explanation of athlete behaviour, encompassing numerous scientific disciplines and recognising that athlete behaviours are coupled with information from the environment and their interactions with it [16,38].

The breadth of scientific disciplines encompassed in the present review provides some insight into how combining approaches, by using mixed methods and/or interdisciplinary approaches, would enable multiple valid accounts of a phenomenon by improving trustworthiness, dependability, confirmability, transferability and authenticity in research [21]. There is a place for quantitative laboratory-based research that examines specific elements of performance, just as there is equally a place for qualitative investigations exploring the nuances and meanings that shape the decisions and actions of a athletes in competition [30].

To be competitive at the elite level, a cyclist needs a high level of physiological fitness, but team managers, coaches, and athletes seeking to improve performance should give attention to features beyond those of the individual. Competitive performance is also constrained by tactical features emerging from the inter-personal dynamics between cyclists, strategic features related to the competition, and global features related to the organization of the sport.

CHAPTER 5:

PERFORMANCE CHANGES IN THE PRESENCE OF OPPONENTS

This chapter comprises the following paper [submitted for publication] in Psychology of Sport and Exercise: Phillips, K. E., Corban, R.M., & Hopkins, W. G. The Influence of Opponents in Elite Cycling Races: A Qualitative Analysis**.**

5.1 Overview

Introduction: Athletes are known to change their behaviour and performance in race events that permit competitor interaction, but the mechanisms of these changes remain relatively under-explored. The purpose of this study was to compare cyclists' perceptions of the factors underpinning their performance and chances of success in solo time-trials with those in race events characterised by interpersonal competition. *Method:* Utilising a qualitative methodology and assuming a critical realist ontology and epistemological position, we conducted semi-structured interviews with 15 elite cyclists from three cycling disciplines, all of which incorporated solo time-trial and racing formats. Cyclists were interviewed with regards to the factors they retrospectively considered to have modified their chances of success in both event formats in actual competitions. Inductive and deductive content analyses were used to analyse the transcribed interviews and create themes and sub-themes from the data. *Results:* The responses of the interviewees indicated that the presence of opponents in race events led to perceptions of an increased cognitive load and other psychological changes, changes in the assessment of optimal energy distribution, an increased focus on tactical execution, and changes in perceptions of risk. These effects were modified by environmental and task constraints, as well as a cyclist's perceptions of their own capabilities, which together shaped their decisions and behaviours during competitions. *Conclusion:* In events characterised by interpersonal competition, cyclists' decisions and actions are dependent on the actions of their opponents, providing insight into the mechanisms responsible for previously observed changes in performance between solo time-trial and race events. The results of the current study provide further support for taking a systems approach to investigate the complex interplay between performers, their opponents, and the race environment.

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DECLARATION OF CO-AUTHORSHIP AND CO-CONTRIBUTION: PAPERS INCORPORATED IN THESIS

This declaration is to be completed for each conjointly authored publication and placed at the beginning of the thesis chapter in which the publication appears.

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I declare that the publication above meets the requirements to be included in the thesis as outlined in the HDR Policy and related Procedures – policy.vu.edu.au.

[redacted]	14/07/2020
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3. CO-AUTHOR(S) DECLARATION

In the case of the above publication, the following authors contributed to the work as follows:

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2. They take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

3. There are no other authors of the publication according to these criteria;

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Name(s) of Co-Author(s)	Contribution (%)	Nature of Contribution	Signature	Date
Dr Rod Corban	10	Assistance with conceptual work and study development, pilot interview observation and revision, review of manuscript	[redacted]	14/07/2020
Professor William G. Hopkins	5	Review of manuscript		14/07/2020

5.2 Introduction

A race refers to any competition where two or more athletes start together from the same point and compete against each other for the win. In a race the goal is to cross the finish line before your opponent(s), whereas in a time trial, cyclists compete independently of each other, and the goal is to complete the course in the shortest time. The direct interaction permitted between opponents in racing contests results in behavioural dynamics not evident in time trials, as cyclists continually adapt to the actions of their opponents and the changing structure of the race environment [1–3]. Furthermore, the presence of opponents in elite competition is known to alter the predictability of athlete performance [18,53,57,58,98,144], yet the mechanisms underlying these performance changes have received limited attention in the research literature, particularly in race events where opponents are able to directly interact. The aim of the present study was to address this oversight in the literature.

Studies examining the performance of elite cyclists have adopted predominantly a traditional reductionist approach and examined the performance of individuals in lab-based experiments or solo time trials [44–46,79]. While these studies have resulted in a large body of research characterising features of individual cyclist performance, less is known regarding how well these features transfer to the performance of cyclists competing in race environments. In recent years there has been increasing recognition that performance emerges from interactions between the athlete and their environment, and a call for research that considers the system as a whole, rather than reducing performance to its various components [160]. Ecological dynamics and complex-systems approaches have been advocated as paradigms that may help us better account for and explain the interactions, causative mechanisms, and processes underpinning athlete performance in competitive environments [5–8,16,155,159,161]. Given that most cycling formats permit interaction between opponents, it seems important to better understand how performance emerges in competitive racing environments and the factors regulating the decisions and actions of athletes in these events.

Various experimental laboratory studies have explored the effect of competitor presence on athlete behaviour and performance [144,162–165]. These studies have examined the changes in participants' behaviour and performance during cycling time trials under different race conditions, including the addition of visually simulated competitors. A majority of these studies recorded an improvement in time-trial performance in the presence of competitors, an effect attributed to modifications in pacing, motivation, fatigue tolerance, and attentional focus. Studies investigating the influence of opponents on the performances of athletes in actual competition and in events with more than one competitor remain relatively rare. Brown [18] illustrated that 800- and 1500-m runners modified their pacing strategies during a race to improve efficiency, conserve energy, reduce the psychological burden, and disrupt the perceived pacing preferences of their opponents. Similarly, Thiel and colleagues [166] found the pacing strategies and competitive tactics used by middle-distance runners (800- to 10,000-m) differed according to the goal of the race: in races where the goal was to be first-across-the-line (rather than record the shortest possible time) runners modified their speed in response to the position and pacing of their opponents. Konings and Hettinga [10] also found that aspects of the competitive environment, including the number of competitors in a race, modified racing behaviour. While the presence of an opponent is known to influence performance in both interactive and non-interactive competitions, the mechanisms underpinning these performance changes, and whether these changes remain evident in the complex environments that characterise professional cycle racing, remain to be seen.

To adequately capture, assess, and understand the complex dynamics that characterize sporting contests, multiple approaches will be necessary [19]. Using semi-structured interviews to gather the perspectives of athletes provides another dimension to understanding the dynamics of performance in competitive racing contests, building on existing knowledge from experimental and quantitative research studies [18,19,167,168]. The potential of interview data to provide enhanced detail and understanding of sporting performance has been demonstrated by researchers such as Mouchet [168], who highlighted the complex and emergent nature of decision making of elite rugby players during a match. Brown [18] also demonstrated the usefulness of combining qualitative and quantitative research techniques, using semi-structured interviews to provide insight into the contextual features influencing 800- and 1500-m runners' behaviours and decisions during competitive racing. Qualitative investigations of the athlete viewpoint enable us to build an in-depth insight into the complex circumstances surrounding the emergence of particular behaviours [169].

In this study we explore a number of the issues not addressed by the current research on the effects of opponents on performance. First we investigate performance utilising a representative study design to increase ecological validity, exploring the experiences of cyclists in real world competition rather than in an experimental laboratory setting. Secondly, we examine perceptions and attitudes of elite performers, who are experienced in their disciplines and familiar with the task demands. And finally, the inclusion of Omnium and ProTour cyclists enables us to provide insights into races involving multiple opponents, and in the case of ProTour cycling, the presence of teammates.

5.3 Methods

5.3.1 Philosophical Underpinnings

As research-practitioners with backgrounds in both quantitative and qualitative research, our work is underpinned by critical realism, based on the principles of 'ontological realism, epistemological relativism and judgemental rationality' [32: p.414]. We hold that knowledge is a social construct and that we, as researchers, influence its development. Equally we argue that behind the subjective and socially-influenced knowledge we are able to access as researchers, there is a real and knowable reality, with causal mechanisms that give rise to observable events and phenomena [31,33]. In the interest of reflexivity, we note that our position and prior experience mean we bring inherent biases to this research. The primary author's experience working in a support role with elite cyclists as part of the national training programme led to the development of this research project, with the intent of addressing the limitations of the existing research on athletic performance in complex racing events. Her co-authors also have extensive experience in elite performance research and practice, one in a support role with elite athletes across numerous sporting codes for over 20 years and the other with more than 20 years of experience with quantitative assessment of athletic performance. Malterud [83] notes that professional experience and knowledge provide a valuable lens, and for this study, it was our professional experience and work within the field that enabled us to gain access to, and interview, cyclists of such high calibre. The primary author's professional relationships with the interviewees also helped to ensure a sufficient level of trust and rapport was established, and to encourage honest reflections from the cyclists. We also recognise that the findings we present in this paper represent our interpretations of the athletes' experiences.

5.3.2 Participants

A purposive sampling scheme was used in this research project, with sample selection and size designed to provide in-depth insight and information on the factors affecting cycling performance from elite cyclists who had competed at the highest levels in their respective disciplines [21,31]. The research protocol and consent to undertake the research was approved by the Ethics Committee of Victoria University, Melbourne, Australia. The high-performance director of the national cycling federation granted consent for the athletes to be approached in person or via e-mail to seek interest in participating in this study. Sixteen cyclists were contacted and given an outline of the research project, which explained the process, including the intent of the research, how the project would be conducted, how the information would be used, and a request to notify the researcher of their interest in participating. Fifteen cyclists (11 male, 4 female) agreed to participate in the study, all of whom were 'elite', in that they had competed at either two or more World Cup or World Championship competitions in track cycling, or had completed one or more seasons as a professional at UCI ProTour level. The total sample consisted of three groups according to cycling discipline: Match Sprint (n = 5; mean age, 27 y; age range, 25-30 y; 80 % male), Omnium (n = 4; mean age, 27 y; age range, 25-27 y; 75 % male), and ProTour road cycling (n = 7; mean age, 30 y; age range, 25-35 y; 71% male). The cyclists had a combined total of 34 World Championship medals, 22 Commonwealth medals, and 8 Olympic medals. Match Sprint and Omnium cyclists were all of the same nationality, while the road cyclists were of three different nationalities, which are not disclosed here to protect their anonymity.

5.3.3 Interview Schedule

A semi-structured interview schedule was developed to guide and prompt the cyclists to comment on (a) the factors they were focused on when competing in solo time-trial events, (b) the factors they were focused on when competing in race events involving interpersonal competition, and (c) their perceptions of the factors that determined who won in each of these types of events. The interview guides were adapted slightly between each of the three cycling disciplines to reflect the nuances of each, with the most relevant schedule used for each athlete according to the discipline they had primarily competed in. Each schedule included core questions asked of all interviewees, questions specific to their particular discipline to elicit information that gave specific insights and enabled comparisons between disciplines and events, and probing questions that prompted more detail and depth of discussion. Two pilot interviews were conducted with international-level coaches who had previously competed as cyclists at the elite level (Match Sprint and endurance track cycling). Both pilot interviews were conducted in conjunction with one of the co-authors, and feedback from the coaches and co-author was used to refine the interview schedule and content. Additional probing questions were then added to the interview schedule.

5.3.4 Data Collection

Each cyclist provided signed informed consent prior to commencing a retrospective semi-structured interview with the primary author at a location and time the cyclist had selected. The cyclists were asked a series of open-ended questions with follow up prompts to explore their experiences of racing at the elite level and their perceptions of what determines success in their cycling discipline. All cyclists elected to answer all questions, and none withdrew their participation in the study. With the exception of one interview, which was conducted by phone for logistical reasons, interviews were face-to-face and ranged in length from 55 to 120 minutes, with the average interview taking 77 minutes. All interviews were audio recorded and transcribed verbatim. Transcripts of the interviews were sent to cyclists so they could add, delete or make changes. To respect the anonymity of the cyclists their real names and identities were replaced with coding.

5.3.5 Data Analysis

The aim of our study was to examine how the presence of opponents in elite competition affected cyclist performance and provide insight into the mechanisms underlying the changes in performance predictability in race events. Thematic inductive content analysis was used to provide a systematic and objective means of exploring the interview data and develop initial themes [31,170]. The first stage of analysis involved a thorough reading and re-reading of the transcribed interviews to become familiar with the data and identify statements where cyclists discussed factors they considered to affect their performance and chances of success. Statements were open coded before being grouped and categorized around central organizing concepts [31] into higher-order themes using NVivo Qualitative Analysis software (Version 12, 2019, QSR International Pty Ltd) [170]. Following the initial complete coding of the data set, we conducted a second pass of selective coding [31], identifying statements that were related to time-trial performance, and categorising these separately from statements that were related to performance in events permitting competitor interaction. The analyses were segmented into two parts to reflect the intent of the original research question and the interview schedule. In the first part, which forms the focus of this paper, we focused on the changes in cyclists' articulations when discussing optimal performance in solo time-trials against optimal performance in races involving direct interaction with opponents. The second part, in which we took a broader view of the data, will be addressed in a subsequent paper. A systematic review of existing research from a range of academic disciplines investigating elite cycling performance in competitive race environments [171] was used to cross-validate the themes that had been constructed during the inductive content analysis. Using deductive reasoning at this stage of the analysis enabled the abstraction of higher-order themes into appropriate performance dimensions and helped to enhance the credibility and trustworthiness of the themes and sub-themes, acting as a form of triangulation [31,169,170]. The next phase of analysis involved actively exploring and critically analysing the differences and similarities in cyclists' responses between these coding groups, and attaching descriptive labels that represented our interpretations of the latent meaning in the data. Any features that emerged during the coding process that did not fit within the themes and categories determined from this process were noted, discussed, and considered by the research team for potential inclusion as new categories. The process of defining the themes and sub-themes and grouping the features was a recursive one, moving repeatedly through inductive analyses (familiarisation with data, generation of the codes, grouping of the coded data into categories) and deductive analyses (reviewing the categories against the academic literature, evaluation and refinement of categories, development of higher-order themes and sub-themes) until coherence was achieved between the data, the literature, and our interpretations.

5.3.6 Research Quality

Given our ontological and epistemological stance, the criteria we used to enhance the dependability of the research were selected based on their appropriateness for the context and purposes of this project [31,172]. We drew on the following list of criteria: worthy topic, meaningful coherence, generalizability, rich rigor, and credibility [169]. In fitting with our positioning within critical realism, a topic can be considered worthy if it provides 'thoughtful in-depth research with the objective of understanding why things are as they are' [33: p.119]. It is acknowledged both anecdotally and within the research literature that cyclists' performances in solo timed events differ from their performances in the more complex racing events involving direct interaction with opponents, and this project enabled us to generate new insights into the causal mechanisms driving the differences. The selection of semi-structured interviews as a method of data collection enabled us to elicit rich descriptions of the phenomenon of interest, and to dig below the surface of what can be observed. Methodological coherence was achieved by using a recursive and reflexive analysis process in which information and descriptions from the cyclists were 'synergised' [173] with findings from existing academic literature and our experience and knowledge of the sport. Next, generalizability was supported by adopting a purposive sampling scheme, resulting in a sample consisting of male and female athletes from three cycling disciplines. Furthermore, inductive content analyses allowed us to develop themes across the data, rather than in the responses of specific cyclists, which met the intent of our goal in conducting this research and identifying themes common to cyclists as a group. In keeping with epistemological assumptions of relativism, rich rigor and coherence were achieved by capturing multiple voices on the topic, including not only the experiences of the athletes, but insights gathered from findings in previous literature related to the topic (which had used various theoretical lenses) and our lenses as research-practitioners. Incorporating multiple theoretical lenses acts as a form of triangulation that enabled us to produce a richer view of the phenomenon in question and added to the perspectives and multiple versions of the reality that we then used to shape the conceptual work underpinning the findings we present [31,169].

5.4 Results and Discussion

Four themes emerged summarising the differences in cyclists' responses when discussing performance in solo time trials and race events for their respective cycling disciplines. These themes were psychological changes, altered considerations of optimal energy distribution, an increased focus on tactical execution, and changes in the perception and tolerance of risk. Quotes from cyclists are used to provide examples of these performance changes throughout the discussion, with emphasis added to highlight the relevant point.

5.4.1 Psychological Changes: Arousal, Motivation, and Cognitive Load

Differences were evident in cyclists' perceptions of optimal arousal, motivation, attentional focus, and cognitive load in the events where opponents were able to interact, indicating that the presence of opponents had a substantial effect on psychological aspects of performance.

5.4.1.1 Arousal Level

In the shorter distance time trials of the Match Sprint and Omnium competitions, there was a perception amongst the cyclists that it was beneficial to be *fired up*, owing to the maximal nature of performance in these events. As time-trial distances lengthened to 3 km or greater in the Omnium and Pro-Tour competitions, the cyclists perceived a lower level of arousal to be beneficial to their time-trial performance, as being over-aroused could lead to cyclists adopting a pace that was unsustainable. In contrast, being over-aroused was perceived to be detrimental to performance in all of the race events, regardless of race distance, with sprinters and the ProTour cyclists using terms such as *focused* or *calm* to describe the optimal arousal state. The following two quotes exemplify the contrast in arousal states between race and time-trial events:

> You go into a completely, almost polar opposite feel for the Match Sprint and… for that I think it requires [you] to switch off. You need to relax from the intensity of the Flying 200-m that is required and you have to become a lot more fluid with your thinking. You have to actually get to a state where you back yourself, where you feel sharp and alert but you're not too alert. (Sprint Cyclist 3)

> I see the calmness in some riders you know? Like in a really pressured situation when I am in the same situation thinking 'I want to get the [expletive deleted] out of here' they're riding down this hill in a bunch which is altogether, close, knowing there's a really important part of the race coming up, and I'm thinking 'how the [expletive deleted] am I going to stay here?' like, it's scary, you know? But they're calm. (ProTour Cyclist 1)

A number of the cyclists referenced how features of a competition, such as the perceived depth of field or quality of their opponent, race importance, and *parcours* (terrain) could affect their arousal leading into an event. An cyclist's levels of confidence and self-belief also altered their arousal and perceived chances of success, particularly for the four female cyclists. The two female track cyclists described feeling more confident in their time-trial performances, because they felt more of the variables were under their direct control; when it came to racing opponents, they felt an increase in nervousness and pressure, which they considered to negatively impact their performances. The two female Pro-Tour cyclists had teammates who would share the workload in the race events, but described an increase in nervousness and pressure in the lead up to a time-trial events. Their perception was that time trials were 'a race of truth' and 'everyone could see how bad or good you're going' and when they lacked confidence, they discussed doubting their abilities, overthinking situations, and making more mistakes. In summary, the responses of the cyclists indicated that optimal arousal across the various cycling disciplines was influenced by the presence of opponents but also modified by features of the competition environment and race structure.

5.4.1.2 Motivation

> If you're side by side with someone you could probably get a little bit… I mean, potentially get a little bit more out of your body just with someone there… yeah, yeah, or someone in front of you, you're always… you're always going to get that

> slight bit more out of yourself I think. And I don't think that's a physical thing, that's got to be a mental thing. (Sprint Cyclist 2)

Five of the cyclists described a change in mindset that seemed to occur when they were racing an opponent, believing they could get more out of themselves when racing against someone else or when a major prize was on offer. The increased motivation provided by the presence of an opponent was not unique to the racing events, with one Omnium cyclist describing the increase in motivation she felt when competing against a top-ranked opponent in the Individual Pursuit. The cyclist described catching glimpses of her opponent on the opposite side of the track and the motivational boost it gave her, because being able to see the other cyclist meant she was riding strongly. The perception of an improved time-trial performance for this cyclist reflects what has been found in a number of controlled laboratory experiments, where participants improved their time-trial performances in the presence of a non-interactive racing opponent [162,163,174].

The presence of opponents appeared to improve motivation in head-to-head racing, the individual pursuit, and to some extent, in mass-start Omnium races, but with increasing race length and number of opponents, motivation decreased. In assessing the cyclists' responses further, it appeared that their motivation was more dependent on their perception of their chances of success and the constraints imposed by the structure of the overall competition, rather than the presence of their opponents per se. In head-to-head racing, cyclists were highly motivated to beat their opponents as losing a race (or a best of three) had high consequences, with the losing cyclist eliminated from the overall competition. In the Omnium, the competition winner was determined by cumulative finish ranking in all six events, and consequently cyclists began to weigh the cost of the effort required to win an event against their perceptions of their opponents' capabilities, their chances in that event, and their chances in the overall competition. The responses of the Pro-Tour cyclists further highlighted the influence of contextual features on motivation, with the presence of an opponent only motivating if the cyclist was in contention for the win. ProTour cyclists described the struggle to remain motivated or to mentally 'get up' for a particular stage if they perceived their physique or skillsets to be unsuited to the terrain, their opponent(s) to be better suited to the terrain or stage, the team goal to be on a subsequent event or stage, or if they had already 'done their job' supporting the team leader:

> I think if you've got a chance to be in the results you're a… much better bike rider. If you've got no chance, there's plenty of days where you are literally just surviving. And ah… of course you do the job to the best you can and sometimes… sometimes you're on your knees, just, absolutely got nothing left and you're just trying to survive to get through… but I definitely do believe that if you're up for a result, you're a different bike rider. (ProTour Cyclist 4)

Although some experimental studies have linked competitor presence to improvements in athlete performance, these studies have tended to examine only head-to-head competition [144,162–164,175]. In the complex environments that characterise professional cycling, most race events are situated within a tournament structure, where the winner is determined by cumulative ranking (relative performance) after numerous races against multiple competitors, rather than absolute levels of output [176]. Tournament theory stipulates that a pure strategy equilibrium, where all athletes choose the same level of effort as the best strategy response, exists only when all opponents perceive themselves to have an equal chance of winning. Where athletes' abilities are known to one another and differ, the athletes will weigh the cost of expending effort against their own levels of talent, the effort and abilities of their opponents and the potential rewards [177]. Rational participants will select racing strategies (Section 5.4.3) that allow them to maximise their chances of success [177], and where participants perceive their opponents to be significantly stronger, they have been known alter their competition goals rather than trying to win [175]. Connelly and colleagues [176] argue the importance of integrating tournament theory with other theories, such as expectancy theory and social network theory, to explore how an individual's beliefs and values will shape their perceptions, motivations, and willingness to expend effort in a tournament setting.

The effects of competitor presence and tournament structure on cyclists' motivation could explain the increased race-to-race variability observed in the performance of cyclists in events where opponents are able to interact [53,58,98]. In the time-trial events of the Match Sprint and Omnium, and in the head-to-head races of the Match Sprint, there are limited opportunities for cyclists to capitalise on the presence of opponents, which incentivises cyclists to deliver a maximal performance. Accordingly, qualification time-trial performance is highly predictive of overall competition performance in the Match Sprint [98], but in events that permit a substantial amount of competitor interaction, such as the mass-start events of the Omnium, the greater race-to-race variability observed [58] may be a result of changes in athletes' motivation and perceived chances of success.

5.4.1.3 Attentional Focus and Cognitive Load

During time-trial events the cyclists were predominantly focused on internal cues related to their rate of energy expenditure and technical execution. External cues, such as the number of laps remaining, were used to monitor and regulate effort levels. Cyclists had an awareness of technical aspects of their opponents' performance and finish times, but noted the importance of sticking to their planned strategy and not letting an opponents' performance change what they did. On the other hand, during race events the cyclist's focus shifted to primarily external cues, such as the location, speed and actions of opponents, the remaining race distance, and upcoming features of the race, such as a sprint lap or a change in terrain. Cyclists described continually assessing and responding to the actions of their opponents and the collective behaviour of the *peloton,* a term used to describe a group of cyclists that ride as a pack or a bunch to benefit from the advantages of drafting [110,171], Cyclists considered a key characteristic of the top cyclists was their ability to make accurate and quick assessments of the constantly changing and dynamic environment. This ability to 'read a race' was perceived to develop with increasing race experience. The best cyclists were thought to be able to pick up cues that other cyclists might miss and respond instinctively:

> We had a guy, [cyclist name removed], he was the kind of guy that would go with one move, like… there would be a million attacks and he'd go with one and he'd be in the break… There'd be a group of us trying to be in the break and I would try a hundred times and then just see him go with one group. And you're like, 'oh what?!'… And then you'd hit him up afterwards. You know, 'how do you do that?' but then… he'd be, he'd just say stuff like 'oh, I could just… feel like it was going'. (ProTour Cyclist 3)

The presence of opponents was perceived to increase the number of informational sources cyclists had to attend to, adding uncertainty to the external environment and making races harder to predict and train for. The increase in uncertainty resulted in a perception of heightened cognitive load, leading to increased feelings of mental fatigue and a perceived impairment in cyclists' ability to perform. A number of the cyclists described the mental fatigue associated with racing, and while top performers appeared to be adept at dealing with it, the less experienced cyclists described how it affected them:

> You ride [expletive deleted] rides because you're mentally fatigued, because you're tired… then well, if one's bad then the other two will be bad. So if you're physically poor then you're probably mentally tired and then your tactics are [expletive deleted]. So um… and if you're mentally [expletive deleted] then your tactics will be [expletive deleted] and ah… you won't use your body to its proper physical state. (Sprint Cyclist 4)

Increases in duration, intensity and complexity of a task have been shown to increase cognitive load and lead to impaired performance [178,179]. For the majority of cyclists in the current study, there was a perceived increase in cognitive load as races lengthened and the number of opponents increased. Renfree and colleagues [180] argue that part of the reason athletes engage in collective behaviour, epitomised in cycling events by the emergence of pelotons, is to reduce the requirement for continuous decision making and assist in reducing perceptions of cognitive load and fatigue. Expert performers appear to have a cognitive superiority when it comes to complex tasks and a higher resistance to mental fatigue in comparison to novices [181,182]. The responses of the cyclists in our study supported this notion, as they described how the most successful cyclists appeared less affected by the increased cognitive load and mental fatigue of the race events. Researchers exploring the concepts of social facilitation have also noted that improvements in performance due to the presence of opponents are altered by task complexity [183,184]. In situations where tasks are familiar or simple, the presence of others will often result in performance improvement, while in situations where the task is complex or unfamiliar, performance is likely to be impaired in the presence of others [183,184].

5.4.2 Energy Regulation and the Opportunities for Efficiency

The ability to directly interact with opponents provided opportunities for energy efficiency, with cyclists able to position themselves behind their opponent(s) in the race events and thereby benefit from the aerodynamic advantages of drafting [9]. The cyclists believed effective use of the drafting and positional resources enabled them to reduce the accumulation of fatigue and improve their chances of success. Consequently, while pacing was a key theme across all formats, the presence of opponents in race events modified the way cyclists regulated their energy expenditure.

5.4.2.1 Pacing

Pacing is referred to as the mechanism by which an individual balances the execution of a task against the known task demands and perceived physical capabilities [185]. The cyclists described having clearly defined pacing strategies leading into time trials, aiming to distribute their energy as effectively as possible across the race distance in order to record the fastest time. In time trials of up to 1 km in the Match Sprint and Omnium competitions, cyclists described using 'all-out' pacing strategies for the timed section, although there was some discussion of pacing in the lead-in laps for the time trials with flying starts. In the 4-km individual pursuit of the Omnium, cyclists perceived even-pacing strategies as being optimal. In the ProTour individual time trials, variable pacing strategies were used, with cyclists carefully considering where to expend and where to conserve energy across the race distance. In particular, the cyclists described regulating their energy expenditure according to the perceived demands of the upcoming course features (particularly in reference to terrain) and the total race distance. Across all three cycling disciplines the perception was that time trials were won by the cyclists who were in the best physical condition on that day. Although poor technical execution was perceived to be detrimental to time-trial performance, cyclists didn't believe that good technical execution could make up for a lack of physical capability:

> Physically you have to be able to win an IP [individual pursuit]. You can't show up in bad condition and get through on tactics or gear decision or any equipment. You still have to be, like… the same with time trial on the road, they're not very tactical

> at all they're just… you have to have plans from before… but… yeah, you just have to be physically good. (Omnium Cyclist 1)

When it came to race events, the cyclist's regulation of energy expenditure was clearly modified by the presence of, and ability to interact with, opponents. The presence of other cyclists enabled drafting to occur, whereby the cyclist could reduce the energy cost of maintaining a particular speed by riding in the slipstream of other cyclists [9,65,119,146]. The cyclists discussed balancing the potential risks, rewards and physiological demands of their position and actions against the relative positions and actions of their opponents and the constantly evolving race environment. In the Match Sprint competition, the cyclists described being acutely focused on the actions of their opponent, and discussions centred around the merits and disadvantages of 'leading from the front' or 'riding from the back'. In the mass-start races of the Omnium, where up to 24 opponents competed simultaneously, regulation of energy expenditure was modified by the actions or inactions of opponents and of the peloton. The frequent attacks and pace changes amidst the cyclists in the peloton made it much more challenging for the cyclists to manage their energy expenditure.

5.4.2.2 Opportunities for Efficiency

Without the benefits of drafting in solo time trials, there were limited options to recover from an action that wasted energy resources; accordingly, technical errors were perceived to have high consequences. As performance in these events is measured against the clock rather than first-across-the-line, technical errors are compounded, because every second counts towards the final result. Conversely, the aerodynamic benefits of drafting and pack riding provided opportunities for energy efficiency in the race events. The presence of opponents and non-timed structure appeared to soften the effect of making mistakes and to provide cyclists with a chance to succeed through effective positioning:

> If you're not perfect all the time... it doesn't really matter. And even if a break goes in the first half of a scratch race…that could come back so that didn't affect you at all. So even though you weren't there and you needed to be, because the outcome is done on positions, when you go over the line, …it doesn't matter what happened the rest of the race, it's where you finished up at that point, on the end of those 40 laps. (Omnium Cyclist 4)

The Omnium and ProTour cyclists perceived the top cyclists to be very effective at positioning in the peloton and riding in a way that prioritised energy conservation, allowing these cyclists to save energy for more critical moments in the race:

> And also those people who can put themselves in good positions. They might not be a… you know, they might not have performed well in the IP but they can be kind of like, sneaky, and they can sit in there, in the middle of the bunch and they're quite confident with themselves, sitting in there, sitting behind people and everyone else does more work but they just, kind of just move, they can move themselves well in between people to not use much energy. (Omnium Cyclist 4)

An additional advantage for the leaders of ProTour teams was that they had teammates (known as *domestiques*) whose entire focus during a race was on helping them to optimise their efficiency and deliver them to the *finale* with as much energy as possible. The influence of team work was clearly evident in the discussions of the ProTour cyclists, whose considerations about energy distribution were shaped by their role in the team. Most cyclists considered it to be their 'job' to expend their energy resources in service of their team leader:

> It's all about protecting that leader so that all that he has to focus on is that at a certain point he goes. And at that point he's got full energy stores. And so anything from chasing a break,… making a break… whatever it is that is going to save him energy… You know, the leader's actually got a pretty simple job. He's just got to get to the final without wasting too much and he has a chance to win. (ProTour Cyclist 1)

5.4.2.3 Fatigue Management

Dealing with accumulating fatigue was a major consideration for the cyclists, who discussed having to manage their energy resources not only during the event, but throughout all events of a competition. In time-trial events, drafting behind an opponent wasn't an option, and fatigue management was focused on correct pacing and technique. In Match-Sprint tournaments, the one-versus-one, knock-out structure of the racing also provided limited opportunities for efficiency. Drafting opportunities were minimal when racing a single opponent over such a short distance, and cyclist's felt they had to give maximal effort, because if they lost, they were eliminated from the competition. In contrast, for cyclists in the Omnium, success was predicated on cumulative ranking across all six events, and a poor result in one event did not preclude them from winning the overall competition. Drafting opportunities abounded for Omnium cyclists, who described managing their energy resources in order to limit fatigue and conserve energy for the 'critical' and decisive moments in any particular race. If a breakaway or an attacking move by opponents was unlikely to threaten an cyclists overall standing, they often deemed it more prudent to save their energy for countering moves by cyclists who did threaten their chances of success:

> You'd be thinking before [the race]… [doing well in] the scratch race would be good but I don't want to be completely buggered at the end of it cos I've still got five events to go. (Omnium Cyclist 3)

In multi-day stage races, ProTour cyclists were similarly focused on limiting fatigue and managing their energy resources across the various stages of the competition in order to be competitive in the decisive moments of the racing. Stage characteristics, tour length, the team leaders current ranking, team goal(s), and competition importance, all modified cyclists consideration of energy use, highlighting the influence of race context on energy considerations. The effect of contextual features on performance was particularly evident in Pro-Tour and Omnium cyclists discussions of how they approached stand-alone races in comparison to those that were part of a multi-race competitions:

> A stage race generally comes down to mountain top finishes or time trials. Because that's where you take time. Whereas a one-day race you have peloton of two-hundred that you need to thin down over the space of four or five or six hours. You know?... so if it comes to a person like me, and I'm in a support role, that means… absolutely emptying the tank in a one-day race… minimising the, the cost to the number one rider, the leader. When it comes to a stage race it's quite the opposite. The finish line isn't till a couple of weeks away… and you're purely trying to make things as easy as possible for you and your whole team to not lose time. (ProTour Cyclist 2)

Pacing during competitions has received considerable attention in the academic literature, with numerous researchers exploring the optimal pacing for athletes competing in solo time-trial events [141,186,187]. A recent review by Konings and Hettinga [188] provided a comprehensive overview of the effects of interpersonal competition on the pacing considerations of athletes and demonstrated the influence of race structure on athlete performance. In head-to-head competitions where athletes were able to interact, the authors showed there was a clear interdependency in athletes' pacing behaviours, and opponents' actions modified pace selection. In competitions with more than one other opponent, examples of group synchronicity became apparent, evident in cycling races with the emergence of pelotons in the mass start events [188]. The results of the present study provide further evidence that athletes adapt their pacing and energy regulation according to features resulting from the presence of, and ability to interact with opponents, in addition to modifying features of the competition, race format, and terrain.

5.4.3 The Emergence of Tactics

There was a shift in emphasis from strategy in time-trial events towards tactics in the race events, as cyclists responded to the actions (or inactions) of their opponent(s) during the race. Despite often being used interchangeably, the terms strategy and tactics are distinct, with the fundamental difference being their relationship to time [168,189,190]. Strategy refers to planning actions prior to task execution in order to organise an activity towards achieving a particular goal [185,189]. Tactics refer to what occurs within a race, 'a punctual adaptation to the new configurations of play… an adaptation to the opposition' [187: p.166]. In time trials cyclists had clear strategies focused on technical execution and pacing considerations. Cyclists were able to rehearse and train the technical elements of time trials for months preceding the event, experimenting with different approaches and working with their support team to determine a strategy that best suited their form, a particular track, and the environmental conditions on race day. By the time it came to competing in the event, cyclists had strategies for how to execute the ride in order to record the race time they believed they were capable of:

> Before an IP we would look at the conditions. What's the track running like? What's the temperature? What's the pressure? And then we would think, you know, with these conditions, look at historical data and see what had you done in these, similar conditions, when you've been in this kind of form? And then work out what time you're going to do and then we'll work on the lap splits back from there. (Omnium Cyclist 4)

When it came to race events, the dialogue about planning and strategies shifted, particularly for the Match Sprint cyclists, who believed having a planned strategy was *detrimental* to race performance. The sprint cyclists felt it was more important to be able to adjust rapidly to the opportunities presented during the race:

> I don't like the thought of having a plan. Um… you need to understand what you're up against. You need to understand your opponent… so there are certain, certain factors that you keep track of. So to have, yeah, a bit more of a fluid mindset than a concrete plan is quite key. (Sprint Cyclist 3)

The Omnium cyclists still appeared to use some sort of strategy going into the race events, which they used to evaluate tactical opportunities during the race. For example, one Omnium cyclist made a plan to look for opportunities to 'take a lap' in the earlier stages of the scratch race, because she didn't consider herself fast enough to be in contention should the race finish in a bunch sprint. Cyclists also based their race strategies on where they sat in the overall standings, which altered their tolerance for risk and the type of tactical moves they were willing to make (see Section 5.4.4). In this sense, Omnium cyclists' strategies were linked to perceptions of their physical capabilities, the likely format of the race, and perceptions of opponent capabilities and preferences:

> For the points race you would think about where you were sitting and what kind of points you needed to move up. Um… for me I was quite a way down in the rankings coming into the points race so I knew that, you know, the five points that you'd get for winning a sprint was not going to be enough and a complete waste of energy so I just need to take those laps and look at those opportunities to take them. Either, you know, I would go into it and look at, 'ok, who would ride the race similar to me?

> Who needed to get laps?' So I would look at going with those people um… to get laps with them. (Omnium Cyclist 4)

Once racing was underway, Omnium cyclists described looking for opportunities to gain an advantage over their opponents and improve their chances of success in the race or overall competition. Tactical opportunities were perceived to be both given (luck) and created (skills), and a cyclist's chances of success in executing a tactical move was tied in with many contextual modifiers: the actions of opponents, collective behaviour of the peloton, a cyclist's ranking going into the race, their goals and motivations, distance elapsed, speed and variability in the pace of the race, competition importance, and crashes.

In ProTour racing, the dialogue was also balanced between strategy and tactics. Cyclists described how their teams would go into a race or competition with a clear plan of what they wanted to achieve, who they were riding in support of, and which stages they would target. Although teams and cyclists tried to control the race, the cyclists described how the unpredictable nature of racing prevailed, and that it was a team's tactical execution that determined whether their leader stayed in the running for the overall title (or whichever goal they had set for themselves). Both Omnium and ProTour cyclists found it helpful to have a strategy going into races events, but felt that they had to be able to adapt to the changing configurations of the race to be successful:

> It might just be that, for whatever reason, you had an idea in your head 'I'm going to wait until this, this sort of time to attack', and then somebody else attacks and you think 'well hang on, I might just go with him because life will be a lot easier if there's two of us'…[or] it might just be that… the pace is just so high for the entire duration of the race that there's simply… zero opportunity to attack. That you just end up waiting for the sprint because you haven't had an opportunity to do anything else. (Omnium Cyclist 3)

The concept of affordances, a tenet of ecological dynamics, provides an explanation for this shift from strategy towards tactics in events where direct interaction between opponents is permitted. Affordances refer to the fleeting opportunities for action an athlete may perceive at any given moment, based on the coupling between perception, action and the current constraints of the performance environment [191]. The interaction permitted between opponents (and teammates) in race events leads to continual changes in the temporal and spatial constraints of the performance environment, altering the best course of action for an athlete at any given moment [82,191,192]. Athletes are known to adjust their competitive tactics according to the behaviour of their opponents and features of the competition [18,166,193]. The results presented here provide further support that an individual's goal orientation and motivation together influence and regulate behaviour in relation to the actions of opponents [185].

5.4.4 A Whole Lot of Risk and a Little Bit of Luck

The final major theme that emerged was a difference in cyclists' perceptions of the role that risk and luck played in their chances of success when racing directly against opponents. In time trials across all three cycling disciplines, risk was perceived to play a minor role in a cyclist's chances of success, and luck was perceived to play no role at all. In the race events, the ability to interact with opponents substantially increased the perceived risks, with cyclists discussing the risk of crashing, the physiological risks associated with expending too much energy at the wrong time, and the contextual risks associated with current ranking or losing time to key opponents during a race. There was also a concession from the cyclists that sometimes they just needed a little bit of luck in the race events.

5.4.4.1 The Risk of Crashing

The risk of crashing or colliding with opponents had a strong effect on a cyclist's decisions and actions during a race. Cyclists discussed the importance of being able to manoeuvre their bikes in close proximity to their opponent(s), hold an aerodynamic position at high speed, avoid collisions, and take opportunities (such as a gap between two cyclists) when they arose. The perception was that a cyclist with strong bike handling and technical skills could maximise the benefits of drafting while keeping the risks of crashing to a minimum:

> Ah… you've got to have the ability to come over someone close, to be able to… sit shoulder-to-shoulder, and I mean, if you're the second wheel coming over someone, you're travelling further than they are, so it's about… making that margin as little as possible, so you're travelling the least amount of distance. Um… running at a wheel. Making the most of the draft that you get from someone who's in front of you, and being able to move your bike right at the last minute to, to get that extra km/hr. (Sprint Cyclist 2)

The risk of colliding with opponents had various effects on performance, depending on the cyclist's personality, skillset, and motivations. Each of these altered the perceived value of particular positions and altered the opportunities perceived by an cyclist during the race. The most successful cyclists in the race events were perceived to be those who could tolerate the risk of crashing, were able to hold their nerve when things got tight and pushy, and moreover, were willing to take risks with where they positioned themselves. Cyclists with a higher tolerance for risk saw opportunities for action where other cyclists might hesitate:

> Some people are more scared to crash than others and you can also use that as an advantage. If they have a handlebar under them or over them they're generally going to back out of there. And that's the thing in an Elimination. You have to take those

> risks. It's the same like, a bunch sprint in the World Tour, like if you don't take those risks you won't be there. You'll be a minute behind for sure. (Omnium Cyclist 1)

Some elements of colliding and crashing were attributed to a lack of skill, but there was also a perception that sometimes a cyclist was just unlucky. In a time trial, if a cyclist made a technical error that resulted in a crash, it was their own fault, but in a race, they might do nothing wrong but get taken down in a crash caused by somebody else. That was 'just racing'.

5.4.4.2 Perceptions of Physiological Risk

When athletes misjudge their energy expenditure, they risk approaching levels of homeostatic disturbance leading to a progressive reduction in their physiological capabilities prior to the completion of the race [146]. Cyclists acknowledged this risk in discussions of solo time-trial and racing performance, but the extremes to which cyclists were willing to push themselves varied depending on the presence of opponents. As highlighted earlier, cyclists approached time trials with clear pacing strategies, which had been developed with the intent of maximising performance output while minimising the physiological risks. When it came to racing, the physiological output that would be required was unknown, as the pace of a race was dependent on the actions of the other cyclists and collective behaviour of the peloton. Cyclists had to make decisions on energy use without knowing how the rest of the race would unfold. Opportunities came and went, and cyclists had to weigh up the physiological risks of making a tactical move against the potential rewards. Luck was perceived to play a role in whether taking a physiological risk paid off, and a number of cyclists described 'taking a gamble' during a race, hoping it would unfold a certain way. For example, one Omnium cyclist described making a gear-ratio choice on the assumption that the race would finish in a bunch sprint. It subsequently did, and the cyclist felt she had 'more to step on' than her opponents in the bunch sprint, leading to a better placed finish. Other cyclists described taking risks that didn't work out:

> I tried to take a lap [break away and lap the peloton] and it didn't work. If I was to take a lap now I'd go in with a slightly different approach… [instead of] just pushing myself too far into the red zone too soon with trying to take the lap as quickly as possible, now I'd just button it off a bit and ride it in a more controlled way. (Omnium Cyclist 3)

Contextual features of the race and competition modified the degree of physiological risk cyclists were willing to take. In the head-to-head races of the Match Sprint competition, the short race distance and typically high finishing speeds meant cyclists felt there was no opportunity to recover if they made their move too soon in the race. While each cyclist had an incentive to be the first to make the move, both also had an incentive to leave it until the last possible moment. The cyclists described the importance of committing to a move once they had made it, explaining that it was better to make the wrong move with 100% commitment than make no move at all. For the Omnium and ProTour cyclists, the longer race distances meant these cyclists felt they had more opportunity to take physiological risks during a race. Cyclists described being able to make an attacking move such as a breakaway attempt, and if they were caught by the peloton, they were able to position themselves towards the rear of peloton and use the draft of the group to recover, before having another attempt later in the race. There was a risk in the longer race events, that if they made an attack too early and spent a lot of energy, they might not be able to recover from that effort sufficiently, and risked getting passed, 'dropped' (i.e., off the back of the peloton), finishing last, or not finishing at all. Conversely, not taking a tactical risk or making a move too late in the race meant you risked never making an impact or being caught behind other cyclists and finishing mid-field:

> It depends on how far through the race you are. Um... cos you know that the further into the scratch race, the more fatigued people will get. Um… I think the highest risk would be trying to get a lap up either five laps in, once everyone is settled and ready to race, or sort of, [with only] eight laps to go when the race has been pretty sedentary. (Omnium Cyclist 2)

5.4.4.3 Risk and Relative Ranking

In the race events, both on the track and in the ProTour, cyclists' rankings relative to their opponents clearly affected the degree of risk they were willing to adopt during the race. In the Match Sprint and Omnium competitions, cyclists who were lower in the standings and perceived they had 'nothing to lose' were more willing to take bigger tactical risks to move up the standings. As always, there were contextual modifiers, particularly with regards to the competition format and the consequences of winning and losing. If a cyclist was sitting in a good position in the overall standings, or was one race up in the Match Sprints, they tended to adopt more conservative approaches towards risk. In the final event of the Omnium, which at the time of the interviews, was the points race, the effect or relative ranking was particularly evident:

> Like someone sitting in 3rd, they're probably, you know, they potentially could try to take a lap but that's far too risky. They've got a lot more to lose because they're already sitting in that medal position… so they'll just try to, I guess, stay around those other ones. But when you're further down you take those risks because, you know, I guess, the reward outweighs the risk you're willing to take. (Omnium Cyclist 4)

In the ProTour, there were strong indications from the athletes that cyclists and teams weighed up their goals and ambitions against the current general classification (ranking based on each individual's accumulated race time), the upcoming terrain, what other teams had achieved, and whether it was worth expending energy for a result. Any move by an opposition team or cyclist was weighed against the potential threat or risk it might pose, and whether it was worth the effort to shut it down, let it go, or attempt to join it:

> You just need to look at [the attacking cyclists] and see whether they're going for the stage, which generally you… ok, if they're far enough down on the GC [general classification], meaning if they've lost enough time in the days preceding then… you might be happy to let them go. Whereas if we've decided that we want the stage today or we want to go for the stage then it needs to be someone that we think we can bring back relatively easily. (ProTour Cyclist 2)

Research from the fields of economics and game theory provides insight into the effect of opponents and competition structure on an athlete's behaviour and risk tolerance. Tournament theory provides an explanation for why maximum effort and motivation is observed in the head-to-head Match Sprint races, while in mass-start races and multi-day stage racing, effort and motivation levels are more tempered. In competitions with 'full symmetry'[194], such as that of the Match Sprint tournament, both players have an equal incentive to exert maximal effort, as both need to win in order to proceed [194–198]. In contrast, in tournaments with intermediate prizes or where the winner is determined from a series of cumulative efforts, such as in the Omnium or ProTour stage racing, a contest asymmetry occurs. In these competitions, the cyclist with the existing advantage (e.g., due to a good result in a previous stage) tends to adopt a strategy of loss aversion, favouring performance behaviours that enable them to defend their existing advantage, while reducing the risk of loss. The influence of interim ranking on risk taking and performance has been explored in a number of sports, including weightlifting, chess, diving, and golf [196,198,199]. Genakos and Pagliero [196] noted there was an inverted-U relationship between an athlete's interim rank and performance, finding that professional athletes took greater risks when ranked close to the first-placed athlete. The adoption of lower risk strategies by those with lower interim ranking may reflect that these athletes consider themselves to be 'out of the running', adopting safer strategies and conserving effort for a subsequent event or competition.

5.5 Conclusions

The cyclists' responses indicated their decisions and actions during a race were dependent on the behaviour of their opponents and were modified by features of the competitive environment. The presence of opponents in race events led to a perceived increase in cognitive load and other psychological changes, adjustments to considerations of optimal energy distribution, an increased focus on tactical execution, and changes in perceptions of risk. These changes provide some insight into the mechanisms responsible for the increased race-to-race variability observed in the performance of track-cyclists in events where opponents are able to interact [53,58,98]. In the time-trial events of the Match Sprint and Omnium, and in the head-to-head races of the Match Sprint, there were limited opportunities for cyclists to capitalise on the presence of opponents, and cyclists were motivated to deliver a maximal performance. In contrast, cyclists in the mass-start events of the Omnium and ProTour modified their effort according to actions of opponents, tactical features of the race, and perceptions of both risk and chances of success. In professional road cycling, cyclists' decisions and actions were further modified by the presence of teammates in a race, their designated role, the team's goal, and features of the competition structure and racing terrain. The results of this study also provide further support for the recent assertions of Konings and Hettinga [188] that in events characterised by interpersonal competition, athletes' decisions and actions are dependent on the actions of opponents, modified by features related to the competitive environment and the goals and motivations of the athlete.

5.5.1 Limitations

A limitation of using retrospective interviews to explore the perceptions and practices of elite cyclists, is that we are reliant on cyclists being able to accurately identify and articulate the factors influencing their performance in complex race events. It is difficult to know whether the cyclists accurately described the factors that influenced their chances of success, or whether the factors identified were a result of post-hoc rationalisation. Gouju and colleagues [200] noted that the subjective human experience still presents information that is worthy of research, and when combined with other research approaches, can provide potentially useful insights into elite competition performance. It is also important to recognise that, rather than defining success in any particular way, we allowed the cyclists' perceptions of what constitutes performance success in their disciplines to drive the discussion. Correspondingly, the descriptions of performance success varied and shifted across the course of the interview, at times referring to winning a particular race or event, at other times the tournament, or in other moments referring to features that determined whether they had a successful season or career. Rather than being a limitation, we believe there is an advantage to having such a broad definition of success, in that the cyclists' responses provided some unique insights into the influence of higher order dimensions (e.g., reward and social mechanisms) on their decisions and actions during a race [171]. Exploring performance success in this way also provided insight into the nested nature of constraints [192] and support for the concepts from tournament theory [176].

5.5.2 Future Directions

The purpose of this study was to explore differences in the perceptions and practices of elite cyclists when competing directly against opponents in contrast to competing in solo time trials. A cyclist's decisions and actions during a race were clearly dependent on the behaviour of their opponents and modified by features of the competitive environment. In attempting to understand how performance emerges in complex race environments, the results of the current study provide support for taking an ecological-dynamics approach, recognising there is a complex interplay between the performer, the environment, and multiple dimensions over which constraints exist [16,171,188,192]. A recent review by Phillips and Hopkins [169 and Chapter 4] provides a summary of the dimensions and features known to regulate performance in elite cycling competition, and gives some indication of the breadth of factors shaping observable performances. Whilst the results of the current study indicate the presence of opponents clearly modifies the decisions and actions of elite cyclists, a follow-up study will explore the wider context surrounding the performance of these cyclists. A better understanding of the wider context will enable practitioners and athletes to improve training and identify opportunities for development.

CHAPTER 6:

INITIAL SYSTEMS MODEL OF DETERMINANTS OF ELITE CYCLING PERFORMANCE

This chapter comprises the following paper [not yet submitted but to be submitted for publication]: Phillips, K. E., Hopkins, W. G., & Corban, R.M. An empirical study and initial systems model of the features influencing competition performances of elite cyclists**.**

6.1 Overview

Background Despite a considerable body of research investigating the factors underpinning the performances of elite cyclists, researchers have tended to examine isolated characteristics of the individual athlete in environments lacking contextual relevance. In this study we adopted a holistic ecological dynamics paradigm, with the aim of identifying features influencing a cyclist's performance in the broader context of the complex environments in which they compete. *Design* Assuming a critical realist ontology, we used a qualitative research approach to develop an initial systems model of the features influencing competition performances of elite cyclists. *Methods* Semi-structured interviews were conducted with 15 elite cyclists to provide insights into the factors perceived to influence success in elite competitive racing. Utilising a combination of inductive and deductive content analyses, interview data were open coded before being organized into initial categories. Themes were developed from the categories and additional sources of data: a completed analysis of interviews with the same cyclists focused on the influence of opponents on performance; publications of variability of performance in solo time trials and race events involving direct interaction with competitors; and a published systematic narrative review of prior literature exploring the determinants of cyclists' performance in elite competition. These analyses led to the development of four interrelated dimensions, which were used to organise the features perceived to influence cyclists' performance in elite competitions. The dimensions and features were integrated to form an initial systems model to illustrate the multidimensional nature of performance and the interaction between features. *Results* While performance in time trials is determined largely by features in the individual dimension, including physiological, morphological and psychological attributes, performance in race events is less predictable due to additional features in the tactical, strategic and global dimensions. These include tactical features emerging from the inter-personal dynamics between cyclists, strategic features of the broader competition context, and at the global level, economic, socio-cultural and authoritarian features. The systems model developed to describe competition performances of elite cyclists accounts for the non-linear contributions of the features and of their interactions within and between dimensions across various time scales. *Conclusions* The performances of elite cyclists are strongly influenced by features of the complex environments in which they compete. Those seeking to train cyclists for such events should focus on developing not only an individual's potential but also the ability to respond appropriately to the dynamic racing environment, the social constraints and the cultural constraints of the sport.

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In the case of the above publication, the following authors contributed to the work as follows:

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Name(s) of Co-Author(s)	Contribution (%)	Nature of Contribution	Signature	Date
Professor William G. Hopkins	10	Review of manuscript, Assistance with revision of initial systems model	[redacted]	14/07/2020
Dr. Rod Corban	5	Assistance with conceptual work and study development, pilot interview observation and revision		14/07/2020

6.2 Introduction

Sports performance research aims to understand the performance of elite athletes with a view to enhancing chances of success [7]. In the considerable body of research investigating the factors underpinning the performances of elite cyclists, authors have tended to focus their analyses on factors related to the individual athlete [41,85,201]. Furthermore, the traditional reductionist approach of isolating and examining components of performance in laboratories or experimental settings means our understanding of the features influencing the performances of elite cyclists lacks contextual relevance. In elite cycling, a majority of the competition disciplines sanctioned by the UCI are race events, characterised by the direct interaction permitted between opponents. In such events, the time taken to complete the race distance is inconsequential, and the race win is typically awarded to the competitor who crosses the finish line first. Moreover, racing in many competition disciplines occurs in a tournament format, with cyclists having to compete in numerous rounds of racing, or across multiple stages, from which the competition winner is determined.

Notwithstanding the contribution of reductionist research, our understanding of the factors shaping the performance of elite cyclists in actual competitive racing environments is far from complete. For example, although a number of researchers have investigated the influence of opponents on the time-trial performances of elite cyclists, the studies have been conducted almost exclusively in simulated laboratory experiments, with cyclists riding stationary bicycles against simulated opponents [144,162,163,165,202,203]. These simulations lack contextual relevance, with many of the environmental influences and constraints of actual competitive racing environments removed. It is therefore likely that the observed performances will be only partially representative of what would be observed in elite races [38,85,201]. Furthermore, recent research by Konings et al. [188] and Phillips et al. [202 and Chapter 5] has demonstrated that elite athletes adjust their performances according to features of the competition environment, and that performer-environment interactions are essential determinants of athletes' decision-making processes. These findings align with recent calls for sport researchers to find more encompassing rationales that enable the multidimensional, diverse and interrelated aspects of competitive performance to be considered in concert [16,38].

The complex-systems paradigm has been proposed as a more appropriate research framework for sports researchers, positioning athletes and sports teams as complex adaptive systems that self-regulate according to the context they operate within [16,27,37–39]. Complex systems are comprised of multiple heterogeneous components that interact dynamically with one another at varying intensities and across different spatio-temporal scales, continuously adapting and changing their behaviour to fit the emerging constraints [27,28,40]. Levy [40] defined a complex system as 'one whose component parts interact with sufficient intricacy that they cannot be predicted by standard linear equations; so many variables are at work in the system that its overall behaviour can only be understood as an emergent consequence of the holistic sum of all the myriad behaviours embedded within' [p.7-8]. For example, McLean et al. [4] identified that a football match could be characterised as a complex system, developing a model to illustrate how different factors interact to influence and determine match outcomes in football. Similarly, Trenchard [120] characterised the peloton in elite cycle racing as a complex system, where interactions between multiple components (the cyclists) result in the emergence of collective patterns of behaviour (riding together in a group), and where the system self-regulates according to features of the competition environment. These examples provide support for the complex-systems paradigm, illustrating that some aspects of athlete and team performance will be evident only if the observed performances remain coupled with the information-rich environments that allow certain behaviours to emerge [40].

Ecological dynamics has been advocated as an approach that supports complex-systems thinking, emphasising the performer-environment relationship and the emergent properties of athletic behaviour [16,27,38]. Seifert et al. [16] promoted ecological dynamics as a multi-dimensional framework allowing for an integrated explanation of athletic behaviour that encompasses numerous scientific disciplines. The authors outlined three important aspects of ecological dynamics that make it appropriate for the study of athletes and sports teams as complex systems. First, it allows for non-linearity and non-proportionality in coordination and performance. Secondly, it considers the interactions between the physical and cognitive behaviours of a human system and the environmental context in which the system is acting. Finally, it recognizes that an athlete's behaviour is coupled with information from the competitive performance environment and their interactions with it [16,38]. The benefits of ecological dynamics have been demonstrated in a number of recent studies, where authors have developed models to illustrate the multi-dimensional and nested structure of the constraints shaping an individual's behaviour, while simultaneously ensuring their personal characteristics are not overlooked [37,192,205–207]. For example, Henriksen et al. [37] studied how athletic talent is nurtured in the broader environment in which the athlete, team or club is embedded, identifying features acting not only at the level of the individual athlete (micro-level), but also features of the performance environments and broader socio-cultural contexts in which athletes exist (macro-level). Hulme et al. [206] also illustrated how constraints acting at higher-order levels could impact the development and prevention of running-related injuries.

In elite cycling, we have a limited understanding of how features of the race environment and broader socio-cultural context of the sport shape the performances of cyclists and their chances of success. In two previous quantitative studies we established that features beyond those of the individual performer were contributing to performance, particularly in the more complex race events [58,98]. In Match-Sprint tournaments, the skills and abilities that enable a cyclist to perform well in the solo time-trial strongly predicted a cyclist's chances of success in one-versus-one races, although there was evidence of other factors modifying a cyclist's chances of winning

[98]. In the Omnium, there was little transfer between performance in solo time-trials and mass-start races involving multiple opponents [58]. Reproducibility in the performances of cyclists in the more complex race events of the Omnium was also poor, suggesting additional factors contribute to performance in these events. The completed analyses of the semi-structed interviews that form part of the current study [204] indicated that interactions between opponents in mass-start cycling races have a strong influence on the performance of elite cyclists, suggesting that tactical and strategic factors contribute to the differences in an athlete's performances between non-interactive and interactive events. Further investigation is warranted to determine 'how athletes operate relative to a diverse set of interrelated physical, cognitive, psychosocial, environmental, and wider systemic influences'[40: p.215], and in elite cycling, to understand how features of the race environment and broader socio-cultural context of the sport affect the performance of cyclists in complex race events. The present investigation was undertaken with the intention of constructing knowledge in this area and advancing our current understanding of the features influencing cyclists' performances in the more complex formats of elite racing.

6.3 Methodology and Methods

6.3.1 Philosophical Assumptions

As research-practitioners, our intent is to conduct research that advances current knowledge and provides accurate and useful information to those athletes, coaches, teams, and organisations seeking to improve chances of success in elite competitions. We recognise our experiences lead us to bring inherent biases to this research, and that the findings we present represent our interpretations of the athletes' experiences. However, our knowledge as academics and practitioners also provides a valuable lens through which to gather insights into topic at hand. We have therefore adopted a critical realist ontology, allowing us to retain a belief that there is a 'real and knowable world which sits behind the subjective and socially-influenced knowledge' we are able to access as researchers [30: p.27]. Our work is grounded in a relativist epistemology, in that we assume knowledge emerges from context and reflects our position as researchers [31,33]. Within this framework, we determined a qualitative methodological approach would enable us to explore the subjective experiences of elite cyclists and provide novel insights into the features determining cyclist behaviour in elite competitive racing. The benefits of exploring the subjective human experience to provide insight into athlete performance have been emphasized by a range of authors [18,19,167,168,200]. Our epistemological stance led us to blend inductive and deductive content analysis techniques, using data from multiple sources in order to construct knowledge in this area and advance our current understanding of performance in complex racing events. In addition to the interview data, a narrative synthesis of existing academic literature and our reflections and subjective viewpoints as researchers were also used to support and cross-validate the analyses.

6.3.2 Participants

Interview data were collected as previously described for the study of the effect of opponents [204]. In brief, we adopted a purposive sampling scheme with the aim of selecting participants who could provide in-depth insight and information-rich data [31] on the features influencing performance in elite competitive racing. Following approval from the Ethics Committee of Victoria University, Melbourne, Australia, and with the consent of the high performance director of the National Cycling Federation, the first author approached 16 cyclists within the national high-performance program, either personally or via e-mail, to seek interest in participation. All 16 cyclists met the criteria of 'elite', having competed in either two or more races at UCI World Cup or World Championship level in Track Cycling, or having completed one or more seasons as a professional cyclist at UCI World Tour level in road cycling. An outline of the research project was sent to each cyclist, explaining the project, what would be asked of the cyclist, how the project would be conducted, how the information would be used, and the potential risks of participation. Fifteen cyclists confirmed their interest in participating and were subsequently contacted to establish a date and time for the interview at a location of their preference. The primary author's existing professional relationships with the interviewees helped to ensure rapport was sustained throughout the study, and assurances of confidentiality helped encourage honest reflections from the cyclists regarding their racing experiences [208]. The 15 cyclists (11 male, 4 female) had raced in at least one of the following cycling disciplines at the elite level: Match Sprint (n = 5; mean age, 27 y; age range, 25-30 y; 80 % male), Omnium (n = 4; mean age, 26 y; age range, 25-27 y, 75 % male), and World Tour road cycling (n = 7; mean age, 30 y; age range, 25-35 y, 71% male). The cyclists had a combined total of eight Olympic medals, 22 Commonwealth medals, and 34 World Championship medals. To respect the anonymity the cyclists, their real names have been replaced with numerical identifiers, and any references to teammates, coaches, or nationality removed.

6.3.3 Interview Schedule

Semi-structured interview schedules were developed to prompt interviewees to comment on: (a) their perceptions of what it takes to win the event; (b) their reflections of personal performances in time trials and race events and their perceptions of how they prepared for and raced these events, including reflections on why they believed they achieved the results they had (presented partly in [13] and Chapter 5, with the focus on opponents); and (c) their perceptions on 'trainability' of 'performance factors' they had referenced in the earlier stages of the interview (not presented in this thesis). Interview guides were adapted slightly to reflect the nuances of each particular cycling discipline. The interview schedule included core questions, clarification questions, and probing questions that aimed to elicit responses that would allow cross-discipline comparisons and provide insight into the factors influencing the competition performances of individual cyclists in each discipline. Pilot interviews were conducted with two international-level coaches who had formerly been cyclists and had raced at the elite level. Both pilot interviews were conducted in the presence of one of the co-authors, who had considerable experience in qualitative research. Feedback from the coaches and co-author was used to refine the interview schedule and questioning process. Additional probing questions were subsequently added to elicit more detail from the schedule and facilitate depth of discussion.

6.3.4 Data Collection

All participants provided informed consent prior to the interviews commencing. Cyclists were not obliged to participate and were permitted to withdraw their participation at any point, but none elected to do so. One interview was conducted by phone, while the remaining 14 interviews were conducted face-to-face. All interviews were audio recorded and ranged in length from 55 to 120 min, with the average interview taking 77 min. All interviews were transcribed verbatim and sent back to each cyclist for review.

6.3.5 Data Analysis

Transcribed content was initially assessed using inductive content-analysis techniques, which enabled us to explore the interview data in a systematic and objective way and to develop initial categories and themes [31,170]. Transcribed interviews were read and re-read to identify statements where participants discussed factors they considered to affect their performance and chances of success, or that of other cyclists, during elite races and competitions. Using NVivo qualitative analysis software (Version 12 , QSR International, Cheshire, UK), cyclist statements were open coded before being grouped and categorized. Following the initial inductive content analysis, a systemic review of existing academic literature was conducted to enhance the credibility and trustworthiness of the initial categories and themes [171] and Chapter 4. The literature was used to cross-validate the categories previously identified, a method of deductive reasoning that acts as a form of triangulation and enabled the abstraction of the categories into higher-order themes and appropriate performance dimensions [31,169,170]. The process of defining the categories and themes and of grouping the features was a recursive one, cycling through inductive analyses (familiarisation with data, initial generation of the codes, grouping of the coded data into categories) and deductive analyses (reviewing the initial categories against the academic literature, evaluation and refinement of initial categories, development of higher-order themes and sub-themes) until coherence was achieved between the data, publications, and our interpretations. Any elements of performance that did not fit within the developing framework were noted, discussed, and considered by the research team for inclusion as new categories or themes. The analyses were segmented into two parts to reflect the intent of the original research question and the interview schedule. In the first part, we focused on the differences in cyclists' articulations of the features that influenced performance in solo time-trials and races involving direct interaction with opponents. The results of these analyses have been presented previously

[13] and Chapter 5. In this paper, we present the second part of the qualitative data analyses, in which we took a broader view of the data to gather the perspectives of the cyclists on the features they believed to influence performance and chances of success in elite cycling in general.

6.3.6 Creation of an Initial Systems Model

The cyclists identified 176 features that influenced their decisions and actions during a race and modified their chances of success. These features were grouped into 40 categories and clustered around central organising concepts that became themes [31], before being organised into specific analytical domains under higher-order performance dimensions (see Figure 6.1 for the hierarchy of the groupings, with an example of each). During the analysis we made memos within NVivo noting the links and interactions evident between features, and subsequently utilised the mapping feature to better visualise the connections between features, themes, domains and dimensions. We also noted any contradictions we found in the interviewees' statements, or between the statements of different cyclists during the analysis, for further discussion and review.

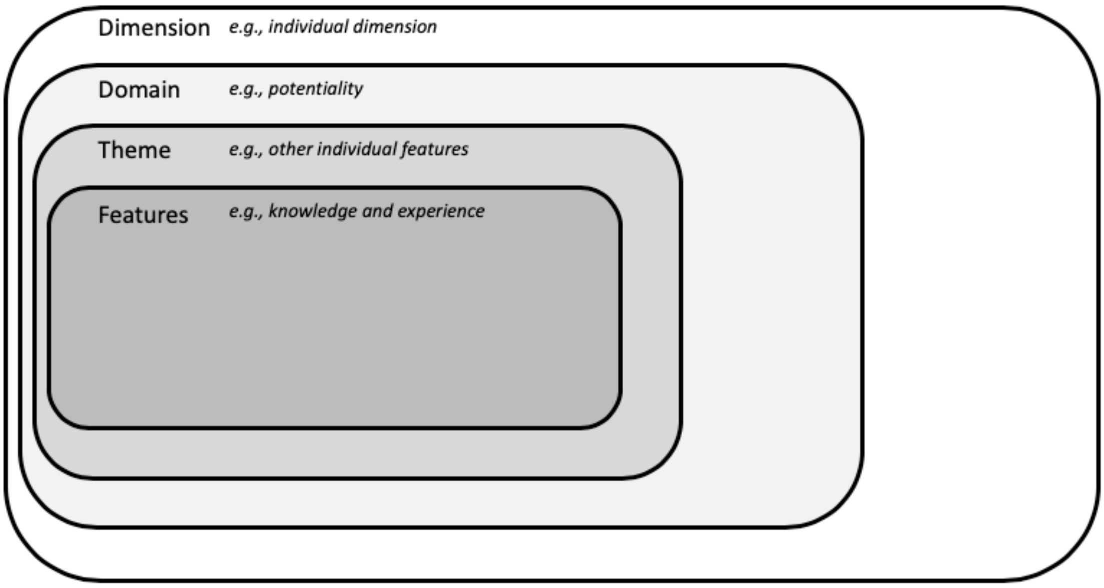

Figure 6.1: Nested Hierarchy of Groupings used to Categorise the Features Identified by Cyclists as Influencing Their Chances of Success in Elite Competitive Racing, Showing the Example of how the Feature 'Knowledge and Experience' was Categorised Within this Framework.

In order to show the multidimensional and interactive nature of the features influencing performance, we formulated an initial systems model (Figure 6.2). The model underwent continuous scrutiny in the latter stages of the analysis, with multiple iterations during drafting of this manuscript. Both co-authors provided constructive critique of the model's structure, analytical levels and interactions. Comparisons between the model, publications, the interview transcripts, and the authors' combined experience and knowledge were continued until no further insights were gleaned. In order to enhance the quality and rigor of the developed model, we gathered the perspectives of other skilled experts who acted as 'critical friends' [43] to challenge the conceptual work and our interpretation of the data. These critical friends included the principle coaches of two national cycling programmes, and a highly experienced lead sport scientist-practitioner with experience in the cycling industry (among others). While a detailed discussion of all features identified through this process is beyond the scope of this paper, we highlight those features that received the most emphasis from the cyclists during the course of the interviews and which present the most relevant insights to answering the research question [209]. We acknowledge that despite our critical analysis and collective efforts to appropriately convey the mechanisms underpinning cyclist performance in complex events, our findings and the model we propose represent our interpretations of the cyclists' articulations. We recognise the importance of further research work to widen the representation of nationalities, genders and cycling disciplines beyond those in the sample, in addition to adding the viewpoints of professionals other than the cyclists (e.g., coaching and management).

6.4 Results and Discussion

The features influencing the performances of elite cyclists in competitive elite racing were grouped into four higher-order performance dimensions [171]. At the micro-level, the individual dimension contained features of the individual cyclist related to their performance capacity and to the decisions and actions they made during a race. The tactical dimension contains features that emerge from the continual interactions between individuals and the changing race environment. The strategic dimension contains features of the competition or race environment that shape the decisions of a cyclist, team, or organisation, both in advance of, and during the racing. And finally, at the macro-level, the global dimension contains economic, social-cultural, authoritarian, and other global features that shape the behaviour and decisions of governing bodies, race organisers, cycling teams, sponsors and the cyclists themselves. In the process of grouping and categorising the various features, the interconnectedness between dimensions, domains, themes, and features became evident, as did the various timescales over which they act (and develop). It should be noted that, while we have assigned features to particular themes and presented a hierarchical model (in part, to aid reader comprehension), many of the features determining a cyclist's action were inseparably connected. Quotes from the interviewees in the subsequent sections illustrate that it is frequently a combination of features acting in concert and

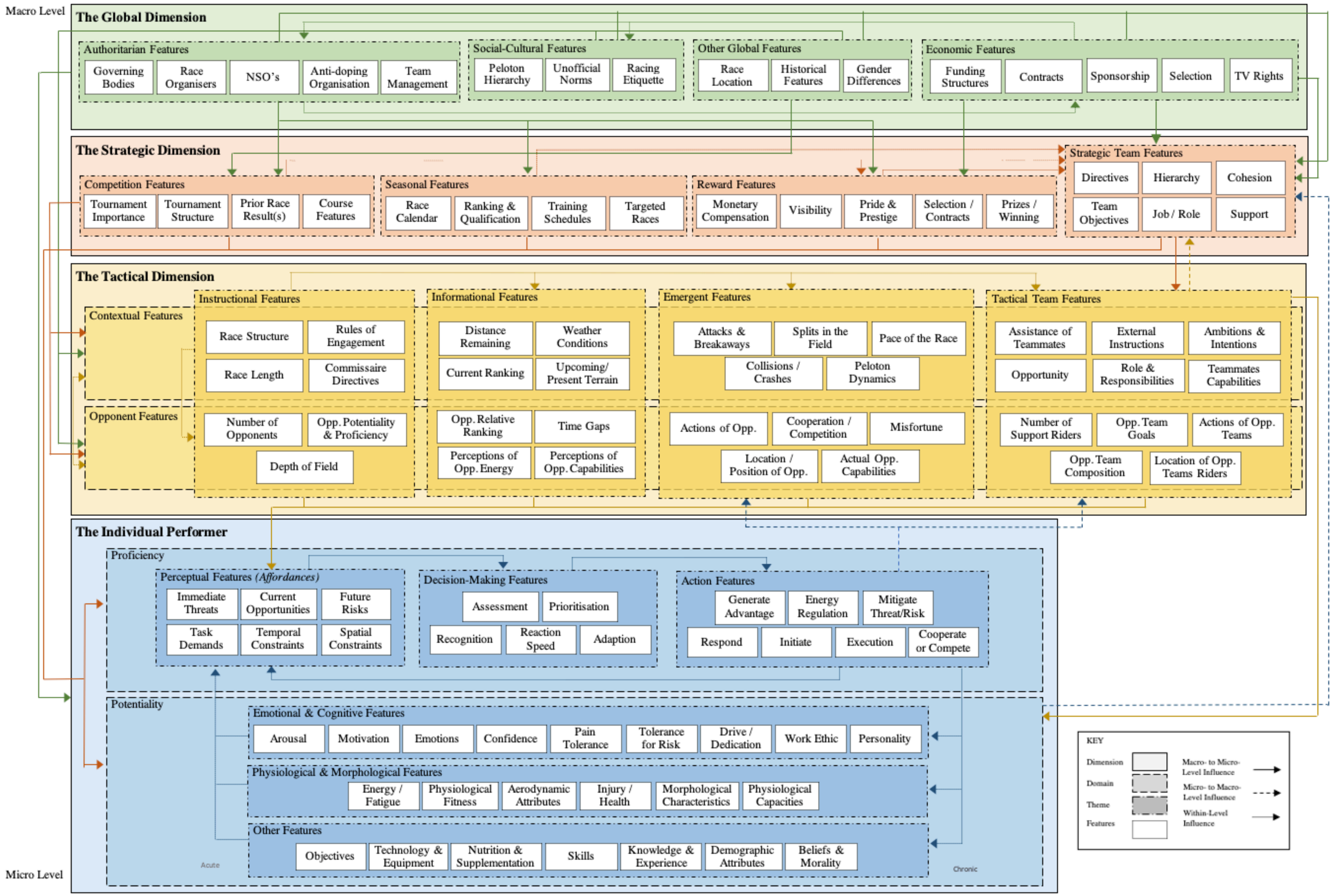

Figure 6.2: Initial Systems Model of Features Determining the Performances of Elite Cyclists in Competitive Elite Racing

relevant to particular timescales that modified cyclists' perceptions of the race environment, what they were able to do within it, and the decisions they made regarding the best course of action during complex racing events.

6.4.1 The Individual Performer

Features of the individual cyclist were perceived by the interviewees to be prerequisites for success in elite cycling. In the process of refining and grouping the features in this dimension, it became evident that there were two analytical domains at the individual level. The first was an individual's *potentiality*, referring to cognitive, emotional, physiological, morphological, and other features that defined the capabilities a cyclist brought to the start line on a given day for a given race. The second domain referred to an individual's *proficiency*, encompassing features related to their perceptions, decisions, and actions during a race and the appropriateness of these in assisting them to achieve their race objectives.

6.4.1.1 Potentiality

The interviewees believed that cyclists had to possess certain baseline characteristics in order to be competitive. We have grouped the characteristics into three themes: emotional and cognitive, physiological and morphological, and other, which act over various timescales. The influence of emotional and cognitive features on a cyclist's performance have been explored by the current authors [171,204] and others [72,114,210], and therefore will not be detailed here. To summarise, in races where competitors are able to interact, there are changes at the acute level to cyclists' perceptions of optimal arousal, levels of motivation, and attentional focus [204]. At the chronic level, a cyclist's personal attributes, including their personality, drive and dedication, work ethic, and ability to tolerate pain also influence their likelihood of performing strongly [114]. As an example, three of the interviewees described competitors who were able to switch between good and poor sportsmanship, and how surprised they were to discover that these competitors, who they had thought to be aggressive and mean spirited, were quite affable outside of racing. As another example, there was a general consensus amongst the interviewees that top cyclists needed a strong appetite for risk, due to the close-contact and high-speed nature of racing:

> It has to be… somebody who's a bit of a daredevil. Someone who's crazy. Someone who's not afraid…to automatically be able to turn off the safety switch that makes you shy away from risk, danger, and want to slow down or put the brakes on… All they see is red. And the finish line. (ProTour Cyclist 2)

Cyclists who were more willing to tolerate the risk of collisions and crashing were considered more likely to be successful, but this tolerance for risk was also believed to diminish with age, which one interviewee attributed to older cyclists often having wives and children to think about, and two others attributed personally to the experience of suffering significant injuries as a result of prior crashes. Nevertheless, increased race experience was perceived positively by most interviewees, leading to feelings of familiarity, a sense of belonging, increased confidence, better decision making, and greater feelings of self-efficacy.

> The more I race the more things start to become second nature. But there is still so many things that I have to consciously have to think about, and that is a limiting factor for anyone in that position. So I think that's why, yeah, experience plays a big role in sprinting. (Sprint Cyclist 5)

The interviewees also placed a strong emphasis on the physical (physiological and morphological) features required to succeed at the elite level; for example, height, weight, muscle fibre type, maximal oxygen uptakes, maximal power output, and endurance capacity. The interviewees had differing beliefs regarding how strongly these features influenced their chances of success in elite racing. For example, Sprint Cyclist 2 attributed 80% of the races he had won to his physical capabilities, while Sprint Cyclist 3 didn't recall a single race where he had won due to physical superiority, other than in non-elite competitions where he believed the physical disparity between competitors was much larger. The Match Sprint cyclists placed a stronger weighting on physical features than the cyclists from the other two disciplines did. In the head-to-head racing of the Match Sprint, if an opponent's qualification time that was more than 0.3 s faster than their own, the cyclists generally believed they could not win, unless their opponent made a mistake. Interestingly, this belief corresponds with the analysis of race data by Phillips and Hopkins [98 and Chapter 3], who found that being the faster qualifier strongly improved a Match Sprint cyclist's chances of winning. The Omnium and ProTour cyclists placed less emphasis on physical features, with most of the interviewees considering the competitors in elite races to be relatively even in this respect:

> Having seen physiological data from multiple different riders and riders who have won big races, you realise that it's actually not that far apart. Like, there is only so far you can go, physiologically, and… maybe the biggest… mental aspect is backing it up day in day out and being tired and being run down and being able to do it at any given point... there's not a huge disparity between the actual physical number done, the power done. (Road Cyclist 4)

The Omnium and ProTour cyclists placed a stronger emphasis on morphological features, which were perceived to limit their chances of success or predispose them to be better suited for certain events, across particular types of terrain, or in certain team roles. For example, all four male ProTour cyclists referenced the limitations of their morphology and where these features positioned them in their ProTeam hierarchy and the role they played within their team.

The term ‘form’ was used by many of the interviewees to describe and encompass the acute condition of their physiological and morphological features on a race day, including their fitness, weight, pre-existing levels of fatigue, and the suitability of their morphology for the racing terrain or event demands. Turning up to the race ‘in good form’ was considered a prerequisite for success in elite racing, and was attributed to the quality, quantity, focus and intensity of training completed leading into the event, in addition to being healthy and free from injury. The trainability of these features highlights the inter-dimensional nature of performance, as training modalities were linked to the directives of coaches, team managers, directors, sponsors and governing bodies at the strategic and global level. The interviewees also referred to the varying timescales over which their training and other strategic and global features can act to influence a cyclist’s potentiality on any given day. For example, the use of periodisation to structure a cyclist’s training load, most often in an attempt to elicit peak performance for a targeted event, illustrated that a cyclist’s physiological fitness varied across the racing season. It is worth noting that the emphasis interviewees placed on physiological features often shifted across the course of the interview, at times being touted as having a strong influence on race outcomes, and yet later in the same interview being relegated to a lesser role as the importance of other features was discussed. These changes in athletes’ articulations may be a result of the multi-factorial nature of performance in complex race events. As the interviews progressed and we sought more detail from the cyclists, including asking for examples and deeper explanations, it is possible the interviewees became more cognisant of other important features.

Features of the individual's potentiality that did not fit into the aforementioned themes were included as ‘other’. At the acute end of the timescale this theme included: a cyclist’s objectives for a given race, tournament, or year; their access to technology and quality equipment; and their diet or nutrition leading into an event, including use of ergogenic aids, be those legal or otherwise. The chronic end of the timescale included: demographic features, such as a rider's nationality, gender, and age; their knowledge and prior race experience; skill level; and their underlying beliefs and acceptance of social norms. For example, all of the interviewees placed emphasis on a cyclist’s bike handling skills, describing the need for cyclists to be skilled at manoeuvring in close proximity to opponents, navigating difficult course features, holding aerodynamic positions while cycling at high speed or under high load, and achieving all of the above while conserving energy. Of note, some of the features that sat within this theme were considered to be necessary but not sufficient to win a race. For example, a number of interviewees described instances where they believed the quality of their equipment or an error in selection of gear ratio (in track cycling) had cost them a chance at the win.

With the exception of demographic and some morphological features (e.g., height), almost all features of a cyclist’s potentiality were perceived to be trainable, given enough time, appropriate training methods, opportunity, and race experience. There was a belief that the top-performing cyclists were well rounded, possessing the full range of cognitive, emotional, physiological, morphological, and other features required to perform strongly, and that these cyclists had learned how to optimise the use of their particular characteristics:

> There is a real art to it. You need to be able to do both [time-trial and race]. And… mentally you have to be very strong 'cos cycling is just a brutal sport. You look at all the hours of a stage race. Add it all up. That's how many hours of competition. Different weather. Different road surfaces. Um… descending. Ascending. It's, it's so… you have to have such a wide range of skill… You've got to be able to handle the pressure. Constantly. Over a week. Two weeks, three weeks. And it's a big mental load. You gotta be able to handle the pressure of a build-up. Training. Like any athlete I guess I'm speaking now. Um… and also you have to be fairly good at um… handling a bike. You know? (ProTour Cyclist 2)

6.4.1.2 Proficiency

In considering what characterised the most successful cyclists in their disciplines, the interviewees described that it was not a cyclist's capabilities within the domain of potentiality (which at the elite level were perceived to be reasonably uniform), but how a cyclist made best use of their capabilities in a given race. A cyclist's ability in the domain of proficiency encompassed features related to their perceptions, decisions, and actions during a race, and the appropriateness of these in assisting them to achieve their race objectives.

Gibson [211] proposed the theory of affordances to explain how the behaviour of an organism depends on its perception of, and its interaction with, the surrounding environment. Affordances are considered to emerge and dissolve according to how an individual both perceives and moves in respect to their surroundings and interactions with others [156,192,211]. The interactions permitted between opponents (and team mates) in the race events of elite cycling led to continual changes in the temporal and spatial constraints [204], and the interviewees described having to continually assess the current race situation and their best choice of action within it. Seifert et al. [16] explained that expertise develops as a result of athletes becoming more perceptually attuned to affordances (opportunities for action) within the competitive performance environment, and as they improve their ability to regulate their behaviour and actions accordingly. In analysing cyclists' recollections of racing, it became apparent that they scanned and assessed the race environment according to three perceptual themes: immediate threats, future risks, and current opportunities. Immediate threats referred to the actions of opponents that posed an immediate danger to the cyclist, be it the risk of a collision, or a direct threat to their chances of attaining their race goal. In contrast, future risks referred to situations in the race environment that invited a response from the cyclist, but in which the threat was not immediately evident. For example, a breakaway attack from a lesser ranked cyclist posed no immediate threat, and there was a risk associated with expending energy to shut down the attack. Current opportunities referred to specific situational moments in which the cyclist perceived they could potentially benefit in some way, gaining an advantage or moving closer to achieving their race goals. If none of these perceptual themes was relevant to the current race situation, cyclists simply conserved their energy for a more critical moment of the race. In this sense, cyclists' perceptions of the threats, risks and opportunities afforded by the racing environment were highly dependent on features in the tactical dimension. For example, whether an attack by a competitor or group of competitors was perceived as a threat depended on tactical features such as the remaining race distance, the capabilities of the breakaway riders, number of attacking riders, and the relative ranking of the attacking riders in relation to a cyclist's own rank.

The most successful cyclists were perceived by interviewees to be characterised by their ability to make rapid, accurate assessments of the current race situation and subconscious fast decisions in their response. Opportunities were considered to be fleeting, and if a cyclist hesitated, the opportunity would be missed. Several of the interviewees stated that the accuracy of the decisions a cyclist made during a race was less important than how quickly and decisively they responded to an opportunity. One of the cyclists summarised the tension between accuracy and speed of cognition in this way:

> You go into a very uncertain event that is extremely fluid and… that requires commitment. Potentially to a wrong decision at certain times… to understand that, and not have that little bit of fear, or that thing in the back of your head that makes you change your decision. You have to get to a state where you back yourself. Where you feel sharp and alert, but you're not too alert. And you can… race off instinct primarily rather than racing off logical thought. Because nine times out of ten logical thought is too slow... It becomes very subconscious… You don't have to think, it just [snaps fingers]…you instinctively know how to react… I guess it's about knowing your surroundings really well. If you don't… you get to race day, coaches tell you what to do, and when something unpredictable happens in the dynamic environment, you're just along for the ride. (Sprint Cyclist 3)

The importance of accuracy in expert decision making was critiqued by Russell et al [212], whose analysis of football referees' decision-making processes indicated that, rather than pursuing accuracy, the referees' decisions and actions were guided by their desire to maintain control of the game and preserve the integrity of the match. The authors concluded that referees made strategic decisions according to the state and context of the game in pursuit of safety, fairness, accuracy and entertainment. Cyclists' decisions during race events appeared to be similarly guided by their pursuit of particular objectives within the transient and dynamic context of the race, with cyclists prioritising their actions according to the risks, threats and opportunities they perceived. In any case, there is no best decision in open dynamic systems, because a decision in any moment has the potential to compromise future decisions, as noted by Araujo et al. [38] in their discussions of expert decision-making in sport.

The interviewees referenced numerous features across all four performance dimensions when describing how they determined what actions to take and the best use of their available energy stores. Cyclists' actions were governed by contextual features of the race, the affordances a cyclist perceived within the current race situation, and their objectives in that particular race, tournament or season. The cyclists had to react and adapt their behaviour accordingly, with the actions they took underpinned by one of the following three motivations: generating an advantage, conserving energy for a more critical moment in the race, or expending energy in order to mitigate a risk or threat. The energy demands of time-trial events were perceived to be well known, and the cyclists described planning their energy expenditure (e.g., setting a pacing strategy) and optimising the set-up of their equipment in advance and to suit the environmental conditions on the day. In head-to-head or mass-start races, it was apparent that the energy demands were an emergent property of the interactions between an individual, their competitor(s), their team mates, and features of the race environment. As has been noted in other sports [38,213], cyclists' actions throughout the race also generated additional perceptual information that constrained and informed their subsequent decisions. In addition to features at the tactical, strategic and global level, features of a cyclist's potentiality (capabilities and skills) also constrained the affordances they perceived and their possible actions. The cyclists described this continual assessment of the current race situation against their regulation and use of energy, for example:

> You're just always analysing what's happening in the race and who's wheel you're on… who's around you… The top contenders will surround themselves, or cluster [together] quite often. And then you'll get… a patch in the bunch that you don't want to be in… because you know that, yeah, if you get stuck behind the wrong people, the race could go away from you. …If there's a group half a lap up but they look like they're mucking around or they've been out there for 5 km, you'd probably, yeah, you'd have to sort of weigh up what's going to happen. If you're going to make it [across the gap to join the breakaway] or not. (Omnium Athlete 2)

Being able to recognise, respond and adapt instinctively to the actions of opponents and the current race situation was defined as the ability to 'read a race' by the interviewees, and was perceived to develop as a result of years of racing experience. Intriguingly, a number of the interviewees commented that their training sessions, either as part of squads in the national track cycling program or as part of their ProTour teams, were ineffective at honing their ability to read a race. All of the interviewees attributed their abilities in the domain of proficiency to having raced and competed in cycling events from a young age. The interviewees felt that it took years to develop the ability to perceive, decide and respond instinctively to the cues around them during a race, a perception that is backed by the research literature [16,214,215].

6.4.2 The Tactical Dimension

The tactical dimension contains features that emerge or are altered by the interactions between a cyclist, their opponent(s), and the race environment. These features shape the decisions and actions of a cyclist *during* the race, whereas strategic features are known in *advance* of the race. Tactical features that modified the decisions and actions of cyclists during race events were categorised into either contextual or opponent features, and then further categorized into four themes; instructional features, informational features, emergent features, and features related to team riding (see Figure 6.2). The development of these themes and their position in the current model is based partly on previous research [156,192].

6.4.2.1 Instructional Features

Instructional features tended to constrain a cyclist's behaviour and limit action possibilities during a race. This theme included features such as race structure and length, rules of engagement, and directives from the race commissaires (the equivalent of a referee in cycling).

UCI regulations define the structure of each event, setting the parameters of the task at hand, dictating whether competitors were able to interact and to what extent, the distance of the race, and how a win was generated. For example, at the time of the interviews, the Omnium was contested by up to 24 cyclists, who competed in six track events across a two-day period, with cyclists awarded points according to their finish rank in each event. Of the six events, three were solo time-trials, and three were mass-start races, with the overall competition winner determined from a cyclist's combined points total at the conclusion of the final event. The responses of the interviewees indicated that the race rules significantly altered their decisions and actions during each event. For example, positions towards the rear of the peloton were strongly valued for their drafting benefits during the Scratch and Points races (unless points were on offer or the race was nearing completion), but in the Elimination these positions were considered unfavourable throughout the entire race, as they placed the rider at a far greater risk of early elimination:

> It's the nature of the event… I really try to get up the front… it's safer in the front, because you can be towards the back and think you're safe and then suddenly you're boxed in and everyone's coming around you and you get… to the line and you've got nowhere to go. You might…still feel really strong, but you've got nowhere to go so… you'll be eliminated from the race. (Omnium Cyclist 4)

UCI regulations also dictate the rules of engagement, constraining the degree of contact permitted between competitors, restricting where on the track or course a cyclist was permitted to ride, and in certain instances, the position they were obligated to maintain. For example, in the head-to-head races of the Match Sprint, the starting position of each rider was determined from a pre-race draw, with the rider who drew the inside position obligated to take the lead off the start line, and for the following half lap the lead rider was not permitted to attempt any manoeuvre that may force their opponent to take the lead. The regulations also stipulated that cyclists could not make manoeuvres that may provoke a collision, fall, or force another rider off the track, and that they must leave sufficient space for their opponent to pass, all of which constrained the options available to a cyclist in any given moment of the race. Race regulations were enforced by commissaires, but cyclists' perceptions of 'what they could get away with' depended on whether they believed the commissaires would remain impartial by enforcing the rules and issuing appropriate penalties. Two interviewees referenced how the enforcement of race rules regulating the amount of contact permitted between competitors had increased during their racing career, and that they had to adapt their behaviour accordingly in order to prevent being repeatedly penalised.

Within the instructional theme, features related to the number of opponents, their capabilities at the individual level (i.e., opponent potentiality and proficiency), and depth of field also altered cyclists' performance considerations. As outlined in our previous paper [210 and Chapter 5], as the number of opponents in a race increased, the number of informational and emergent features a cyclist felt they had to attend to also increased, inducing psychological changes due to a perceived increase in cognitive load, changes to cyclists' considerations of energy use, an increased focus on tactical features, and changes to cyclists' perceptions of risk. Match Sprint cyclists in the current study described being able to focus on their opponent's every move, but in the mass-start and ProTour races, interviewees described assessing the behaviour of collective groups of competitors (e.g., peloton, breakaway). The increased number of opponents in these events made it infeasible for a cyclist to monitor every opponent, and instead cyclists' descriptions were focused either on the emergent behaviour of peloton and breakaway groups, or on the behaviour of specific competitors who were perceived to pose the biggest threat (be this due to current rankings, the current actions of these competitors, or their perceptions of particular riders' capabilities). For example, one Omnium rider recalled using the national jersey colours of his two biggest rivals as a visual cue, which enabled him to more easily monitor their movements amongst the mass of other riders. The depth of field, racing style and capabilities of opponents were also perceived to constrain a cyclist's action possibilities during a race:

> I guess that [it] comes down to the style of the race and who else is in the race too, because it might be that… sometimes your tactics are thwarted by the style of riders that are in there. So you might have two or three riders that might be in a race on a given day… that have a different style of racing, and your tactics might work against specific riders but not against other riders. So I guess…. it's about being aware of who your opponents are sometimes, and a lot of it can just be on the fly. You might not know until you get up to the fourth sprint and you realise 'uh oh, I'm not going to be able to win sprints anymore'. (Omnium Cyclist 3)

6.4.2.2 Informational Features

Informational features also shaped a cyclist's behaviour and perceptions of the task demands in any particular moment of the race. Features in this theme included the distance remaining, changes in weather conditions, upcoming or present race terrain relative to the current race situation, cyclist’s perceptions of their opponents' capabilities, and a rider's or team's current ranking.

During races, cyclists had to make continual decisions regarding their use of energy, describing it as a balancing act between expending energy to capitalise on opportunities and generate an advantage, and conserving energy in order to respond to threats or mitigate risks when they arose. Gaining an advantage often required high levels of effort, which came with the risk of accumulating so much fatigue that they could no longer remain in contention for the win, getting ‘dropped’ from the peloton, or being unable finish the race. The alternate option was to conserve energy by drafting and remaining in the peloton, but then a cyclist risked running out of time to make a move, letting the race ‘get away from them’, and finishing mid-pack. Informational features such as the distance remaining altered cyclists’ perceptions of the current race situation, their assessment of the threats, risks, and potential opportunities within it, the perceived value of drafting and positional resources, and whether a cyclist perceived it to be more prudent to expend or conserve energy.

Weather and terrain features also informed cyclists’ decisions and actions during a race. In track cycling, where competitions occurred indoors and the environment was highly regulated, these features played a role at the strategic level, but not at the tactical level, as altitude, temperature and air pressure were known in advance of the race, and cyclists were able to plan their pacing strategies and gear selections prior to the race start. However in ProTour racing, which occurs outdoors, environmental conditions could change throughout the duration of a race, and a number of the cyclists described instances where weather conditions were perceived to have strongly influenced the outcome of a race:

> There was a crazy cross wind stage… so… they [ProTour Team X] managed to cause a really significant split… in the peloton on what was… meant to be a fairly uneventful stage. From a to b in a straight line… with a sprint at the end. [But] they caught [ProTour Team Y] out… which meant that [ProTour Team Y’s] number one guy was back on the wrong side of the split… losing time. So [ProTour Team Y] sent riders… from the front group back to go and try and help him [ProTour Team Y Leader], to pace him, but… you’re never going to… catch back up to a fast moving big peloton that’s gone in a cross wind. (ProTour Cyclist 2)

Differences were evident in the language cyclists used to describe the influence of weather and terrain features, illustrating how the affordances perceived by a cyclist depended on features of their potentiality, including their skill level, morphology, or appetite for risk. For example, while one of the interviewees felt she tended to be 'heavy on the brakes' in rainy conditions and would reduce her speed to avoid the risk of slipping and crashing on the wet surface, she felt others cyclists in the peloton saw this as an opportunity to gain an advantage, describing their behaviours on course as 'reckless' and 'crazy'. Another ProTour rider recalled an instance where a competitor had capitalised on foggy race conditions at the top of an alpine pass to gain an advantage and break away from the main peloton. The cyclist, who lived in the area and was highly familiar with the course, was able to maintain a speed throughout the descent that the other competitors found too risky in such foggy conditions. Such shifts in the weather provided opportunities for cyclists to gain an advantage over their opponents, depending on their tolerance for risk.

The terrain over which a race was run, referred to as the *parcours* in elite cycling, was one of the most commonly referenced informational features amongst the ProTour cyclists. At the tactical level, the racing terrain influenced cyclists' regulation of energy and the value they placed on the positional and drafting resources at particular points in the race. The following example from one of the ProTour cyclists illustrates how aspects of terrain, when combined with temporal, positional, and action features of opponents' behaviours, interact to affect the amount of energy a cyclist is required to expend:

> You go from a big road onto quite a narrow road, and if you're not in position… there's a cobbled section… and if you're not in position before that narrow road, you can't move up. The road is blocked and no one gives an inch… you've got to be in the front there… If you're at the back, you almost stop… The guys that are on the front…give a little acceleration out of the corner to make it even worse for the guys that are out of position… it tires you out… if you're in bad position and you've had to sprint out of that, and you go hard on the cobbles, and then you hit this pinch climb… if you're at the back …you end up wasting so much energy. (ProTour Cyclist 3)

In recalling this particular section of the race, the cyclist noted that the first time he raced it, he didn't understand why other cyclists were expending so much energy fighting for a forward position in the peloton so early in the race. Having then experienced what he describes in the above example, the following year he fought to be in more forward position prior to reaching this section, which made it 'so easy' in comparison to the prior year.

Terrain was almost always referenced in combination with features from other themes and dimensions, and it was the interaction between these features that determined how cyclists chose to apply their energy and the affordances they perceived during the race. As is evident in the quote above, aspects of the racing terrain were typically referenced in combination with other features including: an individual's morphological characteristics and suitability; physiological fitness and available energy; position within their ProTour team hierarchy and associated responsibilities; the relative position of the peloton, breakaway groups, and opponents during the race; current rankings; time gaps; and finally team objectives and other strategic features.

In addition to contextual features of the race environment, informational features included cyclists' perceptions of their opponents' capabilities, the relative ranking between opponents during the race, and time gaps between groups of riders or to the lead rider. Each of these features modified the cyclists' racing behaviours, with 11 of the 15 interviewees recollecting races in which their perceptions of their opponents' strengths or weaknesses had informed their decisions and actions during a race:

> You might give certain riders a bit more leeway when they're, they've got a bit of a gap, because you know that it's unlikely to succeed. Whereas you know if a couple of riders that are breakaways specialists get together it's, it's quite dangerous. (Omnium Cyclist 2)

Cyclists' perceptions of their opponents' racing capabilities were based on prior experience, from watching footage of previous races, current rankings within the competition, results in prior races or stages of that particular competition or season, and social influences and beliefs that were shared between teammates or within the peloton. Informational features influenced the perceived demands of the race and the threat posed by opponents to a cyclist's own race goals. Ranking features also altered the degree of risk a cyclist was willing to adopt, a concept we explored in detail in our previous study [210 and Chapter 5].

6.4.2.3 Emergent Features

At the tactical level, emergent features of the race resulted from an individual's prior movements and actions in the event and, where applicable, interactions with competitors, teammates, and the instructional features of the competition. Unlike instructional and informational features, emergent features do not exist prior to the race and develop only as a consequence of an individual's actions within, and engagement with, aspects of the competitive environment.

The formation of pelotons in race events is an example of an emergent feature that can influence the energetic demands of a race and the opportunities perceived by a cyclist. There are significant energetic benefits associated with peloton riding, with a recent analysis by Blocken et al. [147] indicating a drag reduction of ~90% for cyclists riding in the mid to rear positions of a peloton of 120 riders. Such energetic benefits allow a group of cyclists who share the workload to sustain a higher speed than any could sustain individually [9]. The collective behaviour of the peloton was a key feature referenced by the riders with regard to their decision making and the actions they took during racing. Cyclists described how the collective behaviour of the peloton could determine whether attacking riders were successful in forming a breakaway group, and its chances of success:

> It's the peloton that decides if the breakaway stays away. If the breakaway is allowed to go or not…it's not like a collective decision, it's just… guys start pulling. They just start riding full gas. If that break[away group] up there is a little bit dangerous… [the peloton] will just ride full gas until they catch it. And there is 180 guys here and there's five up there. You know? There is only one way that is going to go. (ProTour Cyclist 1)

The behaviours of breakaway groups and attacking riders were another emergent feature of racing. The interviewees discussed assessing the perceived threats, future risks and current opportunities presented by the position and behaviour of breakaway groups and attacking riders in order to make decisions regarding their own use of energy and best course of action during a race. The energetic savings associated with drafting behind an opponent, and/or cooperating with opponents to share the workload and ride as a group, had to be weighed against the perceived disadvantages of these actions. Being positioned behind an opponent or towards the rear of the peloton increased cyclists' perceptions of risk, including the likelihood of being caught up in a crash, and made it more difficult to respond to threats at the front of the race, because the cyclist had to manoeuvre past opponents in order to do so [171]. Albert [136] detailed how the drafting benefits associated with peloton riding result in a tension between competitive and cooperative behaviours for cyclists throughout the course of the race. Cyclists move between these behaviours, according to which of these they perceive to provide a competitive advantage [136]. The cyclists in the present study repeatedly referenced this tension, describing how breakaway groups were often tolerated by the peloton, particularly in longer races such as those in the ProTour, but this depended on multiple features of the race, including: who the cyclists were and what teams they rode for; the current ranking of each cyclist in the breakaway and their chances in the overall competition; the number of cyclists in the breakaway; the number of teammates in the breakaway; and the goal of the strongest teams or cyclists in that stage or race. These features determined how the breakaway was perceived by the peloton, whether it was considered to be competitive (i.e. a threat), and therefore whether it would be tolerated or chased. These features are consistent with those identified in the mathematical modelling of Olds [3], who examined factors affecting the likelihood of a breakaway group's success. In addition to the aforementioned features, two interviewees in our study noted, as did Olds [3], that a breakaway group's best chance of success occurred when they had to defend their lead on an uphill slope (due to the reduced influence of aerodynamic drag). Additional strategic and global features that influenced the dynamics of breakaways, including why they formed, are explored in subsequent sections.

Unexpected or unforeseen circumstances were also emergent features of the race. Examples from the cyclists included; a crash that removed a race favourite or team leader from contention, a key rival appearing to struggle, getting dropped from the peloton, missing a critical breakaway, a mechanical failure, or splits in the field. Each of these unexpected circumstances could present an immediate threat, future risk or an opportunity. For example, two riders described instances where they found themselves in unexpected situations during a race due to the actions of opponents. In the first instance, an Omnium cyclist described suddenly finding himself 'off the back' of the race, because a rider ahead of him had been unable to hold the pace and had lost contact with the main peloton. The cyclist described having to expend a significant amount of energy to ride around this weak cyclist and 'bridge the gap' back to the main group in order to remain in the race. In contrast, a ProTour cyclist recalled a particular race in which a change in circumstances meant he found himself unexpectedly in contention for the win:

> I did a race this year where all of a sudden mid-race… it was literally 100 kilometres to go in a 200-kilometer race and ah… the race split, and I found myself off the front [with a gap back to the main peloton] with Team Sky's two main riders. So all of a sudden you're in, that is the bike race. Generally that happens later in the race so no one really… it's a bit of a suicide mission to light that up with 100 kilometres to go, but they did. And all of a sudden [I was] in complete contention. (ProTour Cyclist 4)

A key distinction of racing in events characterised by interpersonal interaction in comparison to solo time-trials was the increase in uncertainty caused by the actions of opponents. The interviewees described how they could never be certain how the race was going to unfold and what their opponents were going to do. Consequently, rather than having clear pre-race strategies, which were common in solo time-trial events, cyclists in the racing events described needing a much more fluid mind-set, enabling them to make decisions on the fly and adapt to the emergent features of the race.

Emergent features were present in the discussions with cyclists from all three disciplines, but were more frequently referenced in the mass-start races, where longer time frames and multiple opponents increased the uncertainty and number of features cyclists were having to monitor and respond to.

6.4.2.4 Tactical Team Features

The global and strategic features underpinning many elements of teamwork in ProTour races are detailed in later sections, but features related to team work, team structure, a cyclist's role within their team, and directives of team directors also influenced the tactical decisions of cyclists during racing.

Amongst the ProTour cyclists we interviewed, there was an acceptance that teammates would work together to improve the chances of success for a particular individual within the team. When queried on what determined who won a race in ProTour cycling, all of the cyclists who had competed in this discipline highlighted the influence of teamwork, with a number of them describing it as a mathematical game. The number of teammates riding in support influenced the amount of work the team leader had to do, and was perceived to be a key feature that determined who won the race. The cyclists provided numerous examples where the support of teammates was perceived to have contributed to the victory of a team leader; for example, one cyclist described a sprint finish during a stage of a Grand Tour in which he perceived the sprinter in his team to have a reduced chance of success in comparison to sprinters in other teams:

> It's mathematical… Cycling sometimes is a numbers game… There's always a team behind every bike rider. [Our sprinter] is definitely capable of it [winning a world-class race] but when you've only got 20 % of the support of other teams? One rider versus five?… I'm doing the job [leading out the sprinter] from eight kilometres out, to 300, 250, 200 metres out [from the finish line]. More like 150 [metres] if I do my job right, and other guys have got five guys to do that work. So that makes it very difficult. (ProTour Cyclist 1)

The hierarchical structure of ProTour teams (see Section 6.4.3.4) led cyclists to adopt certain roles and responsibilities during a race, which altered the affordances they perceived, the opportunities they could take, and often led to behaviour that reduced their own chances of success. For example, in the quote above, the cyclist described the job of 'leading out' his team's sprinter, exhausting his own energy stores in the final kilometres of the race in an attempt to provide the sprinter with the best possible chance of winning. In addition to this positional or aerodynamic support, other responsibilities described by the interviewees included: chasing down threatening breakaways or attacks by opposing riders or teams; going back to the team cars to collect water bottles, food or clothing for other members of the team; and providing physical protection for selected riders in a peloton.

The presence of race radios enabled team managers and directors to issue direct instructions to their cyclists and inform them of situational features of the race that might be difficult for the cyclist to perceive from their vantage point within the peloton. These communications could directly alter cyclists' behaviours during a race, and one cyclist recalled an instance where the calls of the director over the race radio had completely altered the goal for the stage and his role within it. He described a tour in which their team had taken eight cyclists whose job for the week was to support the general classification (GC) ambitions of their team leader. After riding in support of the leader all week, the cyclist described what unfolded after their leader was caught in a minor crash in Stage 10:

> The next day, it was quite clear that he [the team leader] just… he had either nothing in the tank or he'd cracked mentally and didn't want to be there anymore. He was out the back of the race and… our director made the call that we were going to just… [laughs] abandon him… and [the rest of the team were to] go for the stage result that

> day… That meant being very aggressive at the head of the race, trying to create a situation where we could win and basically moving the race away from our number one rider...That was quite a dramatic shift in the middle of a stage… In the space of one hour we'd gone from, 'yep, we're still looking after this guy. He's had a knock but it's just surface injuries, … he's our number one concern'… to, 'he's out the back, he's gone' [laughs] 'sorry, forget about him'. (ProTour Cyclist 2)

Actions taken by opposing teams similarly shaped the affordances perceived by a cyclist or team during a race, particularly when it came to evaluating the threats, opportunities or risks within the current race situation. The dynamics between teams and riders in the peloton, evident in interviewees' discussions of racing, were complex and highly nuanced, and a detailed discussion of these is beyond the scope of this paper. In numerous examples, the cyclists attached meaning to particular actions of opponents within the race context, and what these signalled about that team's goals or ambitions within the race. Absent from the interviews, but highlighted in the literature [106,135], was any discussion of collusion, where cyclists form tacit alliances or agreements with opposition cyclists (beyond that of the aforementioned collective behaviour) in order to improve the likelihood of their chances of success. The reason for this is unclear, but likely to be either an unwillingness to divulge complicity in subversive behaviours, or a reduced incidence of these types of performance behaviours in recent years.

6.4.3 The Strategic Dimension

While tactical features *emerge* from the interactions between the performer and their environment, the features constraining performance at the strategic level are known in *advance* of the race. This dimension incorporates known features of the competition or race environment that shape the decisions of a cyclist, team, or organisation both in advance of, and during, a race [171]. Features at the strategic level were categorised into four themes: competition, seasonal, reward, and team features.

6.4.3.1 Competition Features

This theme refers to broader aspects of the tournament, competition or race that shaped cyclists' objectives and strategies leading into a race, and modified their decisions and actions during a race, including: tournament structure, tournament importance, and course features. Tournament structures are known to modify the behaviour of athletes, depending on the effort required and the reward structures [75,176,177]. In tournaments where the winner is determined by cumulative rankings across multiple races, the reward structure leads to the emergence of efficiency and non-competitive behaviour [171,176,177]. In the present study, nine of the cyclists referenced the tournament structure when describing their decisions regarding use of energy and effort levels during racing. In the Match Sprint, the seeded knock-out structure of the tournament resulted in cyclists perceiving that maximal effort was required in every race. If they lost a race, they were either eliminated from the competition, or had to race through repecharge rounds, which placed them on the 'unfavourable' side of the draw against the most strongly seeded opponents. The structure of the Match Sprint tournament was perceived to provide little opportunity for efficiency, particularly at the elite level of competition. In contrast, the structure of Omnium and multi-day stage races in the ProTour appeared to reward efficiency, with numerous examples provided by the cyclists, in which they would withhold their best efforts to ensure sufficient energy stores for subsequent races or stages:

> You have to know when to use your energy. As much as the leader's gotta manage his energy and save his energy, you've also gotta save your energy the whole race, whilst trying to do a job. So it's really quite hard. As soon as your job is done in the race you ride easy to the finish. You don't ride hard to the finish to try and finish in the top 20 in the Tour de France. That isn't a priority. We were getting paid well, we were going to get a big bonus if [the team leader] won. So do your job, save your legs. (ProTour Cyclist 1)

The influence of tournament structure on performance was evident also in cyclists' comments regarding the differences in how stand-alone races tended to unfold in comparison to races within tournament structures. The interviewees described how the knowledge that there were still numerous stages or events yet to race modified their willingness to expend energy or take risks, a phenomenon that we explored in a prior paper [210 and Chapter 5] and that is well documented within the research literature [75,176,177].

A cyclist's or team's prior results within a tournament also had a strong influence on their strategies going into subsequent races. In the Match Sprint, a cyclist's qualification position and the differential in qualifying times between a cyclist and their opponent shaped their perceptions of how difficult the race would be, while in the Omnium, cyclists described how their results in the previous events determined their strategy for the upcoming races. For example, one Omnium cyclist described knowing that her ranking going into the final race meant she was unlikely to be considered a threat by those in the medal positions. Knowing this, she went into the race with the intention of 'taking laps' (initiating breakaways), as the top riders were unlikely to expend effort trying to chase her down. The ProTour cyclists tended to reference differences in accumulated race time rather than relative rankings to determine the threat or risk posed by a breakaway group or an attacking cyclist: the peloton would just 'let them go' if their accumulate race time was sufficiently large.

As highlighted in our previous paper [210 and Chapter 5], a cyclist's perception of their chances of success influenced their strategy for particular races. Amongst both the Omnium and ProTour cyclists, the structure of the race and course features influenced cyclists' perceptions of their capability for particular events and stages. Many of the ProTour riders attached labels to certain stages according to the course profile, describing them to be ‘a sprinter's or climber's’ stage, and adjusting their efforts accordingly. In addition to competition features, cyclist and team strategies were developed in combination with features in other dimensions, including features of an individual’s potentiality, seasonal features, and reward features.

6.4.3.2 Seasonal Features

The importance of efficiency was also evident across the course of a season, with cyclists describing the need to manage their energy expenditure throughout the year, leading to periodisation of training and the targeting of particular races. Races and tournaments were not all valued equally, and it was evident that cyclists’ motivation differed according to the prestige associated with particular events. The interviewees described being highly motivated in races such as the Tour de France, Spring Classics, Olympic Games and World Championships, but in the less prestigious races, a number of cyclists noted a tendency for riders to withdraw from the race, should it not go to plan. Race importance was also linked to qualification, selection, and training objectives that underpinned cyclists’ strategies during particular races. For example, one Omnium cyclist described adopting a conservative strategy in the points race (the final event) at the World Championships despite being well placed and within reach of a podium finish. Rather than attempting to improve her overall rank and finish in a medal position, she instead described racing with the goal of achieving a top-10 finish, which she knew would secure her a qualification spot for the upcoming Olympic Games. By racing conservatively she hoped to avoid any crashes, reduce her risk of injury, and ‘do just enough’ to secure qualification. These objectives were considered more important than contesting for a podium finish in that particular tournament. There were other examples of cyclists actively conserving energy for more important stages, particularly amongst the ProTour cyclists. If a cyclist’s personal result did not influence their team’s chances of success, and there was no perceived reward for the effort given, the cyclists often ceased competing to save their energy.

Seven of the cyclists described how they periodised their training in an attempt to elicit peak performance for the most important competitions. One of the sprinters explained that his physical condition differed across the course of a season, as he focused his training towards being in peak condition for achieving optimal performance at the World Championships. He accepted that his training regime meant he would be ‘underdone’ at some of the World Cup races, but believed this would be beneficial to his overall goals for the season. The attitudes amongst the Omnium cyclists towards training periodisation reflected those of this sprint cyclist, but the ProTour cyclists raced far more regularly, and held quite a different view of periodisation and ‘peaking’ for key races. The cyclists all dealt with the demands of a hectic racing schedule in differing ways, and there was a strong link between a rider's position in their team hierarchy and their ability to have a clear structured plan across the racing season. One ProTour cyclist described being on a training program that was designed to get him into ‘good form’ in time to target the

Classics, which were contested during the European spring. After completing this block of racing, his training would be ‘backed off’ and he would get a mid-season break before ‘ramping up’ his training again in preparation for key races towards the end of the professional racing season. In contrast, two of the other ProTour cyclists, who were less senior in their teams, described living out of their suitcases, being shunted from race to race depending on where their teams sent them. One of them described having to adjust to a ProTour racing schedule of around 80 races a year, rather than the 10 events per year he had previously prepared for as a track cyclist:

> It was real hard for me to get my head around starting a race with tired legs… I was real against it at first, I was a little, almost angry about the team doing it… Isn’t the point of racing to be good and focused and target this one race and try and win? Not come here just to race, to fill up numbers… But then as I went on, it’s so normal. Guys just race and race and race. Even the week after a Grand Tour, you know, you can be racing. (ProTour Cyclist 3)

The cyclists' training schedules and decisions regarding their racing calendars were often controlled by team management, with most of the cyclists we interviewed having little choice about the training they did or the races they were selected for. The cyclists described using the events they were selected for as opportunities to prove their capabilities to those making these decisions, highlighting the connections between seasonal features and those in other themes and dimensions. For example, a number of cyclists described taking particular actions in a race in order to catch the attention of a director or manager in an attempt to gain selection for a prestigious event, or to prove they were worthy of being offered a ProTour contract (or having their current contract extended).

6.4.3.3 Reward Features

Harwoood and colleagues [216] contend that athletes’ motivations and behavioural responses occur across several levels of analysis, using achievement-goal theory as a framework to understanding the motivations of athletes in the sporting domain. Athletes have been shown to adjust their behaviour according to the structure of a tournament and the perceived rewards their efforts are likely to net them [75,138,176,177,194]. While success in the sporting domain is most often associated with winning, the responses of the cyclists in the current study indicated that they were also motivated by other extrinsic rewards including: secondary prizes, such as a stage win or a minor classification; monetary compensation, including a share of the team leaders prize purse; and intrinsic rewards, such as the pride and prestige associated with racing and finishing particular events.

Winning races appeared to be the primary motivation for the track cyclists, with one track rider describing living for that moment when you circled the track in front of the crowd with your hands raised in victory. The ProTour cyclists were also driven to win races, but those in our sample were rarely given the opportunity to personally contest for the win, due to their position in their team hierarchy. These cyclists described winning in a collective sense, where a win by their team leader was described as a personal win, regardless of the cyclist's actual finish ranking. The responses of the cyclists indicated they frequently raced with underlying secondary motivations, which reflected their need to contribute to their own personal success and career longevity. Secondary motivations included: gaining selection for more prestigious races; securing or retaining ProTour contracts; receiving monetary compensation for their efforts; and the prestige associated with competing in events such as the Tour de France. These secondary rewards could induce a cyclist to expend a significant amount of energy, for example, initiating a breakaway, in full knowledge that by doing so, they were reducing their own chances of winning:

> You want to win every race you go to, but if it's a very high-profile race, obviously there is more money on the win. There is more um… more publicity, more media for the team, for you personally. So for sure, it makes a big difference. Also, if you have maybe a personal bonus written in, for a particular result, written into your contract, then that's a big, a big ah carrot that can be dangled in front of a rider, you know? (ProTour Cyclist 2)

Reward features shaped the behaviour of teams as well as individual cyclists, with a number of interviewees providing examples of team managers setting objectives that had nothing to do with winning the race or tournament. Race organisers are known to manipulate reward structures in order to enhance the competitiveness of contests and the spectacle of the race, in order to entice viewers and spectators, which are often the route to generating sponsorship, TV rights or ticket/gate revenue [137,171]. These secondary rewards appear to achieve this aim, with ProTour cyclists describing how their teams would seek to either win one of the secondary classifications (team, sprint, mountain, young rider classifications), target individual stage wins, or get media exposure for their sponsors, if their director did not perceive the team was capable of achieving success in the overall tournament.

6.4.3.4 Strategic Team Features

The team environment had a strong influence on the decisions and actions of a cyclist at the strategic level, with their efforts constrained by the objectives of their team management or coaches, the opportunities these objectives afforded, and the cyclist's role and position in the team hierarchy. The influence of team features amongst the Match Sprint and Omnium cyclists was evident in discussions on how they targeted these particular race disciplines. Several of the cyclists noted that the Match Sprint and Omnium were considered to be secondary priorities by coaches and team management, and consequently the athletes felt their training and preparation had been inadequate for optimal performance. Amongst the ProTour cyclists there were clear indications of team hierarchy and management influencing strategy and race planning, with these cyclists describing the 'job' they had to do in any particular race. A cyclist's potentiality and proficiency seemed to dictate their position within their team hierarchy. Those lower on the team hierarchy were expected to execute certain tasks during the race in support of their team goals, which as *domestiques,* typically involved reducing the energy demands on their team leader and assisting to control the race. The influence of team hierarchy, the composition of ProTour teams, and the opportunity riders are given, on a cyclist's behaviour in a race and their chances of success have all been explored previously in the literature [100,105,107,123,128,133,150].

Amongst other strategic team features mentioned by the riders, team cohesion was perceived to have strong influence on an individual's or team's chances of success. Netland et al. [138] have previously explored the influence of cooperation dynamics of the performance of cycling teams, detailing the tensions that exist between what is best for the individual and for the collective, and the influence of team management, reward features and social norms (global dimension) in mitigating these tensions. Amongst the track cyclists in our study, team cohesion was perceived to influence the quality of training and preparation, while within the ProTour, team cohesion influenced how the team raced, and the likelihood of all the riders in the roster being willing to work selflessly for their team leader:

> You are seeing each other all the time… you're travelling together, you have a roommate, you're in the bus all the time, you're in the bunch all the time… the better the bond between [the team], the more… the more you believe in yourself, the better the morale, the more drive you have collectively to succeed, and often the harder you can push yourself to ah… to get a result. (ProTour Cyclist 2)

6.4.4 The Global Dimension

The economic, socio-cultural, and authoritarian features that constrain cyclist behaviour as a result of the complex social and organisational settings in which elite cycling competitions take place were classified into the global dimension [171]. Features in this dimension are not related to specific races or tournaments, but instead shape the underlying belief systems and overarching dynamics of the sport that impact on the decisions and actions made by cyclists and team management in pursuit of success. Features in the global dimension were grouped into four themes: economic, social-cultural, authoritarian and other global features.

6.4.4.1 Economic Features

Larson and colleagues [137] provided an in depth analysis of the economic features underpinning performance in professional cycling, including the influence of the financial structure of professional teams, sponsorship, TV rights, and the UCI's attempts to globalise the sport. In addition to these features, the cyclists in the present study made reference to how economic drivers constrained their adherence to team protocol, to directives from leaders, and to the social norms within their team and within the sport. The cyclists all seemed to enjoy what they did for a living, but many of them perceived it took considerable personal sacrifices to be a professional cyclist. The salary or financial compensation a cyclist received for competing at the elite level was one of the economic features motivating them to continue cycling as a career. One of the ProTour cyclists explained his motivation:

> Coming from [country name removed] you have to do it the super hard way. Not having much time with your family, pretty much falling out of relationships with all of your close friends to pursue a career that might not work. So once you get that career, you don't give it up easily. Other riders hang it up just for the sake of it, because they don't… like it anymore. And they know that if they leave cycling something else will be gifted to them. Whereas I know that if I leave cycling, I'll be working two and half k[ilometers] from here at the meat works, because that's about all that my qualifications allow me to do. And no one wants to be doing that unless you have to. (Omnium Cyclist 1)

The influence of team finances were also referenced by a number of the ProTour athletes, particularly the females, who believed that discrepancies in teams' financial means altered the professionalism of cyclists. Team finances influenced cyclists' ability to train fulltime, access quality equipment, and ultimately, their potential to perform strongly in any particular race. They thought there were much larger discrepancies in the quality and capabilities of female cyclists at the professional level in comparison to those in men's racing, and this heterogeneity altered the competitiveness of the league and the typical format of the racing. The cyclists attributed the differences to the more relaxed UCI regulations regarding the formation of a UCI team in the female league, which meant teams were not required to prove they were able to pay riders and staff a minimum salary or wage:

> Everyone calls it professional. It's a long way from professional. A long way. The UCI have got to change that… The teams can keep coming, the teams will keep disappearing too, because until there's a setup similar to the men, it's never going to work. Never. …Our staff are paid per day. They don't... maintain anything… You might turn up to a race and you don't even feel like a good rider. You don't feel important. And then you have the really professional teams with [expletive removed] tonnes of money… Everyone's on a yearly salary or monthly salary … It's such a big difference and makes such a big difference… If you're a so-called professional bike rider, how can you be expected to perform, if you're not being given the right environment, or equipment, or staff, or whatever to perform? It's impossible. (ProTour Cyclist 6)

6.4.4.2 Socio-Cultural Features

An important aspect of expert performance involves acting in a manner that is consistent with ways that are socio-culturally endorsed [38]. Social mechanisms or unofficial norms refer to the expectations shared between cyclists and those within the industry that shape the way cyclists behave and their subsequent performances [134,136,138]. In his analysis of norms within the Tour de France, Fink [134] provided the example of a ProTour cyclist who was contention for the overall tournament title, stopping to take a bathroom break. In this instance, the unofficial norm dictates that the other cyclists in the peloton must refrain from making any attacking moves until this cyclist re-joins the group. Within the current study, socio-cultural features of performance were especially prevalent in the statements of ProTour riders, who directly and indirectly referenced the unofficial norms that governed acceptable racing etiquette. The cyclists' responses indicated the existence of a hegemony hierarchy and informal peloton rules that regulated the collective behaviour of almost all cyclists. Unofficial rules determined when and where cyclists were allowed to make attacking moves, in what circumstances it was unacceptable to attack the race leader, and when it was appropriate to allow a rider to move through the peloton to re-join their team. These norms are collectively adhered to and enforced by those within the peloton [134], but appear to have changed over time. Interestingly, the two most experienced ProTour cyclists claimed that adherence to these norms was diminishing:

> Years ago race cycling was totally different. Years ago you had people like [Mario] Chippolini, [Marco] Pantini, the big, big heads of cycling. They would decide right there on the spot 'breaks gone' and nobody would attack… They'd would just say 'that's it, no one attacks', and no one attacks. If you attacked, you'd just get abused, verbally abused... but you just wouldn't do it. It was a respect thing. Nowadays that's gone. You know? That's totally gone. (ProTour Cyclist 1)

> Even yellow jerseys you don't respect anymore the same way… Might as well be no jerseys. People are attacking… when people are having toilet stops [and in] feed zones. I mean yeah, they get shouted at, and like they get shamed a bit, but it's not the same as it was…you know? That respect has gone… That fear has gone. That fear of… 'that's, that's a big rider'. It has completely vanished from the peloton for whatever reason. (ProTour Cyclist 6)

The cyclists' responses also indicated an expectation that races would unfold a certain way at the elite level, providing further evidence of underlying socio-cultural expectations governing racing behaviour. For example, in the Match Sprint there was an expectation that opponents would not initiate an attack off the start line, with both competitors taking the initial laps at a relatively pedestrian pace before the race 'really began'. ProTour races were also described as following a fairly formulaic structure, with one interviewee providing a detailed explanation of the typical format each ProTour race followed:

> I would say for probably 7 out of 10 days the break goes somewhere in the first hour... and then it's given a certain amount of leeway… The break goes out to maybe five, six, seven minutes, depending on… who's in it, if they're going to be hard to chase… [The] team with the GC guy or the sprinter gets on the front with some help from other sprint or GC teams and they wind it back. Not too early… they don't want it to come back at 30 km to go, because [then] it's chaos. So they generally time it really well, into the last 10 km, before the last bit of the stage… and then the race starts again. A lot of days the race is on for 45 minutes, off for 3 to 4 hours, and then on for an hour. It's surprising given the variety of terrain, and competition, and the sheer number of races, but I'd say more often than not, that's how they play out. (ProTour Cyclist 4)

6.4.4.3 Authoritarian Features

At the global level authoritarian features were related to the governance of cycling as a sport rather than any particular race. These features included mandates of the UCI, national sporting organisations, sponsors, team management, race organisers, and anti-doping agencies.

The effect of UCI regulations on racing performance was particularly evident in the responses of the female ProTour riders, who discussed the impact of differences in UCI regulations between the men's and women's racing leagues. The financial implications of these differences were outlined in section 6.4.4.1. Other UCI regulations include the use of radio communications in ProTour races, with two cyclists recounting the difference a change in this regulation had made to the dynamics of racing. During the ban on radio communication, the cyclists described that breakaways had been able to get ten to twelve minutes ahead of the peloton, but once radios were reintroduced, this gap was kept to only four or five minutes. Larson and Maxcy [122] analysed the effect of the radio ban on the predictability of racing outcomes in the ProTour, noting that in addition to influencing the likelihood of a breakaway group's success, the absence of radio communications had additional implications on socio-cultural features of the sport.

The governance decisions of national sporting organisations (NSO's) are also known to impact the development, training, and performance capabilities of cyclists within each particular country [171]. In the current study, there was a perception amongst the interviewees that gaining race experience was a crucial part of the developmental process to become an elite rider. The cyclists believed that it was only through repeated trial and error in racing that they gained the tactical knowledge needed to be successful. If the NSO did not provide opportunities for developing cyclists to race regularly and focused only on their physical training, the perception was that they would end up with cyclists high in potentiality, but low in proficiency. As mentioned earlier, the track cyclists in the current study frequently felt under-prepared for Match Sprint and Omnium tournaments, as these were considered non-targeted events within their national training program. The cyclists felt the mandated training of their national programs compromised their performance potential in these events.

The expectations of team sponsors also shaped the performances of the athletes. One interviewee described that being a professional cyclist was about so much more than riding a bike, going on to outline the expectations that came with being part of a ProTour team:

> Riding the bike isn't everything. You have to be a good employee, like you'd have to be for any company you know? You have to get out and represent the team well. The sponsors well. To be a good face for the… brand of the team. The… products that sponsors might be, or will be promoting throughout the season. (ProTour Cyclist 2)

The influence of sponsorship and team management in professional cycling has received a significant amount of attention in economic and management literature [105,137,149,152], with Lagae [217] providing a particularly insightful commentary on the influence of sponsorship within professional teams. The brand name of the team sponsor serves as the name of the ProTour team, providing the sponsor with numerous opportunities for their brand to receive auditive, written, and visual promotion [217]. It is therefore in the interest of team sponsors to have their cyclists race in a manner that gains the attention of commentators, TV cameras, or the print media. The cyclists in the current study highlighted instances in which cyclists had fought to be in the breakaway in certain races for the express purpose of generating media coverage for their team sponsor.

There was some indications amongst the cyclists that team managers and coaches limited the opportunities cyclists had to personally influence the decisions that were made regarding their race schedule, whether they were permitted to race for the win, and whether they could have any input into their training or aspects of their race preparation. A number of the older cyclists described disagreeing with the directives of team coaches or managers, which at times they felt contradicted their own personal beliefs and experiences and limited their ability to reach their potential. ProTour teams appeared to have a strong hierarchy, with a number of cyclists describing having to 'do their time' and explaining there were very few races throughout a season in which they were 'given a green light' to personally race for the win:

> At the beginning [of your career in the ProTour] you're just doing what you're told… I mean it depends what kind of a rider or how big a rider you are I guess. Like if I went and said I wanted to target the Tour de France prologue they'd be like 'well

> you, you might not even be going, you're not even on the list' you know? (ProTour Cyclist 3)

6.4.4.4 Other Global Features

Location of the race, historical significance, features related to a cyclists' nationality, and gender effects are all additional features in the global dimension. A number of the cyclists referenced their enjoyment of racing in particular European regions where professional cycling had a strong fan base. These races were often 'exciting' and 'hotly-contested' because of the number of spectators that attended the races, and the cyclists enjoyed performing in front of a crowd that 'understood' the sport.

The location of a race also appeared to have a 'home-race' effect, with examples of cyclists who were racing in their home country being more combative and taking bigger risks in an attempt to win in front of a home crowd. Interestingly, this effect created a social norm, where breakaway and attacking cyclists' were given leeway, if the race was in their home town or there was a significant cultural link. For example, there appeared to be a general acceptance amongst the male ProTour riders that a French rider or team would be allowed to instigate the breakaway on Bastille day, a French national holiday that falls during the Tour de France.

Cyclists also attached historical significance to particular races, particularly within the ProTour. Races such as the Paris-Roubaix, Milan-San Remo and Tour de France were described with a degree of reverence, and as highlighted earlier, the cyclists perceived a significant amount of prestige came with being selected for and finishing these events. The prestige of these races motivated a number of the cyclists to keep racing in circumstances which would have otherwise resulted in their withdrawal.

The cyclists also believed nationality impacted their ability to perform. In our sample, nationality was perceived to have a negative influence on performance due to the effects of travel (for the track cyclists) or the challenges associated with living overseas at European training bases for large periods of each year, removed from family and social support networks. For the ProTour cyclists, there were also several references to a language barrier within their professional teams, with two cyclists commenting that they would highly recommend young developing riders to take the time to learn a European language. A majority of the cyclists in our study came from countries that held very few elite international competitions, and almost all of them believed the amount of travel they were required to do impacted their ability to perform:

> I always felt I could get more out of myself… at Nationals, for example, versus [racing in] Europe. I don't know what it was. Whether it was being home, in the comforts of home versus living in a, you know, in a foreign environment. But I always performed better at home. If I could [race like] that in Europe, I'd be a totally different

rider… but I could never just quite, just do it. It was always… always a bit different. (ProTour Cyclist 1)

Numerous differences were evident in the responses of the male and female cyclists in our sample, and while not the focus of this paper, it is an area that should receive more attention within academia. Of particular note, the tolerance for risk appeared to be strongly influenced by gender, with the women appearing much less prone to taking risks during racing. In general, the females appeared to race more conservatively; for example, the female ProTour cyclists described the desire to finish in the bunch as being more desirable than risking failure to try and finish first:

I think females are, they're scared to lose rather than… than win. I think that they're scared to give everything for the chance to win than… get dropped. Like that's the reality, that's the mentality that you have. (ProTour Cyclist 6)

The men just race more aggressively… they're willing to try and fail and... Try and… yeah, win the race, like they're actually trying to win the race rather than to get a top-8 or a top-10 performance. (Omnium Rider 4)

Gender differences in the perspectives on economic features were noted in Section 6.4.4.1. The female cyclists also appeared to be more deferential towards governance and those in leadership positions. We recognise that our sample of female cyclists was small, and further research on gender issues is required.

6.5 Limitations

The present study has several methodological limitations. First, the sample was limited to three disciplines of cycling, four to six cyclists from each discipline, one or two female cyclists in each discipline, and three nationalities. With one exception, all were native English speakers, the majority of whom came from countries located outside of the main racing regions. As such, the cyclists' experiences that formed the basis of our model and the dimensions and features we have outlined are limited to these demographics. Secondly, as noted in our previous qualitative study [210 and Chapter 5], using retrospective interviews to explore the cyclists' perceptions and experiences means that we are reliant on their being able to comprehend, recall and describe the determinants of performance in complex racing events [200]. Thirdly, the interview schedules did not specifically probe the global dimension, which only became apparent as an important dimension during the qualitative analysis. Additional questions may have elicited more insights on the features within this dimension. Finally, the restrictions on manuscript length and time for postgraduate research projects limited the depth to which each dimension and feature has been presented.

There are also limitations with the model we have developed. First, our analyses are based at the systems level, meaning that the model does not account for features below the physiological level, or equally, for features in higher-order dimensions, such as those of the ecosystem or of society generally. Our model reflects the approach of Hulme and colleagues [206], in that the scale of analyses in our model reflects the lowest and highest dimensions relevant to our ontological position and research aims. Secondly, as in any research that utilises inductive content analysis, the categorisations in our model were developed by the researchers and consequently reflect our interpretations of the data and the research literature. It is inevitable that we did not identify all of the features underpinning cyclists' performances during competitive racing. Finally, we recognise that the features determining a cyclist's performance interact with each other across varying timescales in ways that are incorporated only superficially in our hierarchical model. We welcome further research and refinement of this initial systems model.

6.6 Conclusions

The aim of this research was to provide athletes, coaches, teams, and organisations seeking to improve their chances of success in elite competitions with accurate and useful information on the features influencing cyclists' performance in the complex environments of elite competitions. In exploring how athletes behave in the race environment, it was evident that features influencing performance existed across multiple dimensions. To summarise these findings, and to improve comprehension of the interrelatedness between determinants, we developed an initial systems model of elite cycling performance. We reiterate that model is a prototype, based on the results of this study and its predecessors [171,204], which focuses on the key features identified through the responses of the cyclists we interviewed.

The model was structured into four high-order performance dimensions from the micro- to the macro-level, with features grouped into domains and themes within each of the dimensions. Many of the features interacted across multiple dimensions and timescales, suggestive of a non-linearity that makes it difficult to decouple and clearly define the determinants of a cyclist's chances of success in complex racing events [171,188,192]. The non-linearity in our model underscores the importance of flexibility and adaptability in cyclists' tactical and strategic behaviours. Those who coach and train cyclists may therefore wish to consider the implications of how performance emerges in the complex environments that characterise competitive racing. Classical training paradigms that focus on developing an individual's physical and technical capabilities through repetition and isolated training exercises are likely to be inadequate [218]. Our results indicate that to succeed at the elite level, a cyclist must have skills that extend beyond their physical potential, which appear to be a baseline requirement rather than a predictor of winning. At the elite level, features related to a cyclist's proficiency, which were perceived to develop as a result of increased racing experience, are more likely to determine their chances of success. For those seeking to improve performance, the development of expertise therefore relates not only to an individual’s potentiality but also to their ability to operate within complex racing environments and navigate the social and cultural constructs of the sport.

Our study provides further support for the argument that any explanation of performance in complex race environments must account for the athlete-environment interactions and the multitude of interconnections between various dimensions and features regulating the task constraints. As a framework for understanding how performance emerges in complex race environments, ecological dynamics appears to provide a useful path forward, because it recognises this complex inter-connectivity [16,27]. The model we present serves as an initial framework to capture the complexity of elite cycling performance and the features likely to influence a cyclist's chances of success in complex racing events. By understanding the complexity of performance, we hope this framework will help those working in elite sport to understand the mechanisms and features at play and better develop appropriate approaches to the enhancement of athletic performance. The findings of this research also suggest that those working in sports performance research would benefit from collaboration. Understanding how physiological, psychological, demographic, biomechanical, aerodynamic, inter-personal, contextual, economic, authoritarian, socio-cultural, and historical features fit into the complex system that is athletic performance in actual competitions will advance our current knowledge of how expertise can be enhanced with training and experience.

CHAPTER 7:

DISCUSSIONS AND CONCLUSIONS

The overall aim of this doctoral thesis was to advance knowledge about the performance of cyclists in the complex environments that characterise elite competitive racing. Concepts from ecological dynamics and complex systems theory informed the theoretical framework and methodology adopted for this research. Ecological dynamics and complex-systems theory emphasise the importance of the performer-environment relationship in the study of sport-related behaviour, advocating that athletic performance emerges as a result of interacting features acting across multiple levels of analysis and varying timescales. These approaches replace traditional reductionist paradigms, which have received increasing criticism for their inability to provide a comprehensive explanation of performance in the complex environments that characterise actual elite competition. Despite the increasing calls for ecologically valid sports performance research, applications of complex systems theory and integrated explanations of sporting performance have remained scarce.

In the first part of this thesis (Chapters 2 and 3) I sought to establish how cyclists' performances changed in complex racing environments featuring competitor interaction and to quantify the extent of these changes. In the second part of this thesis I sought to understand what was known within the literature that might explain these changes in performance (Chapter 4). And in the final part of this thesis, I sought to characterise the performer-environment relationship by identifying the features underpinning performance, their interactions, and the levels and timescales across which they acted (Chapters 5 and 6). I will summarise the key elements of each chapter here, including the rationale for each research approach and what the results add to existing knowledge about the performance of elite cyclists. Finally, I will outline how this thesis contributes to existing sports-performance research utilising non-traditional paradigms, before finishing by summarising the practical applications of this work, its limitations, and directions for future research.

7.1 Contribution to the Field

Despite criticisms of the traditional reductionist approach, and the assertions of those advocating for ecological-dynamics or complex-systems approaches that 'the sum of the parts does not equal the whole', the factors related to achieving success in elite cycling continue to be examined primarily divorced from the environments that characterise actual competitive racing. Notwithstanding the contribution of reductionist research, there has been a major gap in our knowledge regarding the extent to which features known to contribute to performance in controlled settings or solo time-trials, contribute to or predict performance in actual competitions. In line with recent calls for sport researchers to find more encompassing research methods in order to adequately capture, assess and understand the complexity of performance [19,38], a sequential explanatory mixed-method design [219] was used for this thesis. Guided by the ontological assumptions of critical realism, a quantitative approach was first used to provide a general understanding of the changes in the competitive performances of elite cyclists in increasingly complex racing events. Qualitative approaches were then used to explore existing research and gather in-depth insights into elite cyclists' perceptions and experiences in competitive racing.

The goal of the quantitative phase was to establish the extent to which factors contributing to performance transferred between different racing formats. By utilising linear mixed modelling to explore race data, in Chapters 2 and 3 I was able to clearly demonstrate that the predictability of cyclists' performances decreased as race environments becoming increasingly complex and the number of opponents increased. In the Omnium competition, the greater race-to-race variability observed in the mass-start events indicated that features other than those that contributed to performance in the solo timed events were modifying cyclists' chances of success. In the Match Sprint, performance in the preceding solo time-trial was a strong predictor of a cyclist's chances in head-to-head races and in the overall competition, but there was also evidence of other factors. The findings from these two chapters were consistent with the view of cyclists as complex adaptive systems whose performances are influenced by their interactions with opponents and the environments in which they compete. However, at this stage of the PhD, the factors affecting these performance changes were speculative and required further investigation.

In Chapter 4, a review of existing academic literature was undertaken with the goal of identifying the factors affecting performance in the more complex races of elite cycling competitions. A narrative-synthesis approach enabled me to draw on expertise from a wide range of disciplines: physiology, psychology, biomechanics, aerodynamics, motor-learning, ergonomics, pedagogy, economics, mathematics, game-theory, sociology, history, and management. While the determinants of cycling performance have been reviewed within some of these disciplines (e.g., psychology, Spindler et al. [114]) or at particular levels of analysis (e.g., individual performer, Faria et al. [46,79]), to the best of my knowledge this review is the first to take a more holistic approach. The review highlighted the multidimensional nature of performance, with features not only at the individual level but also at the tactical or interpersonal, strategic, and global levels shaping cyclists' decisions and actions during competitive racing. Complex interactions between features were also evident. The features identified in this process were grouped and used to shape a conceptual framework, which I hope will be helpful for those working in the industry or conducting research on performance in interactive race events.

During the qualitative phase of the thesis, semi-structured interviews were conducted with elite cyclists to gather their perspectives on the factors they retrospectively considered to have modified their chances of success in competition. The rationale for incorporating qualitative methods was to capture additional data, gather new and unanticipated insights into cyclist behaviour, and develop a more nuanced understanding of features underpinning performance in competitive cycle racing. The use of multiple methodologies has also been argued to assist in building a more complete picture of sporting performance [25]. Complex-systems theory postulates that systems (in this case, the cyclist) will self-regulate according to their environment in order to maintain stability. By exploring cyclists' subjective experiences, I was able to gain novel insights into the features shaping interactions between competitors and their performance environments. Qualitative analyses of the interviews were in two parts.

In the first part, detailed in Chapter 5, I focused on how the presence of opponents in elite competition affected cyclists' performances, with the aim of gaining insight into the mechanisms underlying the performance changes observed between solo and interactive race events in Chapters 2 and 3. The interaction permitted between opponents in race events clearly modified the decisions and actions of elite cyclists, leading to changes in perceptions of risk, an increased focus on tactical execution, adjustments to considerations of optimal energy distribution, a perceived increase in cognitive load and other psychological changes. These findings indicate the presence of opponents induces behavioural changes, providing insight into possible reasons for the changes observed between cyclists' performances in solo-timed events, head-to-head Match Sprint and mass-start Omnium races. These findings further our understanding of how the presence and actions of opponents modify the demands on athletes in race events and could assist those seeking to improve athletic performance to devise improved methods for preparing athletes for the additional cognitive and tactical demands.

The responses of the cyclists in Chapter 5 indicated that features of the competitive environment further modified their decisions and actions during competitive racing, which provided the rationale for the second part of the qualitative analyses, Chapter 6. Here I took a broader view of the interview data, with the aim of understanding how features of the race environment and socio-cultural context of the sport affect performance. I used a combination of inductive and deductive content analysis to synthesize additional data from the interviews, the findings of the previous chapters and existing academic literature to construct a holistic and meaningful account of the features underpinning performance in complex race events. The multidimensional and interactive nature of the features were incorporated into an initial systems model of the determinants of cyclists' performances. The model provides further support for ecological dynamics and the assertion that athletic performance emerges as a result of the complex interconnectivity between a performer and their environment. My hope is that this model promotes sport-performance researchers, and those working within the cycling industry, to take a more holistic view of athlete development and performance.

As with any sequential explanatory design, it is important to note the timing of the data collection and analyses for these studies. The interviews, their transcription, and initial inductive content analysis for Chapters 5 and 6 were conducted prior to the systematic review (Chapter 4), in a deliberate attempt to limit the extent to which the literature shaped our interpretations and categorisation of the interview data, and to remain open to alternative interpretations [220]. Subsequently, findings from the previous chapters and the literature were used to compare, corroborate, and refine the themes and features that had been constructed from the initial content analysis of the interview data. Combining inductive and deductive content analysis in this way improves the validity of the findings and acts as a form of triangulation [25,219].

In summary, the projects of this PhD represent a novel application of complexity principles and ecological dynamics to enrich our understanding of the factors shaping the performance of elite cyclists in actual competitive racing environments. Furthermore, I have demonstrated the advantages of using a sequential explanatory mixed-method design, combining quantitative and qualitative research techniques and drawing on research across a range of scientific disciplines to capture the complex dynamics and interconnectivity of features shaping sporting performance.

7.2 Practical applications

There are clear implications of this research for team managers, coaches, and athletes seeking to improve cyclists' performances in complex racing events. The research findings may also be of use for those in governance or positions of authority, and for sport researchers seeking to better understand cycling performance.

Coaches and trainers seeking to improve competition performance need to recognise that features other than those that enable a cyclist to perform well in solo events influence their chances of success as the races became increasingly complex. In addition to the high levels of fitness and skill that cyclists require in order to be competitive at the elite level, their chances of success are constrained by features at the tactical, strategic and global level. The complex interplay that occurs between a cyclist, their opponent and the race environment, underscores the importance of flexibility and adaptability within the domain of expertise. The emergent nature of optimal performance challenges traditional training paradigms, in which skills are practiced devoid from such tactical, strategic or global influences. For those seeking to improve performance, the development of expertise therefore relates not only to the improvement of features comprising an individual's potentiality but also to their skills in the domain of proficiency. Furthermore, given that proficiency develops as a consequence of experience, those working in talent development should consider the importance of regular competitive racing as part of the training program for young athletes. While a young athlete may show strong *potential* at the lower levels, their proficiency should also be developed.

Team managers and coaches should also give consideration to features beyond those of the individual, including the influence of strategic and global features such as team cohesion, selection, support and funding structures, on the behaviour and performance of those within their program. It is my hope that the model presented in Chapter 6 will assist those working with elite cyclists to better understand the mechanisms and features shaping behaviour and promote the development of more appropriate management and training methods. The model should also assist those in governance or authoritarian positions to take a more holistic approach when considering new regulations, changes to the structure of the sport, or the introduction of additional sanctions. For example, in seeking to limit or eradicate the prevalence of subversive behaviours, such as doping, governing bodies would benefit from considering the other mechanisms at play in order to better understand why such behaviour is an attractive option for cyclists. Beyond the rewards associated with winning races, our model illustrates cyclist behaviour is influenced by the race calendar (number of races a year), hierarchy of ProTour teams, selection considerations, economic concerns, and social norms. Each of these features (and their interactions) could influence a cyclists' likelihood of engaging in subversive behaviours, and consequently, attempts to curb doping would perhaps be more successful if these mechanisms were addressed, rather than seeking to control behaviour via more rigorous testing or additional sanctions.

Sports performance researchers seeking to understand the complexity of athlete performance in actual competition would also benefit from taking a holistic and collaborative approach. From a complex-systems perspective, these findings identify key interconnections where features in one dimension or scientific discipline interact with those in others, highlighting areas for future investigation. The breadth of scientific disciplines encompassed by the review of literature and reflected in the dimensions and features forming the initial systems model, suggests that combining approaches and integrating knowledge across traditionally separate disciplines will provide a more comprehensive picture of the behaviour of complex systems beyond cycling. Furthermore, the sequential explanatory mixed-method design used in this thesis illustrates the benefits of combining quantitative and qualitative approaches to produce a more nuanced understanding of the complexity of athletic performance in actual competition. By continuing to improve our understanding of athlete-environment interactions and the multitude of interconnections between various dimensions and features, we will advance our knowledge of how racing expertise in complex events can be enhanced with training and experience. Despite these advancements, it should be noted that there is an almost infinite number of ways the features that contribute to performance can interact and therefore there will always be random elements and unexplained variation in competitive performance.

7.3 Limitations and Future Directions

It is important to acknowledge some of the broader limitations of the work that forms this PhD, including restrictions regarding higher-degree research, researcher preconceptions, and the theoretical frame of reference adopted. There are also limitations specific to each of the various studies comprising this thesis. These are detailed further below, along with some suggestions for future research.

First, the timeframe in which a PhD is required to be conducted and submitted constrained the volume of data collected, scope of the analysis, and depth of reporting throughout the thesis.

Although this study provides some useful insights into the performance of elite cyclists in racing environments, the work is formed from investigations of just three cycling disciplines; Match Sprint, Omnium and ProTour racing. A number of other cycling disciplines remain underrepresented in the academic literature and are worthy of future consideration, including mountain biking, cyclo-cross, BMX, trials, and free-ride disciplines. As a result, the initial systems model presented in Chapter 6 requires further research and validation before it can be applied to other disciplines of cycling. Furthermore, we were able to provide some insight into gender differences (and similarities) in elite racing, but the issue of gender requires further consideration and dedicated analysis.

Secondly, in order to fulfil the requirements of a doctoral thesis, the work is largely my own (with significant guidance from my supervisory team), and the insights developed are therefore limited by the skills, knowledge and expertise I was able to develop or access during the course of the PhD. Given the multidimensional nature of performance and broad range of features identified in the initial systems model, future research would benefit from a more collaborative interdisciplinary approach, combining the expertise of multiple researchers to elicit more in-depth insights on the specific nature of features and their interactions.

Thirdly, as a research-practitioner, I had worked within the cycling industry for close to a decade prior to commencing this project, and I brought preconceptions to this work. The formulation of the project grew from discussions with coaching staff regarding the lack of knowledge on how to train athletes for the racing disciplines of track cycling, and from the absence of literature to provide any guidance on the subject. While professional experience and knowledge provide a valuable lens, it must be acknowledged that a researcher's background shapes research design, the focus of investigation, method selection, analyses, which findings are considered interesting, and elements of their interpretation [83]. The research approach adopted for this work was selected, in part, to minimise the effect of my background and the preconceptions I brought to the projects. For example, by taking a mixed-methods approach to examine the complexity of racing from different positions and perspectives, I attempted to elicit differing accounts of cycling performance. These accounts included the perspectives of elite cyclists, two pilot interviews with coaching staff, the feedback and critique of my supervisory team, and a broad critical reading of literature from a range of disciplines. Future work would benefit from adding other perspectives, (including coaches, administrators, and race organisers) and including additional methodologies.

With respect to the specific studies, Studies 2 and 3 provide novel insights into the changes in competitive performance between solo time-trials and one-versus-one or mass-start cycle racing. There is an apparent assumption in our analyses and interpretation that cyclists were attempting to execute their best performance in every race and competition that was a part of our data set. In fact, the analyses did not require cyclists to do maximal or even near maximal efforts; any performances that were so poor as to be identified as outliers were removed, but many performances could be submaximal without being noted as outliers, and these performances would contribute to the residual or unexplained race-to-race variability. In the subsequent qualitative studies, it became evident that cyclists sometimes will deliberately withhold their best effort during a race, which was evident in the lower predictability we observed in the mass-start events of the Omnium. Any research that attempts to make inferences regarding performance and chances of success from analysis of race results should acknowledge the potential modifying effects of features such as a cyclist's motivation, prior race results, and risk tolerance, on the observed performances.

The limitations of Study 4 lie predominantly within the constraints imposed by the inclusion criteria used to select those articles from which the narrative synthesis was based. The use of inclusion criteria was necessary to reduce the available research down to a manageable level, but there are likely to be findings from excluded studies that could further inform our understanding of the dimensions and features shaping the performance of elite cyclists in competitive racing. For example, Williams [221] provided a fascinating commentary on the concept of hegemony and dominant ideologies that shape cycling subculture, but as his work was conducted with amateur cyclists, it did not meet the inclusion criteria for this chapter. Future work focused on improving our understanding of cyclist performance in competitive environments would likely benefit from incorporating research that sat outside the scope of the current project.

In Chapters 5 and 6, a purposive sampling scheme was used to gather insight from cyclists who had been part of the data set in Chapters 1 and 2, and that were accessible and willing to be a part of this project. As a result, the insights generated in this phase of the project are limited to the demographics of our sample. Furthermore, I was reliant on the cyclists we interviewed being able to comprehend, recall and accurately describe the factors that had influenced their performance. In addition to potential problems with cyclist recall, and in the absence of video prompts, their recollections were likely to be shaped by pre-existing socio-cultural norms and personal beliefs. It is also important to acknowledge that while my work within the industry enabled me to recruit athletes of such high calibre for this project and ensure rapport, the position I held within the National program is likely to have influenced cyclists' willingness to be open and transparent regarding their perceptions of the influences of coaches, team management, team culture or governing bodies on their performance. Similarly, the ethics approval process required me to advise athletes prior to the interview that any admission of doping offences would have to be reported, and therefore if the cyclists had experience in this space, they were highly unlikely to divulge this in the course of the interview. Finally, as mentioned earlier, the initial systems model presented in Study 6 requires further investigation to establish its accuracy.

7.4 Final Concluding Remarks

The aims of this PhD were to explore whether concepts from complex-systems theory and ecological dynamics could better account for cycling performance in the complex environments that characterise competitive racing and to examine whether a mixed methodology could provide an avenue to move beyond traditional reductionist approaches. I have established that a cyclist's decisions and actions during competitive racing are shaped by factors not evident in solo time-trials, and that performance is modified by features existing across a range of performance dimensions from the individual through to the global level and their interactions. I have further demonstrated the benefits of utilising both quantitative and qualitative methods to provide a richer insight into the dimensions and features influencing competitive performance. I have provided a summary of the dimensions and features known to regulate performance in elite cycling competition, at least for Match Sprint, Omnium and ProTour cyclists, and I have provided an initial systems model to describe the breadth of factors shaping the observable performances of cyclists in competition. Further research is required to validate this model beyond the demographics of the sample and to examine its transferability to other competitive cycling disciplines. The research methods used in this study may be of use for those wishing to build similar holistic models of the features influencing performance in other sports characterised by complex environments.

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VICTORIA UNIVERSITY
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APPENDIX A

INTERVIEW SCHEDULE:

Introduction of the Interview

Hello, my name is Kathryn Phillips and I am currently undertaking PhD studies at Victoria University under the supervision of Professor Will Hopkins and Dr Rod Corban from the College of Sport and Exercise Science.

The purpose of my studies is to investigate performance in mass-start cycling races, and in particular how the proximity of opponents influences what occurs. Most of the research that has examined what predicts performance in cycling has been conducted in laboratories or in competitive environments where the rider is competing solo (i.e. in a time-trial). Yet the majority of cycle races on the UCI calendar are bunch races, where you're riding alongside your opposition and able to interact with them. Our previous work has already identified that the performance of cyclists in bunch races is clearly different than that of those same cyclists in solo time-trial races. In these interviews I want to explore your viewpoint and find out what you think the differences are between being successful as a cyclist when you are racing against the clock versus when you have to race against opponents.

ELITE MATCH SPRINT RIDERS

Part One: Perceptions of what it takes to win the event:

The first part of a Match Sprint competition is a flying 200m time-trial against the clock which is used to rank the field from fastest to slowest. Can you talk me through what factors you think determine who qualifies the fastest at a competition?

- Probe: What are the things a rider has to get right to ensure they perform strongly in the 200m TT?
- Probe: Is there anything else you can think of that matters to performance in the 200m TT?

Talk me through what you think it takes to win the whole competition.

- Probe: Is there anything else you can think of that matters to winning the competition?

What are the key differences between performing well in the flying 200m TT and performing well in a match sprint race?

- Probe: Is there anything else you can think of that is different between the TT and the Sprint rounds?

Tell me what the most successful riders tend to be good at. Use examples if you can.

- Probe: Is there anything else you can think of that characterises the top match sprint riders?

Part Two: Reflection of personal performances:

Tell me about your best ever competition result.

What do you think contributed to you riding so well at that competition/race?

Can you talk me through how you prepare for the flying 200m time-trial?

- Probe: What things do you have to do in training prior to the competition to ensure you perform well in the 200m TT?
- Probe: What things do you do on the day prior to going out on to the track to ensure you perform well?
- Probe: What things do you have to get right during the ride?

Now talk me through a match sprint race. How do you prepare for that?

- Probe: What things do you do in training prior to the competition to ensure you perform well in the match sprint rounds?
- Probe: What things do you do on the day prior to going out onto the track for the race to ensure you perform well?
- Probe: What things do you have to get right during the race?
- Probe: Do you approach each race the same or are there differences? What are they?

Have you ever beaten a guy who you thought was physically superior to you? (if no: Have you ever seen it done?)

Describe to me how you manage to beat him.

Or/ describe to me what happened, how the other guy managed to win.

Do you think you can win a match sprint race with superior tactics?

- Probe: why/why not?
- Probe: can you give me a scenario when you could?
- Probe: can you describe a scenario where you couldn't?

Do you think you can win a match sprint tournament with superior tactics?

- Probe: why/why not?
- Probe: can you explain your answer a little more?

Part Three: Perceptions on trainability of various 'performance factors':

Which factors do you think tend to determine performance in match sprinting?

- Probe: are there any other factors you can think of?

Going back to the things you said determined performance in your event [rename if necessary], how much time do you spend working on improving each of these factors?

Final questions: (bottom of sheet)

ELITE OMNIUM RIDERS

Part One: Perceptions of what it takes to win the event:

There are six events that make up the Omnium competition, going through each of them one-by-one, what do you think determines success in each event?

- Probe: What are the things a rider has to get right to ensure they perform strongly in [x] event?
- Probe: Is there anything else you can think of that matters to performance in [x} event?

Talk me through what you think it takes to win the whole competition.

- Probe: What are the differences between performing well in the one event and performing well in the competition as a whole?
- Probe: Is there anything else you can think of that matters to performance in an Omnium competition?

Are there differences in what it takes to perform well in the timed events and what it takes to perform well in the bunch race events of the Omnium?

- Probe: can you explain that a little more?

Tell me what the most successful riders tend to be good at. Use examples if you can.

- Probe: Is there anything else you can think of that characterises the top match omnium riders?

Part Two: Reflection of personal performances:

Tell me about your best ever competition result.

What do you think contributed to you riding so well at that competition?

Can you talk me through how you prepare for the scratch race?

- Probe: What things do you have to do in training prior to the competition to ensure you perform well in the scratch race?
- Probe: What things do you do on race day, before you line up for the race, to ensure you perform well?
- Probe: What things do you have to get right during the race?

Now talk me through the individual pursuit. How to you prepare for that?

- Probe: What things do you do in training prior to the competition to ensure you perform well?
- Probe: What things do you do on race day, before you get in the start gate, to ensure you perform well?
- Probe: What things do you have to get right during the race?

What about the other four races? Talk me through each one and outline any differences in the way you approach those races to the ones you've just described.

- Probe: What do you have to get right during [x] race?
- Probe: Can you explain why you think that?
- Probe: Can you explain why you do that?

Have you ever beaten guys who you thought were stronger riders than you? (if no: Have you ever seen it done?)

- Probe: What event was it in?
- Probe: Describe to me how you manage to beat him.

Do you think you can win an Omnium event with superior tactics?

- Probe: explain your answer to me and why you think that?
- Probe: can you give me a scenario when you could?
- Probe: can you describe a scenario where you couldn't?

Do you think you can win an Omnium tournament with superior tactics?

- Probe: can you explain your answer to me and why you think that?

Part Three: Perceptions on trainability of various 'performance factors':

Which factors do you think tend to determine performance in an Omnium competition?

- Probe: are there any other factors you can think of?

Of the factors which you've just outlined as determining performance in an Omnium, which of these do you work on improving?

- Probe: which are the ones you spend the most time on developing and which are the ones the least amount of time developing?

PROTOUR ROAD RACE RIDERS

Part One: Perceptions of what it takes to win:

Tell me about how a Grand Tour works and what you think it takes to win.

What characteristics does a rider need to have to win the General Classification (GC)?

What about the other classifications, what characteristics does a rider need to have to win the other jerseys? (Mountains, Sprint, U23, Team Classification)

Talk me though what you think it takes to win a stage at a Grand Tour.

- Probe: What are the things a rider has to get right to win a stage at a tour?
- Probe: Is there anything else you can think of that matters to performance success in a stage race?

Tell me about some of the top riders on the UCI World Tour and what you think it is that makes them so good.

- Probe: Is there anything else you can think of that characterises the top road riders?

Part Two: Reflection of personal performances:

Tell me about your best ever result at a Grand Tour.

What do you think contributed to you riding so well at that race?

What things do you have to get right to perform well in a road race?

- Probe: What things do you have to do prior to the race to ensure you perform well?
- Probe: What things do you do on race day before the race starts, to ensure you perform well?
- Probe: What things do you have to get right during the race?

What things do you have to get right to perform well in an individual time-trial?

- Probe: What things do you have to do prior to the race to ensure you perform well?
- Probe: What things do you do on race day before the race starts, to ensure you perform well?
- Probe: What things do you have to get right during the race?

Have you ever beaten guys who you thought were stronger riders than you? (if no: Have you ever seen it done?)

- Probe: Describe to me how you managed to beat them.

Do you think you can win a road race with superior tactics?

- Probe: explain your answer to me and why you think that?

Do you think you can win a Grand Tour with superior tactics?

- Probe: explain your answer to me and why you think that?

Can you win a individual time-trial with superior tactics?

- Probe: explain your answer to me and why you think that.

Part Three: Perceptions on trainability:

What do you think are the factors that determine whether you'll have a successful performance in a road race?

- Probe: are there any other factors you can think of?

Of the factors which you've just outlined as determining performance in a road race, which of these do you work on improving?

- Probe: which are the ones you spend the most time on developing and which are the ones the least amount of time developing?

Final Question:

That is the end of the questions I have for you today. Do you have any further comments or anything else you would like to add?